Antenna and Wave Propagation (4341106) - Winter 2023 Solution

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Question 1(a) [3 marks]

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

Solution

Parameter	Definition
Directivity	Ratio of maximum radiation intensity to average radiation intensity of an antenna.
Gain	Ratio of power radiated in a particular direction to the power that would be radiated by an isotropic antenna.
HPBW (Half Power Beam Width)	Angular width where radiation intensity is half (3dB less) of the maximum value.

Mnemonic

“”DGH: Direction Gives Half-power””

Question 1(b) [4 marks]

List the properties of electromagnetic waves

Solution

Property	Description
Transverse Waves	Electric and magnetic fields are perpendicular to the direction of propagation.
Velocity	Speed of light (3×10^8 m/s) in vacuum.
No Medium Required	Can travel through vacuum, unlike mechanical waves.
Polarization	Defined by the direction of the electric field vector.
Energy Transport	Carries energy through space.
Reflection/Refraction	Can be reflected and refracted at boundaries.
Interference/Diffraction	Exhibits wave-like properties.

Mnemonic

“”TVNPER: Transverse Velocity No-medium Polarized Energy Reflection””

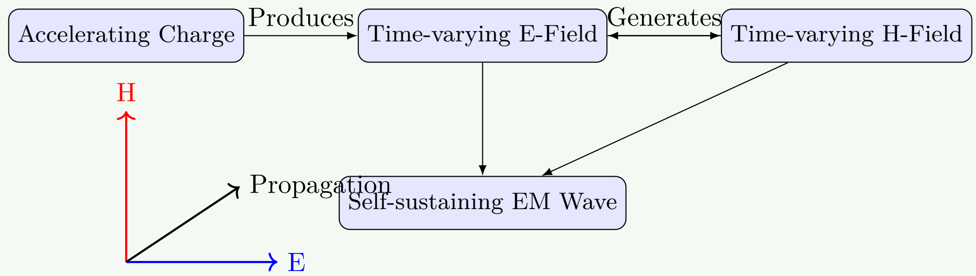
Question 1(c) [7 marks]

Explain physical concept of generation of Electromagnetic wave

Solution

Concept: Electromagnetic waves are generated by accelerating electric charges.

Figure 1. Generation of EM Waves



- **Charge Acceleration**: When electric charges accelerate (e.g., in an AC circuit), they generate changing electric fields.
- **Field Coupling**: Maxwell's equations state that a changing electric field produces a magnetic field, and a changing magnetic field produces an electric field.
- **Self-Propagation**: This mutual generation allows the fields to detach from the source and propagate through space as a wave.
- **Field Orientation**: E and H fields are perpendicular to each other and to the direction of propagation.

Mnemonic

“”CASES: Charge Acceleration Self-propagates Electro-magnetic Signals””

OR

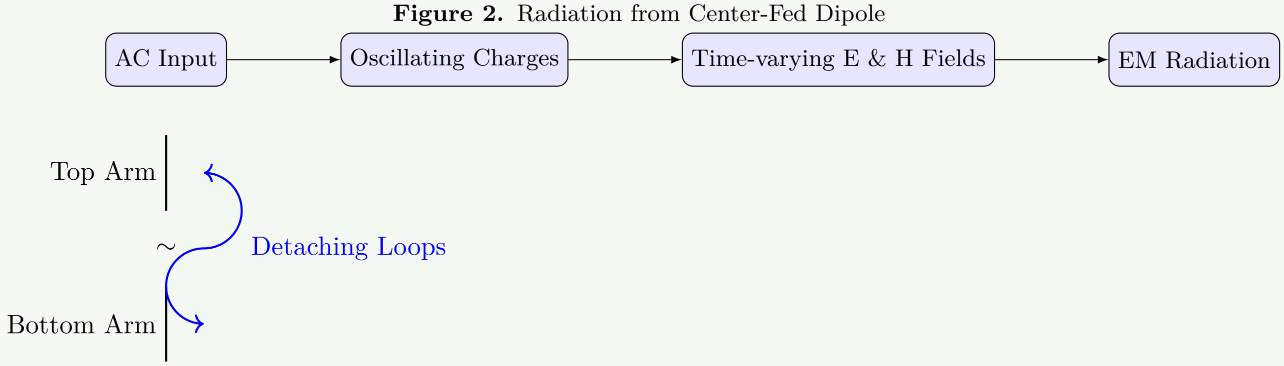
Question 1(c) [7 marks]

Explain how electromagnetic field radiated from a center fed dipole

Solution

Radiation Mechanism of Dipole:

Figure 2. Radiation from Center-Fed Dipole



- **Center Feeding**: An AC voltage source is applied at the center, causing current to flow back and forth.
- **Charge Distribution**: As current oscillates, charges accumulate at the ends of the dipole, reversing polarity

every half cycle.
- **Field Generation**: The oscillating charges create a time-varying electric field. The current flow creates a magnetic field around the wire.
- **Radiation**: As the polarity reverses, the field lines pinch off and detach from the antenna, traveling outwards as electromagnetic waves.
- **Pattern**: Maximum radiation is perpendicular to the wire axis (broadside).

Mnemonic

“”CORONA: Current Oscillates, Radiation Occurs, Near-far Areas””

Question 2(a) [3 marks]

Differentiate the resonant and non-resonant antennas

Solution

Feature	Resonant Antennas	Non-Resonant Antennas
Length	Integer multiple of $\lambda/2$	Not related to wavelength (typically long)
Standing Waves	Present	Not present (Traveling waves)
Impedance	Resistive (Real)	Complex (Real + Imaginary)
Bandwidth	Narrow	Wide
Example	Half-wave dipole	Rhombic antenna

Mnemonic

“”RESI: Resonant Exhibits Standing-waves Impedance-real””

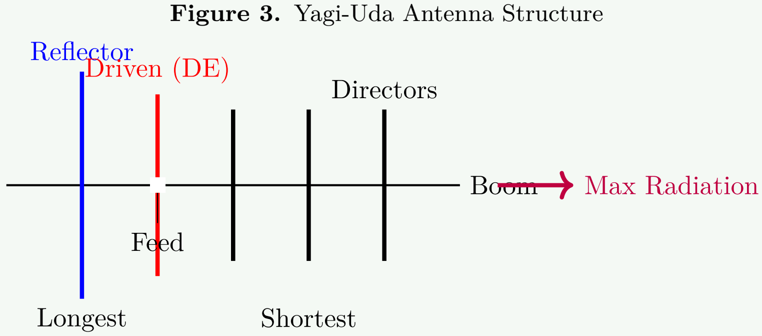
Question 2(b) [4 marks]

Explain Yagi antenna and discuss its radiation characteristics

Solution

Yagi-Uda Antenna: A high-gain directional antenna consisting of a driven element and parasitic elements.

Figure 3. Yagi-Uda Antenna Structure



- **Structure**: 1 Reflector (longest), 1 Driven Element ($\lambda/2$), Multiple Directors (shortest).
- **Directivity**: High (8-12 dB) towards the directors.
- **Gain**: increases with the number of directors (up to 15 dB).
- **Bandwidth**: Narrow (2-5% of center frequency).

- **Application**: TV reception, point-to-point links.

Mnemonic

"”DRAGONS: Directional Reflector And Gain-improving Directors Offer Narrow Signals”"

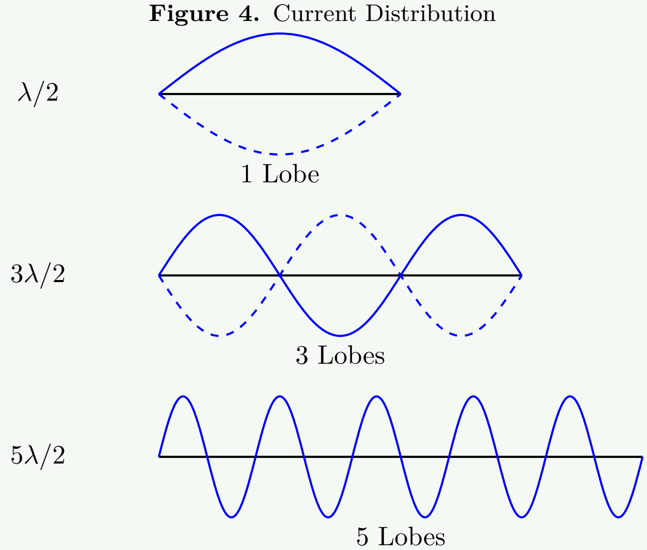
Question 2(c) [7 marks]

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

Solution

Resonant wire antennas have standing wave current distributions with nodes (zero current) at the ends.

Figure 4. Current Distribution



- **Half-Wave ($\lambda/2$)**: Current max at center. Radiation pattern is a simple figure-8 broadside to the wire.
- $3\lambda/2$: Three current loops. Radiation pattern splits into 3 lobes per side (6 total). Major lobes tilt towards the wire axis.
- $5\lambda/2$: Five current loops. Pattern has 5 lobes per side. As length increases, major lobes align closer to the wire axis.
- **General**: Number of current loops = $2L/\lambda$.

Mnemonic

"”NODE: Number Of Distributions Equals wavelength-multiple”"

OR

Question 2(a) [3 marks]

Differentiate the broad side and end fire array antennas

Solution

Feature	Broadside Array	End Fire Array
Max Radiation	Perpendicular to array axis ($90°$)	Along the array axis ($0°, 180°$)
Element Spacing	Typically $\lambda/2$	Typically $\lambda/4$ to $\lambda/2$
Phase Difference	$0°$ (In-phase)	$180°$ (Out of phase)
Directivity	High	High
Pattern	Bidirectional	Unidirectional

Mnemonic

“”PEPS: Perpendicular Elements Produce Sideways radiation””

OR

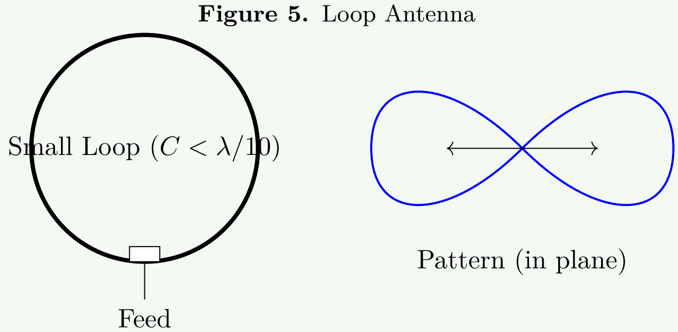
Question 2(b) [4 marks]

Explain loop antenna and discuss its radiation characteristics

Solution

Loop Antenna: A closed circuit antenna, often circular or square.

Figure 5. Loop Antenna



- **Small Loop ($C < \lambda/10$)**: Acts like a magnetic dipole. Radiation pattern is a figure-8 (doughnut) similar to a short electric dipole. Pattern null is along the axis of the loop.
- **Large Loop ($C \approx \lambda$)**: Resonant loop. Radiation is maximum perpendicular to the loop plane (broadside).
- **Polarization**: Linear (Horizontal if loop is horizontal).
- **Applications**: Direction finding, RFID.

Mnemonic

“”SPIRAL: Small Patterns In Receiving And Locating signals””

OR

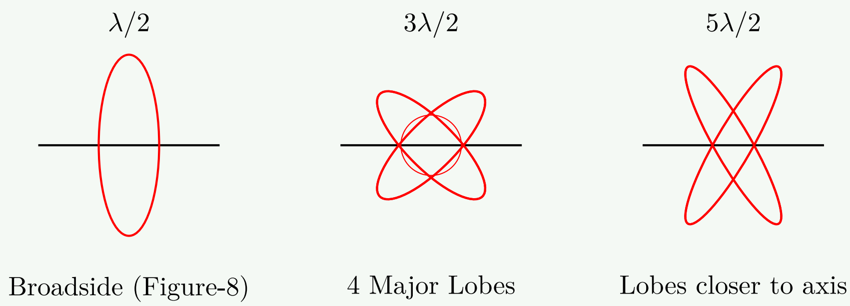
Question 2(c) [7 marks]

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

Non-resonant (Traveling Wave) antennas have matched termination, so no standing waves. However, the question asks for characteristics often associated with resonant lengths in common exams, or long-wire patterns. Assuming the question implies long wire *patterns* (which are directional) or comparison with resonant. Given the specific lengths, standard resonant patterns are usually drawn.

Figure 6. Radiation Patterns



- $\lambda/2$: Single major lobe perpendicular to wire (bidirectional).
- $3\lambda/2$: Major lobes shift towards the wire axis (approx 42°). Minor lobes appear broadside.
- $5\lambda/2$: Major lobes shift even closer to wire axis. More minor lobes.
- **Trend**: As length increases, the main beam sharpens and aligns closer to the wire axis.

Mnemonic

“”TWIST: Traveling Waves Increase Side-lobe Transmission””

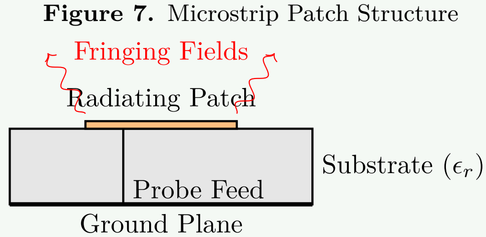
Question 3(a) [3 marks]

Write short note on micro strip (patch) antenna

Solution

Microstrip (Patch) Antenna: Low-profile antenna for modern applications.

Figure 7. Microstrip Patch Structure



- **Structure**: Consists of a metallic patch on a grounded dielectric substrate.
- **Advantages**: Light weight, low profile, low cost, conformable to planar/non-planar surfaces.
- **Disadvantages**: Narrow bandwidth, low efficiency, low power handling.
- **Applications**: Mobile phones, GPS, missiles, satellite communications.

Mnemonic

“”PSALM: Patch Substrate Above Layer of Metal””

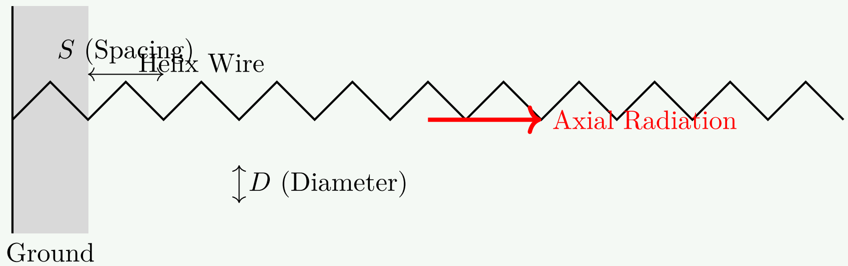
Question 3(b) [4 marks]

Explain helical antenna and discuss its radiation characteristics

Solution

Helical Antenna: Wire wound in the form of a helix/screw, providing circular polarization.

Figure 8. Helical Antenna



- **Normal Mode (Broadside)**: If dimensions << λ, radiation is perpendicular to axis. Low efficiency.
- **Axial Mode (End-fire)**: If Circumference $C \approx \lambda$, radiation is along the axis. High gain and Circular Polarization.
- **Characteristics**: Wide bandwidth (impedance remains resistive).
- **Use**: Satellite tracking (due to CP).

Mnemonic

“”MOCHA: Mode Of Circular Helix Antennas””

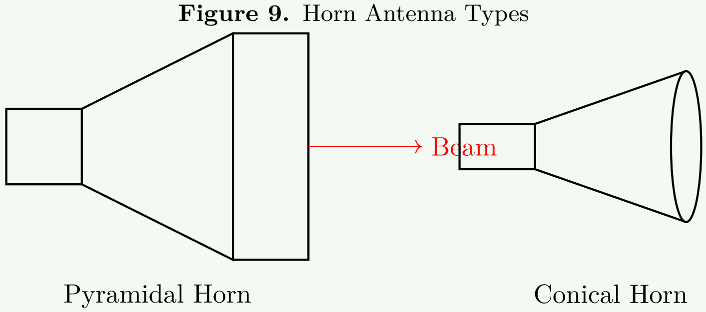
Question 3(c) [7 marks]

Explain horn antenna and discuss its radiation characteristics

Solution

Horn Antenna: Flared waveguide that matches impedance of waveguide to free space.

Figure 9. Horn Antenna Types



- **Impedance Matching**: Smooth flare minimizes reflection coefficient, reducing VSWR.
- **Bandwidth**: Very wide bandwidth compared to other high-gain antennas.
- **Directivity**: Moderate to high (10-20 dB).
- **Side Lobes**: Very low side lobes due to tapered aperture distribution.
- **Types**: Sectoral (E or H plane), Pyramidal (both planes), Conical (circular).
- **Application**: Feed for parabolic dishes, standard gain reference, radar.

Mnemonic

“”POWERS: Pyramidal Or Widening End Radiates Strongly””

OR

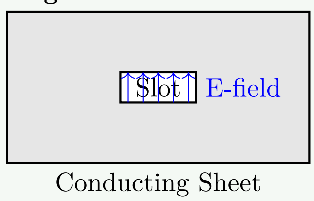
Question 3(a) [3 marks]

Write short note on slot antenna

Solution

Slot Antenna: A slot cut in a conductive surface.

Figure 10. Slot Antenna



- **Babinet’s Principle**: A slot antenna is the ”dual” of a dipole. A horizontal slot radiates vertically polarized waves (opposite to vertical dipole).
- **Impedance**: Related to dipole impedance $Z_s Z_d = \frac{\eta^2}{4}$. High impedance (500 Ω).
- **Application**: Flush mounted on high-speed aircraft/missiles to avoid aerodynamic drag.

Mnemonic

“”CROPS: Complementary Radiation Opening Perpendicular to Surface””

OR

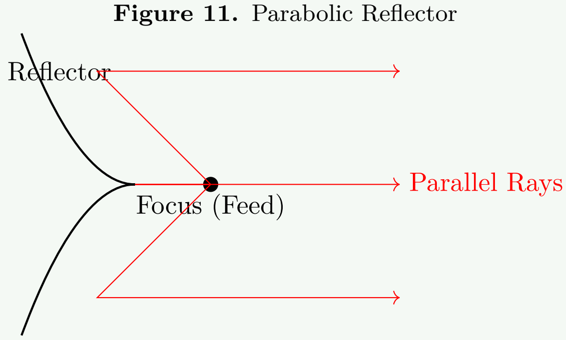
Question 3(b) [4 marks]

Explain parabolic reflector antenna and discuss its radiation characteristics

Solution

Parabolic Reflector: Converts spherical waves from a point source (focus) into plane waves (collimated beam).

Figure 11. Parabolic Reflector



- **High Gain**: Extremely high gain (30-60 dB depending on size).
- **Narrow Beamwidth**: Produces a very sharp ”pencil beam”.

- **F/D Ratio**: Determines the focal length and depth of the dish.
- **Aperture Efficiency**: Typically 55-65%. Affected by spillover, blockage, and surface errors.
- **Use**: Satellite communication links, Radio astronomy.

Mnemonic

“”DISH: Directing Incoming Signals to Hub””

OR

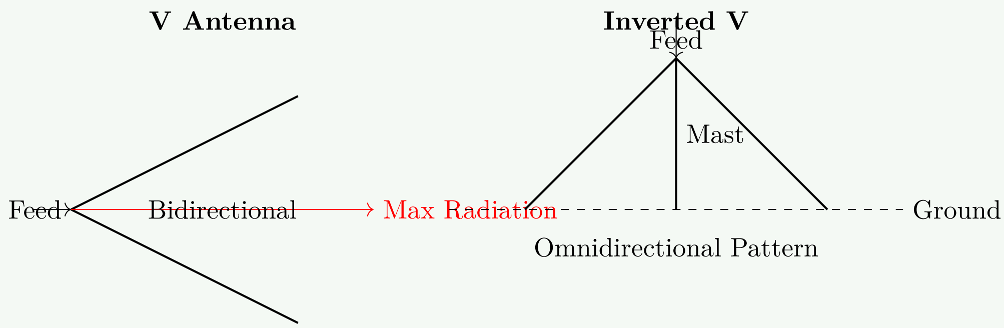
Question 3(c) [7 marks]

Describe V and inverted V antenna

Solution

Traveling wave antennas formed by two wires.

Figure 12. V and Inverted-V Antennas



Feature	V Antenna	Inverted V Antenna
Geometry	Horizontal V shape parallel to ground	Vertical upside-down V shape
Radiation	Bidirectional along the bisector axis	Nearly Omnidirectional (horizontally)
Construction	Needs multiple supports	Needs only one central support (Mast)
Impedance	High (600 Ω)	Low (50 Ω) - easier match
Use	Point-to-point HF communication	Amateur radio (Ham), Limited space

Mnemonic

“”VIVA: V Is Vertical Arrangement, Inverted V Aims downward””

Question 4(a) [3 marks]

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

Solution

Phenomenon	Definition
Reflection	Bouncing back of waves when they strike the boundary between two media (e.g., ground, ionosphere).
Refraction	Bending of waves when they pass from one medium to another with different density/velocity.
Diffraction	Bending of waves around obstacles or spreading through openings. Allows reception behind mountains.

Mnemonic

“”RRD: Rebounding, Redirecting, Detour””

Question 4(b) [4 marks]

List HAM radio application for communication

Solution

Application	Description
Emergency Comm.	Providing vital links during disasters when cell/landlines fail.
DXing	Long-distance international communication for hobby/sport.
Satellite Comm.	Using amateur satellites (OSCAR) for relay.
Digital Modes	Text/data via radio (FT8, PSK31, RTTY).
Morse Code	Traditional CW communication (efficient for weak signals).
Education	Learning electronics and radio physics.

Mnemonic

“”EDSDMVP: Emergency DX Satellite Digital Morse Voice Public-service””

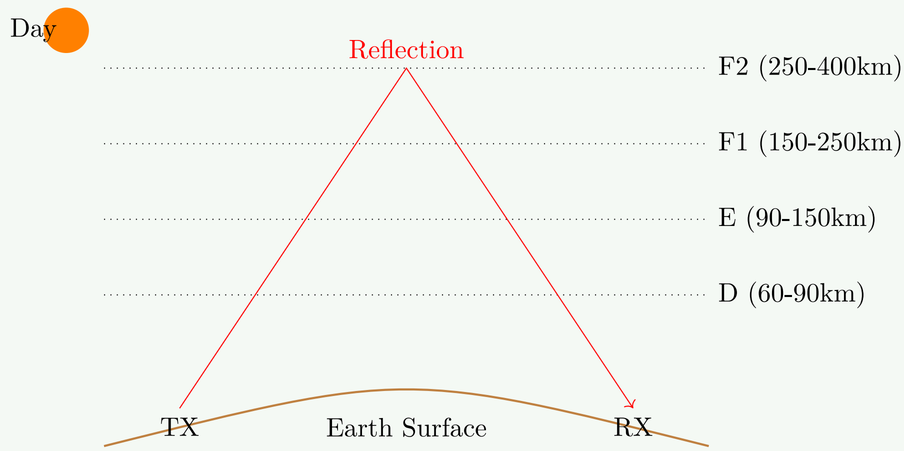
Question 4(c) [7 marks]

Explain ionosphere’s layers and sky wave propagation

Solution

Sky Wave Propagation: Using the ionosphere (ionized upper atmosphere) to reflect signals back to Earth for long-distance (Beyond Line of Sight) communication.

Figure 13. Ionospheric Layers



- **D Layer**: Exists only during day. Absorbs MF/HF signals.
- **E Layer**: Reflects some HF waves. Sporadic-E allows VHF DX.
- **F1 Layer**: Lower part of F-region during day.
- **F2 Layer**: Most important for long-distance HF. Exists day and night (though height varies). Reflects highest frequencies.
- **Mechanism**: UV radiation from sun ionizes atoms. Radio waves enter, bend due to refraction, and return to Earth (Total Internal Reflection).

Mnemonic

“”DEFV: D-absorbs, E-reflects, F-provides Very-long-distance””

OR

Question 4(a) [3 marks]

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

Solution

Term	Definition
MUF	**Maximum Usable Frequency**: The highest f that returns to Earth for a given path. $f_{MUF} = f_c \sec\theta$.
LUF	**Lowest Usable Frequency**: The lowest f where signal > noise. Below LUF, absorption is too high.
Skip Distance	Min distance from TX where sky wave returns. Within this zone, no signal is received (Skip Zone).

Mnemonic

“”MLS: Maximum-highest, Lowest-minimum, Skip-nearest””

OR

Question 4(b) [4 marks]

List HAM radio digital modes of communication

Solution

Mode	Characteristics
FT8	Weak signal mode, 15-second intervals, automated. Very popular for DX.
PSK31	Phase Shift Keying. Narrow bandwidth (31 Hz). Chat-like typing.
RTTY	Radioteletype. Robust, old-school digital text.
SSTV	Slow Scan TV. Transmitting static images via audio tones.
Packet	Data sent in packets (AX.25). Used for APRS.
JT65	Deep space/weak signal mode (precursor to FT8).

Mnemonic

“”FIRST PAD: FT8 Is RTTY SSTV Then Packet APRS Digital-voice””

OR

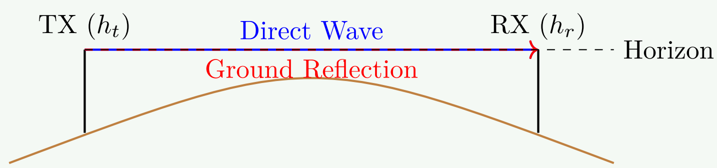
Question 4(c) [7 marks]

Explain space wave propagation

Solution

Space Wave (Tropospheric): Direct Line-of-Sight transmission for VHF, UHF, Microwave (> 30 MHz).

Figure 14. Space Wave Propagation



- **Components**: 1. **Direct Wave**: Travels straight from TX to RX. 2. **Ground Reflected**: Bounces off ground, arriving with phase delay.
- **Range**: Limited by curvature of Earth/Horizon.

$$d = 3.57(\sqrt{h_t} + \sqrt{h_r}) \text{ km}$$

- **Tropospheric Scatter**: Forward scatter from turbulence allows communication slightly beyond horizon.
- **Ducting**: Temperature inversion traps waves, extending range to hundreds of km.

Mnemonic

“”DRIFT: Direct Reflection Inversion Forward Tropospheric””

Question 5(a) [3 marks]

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

Solution

Parameter	Definition
Beam Area (Ω_A)	Solid angle through which all power would radiate if intensity were constant (and equal to max).
Beam Efficiency (ϵ_M)	Ratio of power in the main beam to the total radiated power (Main + Side lobes).
Effective Aperture (A_e)	Virtual area that captures energy from incident wave. $A_e = \frac{\lambda^2}{4\pi}G$.

Mnemonic

“”BEA: Beam Efficiency Aperture””

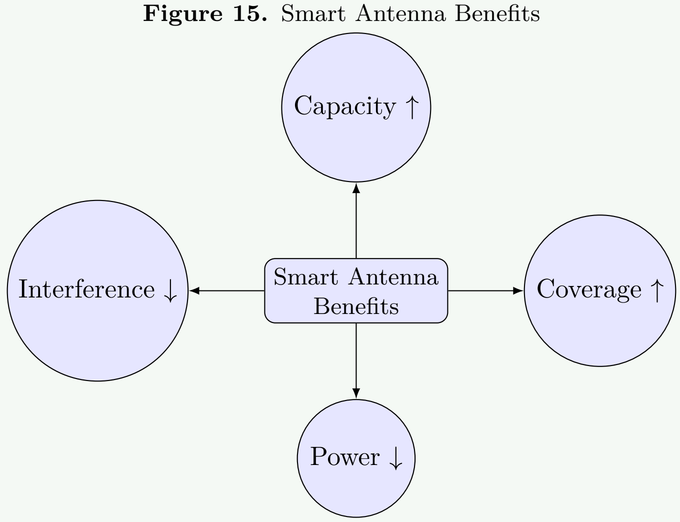
Question 5(b) [4 marks]

Describe need of smart antenna

Solution

Need: To overcome capacity limits and interference in wireless networks.

Figure 15. Smart Antenna Benefits



- **Capacity**: SDMA (Space Division Multiple Access) allows reuse of frequencies.
- **Interference**: Null steering cancels out jammers/co-channel users.
- **Range**: High gain beams extend coverage.
- **Efficiency**: Transmit power is focused only where needed, saving battery.

Mnemonic

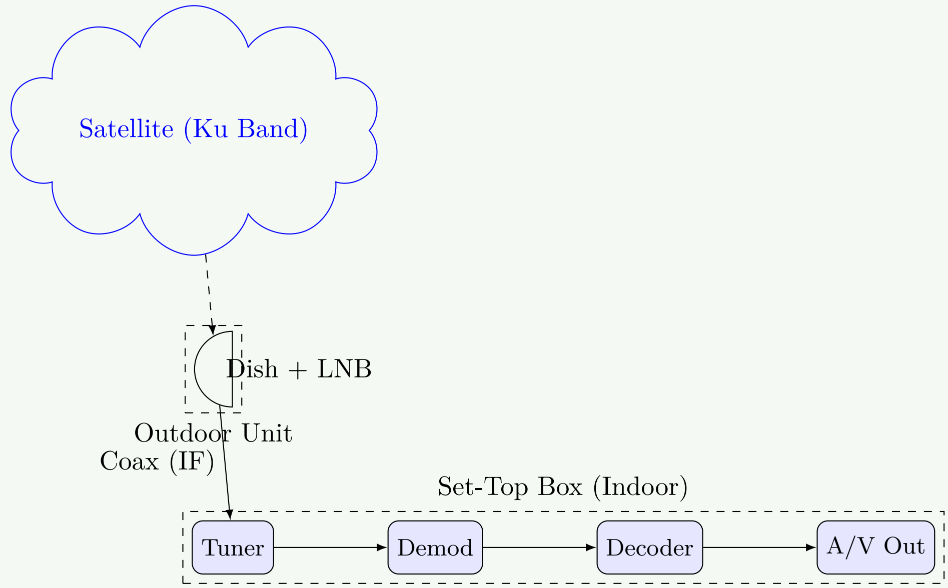
“”PRECISE: Power Reduction, Enhanced Coverage, Interference Suppression, Enhanced Signal””

Question 5(c) [7 marks]

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

Solution

Figure 16. DTH System



- **Outdoor Unit**:
  - **Dish**: Parabolic reflector collects weak satellite signals (10-12 GHz).
  - **LNB**: Downconverts high frequency to Lower IF (950-2150 MHz) for cable transmission.
- **Indoor Unit (STB)**:
  - **Tuner**: Selects the specific transponder frequency.
  - **Demodulator**: Recovers digital stream (QPSK).
  - **Decoder**: Decrypts signals (Smart Card) and decodes MPEG video.
  - **Output**: Sends Audio/Video to TV.

Mnemonic

“”COLD-TDUMS: Collection, Oscillator, Low-noise, Downconversion - Tuner Demodulator Unscrambler MPEG Smart-card””

OR

Question 5(a) [3 marks]

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

Solution

Term	Definition
Antenna	A transducer that converts guided method electrical signals into free-space electromagnetic waves (and vice versa).
Folded Dipole	A dipole with an additional parallel rod connecting the two ends. Higher impedance (300Ω) and wider bandwidth.
Antenna Array	A system of multiple antennas engaged to work together to achieve high directionality and gain.

Mnemonic

“”AFA: Antenna Folded Array””

OR

Question 5(b) [4 marks]

Describe application of smart antenna

Solution

Application	Description
Cellular (4G/5G)	Increasing user capacity, data rates, and reducing dropped calls using Beamforming/MIMO.
Wi-Fi (MIMO)	Wi-Fi routers use multiple antennas to focus signals and improve speed through walls.
Radar	Phased arrays allow rapid scanning without moving parts (AESA radar).
Satellite	Spot beam antennas target specific geographic regions efficiently.
Vehicle	V2X communication for autonomous driving.

Mnemonic

“”MBMRSWI: Mobile Base MIMO Radar Satellite Wi-Fi IoT””

OR

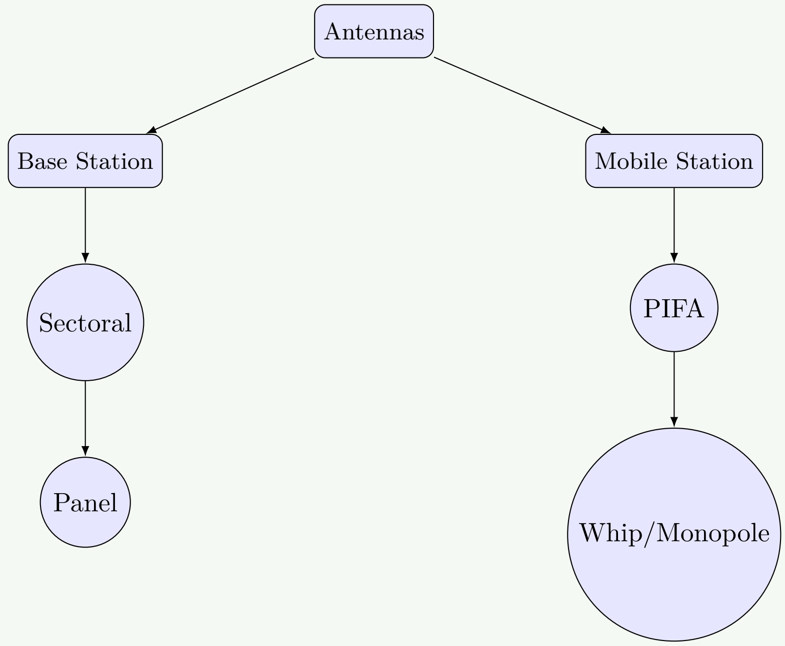
Question 5(c) [7 marks]

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

Solution

Antennas in Mobile Comm:

Figure 17. Mobile Base Antennas



1. **Base Station Antennas (Tower)**:
   - **Sector Antennas**: Vertical panels providing 120° coverage. High gain, directional.
   - **Omni**: Used in rural/sparse areas.
   - **Features**: High poewr handling, weather proof, electrical tilt capability.
2. **Mobile Station Antennas (User)**:
   - **PIFA (Planar Inverted-F)**: Used inside smartphones. Compact, low profile, multiband.
   - **Whip/Monopole**: Used on vehicles. Omnidirectional pattern.
   - **Requirements**: Small size, omnidirectional (to receive from any angle), low SAR.

Mnemonic

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