B.Sc. (HONS.) IN ECE, PART-III, SIXTH SEMESTER EXAMINATION, 2022
ANTENNA AND PROPAGATION
[According to the New Syllabus]
Subject Code: ECE-530827
Examination Code: 5626
Time: 3 hours
Full marks: 80
[N.B. The figures in the right margin indicate full marks. Answer any five questions.]

Marks

Question 1
(a) Function of Antenna (2 marks)
An antenna serves as a transducer that converts electrical energy into electromagnetic waves during transmission and electromagnetic waves into electrical energy during reception. It acts as an interface between the transmitter/receiver and free space, enabling wireless communication by radiating or capturing electromagnetic energy efficiently.
(b) Basic Applications of Antenna (4 marks)
Communication Applications:

- **Broadcasting: Radio and television transmission/reception**
- **Mobile Communications: Cellular phones, WiFi, Bluetooth**
- **Satellite Communications: Uplink and downlink communication with satellites**
- **Point-to-Point Links: Microwave communication links**

Other Applications:

- **Radar Systems: Detection and tracking of objects**
- **Radio Astronomy: Receiving signals from celestial bodies**
- **Medical Applications: Diathermy, hyperthermia treatment**
- **Industrial Heating: Microwave ovens, material processing**

(c) Classification of Antennas Based on Frequency Range (5 marks)

Frequency Band	Range	Antenna Types	Applications
VLF (Very Low Frequency)	3-30 kHz	Large wire antennas, ground wave antennas	Navigation, submarine communication
LF (Low Frequency)	30-300 kHz	Loop antennas, long wire antennas	AM broadcasting, navigation
MF (Medium Frequency)	300 kHz-3 MHz	Monopole, loop antennas	AM radio, marine communication
HF (High Frequency)	3-30 MHz	Dipole, rhombic, log-periodic	Amateur radio, international broadcasting

Frequency Band	Range	Antenna Types	Applications
VHF (Very High Frequency)	30-300 MHz	Yagi-Uda, turnstile, helical	FM radio, TV, mobile communication
UHF (Ultra High Frequency)	300 MHz-3 GHz	Parabolic, horn, microstrip	TV, cellular, GPS
SHF (Super High Frequency)	3-30 GHz	Parabolic reflectors, horn antennas	Satellite communication, radar
EHF (Extremely High Frequency)	30-300 GHz	Horn antennas, lens antennas	Millimeter wave communication

(d) Construction of Lens Antenna (5 marks)
Basic Principle: Lens antennas work on the principle of refraction, similar to optical lenses, to focus electromagnetic waves.
Construction Elements:

1. **Primary Feed: Usually a horn antenna placed at the focal point**
2. **Lens Material: Dielectric material with specific refractive index**
3. **Lens Shape: Designed to provide required phase correction**

Types of Lens Antennas:
1. Dielectric Lens:

- **Made of low-loss dielectric material (polystyrene, Teflon)**
- **Thickness varies to provide required phase delay**
- **Refractive index $n > 1$**

2. Metal Plate Lens:

- **Consists of parallel metal plates with varying spacing**
- **Acts as artificial dielectric with $n < 1$**
- **Lighter than dielectric lens**

Design Considerations:

- **Focal length determines antenna size and gain**
- **Lens diameter affects beamwidth and sidelobe levels**
- **Material selection based on frequency and loss requirements**

Question 2
(a) Radiation Pattern and Radiation Pattern Lobes (6 marks)
Radiation Pattern Definition: A radiation pattern is a graphical representation of the radiation properties of an antenna as a function of space coordinates. It shows how the antenna radiates energy in different directions.
Mathematical Expression: The radiation pattern is typically expressed as: $F(\theta,\varphi) = |E(\theta,\varphi)|^2$ or $F(\theta,\varphi) = |H(\theta,\varphi)|^2$
Where θ and φ are spherical coordinates.
Types of Radiation Pattern Lobes:
1. Main Lobe (Major Lobe):

- **The radiation lobe containing the maximum radiation**

- **Defines the antenna's primary direction of radiation**
- **Contains most of the radiated power**

2. Side Lobes:

- **Radiation lobes adjacent to the main lobe**
- **Separated from main lobe by nulls**
- **Represent undesired radiation in unwanted directions**

3. Back Lobe:

- **Radiation lobe opposite to the main lobe**
- **180° away from main beam direction**
- **Should be minimized for directional antennas**

4. Minor Lobes:

- **All lobes other than the main lobe**
- **Include side lobes and back lobes**

(b) Radian, Steradian, and Beam Area (6 marks)

Radian:

- **Unit of plane angle measurement**
- **One radian is the angle subtended by an arc equal to the radius**
- **Mathematical Expression: $\theta = s/r$ (where s = arc length, r = radius)**
- **2π radians = 360°**

Steradian:

- **Unit of solid angle measurement in 3D space**
- **One steradian is the solid angle subtended by area equal to r^2 on sphere surface**
- **Mathematical Expression: $\Omega = A/r^2$ (where A = surface area, r = radius)**
- **Total solid angle around a point = 4π steradians**

Beam Area (Ω_A): The beam area is the solid angle through which all power would be radiated if the antenna maintained its maximum radiation intensity in all directions within the angle.

Mathematical Expression: $\Omega_A = \iint F_n(\theta,\varphi)\, d\Omega$

Where $F_n(\theta,\varphi)$ is the normalized radiation intensity.

Alternative Expression: $\Omega_A = \left(\int_0^{\pi} \int_0^{2\pi} |F(\theta,\varphi)|^2 \sin\theta \, d\varphi \, d\theta\right) / |F(\theta,\varphi)|^2_{max}$

(c) Total Radiated Power Calculation (4 marks)

Given: $W_{rad} = \hat{a}_r A_0(\sin\theta/r^2)(w/m^2)$

Step 1: Set up the integration Total radiated power $P_{rad} = \iint W_{rad} \cdot dS$

Where $dS = r^2 \sin\theta \, d\theta \, d\varphi$ (surface element in spherical coordinates)

Step 2: Substitute and integrate $P_{rad} = \int_0^{2\pi} \int_0^{\pi} A_0(\sin\theta/r^2) \times r^2 \sin\theta \, d\theta \, d\varphi$

$P_{rad} = A_0 \int_0^{2\pi} d\varphi \int_0^{\pi} \sin^2\theta \, d\theta$

Step 3: Evaluate integrals $\int_0^{2\pi} d\varphi = 2\pi$

$\int_0^{\pi} \sin^2\theta \, d\theta = \pi/2$

Step 4: Final result $P_{rad} = A_0 \times 2\pi \times \pi/2 = \pi^2 A_0$ watts

Question 3

(a) Near Field and Far Field Regions (3 marks)

Near Field Region (Fresnel Zone):

- **Distance from antenna: $r < 2D^2/\lambda$**
- **Electromagnetic fields are complex and vary rapidly with distance**
- **Reactive field components are significant**
- **Field pattern depends on distance from antenna**

Far Field Region (Fraunhofer Zone):

- **Distance from antenna: $r > 2D^2/\lambda$**
- **Electromagnetic fields vary as 1/r**

- **Only radiating field components exist**
- **Radiation pattern is independent of distance**
- **Used for antenna measurements and communication**

Boundary Distance: $R = 2D^2/\lambda$ (where D = largest antenna dimension, λ = wavelength)

(b) Microwave Dish Antenna Construction and Working (6 marks)

Construction:

1. **Parabolic Reflector: Made of conducting material (aluminum, steel mesh)**
2. **Primary Feed: Horn antenna, dipole, or waveguide feed at focal point**
3. **Support Structure: Mechanical mounting system**
4. **Sub-reflector: (In Cassegrain configuration) Secondary reflector**

Working Principle:

Transmission Mode:

- **Feed antenna radiates spherical waves from focal point**
- **Parabolic reflector converts spherical waves to plane waves**
- **All rays travel equal electrical path length**
- **Results in highly directional beam with high gain**

Reception Mode:

- **Parallel incoming waves are focused to the feed point**
- **Parabolic surface concentrates received energy**
- **Feed antenna collects focused energy and converts to guided waves**

Key Features:

- **High gain (25-60 dB typical)**
- **Narrow beamwidth (0.5° to 10°)**
- **Low sidelobe levels when properly designed**
- **Frequency independent reflector (feed limits bandwidth)**

(c) Radiation Resistance and Radiation Efficiency (4 marks)

Radiation Resistance (R_r): The radiation resistance is the equivalent resistance that would dissipate power equal to the total radiated power when carrying the feed point current.

Mathematical Definition: $R_r = 2P_{rad}/I^2$

Where P_{rad} = total radiated power, I = feed point current

Physical Significance:

- **Represents the antenna's ability to radiate power**
- **Higher R_r indicates better radiation capability**
- **Typical values: 36.5Ω for $\lambda/4$ monopole, 73Ω for $\lambda/2$ dipole**

Radiation Efficiency (η_r): The ratio of radiated power to total input power.

Mathematical Expression: $\eta_r = P_{rad}/P_{in} = R_r/(R_r + R_{loss})$

Where R_{loss} includes conductor losses, dielectric losses, and ground losses.

Typical Values:

- **Well-designed antennas: $\eta_r > 90\%$**
- **Electrically small antennas: η_r may be $< 50\%$**

(d) Mutual Impedance (3 marks)

Definition: Mutual impedance between two antennas is the ratio of voltage induced in one antenna to the current flowing in the other antenna when they are in proximity.
Mathematical Expression: $Z_{12} = V_1/I_2$ (voltage in antenna 1 due to current in antenna 2) $Z_{21} = V_2/I_1$ (voltage in antenna 2 due to current in antenna 1)
Reciprocity: $Z_{12} = Z_{21}$
Factors Affecting Mutual Impedance:

- **Distance between antennas**
- **Relative orientation**
- **Operating frequency**
- **Antenna types and sizes**

Applications:

- **Array antenna design**
- **Antenna coupling analysis**
- **MIMO system design**

Question 4
(a) RADAR Range Equation (6 marks)
Basic RADAR Range Equation:
$R_{max} = [(P_t G_t G_r \lambda^2 \sigma)/(64\pi^3 P_{min})]^{(1/4)}$
Where:

- **R_{max} = Maximum detection range**
- **P_t = Transmitted power**
- **G_t = Transmitting antenna gain**
- **G_r = Receiving antenna gain**
- **λ = Wavelength**
- **σ = Target radar cross-section**
- **P_{min} = Minimum detectable signal power**

Derivation Steps:
Step 1: Power density at target $S_1 = (P_t G_t)/(4\pi R^2)$
Step 2: Power intercepted by target $P_{intercepted} = S_1 \times \sigma = (P_t G_t \sigma)/(4\pi R^2)$
Step 3: Power density back at radar (assuming isotropic scattering) $S_2 = P_{intercepted}/(4\pi R^2) = (P_t G_t \sigma)/(16\pi^2 R^4)$
Step 4: Power received by radar antenna $P_r = S_2 \times A_{eff} = S_2 \times (G_r \lambda^2)/(4\pi) = (P_t G_t G_r \lambda^2 \sigma)/(64\pi^3 R^4)$
Step 5: For detection: $P_r = P_{min}$ Solving for R gives the range equation above.
(b) Working Principles of RADAR System (5 marks)
Basic Principle: RADAR works on the principle of echo - transmitting electromagnetic waves and detecting reflections from targets.
System Components:

1. **Transmitter: Generates high-power RF pulses**
2. **Antenna: Radiates and receives electromagnetic energy**
3. **Receiver: Amplifies and processes received signals**
4. **Signal Processor: Extracts target information**
5. **Display: Shows processed information to operator**

Operating Sequence:

1. **Transmission Phase:**
   - **Transmitter generates short RF pulse**
   - **Antenna radiates pulse in specific direction**
   - **Pulse travels at speed of light ($c = 3\times10^8$ m/s)**
2. **Reception Phase:**
   - **Reflected signals return to antenna**
   - **Receiver processes weak echo signals**
   - **Time delay indicates target range: $R = ct/2$**
3. **Information Extraction:**
   - **Range: From time delay measurement**
   - **Bearing: From antenna pointing direction**
   - **Velocity: From Doppler frequency shift**
   - **Size: From echo strength**

(c) Operation of Microstrip Antenna (5 marks)

Structure:

- **Patch: Conducting patch on top layer**
- **Substrate: Dielectric material (ε_r = 2-12)**
- **Ground Plane: Conducting layer at bottom**
- **Feed Network: Microstrip line, probe, or aperture coupling**

Operating Principle:

Resonance Mechanism:

- **Patch acts as resonant cavity with magnetic walls at edges**
- **Dominant mode is TM_{10} (or TM_{01})**
- **Resonant length: $L \approx \lambda_0/(2\sqrt{\varepsilon_{re}ff})$**

Radiation Mechanism:

- **Fringing fields at patch edges create radiation**
- **Patch edges act as radiating slots**
- **Two slots separated by $\lambda/2$ radiate in phase**
- **Results in broadside radiation pattern**

Key Features:

- **Low Profile: Thin structure ($h \ll \lambda$)**
- **Lightweight: Suitable for mobile applications**
- **Easy Integration: Compatible with RF circuits**
- **Dual/Circular Polarization: Achievable with proper feed**

Limitations:

- **Narrow bandwidth (1-5% typical)**
- **Lower gain compared to other antennas**
- **Surface wave losses in thick substrates**

Question 5

(a) Yagi-Uda Antenna (6 marks)

Definition: Yagi-Uda antenna is a directional antenna consisting of multiple parallel elements arranged collinearly with one driven element and multiple parasitic elements.

Construction Elements:

1. Driven Element:

- **Usually a folded dipole (λ/2 length)**
- **Connected to transmission line**
- **Primary radiating element**

2. Reflector:

- **Single element behind driven element**
- **Length: 0.52λ to 0.55λ (longer than driven element)**
- **Spacing: 0.15λ to 0.25λ from driven element**

3. Directors:

- **Multiple elements in front of driven element**
- **Length: 0.4λ to 0.45λ (shorter than driven element)**
- **Spacing: 0.1λ to 0.3λ between elements**

Working Principle:

- **Driven element radiates electromagnetic energy**
- **Parasitic elements re-radiate due to induced currents**
- **Proper phasing creates constructive interference in forward direction**
- **Destructive interference reduces radiation in backward direction**

Characteristics:

- **Gain: 6-20 dB depending on number of elements**
- **Front-to-Back Ratio: 15-25 dB**
- **Bandwidth: Relatively narrow (5-10%)**
- **Impedance: 50-300Ω depending on design**

(b) Helical Antenna (6 marks)

Definition: A helical antenna consists of a conducting wire wound in helical (spiral) form, usually mounted over a ground plane.

Construction:

- **Helix: Conducting wire in spiral form**
- **Ground Plane: Circular conducting plane (diameter ≥ 0.75λ)**
- **Feed Point: Between helix and ground plane**
- **Support Structure: Non-conducting material**

Operating Modes:

1. Normal Mode (Small Helix):

- **Condition: Circumference C << λ**
- **Polarization: Linear**
- **Pattern: Omnidirectional (broadside to axis)**
- **Applications: Mobile communications**

2. Axial Mode (Large Helix):

- **Condition: Circumference C ≈ λ**
- **Polarization: Circular (RHCP or LHCP)**
- **Pattern: End-fire (along axis)**
- **Applications: Satellite communications**

Design Parameters:

- **Circumference: $C = \pi D \approx \lambda$ for axial mode**
- **Pitch Angle: $\alpha = \tan^{-1}(S/\pi D) \approx 12\text{-}15°$**
- **Number of Turns: N determines gain**
- **Spacing: S between turns**

Advantages:

- **Circular polarization capability**
- **Wide bandwidth**
- **Simple construction**
- **Good efficiency**

(c) Maximum Effective Aperture Calculation (4 marks)

Given:

- **Microwave antenna with directivity D = 900**
- **Need to find maximum effective aperture**

Formula: The relationship between directivity and maximum effective aperture: $D = (4\pi A\_max)/\lambda^2$

Rearranging for maximum effective aperture: $A\_max = (D\lambda^2)/(4\pi)$

Substituting values: $A\_max = (900 \times \lambda^2)/(4\pi)$ $A\_max = (900\lambda^2)/(4 \times 3.14159)$ $A\_max = (900\lambda^2)/12.566$ $A\_max = 71.62\lambda^2$ square units

Alternative Expression: If operating frequency is given, $\lambda = c/f$, then: $A\_max = 71.62 \times (c/f)^2$ square meters

Physical Interpretation: This represents the maximum effective area that the antenna can present to an incoming electromagnetic wave for power extraction.

Question 6

(a) Properties of Lens Antenna (3 marks)

1. Focusing Properties:

- **Focuses electromagnetic waves like optical lens**
- **Converts spherical waves to plane waves (transmission)**
- **Focuses parallel waves to feed point (reception)**

2. Frequency Characteristics:

- **Broadband operation possible**
- **Performance depends on lens material properties**
- **Focal length varies with frequency**

3. Radiation Properties:

- **High gain achievable (20-50 dB)**
- **Low sidelobe levels when properly designed**
- **Symmetric radiation pattern**

(b) Dipole Antenna (5 marks)

Definition: A dipole antenna consists of two identical straight conductors placed end-to-end with a small gap where the feed line is connected.

Construction:

- **Length: Usually $\lambda/2$ for resonance**
- **Diameter: Much smaller than length (thin wire approximation)**
- **Gap: Small separation for feed connection**

- **Feed Point: At center for symmetrical operation**

Radiation Mechanism:

Current Distribution:

- **Sinusoidal current distribution along length**
- **Maximum current at center, zero at ends**
- **Current: $I(z) = I_0 \sin[k(h-|z|)]$ for $|z| \leq h$**

Electric Field: The radiated electric field in far field: $E_\theta = j\eta_0 I_0 e^{(-jkr)}/(2\pi r) \times [\cos(kh \cos\theta) - \cos(kh)]/\sin\theta$

Radiation Pattern:

- **Figure-eight pattern in elevation plane**
- **Omnidirectional in azimuth plane**
- **Maximum radiation perpendicular to antenna**
- **Nulls along antenna axis**

Key Parameters:

- **Radiation Resistance: 73Ω for λ/2 dipole**
- **Directivity: 1.64 (2.15 dB)**
- **Bandwidth: About 10% for VSWR < 2:1**

(c) Mechanism of Patch Antenna (4 marks)

Physical Structure:

- **Rectangular/circular metallic patch on grounded substrate**
- **Substrate thickness $h \ll \lambda$ (typically 0.01λ to 0.05λ)**
- **Ground plane prevents back radiation**

Resonance Mechanism:

Cavity Model:

- **Patch and ground plane form resonant cavity**
- **Magnetic walls at radiating edges (E = 0)**
- **Electric walls at patch and ground plane (H = 0)**
- **Dominant mode: TM_{10} for rectangular patch**

Resonant Dimensions: For rectangular patch: $L = \lambda_0/(2\sqrt{\varepsilon_{re}ff})$ Where $\varepsilon_{re}ff$ = effective dielectric constant

Radiation Mechanism:

Fringing Fields:

- **Strong fringing fields at patch edges**
- **Edges act as radiating apertures/slots**
- **Two slots separated by ≈ λ/2**

Equivalent Model:

- **Each radiating edge modeled as slot antenna**
- **Two slots radiate in phase for broadside pattern**
- **Pattern multiplication of single slot pattern**

Field Distribution:

- **Electric field mainly in z-direction (vertical)**
- **Magnetic field in x-y plane**
- **Standing wave pattern inside patch**

(d) Directivity Calculation for Helix (4 marks)
Given:

- **40-turn helix**
- **Pitch angle $\alpha = 24°$**
- **Circumference = one wavelength ($C = \lambda$)**

Directivity Formula for Helical Antenna: For axial mode helical antenna: $D = 15N(S/\lambda)^2/(\tan \alpha)^2$
Where:

- **N = number of turns = 40**
- **S = spacing between turns**
- **α = pitch angle = 24°**

Step 1: Find spacing S From geometry: $S = C \times \tan \alpha = \lambda \times \tan(24°)$ $S = \lambda \times 0.4452 = 0.4452\lambda$
Step 2: Calculate directivity $D = 15 \times 40 \times (0.4452\lambda/\lambda)^2 / (\tan 24°)^2$ $D = 600 \times (0.4452)^2 / (0.4452)^2$ $D = 600$
Step 3: Convert to dB $D_{dB} = 10 \log_{10}(600) = 10 \times 2.778 = 27.78$ dB
Alternative Approximation: For axial mode helix: $D \approx 12N(S/\lambda)^2 \approx 12 \times 40 \times (0.4452)^2 \approx 95.7$ (19.8 dB)
The exact value depends on the specific formula used and design parameters.
Question 7: Short Notes on Antenna Types (Choose any 4 out of 5 - 4×4=16 marks)
(a) Log Periodic Antenna
Definition & Structure: Log Periodic Antenna is a frequency-independent antenna that maintains relatively constant electrical characteristics over a wide frequency range. It consists of multiple dipole elements of varying lengths arranged in a specific geometric progression.
Key Features:

- **Frequency ratio between adjacent elements follows a logarithmic relationship**
- **Elements are connected alternately to opposite sides of a two-wire transmission line**
- **Provides unidirectional radiation pattern**
- **Typical frequency bandwidth ratio of 10:1 or higher**

Applications: Television reception, broadband communications, and EMC testing due to its wide frequency coverage and stable radiation characteristics.
(b) Helical Antenna
Definition & Structure: A helical antenna consists of a conducting wire wound in the form of a helix (spiral) and is typically mounted over a ground plane. The helix acts as a slow-wave structure.
Operating Modes:

- **Normal Mode: When circumference $\ll \lambda$, provides omnidirectional pattern with linear polarization**
- **Axial Mode: When circumference $\approx \lambda$, provides unidirectional end-fire radiation with circular polarization**

Key Parameters:

- **Pitch angle, number of turns, and circumference determine radiation characteristics**
- **Excellent for satellite communications due to circular polarization**
- **High gain achievable with multiple turns**

Applications: Satellite tracking, space communications, and mobile communications where circular polarization is required.

(c) Yagi-Uda Antenna

Definition & Structure: Yagi-Uda antenna is a directional antenna consisting of multiple parallel elements: one driven element (usually a folded dipole), one reflector, and one or more directors arranged collinearly.

Operating Principle:

- **Driven element is fed directly and radiates electromagnetic energy**
- **Reflector (longer than driven element) reflects energy forward**
- **Directors (shorter than driven element) direct energy in forward direction**
- **Elements are parasitically coupled through mutual impedance**

Characteristics:

- **High directivity and gain (typically 6-20 dB)**
- **Good front-to-back ratio**
- **Relatively narrow bandwidth**
- **Simple and cost-effective design**

Applications: Television reception, amateur radio, point-to-point communications, and radar applications.

(d) Loop Antenna

Definition & Structure: A loop antenna consists of a conducting wire formed into a closed loop of various shapes (circular, rectangular, or square). Can be electrically small or large depending on circumference relative to wavelength.

Types:

- **Small Loop ($C \ll \lambda$): Acts as magnetic dipole, provides omnidirectional pattern in plane perpendicular to loop**
- **Large Loop ($C \approx \lambda$): Acts as electric antenna with multiple lobes in radiation pattern**

Key Characteristics:

- **Small loops have very low radiation resistance and high reactance**
- **Null in radiation pattern along the axis of the loop**
- **Can provide sharp directional nulls useful for direction finding**
- **Magnetic field coupling predominates in small loops**

Applications: Direction finding, AM radio reception, RFID systems, and as sensing elements in various applications.

(e) Collinear Array

Definition & Structure: A collinear array consists of multiple antenna elements (usually dipoles or monopoles) arranged end-to-end along a straight line, all lying along the same axis and operating in phase.

Operating Principle:

- **Elements are fed in phase to produce constructive interference in broadside direction**
- **Radiation patterns of individual elements combine to produce narrow beamwidth in elevation plane**
- **Maintains omnidirectional coverage in azimuth plane**

Key Features:

- **Increased gain compared to single element (approximately 3 dB per doubling of elements)**
- **Narrow elevation beamwidth with omnidirectional azimuth coverage**
- **Simple feeding network required**
- **Vertical polarization typically used**

Applications: Base station antennas for cellular communications, FM broadcasting, two-way radio systems, and wireless communication where omnidirectional coverage with increased gain is required.