B.Sc (HONS.) ECE PART-III, SIXTH SEMESTER EXAMINATION, 2020
ANTENNA AND PROPAGATIONS
Subject Code: ECP-314
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Time: 3 hours
Full marks: 80

N.B. The figures in the right margin indicate full marks. Answer any five questions

Question 1

(a) What is the function of antenna? [2 marks]

An antenna is a transducer that converts electrical energy into electromagnetic waves (during transmission) and electromagnetic waves back into electrical energy (during reception). It serves as the interface between guided waves in transmission lines and free-space electromagnetic waves.

(b) Write some important applications of antenna. [4 marks]

1. **Broadcasting**: Radio and television transmission
2. **Mobile Communications**: Cellular networks, WiFi, Bluetooth
3. **Satellite Communications**: GPS, satellite TV, communication satellites
4. **Radar Systems**: Weather monitoring, air traffic control, military applications
5. **Medical Applications**: Microwave therapy, medical imaging
6. **Wireless Networks**: Internet connectivity, data transmission

(c) Define isotropic, directional and omnidirectional antenna. [3 marks]

- **Isotropic Antenna**: A theoretical point source that radiates power uniformly in all directions. It serves as a reference for antenna gain calculations.
- **Directional Antenna**: An antenna that radiates or receives electromagnetic waves more effectively in some directions than others. Examples: Yagi, parabolic dish antennas.
- **Omnidirectional Antenna**: An antenna that radiates power uniformly in one plane (usually horizontal) while having directivity in the perpendicular plane. Examples: vertical monopole, dipole antennas.

(d) Friis Transmission Equation [7 marks]

The Friis transmission equation relates the power received to power transmitted in free space:

$$P_r/P_t = (G_t \times G_r \times \lambda^2)/(4\pi R)^2$$

Where:

- P_r = Power received
- P_t = Power transmitted
- G_t = Transmitting antenna gain
- G_r = Receiving antenna gain
- λ = Wavelength
- R = Distance between antennas

Derivation:

1. Power density at distance R from isotropic source: $S = P_t/(4\pi R^2)$
2. With transmitting antenna gain Gt: $S = P_tG_t/(4\pi R^2)$
3. Effective aperture of receiving antenna: $A_e = G_r\lambda^2/(4\pi)$

4. Power received: $P_r = S \times A_e = (P_tG_t/(4\pi R^2)) \times (G_r\lambda^2/(4\pi))$
5. Therefore: $P_r/P_t = (G_tG_r\lambda^2)/(4\pi R)^2$

Question 2

(a) Radiation pattern and lobes [6 marks]

Radiation Pattern: A mathematical function or graphical representation of the radiation properties of an antenna as a function of space coordinates.

Types of Lobes:

1. **Main Lobe**: The lobe containing the direction of maximum radiation
2. **Side Lobes**: All lobes other than the main lobe
3. **Back Lobe**: The lobe in the direction opposite to the main lobe
4. **Minor Lobes**: Side lobes and back lobes collectively

(b) Define Radian and Steradian [4 marks]

Radian: Unit of plane angle. One radian is the angle subtended at the center of a circle by an arc equal in length to the radius.

- Mathematical expression: $\theta = s/r$ (where s = arc length, r = radius)
- 2π radians = 360°

Steradian: Unit of solid angle. One steradian is the solid angle subtended at the center of a sphere by a surface area equal to the square of the radius.

- Mathematical expression: $\Omega = A/r^2$ (where A = surface area, r = radius)
- 4π steradians = total solid angle around a point

(c) Wave propagation calculations [6 marks]

Given:

- $f = 900$ MHz, $\mu_r = 1$, $\varepsilon_r = 3$, $\sigma = 0.01$ S/m
- $E = 1$ V/m at $Z = 0$

Solution:

(i) Wave impedance: $\eta = \eta_0\sqrt{(\mu_r/\varepsilon_r)} = 377\sqrt{(1/3)} = 217.7\ \Omega$

(ii) Magnetic field at Z = 0: $H = E/\eta = 1/217.7 = 4.59$ mA/m

(iii) Average power in 0.5 m² area: $P_{av} = (1/2) \times \mathrm{Re}(E \times H^*) \times \text{Area} = (1/2) \times (E^2/\eta) \times 0.5 = 1.15$ mW

(iv) Time for 10 cm travel: $v = c/\sqrt{\varepsilon_r} = 3\times10^8/\sqrt{3} = 1.73\times10^8$ m/s $t = 0.1/v = 0.577$ ns

Question 3

(a) Dipole antenna and half-wave dipole [6 marks]

Dipole Antenna: A straight electrical conductor measuring half a wavelength from end to end and connected at the center to a radio-frequency feed line.

Working Principles of Half-wave Dipole:

1. **Current Distribution**: Sinusoidal current distribution with maximum at center and zero at ends
2. **Voltage Distribution**: Minimum at center (feed point) and maximum at ends
3. **Radiation**: Current creates time-varying magnetic field, which produces electromagnetic waves
4. **Resonance**: At half-wavelength, input impedance is purely resistive (~73Ω)

(b) Conduction-dielectric efficiency calculation [6 marks]

Given: $\sigma = 5.7\times10^7$ S/m, $f = 100$ MHz, $b = 3\times10^{-4}\lambda$, $R_r = 73\Omega$

Solution:

1. Calculate loss resistance: $R_l = \sqrt{\pi f \mu_0/(2\sigma)} \times (1/2\pi b)$
2. Surface resistance: $R_s = \sqrt{\pi f \mu_0/\sigma} = 2.62\times10^{-3}\ \Omega$
3. Loss resistance: $R_l = R_s/(2\pi b) = 1.39\ \Omega$
4. Efficiency: $\eta_{cd} = R_r/(R_r + R_l) = 73/(73 + 1.39) = 98.1\%$

(c) Near-field and Far-field Regions [4 marks]

Near-field Region (Reactive Near-field):

- Distance: $r < 0.62\sqrt{D^3/\lambda}$
- Reactive energy storage dominates
- Fields are not in time phase
- Power flow is oscillatory

Far-field Region (Fraunhofer Region):

- Distance: $r > 2D^2/\lambda$
- Radiation dominates
- Wave impedance = η_0
- Fields are in time phase
- Power flows outward

Question 4

(a) Various forms of antenna arrays [4 marks]

1. **Linear Array**: Elements arranged in a straight line
2. **Planar Array**: Elements arranged in a plane (rectangular/circular)
3. **Circular Array**: Elements arranged in a circle
4. **Conformal Array**: Elements mounted on curved surfaces

(b) Antenna gain definition [2 marks]

Antenna gain is the ratio of radiation intensity in a given direction to the radiation intensity that would be produced by an isotropic antenna with the same total input power.

$G = (4\pi/P_{rad}) \times U(\theta,\varphi)$

(c) Array factor for two-element array [6 marks]

For two point sources with equal amplitude and phase: $AF = 1 + e^{jkd\cos\theta}$

Where:

- $k = 2\pi/\lambda$ (wave number)
- d = spacing between elements
- θ = angle from array axis

(d) Maximum effective aperture calculation [4 marks]

Given: $\lambda = 3$m, $D = 300$

Maximum effective aperture: $A_{em} = (D \times \lambda^2)/(4\pi) = (300 \times 9)/(4\pi) = 214.9\ m^2$

Question 5

(a) RADAR system [5 marks]

RADAR (Radio Detection and Ranging): A detection system that uses radio waves to determine range, angle, and velocity of objects.

Working Principles:

1. **Transmission**: Transmitter generates high-power RF pulses
2. **Propagation**: Pulses travel at speed of light to target

3. **Reflection**: Target reflects portion of energy back
4. **Reception**: Receiver detects reflected signals
5. **Processing**: Signal processing determines target parameters

(b) Radar Range Equation for polarization matched antennas [7 marks]

Radar Range Equation: $Pr = (PtGt^2\lambda^2\sigma)/((4\pi)^3R^4)$

Where:

- Pr = Received power
- Pt = Transmitted power
- Gt = Antenna gain
- λ = Wavelength
- σ = Radar cross section
- R = Range to target

(c) Antenna bandwidth and beamwidth [4 marks]

Antenna Bandwidth: The range of frequencies over which antenna performance is acceptable (typically where gain drops by 3dB).

Beamwidth: Angular width of main lobe, measured between half-power (-3dB) points.

- HPBW (Half-Power Beamwidth) = $70\lambda/D$ (for uniform aperture)

Question 6

(a) Scattering and knife-edge diffraction [6 marks]

Scattering: Redirection of electromagnetic waves due to irregularities in the propagation medium.

Knife-edge Diffraction using Huygens' Principle:

1. Each point on wavefront acts as secondary source
2. Obstacles create shadow regions
3. Diffracted waves bend around edges
4. Field in shadow region is vector sum of diffracted waves
5. Fresnel zones determine field strength

(b) Microstrip antenna operation [5 marks]

Microstrip Antenna: Consists of radiating patch on dielectric substrate with ground plane.

Operation:

1. Patch acts as resonant cavity
2. Fringing fields at edges cause radiation
3. Current distribution creates radiation pattern
4. Substrate affects resonant frequency
5. Ground plane provides return path

(c) Communication satellite components [5 marks]

Essential Components:

1. **Transponder**: Receives, amplifies, and retransmits signals
2. **Antennas**: Earth-pointing and space communication
3. **Power System**: Solar panels and batteries
4. **Attitude Control**: Maintains proper orientation
5. **Command & Telemetry**: Ground communication system

Question 7: Short Notes (Choose any 4) [4×4=16 marks]

(a) Radiation Power Density [4 marks]
Definition: Radiation power density (also called power flux density) is the amount of electromagnetic power flowing through a unit area perpendicular to the direction of wave propagation, measured in watts per square meter (W/m^2).
Mathematical Expression:
- For time-varying fields: $S = E \times H$ (Poynting vector)
- For time-harmonic fields: $S_{av} = (1/2) \operatorname{Re}[E \times H^*]$
- For plane waves in free space: $S = E^2/\eta_0 = \eta_0 H^2$

Key Properties:
- Decreases as $1/r^2$ with distance in free space
- Determines the power transfer capability of electromagnetic waves
- Used in link budget calculations for communication systems
- Important for safety regulations (SAR limits)

Applications: Satellite communication link analysis, antenna gain measurements, electromagnetic compatibility studies, and power transmission efficiency calculations.
(b) Horn Antenna [4 marks]
Definition: A horn antenna is a flared extension of a waveguide that provides a smooth transition from the guided electromagnetic waves inside the waveguide to the free-space electromagnetic waves.
Construction and Types:
- **E-plane Horn**: Flared in the direction of electric field (narrow beamwidth in E-plane)
- **H-plane Horn**: Flared in the direction of magnetic field (narrow beamwidth in H-plane)
- **Pyramidal Horn**: Flared in both E and H planes
- **Conical Horn**: Circular cross-section with uniform flaring

Characteristics:
- **Gain**: 10-25 dB (depending on flare dimensions)
- **Beamwidth**: Inversely proportional to aperture dimensions
- **Impedance**: Well-matched to waveguide (low VSWR)
- **Bandwidth**: Very wideband operation possible

Applications: Microwave communication systems, radar feeds, antenna gain standards, EMC testing, and as feeds for parabolic reflectors.
(c) Loop Antenna [4 marks]
Definition: A loop antenna consists of a conductor bent into the shape of a closed curve (usually circular or rectangular) with the overall length typically much smaller than one wavelength.
Operating Principle:
- Acts as a magnetic dipole rather than electric dipole
- Current flows around the loop creating magnetic field
- Radiation occurs due to time-varying magnetic dipole moment
- Equivalent to a short magnetic dipole for small loops

Radiation Characteristics:
- **Pattern**: Figure-8 pattern (doughnut shape in 3D)

- **Polarization**: Linear polarization
- **Nulls**: In the plane of the loop (maximum pickup perpendicular to plane)
- **Radiation Resistance**: $R_r = 20\pi^2(A/\lambda^2)^2$ ohms (for small circular loop)

Types and Applications:

- **Small loops**: Direction finding, AM radio receivers, RFID
- **Large loops**: HF communication, antenna arrays
- **Ferrite rod antennas**: Portable AM/FM radios
- **Multi-turn loops**: Increased sensitivity for receiving applications

(d) Log Periodic Dipole Array (LPDA) [4 marks]

Definition: A log periodic dipole array is a multi-element antenna consisting of dipole elements of different lengths arranged along a transmission line, designed to operate over a wide frequency range with relatively constant electrical characteristics.

Design Principles:

- **Scaling Factor (τ)**: $\tau = L_{n+1}/L_n = d_{n+1}/d_n$ (typically 0.7-0.9)
- **Spacing Factor (σ)**: $\sigma = d_n/(2L_n)$ (typically 0.05-0.2)
- **Active Region**: Only elements near resonant length actively radiate
- **Frequency Independent**: Pattern and impedance remain relatively constant

Operating Mechanism:

- At any frequency, only a few elements near resonance are active
- Forward traveling wave excites progressively larger elements
- Backward wave from larger elements cancels, ensuring unidirectional radiation
- Active region shifts along array as frequency changes

Characteristics and Applications:

- **Bandwidth**: 10:1 or greater frequency range
- **Gain**: 6-12 dB (moderate and constant)
- **VSWR**: < 2:1 over operating band
- **Applications**: TV reception antennas, EMC testing, wideband communication systems, measurement antennas

(e) Helical Antenna [4 marks]

Definition: A helical antenna consists of a conducting wire wound in the form of a helix (screw thread pattern), typically mounted above a ground plane and fed at one end.

Operating Modes:

1. Normal Mode (Small Helix):

- Circumference $C \ll \lambda$
- Radiation pattern: Figure-8 pattern (similar to short dipole)
- Polarization: Linear
- Low radiation resistance and efficiency

2. Axial Mode (Large Helix):

- Circumference $C \approx \lambda$ (typically 0.75λ to 1.3λ)
- Radiation pattern: End-fire along helix axis
- Polarization: Circular (sense depends on winding direction)
- High radiation resistance and good efficiency

Design Parameters:

- **Pitch Angle**: $\alpha = \tan^{-1}(S/(\pi D))$, where S = spacing, D = diameter
- **Optimal values**: $C \approx \lambda$, $S \approx \lambda/4$, $\alpha \approx 12\text{-}15°$
- **Number of turns**: N = 6-8 for good performance
- **Ground plane**: Diameter $\geq 0.75\lambda$

Applications: Satellite communication (circular polarization advantage), space communication, telemetry systems, GPS antennas, and applications requiring circular polarization to reduce multipath fading.

(f) Directivity and Front-to-Back Ratio (FBR) [4 marks]

Directivity (D):

Definition: Directivity is the ratio of the radiation intensity in the direction of maximum radiation to the average radiation intensity over all directions.

Mathematical Expression: $D = U(\theta,\varphi)_{max} / U_{av} = 4\pi U(\theta,\varphi)_{max} / P_{rad}$

Where:

- $U(\theta,\varphi)$ = radiation intensity
- P_{rad} = total radiated power
- $U_{av} = P_{rad}/(4\pi)$

Key Points:

- Purely geometric property (independent of antenna efficiency)
- Measured in dB: $D(dB) = 10 \log_{10}(D)$
- Isotropic antenna has D = 1 (0 dB)
- Higher directivity means narrower beamwidth

Front-to-Back Ratio (FBR):

Definition: The ratio of power radiated in the forward direction to the power radiated in the backward direction, typically expressed in dB.

Mathematical Expression: $FBR(dB) = 10 \log_{10}[F(0°)/F(180°)]$

Where $F(\theta)$ is the power pattern in the specified direction.

Significance:

- Measures antenna's ability to reject signals from behind
- Important for interference reduction
- Typical values: 15-30 dB for good antennas
- Higher FBR indicates better forward/backward discrimination

Applications: Directional communication systems, broadcast antennas, radar systems where backward radiation must be minimized.