B.Sc. (HONS.) IN ECE PART-IV, SEVENTH SEMESTER EXAMINATION, 2019

(Microwave Engineering)

Time—3 hours

Full marks—80

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

Q.1 (a) What do you know about microwave? (4 marks)

Answer:

- Microwaves are electromagnetic waves with frequency range **300 MHz – 300 GHz** and wavelength between 1 m – 1 mm.
- They fall under **UHF, SHF, and EHF bands**.
- Microwave communication mostly uses **line-of-sight propagation**.
- Applications include **radar, satellite communication, mobile communication, remote sensing**, and medical fields.

Q.1 (b) Define VHF, UHF and SHF. (3 marks)

Answer:

- **VHF (Very High Frequency):** 30 MHz – 300 MHz (λ = 10 m – 1 m)
- **UHF (Ultra High Frequency):** 300 MHz – 3 GHz (λ = 1 m – 10 cm)
- **SHF (Super High Frequency):** 3 GHz – 30 GHz (λ = 10 cm – 1 cm)

Q.1 (c) Necessity of microwave in communication. (5 marks)

Answer:

Microwaves are necessary in communication because:

1. **High bandwidth** – supports high data rate.
2. **Line-of-sight propagation** – suitable for long-distance point-to-point links.
3. **Satellite communication** – microwaves can penetrate the atmosphere.
4. **Less interference** – higher frequency reduces noise problems.
5. **Radar & navigation** – essential for defense and air traffic control.

Q.1 (e) Frequency ranges of bands L, S, C, X, Ku. (4 marks)

Answer:

- **L-band:** 1 – 2 GHz
- **S-band:** 2 – 4 GHz
- **C-band:** 4 – 8 GHz
- **X-band:** 8 – 12 GHz
- **Ku-band:** 12 – 18 GHz

Q.1 (d) Underline the various reasons to wide use of microwave. (4 marks)

Answer:

Microwaves are widely used in communication and engineering systems due to the following reasons:

1. **Large Bandwidth Availability:**
   - Microwaves operate in the GHz range, where spectrum is much wider compared to HF/VHF.
   - This allows **high data rate transmission** suitable for TV broadcasting, internet, and satellite links.
2. **Small Antenna Size:**
   - Since wavelength (λ) is inversely proportional to frequency (f), at microwave frequencies λ is very small.
   - Antenna size ≈ λ/2, hence microwave antennas become **compact, light-weight, and easy to install.**
3. **Line-of-Sight (LOS) Communication:**
   - Microwaves travel straight and support LOS links.
   - This is useful for **satellite communication, radar, and point-to-point terrestrial links.**
4. **Low Interference and High Frequency Reuse:**
   - Microwave signals are highly directional → reduced interference compared to low-frequency bands.
   - Same frequency can be reused in different geographical areas, increasing spectrum efficiency.
5. **Penetration through Atmosphere:**
   - Certain microwave bands (like C-band, Ku-band) can pass through the ionosphere and atmosphere with less attenuation.
   - Essential for **satellite and deep-space communication.**
6. **Wide Range of Applications:**
   - Used in **radar, remote sensing, navigation, weather monitoring, medical applications (diathermy, imaging), industrial heating, and defense systems.**

Q.2 (a) Define line impedance and admittance. (6 marks)

Answer:

- **Characteristic Impedance (Z_0):**
  The natural impedance of a transmission line. It depends on the inductance (L) and capacitance (C) per unit length.

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

  For a lossless line (R=0, G=0):

$$Z_0 = \sqrt{\frac{L}{C}}$$

- **Admittance (Y):** Reciprocal of impedance.

$$Y = \frac{1}{Z}$$

Q.2 (b) Explain standing wave and SWR. (6 marks)

Answer:

- When a transmission line is not perfectly matched, incident and reflected waves combine to form a **standing wave pattern.**
- The measure of mismatch is given by the **Standing Wave Ratio (SWR):**

$$SWR = \frac{E_{max}}{E_{min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

  where Γ is the reflection coefficient.
- Perfect match → SWR = 1, complete mismatch → SWR → ∞.

Q.2 (c) Numerical (8 marks)

Given:

- $Z_0 = 50\,\Omega$
- $Z_L = 73 - j25\,\Omega$

1. **Reflection coefficient:**

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{(73 - j25) - 50}{(73 - j25) + 50} = \frac{23 - j25}{123 - j25}$$

Magnitude:

$$|\Gamma| = \frac{\sqrt{23^2 + 25^2}}{\sqrt{123^2 + 25^2}} = \frac{\sqrt{529 + 625}}{\sqrt{15129 + 625}} = \frac{\sqrt{1154}}{\sqrt{15754}} = \frac{33.96}{125.53} \approx 0.27$$

2. **SWR:**

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + 0.27}{1 - 0.27} = \frac{1.27}{0.73} \approx 1.74$$

✅ **Final Answer:**

- Reflection coefficient = **0.27**
- SWR = **1.74**

(a) What do you mean by waveguides? (2 marks)

A **waveguide** is a hollow metallic or dielectric structure used to **guide electromagnetic waves** at microwave frequencies.

- They support **TE (transverse electric)** and **TM (transverse magnetic)** modes, not TEM.
- Commonly rectangular or circular in cross-section.

(b) What are the advantages of waveguides? (2 marks)

1. **Low loss** at microwave frequencies compared to coaxial lines.
2. **High power handling** capacity.
   (Extra if needed: compact size at high frequency, low radiation leakage.)

(c) Give types of waveguides. (2 marks)

- **Rectangular waveguide** (dominant mode TE_{10})
- **Circular waveguide** (dominant mode TE_{11})
  (Other examples: ridge, dielectric, microstrip)

Q.3 (d) Define phase velocity and group velocity in a waveguide. (4 marks)

Answer with formulas:

- The axial propagation constant is β. Angular frequency ω.
- **Phase velocity** v_p: speed of a point of constant phase.

$$v_p = \frac{\omega}{\beta} = \frac{c}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}} \quad \text{(for air-filled guide)}$$

  Thus $v_p \geq c$ (superluminal phase speed is allowed; it does **not** carry information).
- **Group velocity** v_g: speed of modulation/envelope (energy transport):

$$v_g = \frac{d\omega}{d\beta} = c\sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

- **Relationship:** $v_p v_g = c^2$ (for air-filled guides; in a dielectric-filled guide $c \to v = \frac{c}{\sqrt{\varepsilon_r}}$).

Q.3 (e) Derive the wave equation in a rectangular waveguide. (8 marks)

Given: Perfectly conducting rectangular waveguide of inner dimensions $a \times b$ (along x and y), propagation along $+z$.

Step-wise derivation (compact):

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1. **Start from Maxwell's equations** (time-harmonic $e^{j\omega t}$):

$$\nabla \times \mathbf{E} = -j\omega\mu\mathbf{H}, \qquad \nabla \times \mathbf{H} = j\omega\varepsilon\mathbf{E}$$

2. **Obtain Helmholtz equations** for field components using $\nabla \times (\nabla \times \mathbf{E}) = \nabla(\nabla \cdot \mathbf{E}) - \nabla^2\mathbf{E}$ and $\nabla \cdot \mathbf{E} = 0$ (source-free):

$$\nabla^2\mathbf{E} + k^2\mathbf{E} = 0, \qquad \nabla^2\mathbf{H} + k^2\mathbf{H} = 0,$$

   with $k = \omega\sqrt{\mu\varepsilon}$.

3. **Assume propagation along** z: field dependence $\propto e^{-j\beta z}$. Split into transverse and longitudinal parts; write the **scalar wave equations** for the longitudinal components $E_z(x, y)$ and $H_z(x, y)$:

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + k_c^2\right)\{E_z, H_z\} = 0,$$

   In air ($\varepsilon_r = 1$), $v = c$. The **dominant mode** in a rectangular guide is TE_{10} with

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$$f_c^{(10)} = \frac{c}{2a}$$

8. **Transverse fields** follow from E_z or H_z via:

$$\mathbf{E}_t = -\frac{j\omega\mu}{k_c^2}\,\hat{z} \times \nabla_t H_z \quad \text{(TE)}, \qquad \mathbf{H}_t = \frac{j\omega\varepsilon}{k_c^2}\,\hat{z} \times \nabla_t E_z \quad \text{(TM)}$$

   completing the waveguide field solution.

Result to write:

The **wave equation** inside a rectangular waveguide reduces to the **2-D Helmholtz equation** for the longitudinal components with **eigenvalues** k_c set by the boundary conditions, leading to **TE/TM modes** and the propagation constant $\beta = \sqrt{k^2 - k_c^2}$.

where $k_c^2 = k^2 - \beta^2$ is the cutoff wavenumber.

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4. Apply boundary conditions on perfect conductor walls:
   - Tangential E on the walls is zero.
   - For TE modes: $E_z = 0$, solve for H_z.
   - For TM modes: $H_z = 0$, solve for E_z.
5. Use separation of variables $F(x, y) = X(x)Y(y)$ to get:

$$X'' + k_x^2 X = 0, \quad Y'' + k_y^2 Y = 0, \quad k_c^2 = k_x^2 + k_y^2$$

   With PEC boundaries at $x = 0, a$ and $y = 0, b$, the solutions are sinusoidal:

$$k_x = \frac{m\pi}{a}, \qquad k_y = \frac{n\pi}{b}, \qquad m, n = 0, 1, 2, \ldots$$

6. Cutoff and propagation constant:

$$k_c^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2, \qquad \beta = \sqrt{k^2 - k_c^2}$$

   Propagation occurs when $k > k_c$ or $f > f_c$.

7. Cutoff frequency for TE/TM$_{mn}$:

$$f_c^{(mn)} = \frac{v}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}, \quad v = \frac{c}{\sqrt{\varepsilon_r}}$$

(a) Explain the cutoff frequency and wavelength of circular waveguides. (2 marks)

- In a circular waveguide of radius a, the cutoff frequency is:

$$f_c = \frac{c \cdot X_{mn}}{2\pi a}$$

where X_{mn} = root of Bessel function (depends on TE or TM mode).

- The cutoff wavelength is:

$$\lambda_c = \frac{2\pi a}{X_{mn}}$$

- Dominant mode: TE$_{11}$ with $X_{11} = 1.841$.

(b) Briefly explain the operations of circulators and isolators. (4 marks)

Circulator:

- A 4-port non-reciprocal microwave device.
- Signal entering port-1 → port-2,
  port-2 → port-3, port-3 → port-4, and port-4 → port-1.
- Based on ferrite materials and Faraday rotation.
- Used for duplexing (separating transmitter and receiver with the same antenna).

Isolator:

- A 2-port one-way device.
- Allows signal flow in forward direction only (port-1 → port-2), blocks reverse.
- Protects microwave sources (klystron, Gunn diode) from reflections.
- Practical isolator = circulator with a matched load connected to one port.

(c) What is directional coupler? Derive the equation of coupling factor. (6 marks)

Definition:

- A **4-port microwave device** used to sample a small fraction of power from a transmission line without disturbing the main power flow.
- Ports: Input, Output, Coupled, and Isolated.

Operation:

- Input at **port-1** → Output at **port-2**.
- A small portion couples to **port-3**.
- **Port-4 is isolated** (ideally no power).

Coupling Factor (C):

$$C(dB) = 10\log_{10}\left(\frac{P_{in}}{P_{coupled}}\right)$$

where

- P_{in} = input power at port-1,
- $P_{coupled}$ = power at coupled port-3.

Important relations:

- **Directivity (D):** measure of isolation between coupled and isolated port.

$$D(dB) = 10\log_{10}\left(\frac{P_{coupled}}{P_{isolated}}\right)$$

- **Isolation (I):**

$$I(dB) = 10\log_{10}\left(\frac{P_{in}}{P_{isolated}}\right)$$

Applications:

- Used in power monitoring, SWR measurement, and feeding antenna arrays.

(c) Discuss performance and applications of Klystron. (4 marks)

Performance:

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- Frequency range: **300 MHz – 95 GHz** (mainly used at GHz).
- Gain: **up to 60 dB**.
- Efficiency: **20% – 40%** (improved in multicavity klystrons).
- Power output: **few watts to hundreds of kilowatts** (depends on design).

Applications:

- **Radar transmitters** (high-power pulses).
- **Satellite communication** (as high-gain amplifiers).
- **TV broadcasting** (UHF).
- **Microwave relay links.**
- **Particle accelerators.**

(a) What are problems associated with conventional tubes at UHF? (6 marks)

At UHF (Ultra High Frequency), conventional vacuum tubes (triodes, tetrodes, pentodes) face serious limitations:

1. **Transit-time effect:**
   - Electron transit time becomes comparable to the RF period.
   - Causes **phase shift** between input and output, reducing gain.
2. **Lead inductance & inter-electrode capacitance:**
   - Parasitic capacitance and inductance between electrodes become significant at high frequency.
   - Limits frequency response and stability.
3. **Power loss and low efficiency:**
   - Due to higher resistance and stray reactances.
   - Tubes can't handle large RF power efficiently.
4. **Impedance matching issues:**
   - Input/output circuits hard to match at UHF.
5. **Size limitations:**
   - Conventional tubes are bulky; not suitable for GHz-range compact circuits.

👉 **Therefore, special microwave tubes (Klystron, Magnetron, TWT) are developed.**

(b) Describe construction and working of Klystron. (6 marks)

Construction:

- **Electron gun:** Produces and accelerates electron beam.
- **Resonator cavities:** At least two (buncher and catcher).
- **Drift space:** Allows velocity-modulated electrons to bunch.
- **Collector:** Collects spent electrons.
- **Magnetic focusing:** Keeps the beam aligned.

Working principle (two-cavity Klystron amplifier):

1. **Electron beam generation:** Electron gun emits a beam under high voltage.
2. **Velocity modulation:** Beam passes through **buncher cavity** excited with RF input.
   - Electric field in the gap accelerates or decelerates electrons → velocity modulation.
3. **Bunching:** In drift space, faster electrons catch up with slower ones → electron bunches form.
4. **Energy transfer:** Bunched electrons enter **catcher cavity**.
   - They induce RF current, delivering **amplified RF output**.
5. **Collector:** Absorbs remaining electrons.

👉 This provides **high gain at microwave frequencies.**

(iii) Reflex Klystron (4 marks)

- **A velocity-modulated microwave oscillator** with a **single resonator cavity.**
- Electrons emitted from cathode → velocity-modulated in cavity gap → reflected back by **repeller electrode** → bunching occurs → energy transferred back to cavity.
- **Tunable by changing repeller voltage.**
- **Output power:** a few watts, **Efficiency:** 10–20%.
- **Applications:** Local oscillators in microwave receivers, signal generators.

(a) Draw the schematic of a microwave transistor. (6 marks)

Answer (points to write):

- A microwave transistor is a **high-frequency transistor** designed to operate in **UHF and microwave bands.**
- Examples: **BJT (Microwave BJT), FET (MESFET, HEMT), HBT.**

Schematic (you should draw in exam):

- **BJT type:**
  - Emitter (E), Base (B), Collector (C).
  - Very **thin base region** (to reduce transit time).
  - Gold or Pt-doped base for short lifetime.
  - Collector designed to handle high breakdown voltage.
- **FET type:**
  - Source (S), Gate (G), Drain (D).
  - Gate length very small (sub-micron) for high speed.
  - Substrate: GaAs or InP (high electron mobility).

Key points (to write in exam):

- Microwave transistors are fabricated on **GaAs, GaN, InP** for low noise and high cut-off frequency.
- They achieve **cutoff frequencies up to hundreds of GHz.**
- Used in **low-noise amplifiers, oscillators, microwave ICs.**

(b) Briefly describe the operation of an IMPATT diode. (6 marks)

Full form: Impact Avalanche Transit-Time Diode.

Principle:

- Works on **avalanche multiplication** and **transit-time delay.**
- Provides **negative resistance**, making it useful as a microwave oscillator.

Operation steps:

1. **Reverse bias:** The diode is heavily reverse biased near avalanche breakdown.
2. **Avalanche effect:** Carriers generated in depletion region due to impact ionization.
3. **Drift (Transit time):** Generated carriers drift across the drift region with delay (~180° phase shift).
4. **Negative resistance:** The phase difference between RF voltage and current gives **negative resistance**, enabling oscillation.

Performance:

- Frequency range: **3–100 GHz.**
- Efficiency: **10–20%.**
- High power (up to tens of watts).
- But suffers from **high noise.**

Applications:

- Microwave oscillators (radar, communication).
- Local oscillators in receivers.

(c) Explain the construction and working of a TWT. (4 marks)

Full form: Traveling Wave Tube.

Construction:

- **Electron gun** → produces electron beam.
- **Slow-wave structure (helix or coupled cavity)** → slows down RF wave so it can interact with beam.
- **Collector** → absorbs spent electrons.
- **Magnetic focusing** → keeps beam aligned.

Working principle:

1. RF signal is applied to the **helix slow-wave structure.**
2. The **electron beam interacts continuously** with the RF wave along the length.
3. Velocity modulation → bunching → RF power transfer to the wave.
4. At the output end, **amplified RF signal** is extracted.

Features:

- Wide bandwidth (much larger than Klystron).
- Power output: watts to hundreds of kilowatts.
- Efficiency: ~20–40%.

Applications:

- Satellite communication.
- Radar systems.
- TV broadcasting.

(i) Microstrip lines (4 marks)

- A **planar transmission line** consisting of a **conducting strip** on one side of a dielectric substrate and a **ground plane** on the other side.

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- Supports quasi-TEM mode.
- **Advantages:** Low cost, easy integration with MICs (Microwave Integrated Circuits), compact.
- **Applications:** Antennas, filters, couplers, matching networks in microwave ICs.

(ii) Magnetron (4 marks)

- A **high-power microwave oscillator** based on **crossed electric and magnetic fields.**
- Structure: cylindrical cathode at center, anode with resonant cavities, axial magnetic field.
- Electrons spiral under E × B field → excite cavity resonances → microwave output.
- **Advantages:** High efficiency (50–70%), compact, robust.
- **Applications:** Radar transmitters, microwave ovens, industrial heating.

(iii) Reflex Klystron (4 marks)

- A **velocity-modulated microwave oscillator** with a **single resonator cavity.**
- Electrons emitted from cathode → velocity-modulated in cavity gap → reflected back by **repeller electrode** → bunching occurs → energy transferred back to cavity.
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