B.Sc (HONS.) IN ECE PART IV, SEVENTH SEMESTER EXAMINATION, 2020
MICROWAVE ENGINEERING
Subject Code : ECE-401
Time – 3 hours
Full marks – 80

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

Q1 (a) What is microwave system? Draw a proper microwave system. (5 marks)

Answer:

Microwaves are electromagnetic waves having frequency range 300 MHz – 300 GHz (wavelength: 1 m – 1 mm).

A microwave system is a communication or radar system that uses microwave frequency for signal transmission.

Block diagram of microwave system:

1. **Transmitter Section**
   - Oscillator (Microwave source: Klystron, Magnetron, Gunn diode)
   - Modulator
   - Power amplifier
2. **Transmission Medium**
   - Waveguide, Coaxial cable, Free-space
3. **Receiver Section**
   - Low noise amplifier
   - Mixer + Local oscillator
   - IF amplifier and detector
   - Demodulator

📌 Microwaves are used in **radar, satellite communication, remote sensing, wireless LAN, medical applications.**

Q1 (b) IEEE Microwave frequency bands (5 marks)

Band	Frequency Range	Uses
VHF	30 – 300 MHz	FM radio, TV
UHF	300 MHz – 3 GHz	Mobile phones, TV, Wi-Fi
L band	1 – 2 GHz	GPS, Mobile communication
X band	8 – 12 GHz	Radar, satellite comm.
K band	18 – 27 GHz	Police radar, satellite comm.

Q1 (c) Define Noise figure and Noise factor. (6 marks)

- **Noise Factor (F):**
  The ratio of input signal-to-noise ratio (SNRin) to output signal-to-noise ratio (SNRout).

$$F = \frac{SNR_{in}}{SNR_{out}}$$

  Always ≥ 1.
- **Noise Figure (NF):**
  Noise figure is the logarithmic expression of noise factor.

$$NF(dB) = 10\log_{10}(F)$$

📌 Smaller NF means better performance of microwave devices.

Q2 (a) Transmission line (5 marks)

Definition:
A transmission line is a structure used to transmit RF/microwave signals with minimal attenuation and distortion.

Primary constants (per unit length):

- R = resistance (Ω/m)
- L = inductance (H/m)
- G = conductance (S/m)
- C = capacitance (F/m)

Equivalent section:

- Series branch: RΔz + LΔz
- Shunt branch: GΔz || CΔz

Examples: Coaxial cable, waveguide, microstrip line.

Q2 (b) Propagation constant & Z_0 (5 marks)

From transmission line equations:

- **Propagation constant:**

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta$$

  where,
  - α = attenuation constant
  - β = phase constant
- **Characteristic impedance:**

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

Q2 (c) Numerical (6 marks)

Given:

- R = 20.9 mΩ/m = 0.0209 Ω/m
- G = 0.5 mmho/m = 0.0005 S/m
- f = 1 GHz → $\omega = 2\pi \times 10^9 = 6.28 \times 10^9$ rad/s
- L = 8 nH/m = 8×10^{-9} H/m
- C = 0.23 pF/m = 0.23×10^{-12} F/m

Step 1: Calculate Z_0

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

Numerator: $R + j\omega L = 0.0209 + j(6.28 \times 10^9 \times 8 \times 10^{-9}) = 0.0209 + j50.24$
Denominator: $G + j\omega C = 0.0005 + j(6.28 \times 10^9 \times 0.23 \times 10^{-12}) = 0.0005 + j0.001445$

$$Z_0 \approx \sqrt{\frac{0.0209 + j50.24}{0.0005 + j0.001445}} \approx 147.9 - j19.5\,\Omega$$

Step 2: Propagation constant γ

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

= $\sqrt{(0.0209 + j50.24)(0.0005 + j0.001445)}$
≈ $0.178 + j0.268\ /m$

So, α = 0.178 Np/m, β = 0.268 rad/m

Q3 (a) Standing wave & SWR (6 marks)

- **Standing wave:** When incident and reflected waves interfere, stationary voltage/current patterns appear along the line.
- **SWR (Voltage Standing Wave Ratio):**

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

  Shows impedance mismatch.
- Perfect match → SWR = 1.
- High mismatch → SWR → ∞.

📌 Draw standing wave diagram (nodes & antinodes).

Q3 (b) Numerical (10 marks)

Given:

- Z_0 = 40 Ω
- ZL = 70 – j42.5 Ω

Step 1: Reflection coefficient

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$= \frac{(70-40)-j42.5}{(70+40)-j42.5} = \frac{30-j42.5}{110-j42.5}$

Magnitude:

$$|\Gamma| = \frac{\sqrt{30^2 + 42.5^2}}{\sqrt{110^2 + 42.5^2}} = \frac{52.1}{117.8} = 0.442$$

Step 2: SWR

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + 0.442}{1 - 0.442} = 2.58$$

Final Answer:

- Reflection coefficient = 0.442 ∠ -54.7°
- SWR = 2.58

Q4(b) What is waveguide? Write about types of waveguide. (6 marks)

Definition:

A waveguide is a **hollow metallic or dielectric guiding structure** that carries microwave and millimeter-wave signals. Unlike transmission lines, a waveguide supports **TE (Transverse Electric)** or **TM (Transverse Magnetic)** modes, not TEM.

Key features:

- Efficient at **microwave frequencies** (>1 GHz)
- Exhibits a **cutoff frequency** below which no propagation occurs
- Low loss, high power handling capacity

Types of waveguides:

1. **Rectangular waveguide** – Most common, simple to manufacture, dominant mode TE_{10}.
2. **Circular waveguide** – Used in radar and satellite systems, supports multiple degenerate modes.
3. **Elliptical waveguide** – Useful for polarization control.
4. **Ridged waveguide** – Reduced cutoff frequency, supports wider bandwidth.
5. **Flexible/Seamless waveguide** – For practical installations, can be bent.
6. **Dielectric waveguide / Optical waveguide** – Used in millimeter-wave and optical communication.
7. **Substrate Integrated Waveguide (SIW)** – Fabricated on PCB substrates for compact microwave circuits.

Q4(c) Derive the equations of cut-off frequency and cut-off wavelength for rectangular waveguide. (6 marks)

Setup:

Rectangular waveguide of cross-section $a \times b$, with propagation along the z-axis.

Wave equation:

Applying Maxwell's equations with conducting boundaries, the field solutions satisfy:

$$\nabla_t^2 \Psi + k_c^2 \Psi = 0$$

where Ψ represents H_z (for TE) or E_z (for TM).

Cutoff wavenumber:

$$k_c^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2, \quad m, n = 0, 1, 2, \ldots$$

Propagation constant:

$$\beta = \sqrt{k_0^2 - k_c^2}, \quad k_0 = \frac{2\pi}{\lambda}$$

At cutoff, $\beta = 0$, so $k_0 = k_c$. Therefore:

Cutoff frequency:

$$\boxed{f_{c,mn} = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$$

Cutoff wavelength:

$$\boxed{\lambda_{c,mn} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}}$$

Dominant mode (TE_{10}):

$$f_{c,10} = \frac{c}{2a}, \quad \lambda_{c,10} = 2a$$

Q4(d) Write short notes on microwave cavity resonator. (4 marks)

Microwave cavity resonator:

- A cavity resonator is a **closed hollow metallic enclosure** (rectangular or cylindrical) that confines electromagnetic energy in the form of standing waves.
- Acts as the microwave equivalent of an **LC tank circuit**.

Key points:

- **Resonant frequency:**

$$f_{r,mnp} = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2}$$

- Very high **Q-factor** → narrow bandwidth, stable frequency.
- **Coupling methods:** Probe coupling (E-field), loop coupling (H-field), slot coupling.
- **Applications:** Used in klystrons, magnetrons, oscillators, filters, frequency standards.

Q4(e) Write down the difference between transmission line and waveguide. (4 marks)

Aspect	Transmission Line	Waveguide
Structure	Two-conductor system (e.g., coaxial cable, twin-lead, microstrip)	Single hollow metallic conductor (rectangular, circular)
Modes	TEM (or quasi-TEM)	TE and TM (no pure TEM)
Cutoff frequency	Usually none for TEM mode	Has a cutoff frequency; below cutoff no propagation
Frequency suitability	Works well at LF, HF, VHF, UHF; higher losses at microwave	Efficient above ~1 GHz with low loss
Power handling	Limited	Very high power handling
Flexibility	Flexible cables, easy connectors	Rigid sections, flanges required
Applications	RF feeds, CATV, PCB circuits	Radar, satellite communication, high-power microwave links

(a) Explain microstrip lines with proper diagram. (3 marks)

Definition:

A microstrip line is a type of **planar transmission line** consisting of:

- A conducting strip (signal line) on top of a dielectric substrate
- A large ground plane on the bottom

Diagram (must draw in exam):

Top: Metal strip

Middle: Dielectric substrate (εr, thickness h)

Bottom: Ground plane

Key points:

- Supports **quasi-TEM mode** of propagation
- Simple, low-cost, and easily fabricated using PCB technology
- Widely used in **microwave integrated circuits (MICs)**

Applications: Antennas, filters, couplers, amplifiers, PCB microwave circuits.

(b) Describe briefly about the characteristic impedance of microstrip lines. (3 marks)

Characteristic impedance (Z_0):

It depends on strip width (w), substrate height (h), and relative permittivity (εr).

For $w/h \leq 1$:

$$Z_0 = \frac{60}{\sqrt{\epsilon_{eff}}} \ln\left(\frac{8h}{w} + \frac{w}{4h}\right)$$

For $w/h \geq 1$:

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}}\,(w/h + 1.393 + 0.667\ln(w/h + 1.444))}$$

where

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12h/w}}$$

📌 Thus, Z_0 can be controlled by adjusting **w/h ratio** and substrate εr.

(d) Numerical: Characteristic impedance calculation. (3 marks)

Given:

- εr = 5.23
- h = 7 mils
- t = 2.8 mils
- w = 10 mils

Step 1: Compute w/h ratio

$$w/h = 10/7 \approx 1.43$$

Step 2: Effective dielectric constant

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12h/w}}$$

$$= \frac{5.23 + 1}{2} + \frac{5.23 - 1}{2} \cdot \frac{1}{\sqrt{1 + 12(7/10)}}$$

$$= 3.115 + 2.115 \cdot \frac{1}{\sqrt{1 + 8.4}} = 3.115 + 2.115 \cdot \frac{1}{3.07}$$

$$= 3.115 + 0.688 = 3.803$$

Step 3: Z_0 formula (since w/h > 1)

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}}\,(w/h + 1.393 + 0.667\ln(w/h + 1.444))}$$

Substitute:

$$Z_0 = \frac{120\pi}{\sqrt{3.803}\,(1.43 + 1.393 + 0.667\ln(1.43 + 1.444))}$$

$$= \frac{376.99}{1.949 \times (2.823 + 0.667 \times \ln 2.874)}$$

$$= \frac{376.99}{1.949 \times (2.823 + 0.667 \times 1.056)}$$

$$= \frac{376.99}{1.949 \times 3.528} = \frac{376.99}{6.875}$$

$$Z_0 \approx 54.8\,\Omega$$

Final Answer:

$$\boxed{Z_0 \approx 55\,\Omega}$$

(e) Schottky barrier diode (6 marks)

Construction:

- Formed by contact between a **metal** (Al, Au) and lightly doped **n-type semiconductor**.
- Very thin depletion region forms at the junction.

Characteristics:

- Low forward voltage drop (~0.3 V for Si, 0.2 V for GaAs).
- Very fast switching speed (no minority carrier storage).
- High frequency operation (up to THz range).
- Low junction capacitance.
- Non-linear I–V curve used for detection and mixing.

Applications:

- Microwave detector, mixer, frequency multiplier, switching circuits, RF rectifier.

(f) Explain the operation of reflex klystron. (6 marks)

Definition: Reflex klystron is a **single-cavity microwave oscillator** that uses velocity modulation and electron bunching for oscillation.

Operation principle:

1. Electron beam emitted from cathode and accelerated towards resonant cavity.
2. Cavity gap produces **RF field → velocity modulation** of electrons.
3. Electrons enter repeller region (negatively charged plate).
4. They are turned back and re-enter the cavity after a specific delay.
5. Due to velocity modulation → electrons form **bunches** at the cavity gap.
6. Bunched electrons transfer energy to cavity → sustained oscillations.

Key features:

- Frequency controlled by repeller voltage.
- Used as a **low-power microwave oscillator** in radars and instrumentation.

Diagram: (must draw in exam: cavity, repeller electrode, electron gun, collector).

(g) Travelling Wave Tube (TWT) and differences with Klystron. (5 marks)

Travelling Wave Tube (TWT):

- A microwave amplifier device where an electron beam interacts continuously with a slow-wave RF structure (usually a helix).
- Provides wide bandwidth and high gain.

Operation:

- RF input signal applied to helix.
- Electron beam passes through helix → velocity modulation → bunching.
- Continuous interaction transfers energy from beam to RF wave.
- Amplified RF output taken at other end of helix.

Differences between TWT and Klystron:

Aspect	TWT	Klystron
Type	Amplifier (mainly)	Oscillator/Amplifier
Bandwidth	Very wide	Narrow
Interaction	Continuous (distributed) along helix	Discrete at cavity gaps
Gain	Higher (40–60 dB)	Moderate
Application	Satellite transponders, long-distance comm.	Radars, oscillators, local oscillators

(a) IMPATT Diode (4 marks)

Definition: IMPATT (Impact Avalanche Transit-Time) diode is a **high-power microwave diode** that operates using **avalanche breakdown** and **transit-time delay**.

Working principle:

- Reverse-biased p–n junction is operated in avalanche breakdown.
- Carriers generated in avalanche region drift across the drift region.
- Transit-time causes a **–90° phase shift** between voltage and current → negative resistance.

Key features:

- Frequency range: 3–100 GHz
- High output power (up to hundreds of watts)
- Efficiency: 5–20%
- **Applications:** Microwave oscillators, radar transmitters, communication links.

(b) Gunn Diode (4 marks)

Definition: Gunn diode is a **negative resistance microwave diode** that works on the **transferred electron effect** (in GaAs or InP).

Working principle:

- At high electric fields, electrons transfer from low-mass valley to high-mass valley in the conduction band.
- This reduces mobility → causes **negative differential resistance (NDR)**.
- Leads to oscillation.

Key features:

- Frequency: 1–100 GHz
- Low noise, compact, inexpensive
- **Applications:** Gunn oscillators in police radars, intruder alarms, microwave transmitters.

(c) Circulator (4 marks)

Definition: A circulator is a **non-reciprocal multiport microwave device** (usually 3 or 4 ports) in which power entering one port is delivered to the next port in sequence.

Working principle:

- Uses **ferrite materials** with magnetization → non-reciprocal phase shift.

Key points:

- Example: In a 3-port circulator, power entering port 1 exits port 2; from port 2 exits port 3, etc.
- Lossless and matched at all ports.

Applications:

- Isolating transmitter from receiver in radar, duplexers, antenna sharing.

(d) Magnetron (4 marks)

Definition: Magnetron is a **high-power microwave oscillator** that uses the interaction of an electron beam with a magnetic field and a resonant cavity.

Construction:

- Cathode at center, surrounded by anode block with multiple resonant cavities.
- Strong perpendicular electric (radial) and magnetic (axial) fields applied.

Working principle:

- Electrons spiral due to crossed E and B fields.
- Interaction with cavity resonators causes bunching.
- Energy transferred to cavity oscillations → high-power microwaves generated.

Applications:

- Radar transmitters, microwave ovens, industrial heating.

(e) Attenuation factor (4 marks)

Definition: Attenuation factor (α) is a measure of the reduction in signal amplitude as it propagates through a medium (transmission line, waveguide).

Expression:

$$P(z) = P(0)e^{-2\alpha z}, \quad V(z) = V(0)e^{-\alpha z}$$

where α = attenuation constant (Np/m or dB/m).

Causes of attenuation:

- Conductor (ohmic) losses
- Dielectric losses
- Radiation losses

Applications: Used to quantify line losses in **coaxial cables, microstrip, waveguides.**