

Subject Name Solutions

4351103 – Summer 2025

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

List four microwave frequency bands with their frequency range and applications.

Solution

Band	Frequency Range	Applications
L-band	1-2 GHz	GPS, Mobile communication
S-band	2-4 GHz	WiFi, Bluetooth, Radar
C-band	4-8 GHz	Satellite communication
X-band	8-12 GHz	Military radar, Weather radar

Mnemonic

“Little Satellites Communicate eXcellently”

Question 1(b) [4 marks]

Explain the impedance matching process using a single stub.

Solution

Single stub matching removes reflections by adding a **short-circuited stub** at specific distance from load.

Process:

- **Stub length:** Provides reactive impedance
- **Stub position:** Calculated from load using Smith chart
- **Matching condition:** Real part = Z_0 , $\text{imaginary part} = 0$

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting} []
graph LR
    A[Source] --- B[Transmission Line]
    B --- C[Stub Position]
    C --- D[Load]
    C --- E[Short Stub]
{Highlighting}
{Shaded}
```

Mnemonic

“Stub Positioned for Perfect Matching”

Question 1(c) [7 marks]

State characteristics of lossless transmission line and obtain the general equation for a two-wire transmission line.

Mnemonic

“Lossless Lines Love Low Loss”

Question 1(c) OR [7 marks]

Define standing wave. Draw and explain the standing wave pattern for short circuit and open circuit line.

Solution

Standing Wave: Fixed pattern formed by **forward and reflected waves** interfering constructively and destructively.

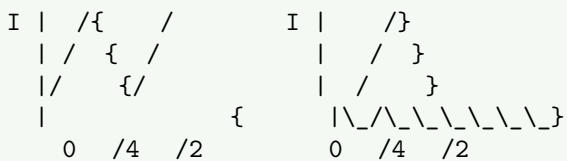
Short Circuit Line:

- **Current maximum** at short circuit
- **Voltage minimum** at short circuit
- Distance between minima: $\lambda/2$

Open Circuit Line:

- **Voltage maximum** at open circuit
- **Current minimum** at open circuit
- Distance between maxima: $\lambda/2$

Short Circuit: Open Circuit:



Mnemonic

“Short Circuits Current, Open Circuits Voltage”

Question 2(a) [3 marks]

Draw and explain the working of Magic TEE.

Solution

Magic TEE combines E-plane and H-plane tees with **four ports** providing isolation between opposite ports.

Mermaid Diagram (Code)

```
{Shaded}  
{Highlighting} []  
graph TD  
    A[Port 1 {- E{-}arm] --> C[Junction]]  
    B[Port 2 {- H{-}arm] --> C]  
    C {--{-}{}--> D[Port 3 {-} Collinear arm]}  
    C {--{-}{}--> E[Port 4 {-} Collinear arm]}  
{Highlighting}  
{Shaded}
```

Working:

- **E-arm and H-arm:** Isolated from each other
- **Sum port:** Adds signals from collinear arms
- **Difference port:** Subtracts signals

Mnemonic

“Magic Tee Mixes Modes”

Question 2(b) [4 marks]

Explain the working of Hybrid ring.

Solution

Hybrid Ring is a **circular waveguide** with **four ports** spaced at specific intervals for power division and isolation.

Construction:

- **Ring circumference:** 1.5
- **Port spacing:** $\lambda/4$ between adjacent ports
- **Matched impedance:** Each port matched to Z_0

Working:

- **Power splitting:** Input splits equally between two output ports
- **Isolation:** Opposite ports are isolated
- **Phase difference:** 180° between output ports

Mnemonic

“Ring Runs Round for Power Sharing”

Question 2(c) [7 marks]

Explain the construction and working principle of “CIRCULATOR”. List its applications.

Solution**Construction:**

- Three-port device with **ferrite material**
- **Permanent magnet** creates magnetic field
- **Y-junction waveguide structure**

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting} []
graph LR
    A[Port 1] --> B[Ferrite Junction]
    B --> C[Port 2]
    C --> D[Port 3]
    D --> A
    style B fill:#ff9999
{Highlighting}
{Shaded}
```

Working Principle:

- **Faraday rotation:** Magnetic field rotates wave polarization
- **Unidirectional flow:** Power flows in one direction only
- **Non-reciprocal:** Different behavior for opposite directions

Applications:

- **Radar systems:** Isolates transmitter from receiver
- **Communication:** Antenna sharing for TX/RX
- **Microwave amplifiers:** Prevents feedback

Mnemonic

“Circulator Circles Clockwise Continuously”

Question 2(a) OR [3 marks]

Compare rectangular waveguide and circular waveguide.

Solution

Parameter	Rectangular	Circular
Cross-section	Rectangle	Circle
Dominant mode	TE_{10}	TE_{11}
Cutoff frequency	Easy calculation	Complex calculation
Manufacturing	Simple	Moderate
Power handling	Lower	Higher

Mnemonic

“Rectangles are Regular, Circles are Complex”

Question 2(b) OR [4 marks]

Draw and explain the working of a directional coupler.

Solution

Directional Coupler samples **forward power** while providing isolation from reflected power.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting} []
graph LR
    A[Input] --{-{-}{}}--> B[Main Line]
    B --{-{-}{}}--> C[Output]
    B --{-.-{-}{}}--> D[Coupled Port]
    B --{-.-{-}{}}--> E[Isolated Port]
    style D fill:#99ff99
    style E fill:#ff9999
{Highlighting}
{Shaded}
```

Working:

- **Coupling factor:** Determines power extracted (10-20 dB typical)
- **Directivity:** Isolates forward from reverse power
- **Insertion loss:** Minimal loss in main line

Parameters:

- $C = 10 \log(P_1/P_3)$ (*Coupling factor*)
- $D = 10 \log(P_3/P_4)$ (*Directivity*)

Mnemonic

“Coupler Couples Carefully in Correct Direction”

Question 2(c) OR [7 marks]

Explain the construction and working principle of “Travelling Wave Tube”. List its applications.

Solution

Construction:

- **Electron gun:** Emits electron beam
- **Helix structure:** Slows down RF wave
- **Collector:** Collects spent electrons
- **Magnetic focusing:** Keeps beam focused

Mermaid Diagram (Code)

```
{Shaded}  
{Highlighting} []  
graph LR  
    A[Electron Gun] --> B[Helix]  
    B --> C[Collector]  
    D[RF Input] --> B  
    B --> E[RF Output]  
    F[Magnetic Field] -.-> B  
{Highlighting}  
{Shaded}
```

Working Principle:

- **Velocity synchronization:** Electron velocity \approx RF wave velocity
- **Energy transfer:** Electrons give energy to RF wave
- **Continuous interaction:** Along entire helix length

Applications:

- **Satellite communication:** High power amplification
- **Radar transmitters:** High gain amplification
- **Electronic warfare:** Jamming systems

Mnemonic

“TWT Transfers Tremendous power Through Travel”

Question 3(a) [3 marks]

Explain the Indirect method for higher VSWR measurement.

Solution

Indirect Method measures **high VSWR** by using **attenuator** to reduce signal level for accurate measurement.

Procedure:

- Insert calibrated attenuator (10-20 dB)
- Measure reduced VSWR ($VSWR_2$)
- Calculate actual VSWR: $VSWR_1 = VSWR_2 \times Attenuatorratio$

Formula: $VSWR_{actual} = VSWR_{measured} \times 10^{(Attenuation/20)}$

Mnemonic

“Indirect method uses Intermediate Attenuation”

Question 3(b) [4 marks]

Write and explain the frequency limitations of conventional tubes.

Solution

Frequency Limitations:

- **Transit time effect:** Electron transit time becomes significant
- **Interelectrode capacitance:** Limits high frequency response
- **Lead inductance:** Parasitic inductance reduces gain
- **Skin effect:** Current flows on surface only

Effects:

- **Reduced gain:** At frequencies above f
- **Increased noise:** Due to shot noise
- **Phase shift:** Delays signal processing

Solutions:

- Reduce electrode spacing
- Use special tube designs
- Employ cavity resonators

Mnemonic

“Transit Time Troubles Traditional Tubes”

Question 3(c) [7 marks]

Explain construction and working of Two cavity klystron with applegate diagram. List its advantages.

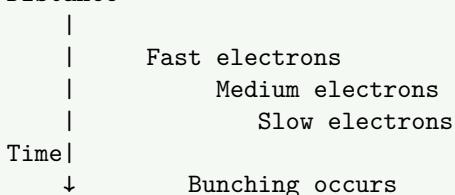
Solution

Construction:

- **Electron gun:** Produces electron beam
- **Input cavity:** Velocity modulates beam
- **Drift region:** Beam bunching occurs
- **Output cavity:** Extracts RF energy
- **Collector:** Collects electrons

Applegate Diagram:

Distance



Working:

- **Velocity modulation:** Input cavity varies electron velocity
- **Density modulation:** Electrons bunch in drift space
- **Energy extraction:** Bunched beam transfers energy to output cavity

Advantages:

- **High power output:** Several kilowatts
- **High efficiency:** 40-60%
- **Low noise:** Better than semiconductor devices
- **Stable operation:** Excellent frequency stability

Mnemonic

“Klystron Kicks with Kinetic Bunching”

Question 3(a) OR [3 marks]

Explain construction and working of BWO.

Solution

BWO (Backward Wave Oscillator) uses **backward wave interaction** for oscillation.

Construction:

- **Electron gun:** Emits electron beam
- **Slow wave structure:** Helix or coupled cavities
- **Collector:** At input end
- **Output:** From input end

Working:

- **Backward wave:** Travels opposite to electron beam
- **Negative resistance:** Beam provides energy to backward wave
- **Oscillation:** When gain > losses

Mnemonic

“BWO goes Backward While Oscillating”

Question 3(b) OR [4 marks]

Explain hazards due to microwave radiation.

Solution

Types of Hazards:

- **HERP:** Hazards of Electromagnetic Radiation to Personnel
- **HERO:** Hazards of Electromagnetic Radiation to Ordnance
- **HERF:** Hazards of Electromagnetic Radiation to Fuel

Effects:

- **Thermal heating:** Tissue heating at high power
- **Eye damage:** Cataract formation
- **Reproductive effects:** Potential fertility issues
- **Pacemaker interference:** Electronic device malfunction

Protection:

- **Power density limits:** $< 10 \text{ mW/cm}^2$
- **Safety distances:** Far field calculations
- **Warning signs:** Radiation hazard markers
- **Personal monitors:** RF exposure meters

Mnemonic

“Microwaves Make Multiple Medical Maladies”

Question 3(c) OR [7 marks]

Explain construction and working of magnetron with neat sketch. List its applications.

Solution

Construction:

- Circular cathode: Central hot cathode
- Cylindrical anode: With resonant cavities
- Permanent magnet: Provides axial magnetic field
- Output coupling: Loop or probe

Mermaid Diagram (Code)

```
{Shaded}  
{Highlighting} []  
graph LR  
    A[Cathode] --> B[Interaction Space]  
    B --> C[Anode Cavities]  
    D[Magnetic Field] -.-> B  
    C -.-> E[Output Coupling]  
    style A fill:#ff9999  
    style C fill:#99ff99  
{Highlighting}  
{Shaded}
```

Working:

- Electron cloud: Forms in interaction space
- Cycloid motion: Due to E and B fields
- Resonant cavities: Determine operating frequency
- -mode oscillation: Alternate cavities have opposite phase

Applications:

- Microwave ovens: 2.45 GHz heating
- Radar systems: High power pulses
- Industrial heating: Material processing
- Medical diathermy: Therapeutic heating

Mnemonic

“Magnetron Makes Microwaves Magnificently”

Question 4(a) [3 marks]

Explain working of P-i-N diode.

Solution

P-i-N Diode has **intrinsic layer** between P and N regions, acting as **voltage-controlled resistor**.

Structure:

- P region: Heavily doped
- I region: Intrinsic (undoped)
- N region: Heavily doped

Working:

- Forward bias: Low resistance ($1-10 \Omega$)
- Reverse bias: High resistance ($>10 k\Omega$)
- RF switch: Controls microwave signals
- Variable attenuator: Resistance varies with DC bias

Mnemonic

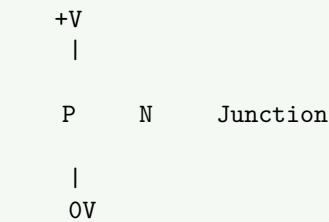
“PIN controls Power IN Networks”

Question 4(b) [4 marks]

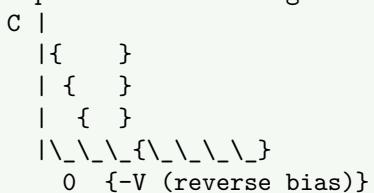
Explain the working of Varactor diode with sketch.

Solution

Varactor Diode acts as **voltage-controlled capacitor** using junction capacitance variation.



Capacitance vs Voltage:



Working:

- **Reverse bias:** Depletes junction, reduces capacitance
- **Bias voltage:** Controls capacitance value
- **Capacitance ratio:** Typically 3:1 to 10:1
- **Frequency tuning:** Used in oscillators and filters

Applications:

- **VCO tuning:** Voltage controlled oscillators
- **AFC circuits:** Automatic frequency control
- **Parametric amplifiers:** Low noise amplification

Mnemonic

“Varactor Varies Capacitance with Voltage”

Question 4(c) [7 marks]

Explain construction and working of Tunnel Diode and explain tunneling phenomenon in detail. List its applications.

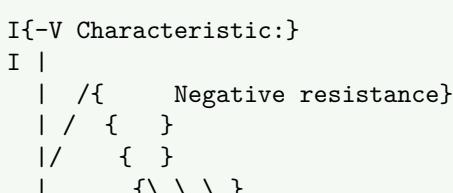
Solution

Construction:

- **Heavily doped P-N junction:** Both sides degenerately doped
- **Thin junction:** ~10 nm width
- **Quantum tunneling:** Electrons tunnel through barrier

Tunneling Phenomenon:

- **Quantum effect:** Electrons pass through energy barrier
- **Band overlap:** Conduction band overlaps valence band
- **Probability function:** Tunneling probability depends on barrier width
- **No thermal activation:** Occurs at room temperature



$$\begin{array}{ccccccc} & & & & & & \\ | & \backslash & _ & _ & _ & _ & _ \\ & 0 & V_p & V_v & & & \end{array}$$

V_p = Peak voltage

V_v = Valley voltage

Working:

- **Forward bias 0-V_p:** Current increases (tunneling)
- **V_p to V_v:** Negative resistance region
- **Beyond V_v:** Normal diode operation

Applications:

- **High-speed switching:** Picosecond switching
- **Oscillators:** Microwave frequency generation
- **Amplifiers:** Low noise amplification
- **Memory circuits:** Bistable operation

Mnemonic

“Tunnel Diode Tunnels Through barriers Terrifically”

Question 4(a) OR [3 marks]

Describe the operation of IMPATT diode.

Solution

IMPATT (Impact Avalanche Transit Time) diode uses **avalanche multiplication** and **transit time delay** for oscillation.

Operation:

- **Avalanche zone:** Impact ionization creates carriers
- **Drift zone:** Carriers drift with constant velocity
- **Transit time:** Provides 180° phase shift
- **Negative resistance:** Due to phase delay

Key parameters:

- **Breakdown voltage:** Typically 20-100V
- **Efficiency:** 10-20%
- **Frequency range:** 1-300 GHz

Mnemonic

“IMPATT Impacts with Avalanche Transit Time”

Question 4(b) OR [4 marks]

Explain the frequency up and down conversion concepts for parametric amplifier.

Solution

Parametric Amplifier uses **time-varying reactance** for amplification and frequency conversion.

Up-conversion:

- **Signal frequency:** f_s (input)
- **Pump frequency:** f_p (much higher)
- **Output frequency:** $f_o = f_p + f_s$
- **Energy transfer:** From pump to signal

Down-conversion:

- **Signal frequency:** f_s (input)

- Pump frequency: f_p
- Output frequency: $f_o = f_p - f_s$
- Mixer operation: Frequency translation

Advantages:

- Low noise: Quantum-limited performance
- High gain: 20-30 dB typical
- Wide bandwidth: Several GHz

Mnemonic

“Parametric Pump Provides frequency conversion Plus gain”

Question 4(c) OR [7 marks]

Describe the construction and working principle of RUBY MASER. List its applications.

Solution

Construction:

- Ruby crystal: Cr^{3+} ions in Al_2O_3 lattice
- Magnetic field: Strong DC magnetic field
- Microwave cavity: Resonant at signal frequency
- Pump source: High frequency klystron
- Cryogenic cooling: Liquid helium temperature

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting} []
graph LR
    A[Ruby Crystal] --> B[Microwave Cavity]
    C[Magnetic Field] --> A
    D[Pump Source] --> B
    E[Liquid Helium] --> A
    B --> F[Amplified Output]
{Highlighting}
{Shaded}
```

Working Principle:

- Energy levels: Cr^{3+} ions have three energy levels
- Population inversion: Pump creates more atoms in upper level
- Stimulated emission: Signal photons trigger emission
- Coherent amplification: Phase-coherent amplification

Three-level system:

- Ground state: E_1 (most populated)
- Intermediate state: E_2 (signal frequency)
- Upper state: E_3 (pump frequency)

Applications:

- Radio astronomy: Ultra-low noise receivers
- Satellite communication: Ground station amplifiers
- Deep space communication: NASA tracking stations
- Research: Quantum electronics experiments

Mnemonic

“RUBY MASER Makes Amazingly Sensitive Electromagnetic Receivers”

Question 5(a) [3 marks]

Draw and explain the functional block diagram of MTI RADAR.

Solution

MTI RADAR detects moving targets by comparing successive echoes and canceling fixed targets.

Mermaid Diagram (Code)

```
{Shaded}  
{Highlighting} []  
graph LR  
    A[Transmitter] --> B[Duplexer]  
    B --> C[Antenna]  
    C --> D[Receiver]  
    D --> E[Phase Detector]  
    F[STALO] --> E  
    F --> G[COHO]  
    G --> E  
    E --> H[Canceller]  
    H --> I[Display]  
{Highlighting}  
{Shaded}
```

Components:

- **STALO:** Stable Local Oscillator
- **COHO:** Coherent Oscillator
- **Phase detector:** Compares echo phases
- **Canceller:** Removes fixed target echoes

Mnemonic

“MTI Makes Targets Intelligible by Motion”

Question 5(b) [4 marks]

Compare RADAR with SONAR.

Solution

Parameter	RADAR	SONAR
Wave type	Electromagnetic	Acoustic
Medium	Air/vacuum	Water
Speed	$3 \times 10^8 \text{ m/s}$	1500 m/s
Frequency	GHz	kHz
Range	100+ km	10-50 km
Applications	Air/space	Underwater

Common features:

- Pulse-echo principle
- Range measurement
- Target detection

Mnemonic

“RADAR Radiates, SONAR Sounds”

Question 5(c) [7 marks]

Obtain the equation of maximum RADAR range. Explain the factors affecting the maximum radar range.

Solution

RADAR Range Equation:

$$R_{\max} = \sqrt[4]{(P_t \times G^2 \times \lambda^2 \times \sigma) / (64^3 \times P_{min} \times L)}$$

Where:

- P_t : Transmitter power (W)
- G : Antenna gain (dimensionless)
- λ : Wavelength (m)
- σ : Target cross-section (m^2)
- P_{min} : Minimum detectable power (W)
- L : System losses (dimensionless)

Derivation steps:

1. Power density at target: $P_t / (4 \pi R^2)$
1. Power intercepted: $\times \text{Power density}$
1. Power at receiver: Intercepted power $\times G / (4R^2)$
1. Set equal to P_{min} and solve for R

Factors Affecting Range:

Increase Range:

- Higher transmitter power: $R \propto P_t^{1/4}$
- Larger antenna gain: $R \propto G^{1/2}$
- Larger target RCS: $R \propto \sigma^{1/4}$
- Lower system losses: $R \propto L^{-1/4}$

Decrease Range:

- Higher frequency: $R \propto f^{-1/2}$
- Atmospheric losses: Absorption and scattering
- Ground clutter: Interfering reflections

Mnemonic

“RADAR Range Requires Robust Power and Proper Parameters”

Question 5(a) OR [3 marks]

Describe the Doppler effect in CW Doppler RADAR.

Solution

Doppler Effect causes frequency shift when target moves relative to RADAR.

$$\text{Doppler Frequency: } f_d = (2 \times V_r \times f_0) / c$$

Where:

- V_r : Radial velocity (m/s)
- f_0 : Transmitted frequency (Hz)
- c : Speed of light ($3 \times 10^8 m/s$)

Characteristics:

- Approaching target: f_d positive
- Receding target: f_d negative
- Factor of 2: Due to two-way propagation

Mnemonic

“Doppler Detects Direction with Doubled frequency shift”

Question 5(b) OR [4 marks]

Explain PPI Display method for RADAR

Solution

PPI (Plan Position Indicator) shows **top view** of RADAR coverage area with range and bearing information.

Display Features:

- **Circular screen:** Center represents RADAR location
- **Rotating trace:** Synchronized with antenna rotation
- **Range rings:** Concentric circles for distance
- **Bearing scale:** $0-360^\circ$ around circumference

Operation:

- **Sweep rotation:** Matches antenna rotation
- **Echo intensity:** Controls brightness
- **Persistence:** Afterglow maintains target visibility
- **Range scale:** Selectable range settings

Applications:

- **Air traffic control:** Aircraft positioning
- **Marine navigation:** Ship and obstacle detection
- **Weather monitoring:** Storm tracking

Mnemonic

“PPI Provides Position Information Perfectly”

Question 5(c) OR [7 marks]

Draw the block diagram of Pulse radar and explain the working principle.

Solution

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting} []
graph LR
    A[Master Oscillator] --> B[Modulator]
    B --> C[Power Amplifier]
    C --> D[Duplexer]
    D --> E[Antenna]
    E --> F[RF Amplifier]
    F --> G[Mixer]
    H[Local Oscillator] --> G
    G --> I[IF Amplifier]
    I --> J[Detector]
    J --> K[Video Amplifier]
    K --> L[Display]
    A --> M[Timer]
    M --> B
    M --> L
{Highlighting}
{Shaded}
```

Working Principle:

Transmission:

- **Master oscillator:** Generates RF carrier
- **Modulator:** Creates short pulses
- **Power amplifier:** Amplifies pulse power
- **Duplexer:** Routes pulse to antenna

Reception:

- **Echo reception:** Antenna receives reflected signals
- **RF amplification:** Low noise amplification
- **Mixing:** Converts to intermediate frequency
- **IF amplification:** Further amplification
- **Detection:** Extracts video signal
- **Display:** Shows range vs amplitude

Key Parameters:

- **Pulse width:** Determines range resolution
- **PRF:** Pulse repetition frequency
- **Peak power:** Maximum range capability
- **Duty cycle:** Average power consideration

Advantages:

- **High peak power:** Long range capability
- **Good range resolution:** Narrow pulses
- **Simple processing:** Direct detection

Mnemonic

“Pulse RADAR Pulses Powerfully for Precise Position”

