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 = $Z_0, imaginary part = 0$

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**: /2

Open Circuit Line:

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

```
Short Circuit:     Open Circuit:

V |    /{           V |  /    /}
  |   /  {            |/    /    }
  |  /    {           |          }
  |\_/\_\_\_\_\_\_{           |\_\_\_\_\_\_\_\_\_\_\_\_\_}
    0   /4   /2        0   /4   /2

I |  /{    /        I |    /}
  | /  {  /           |   /  }
  |/    {/            |  /    }
  |            {      |\_/\_\_\_\_\_\_}
    0   /4   /2        0   /4   /2
```

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**: /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°*betweenoutputports*

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:

- $\mathbf{C = 10\ log(P}_1/P_3)(Coupling factor)$
- $\mathbf{D = 10\ log(P}_3/P_4)(Directivity)$

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 $\approx RFwavevelocity$
- **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**: $\text{VSWR}_1 = VSWR_2 \times Attenuatorratio$

Formula: **VSWR_actual = VSWR_measured** $\times 10\hat{}(Attenuation/20)$

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
    |
    |     Fast electrons
    |          Medium electrons
    |             Slow electrons
Time|
    ↓        Bunching occurs

Input         Drift        Output
Cavity        Space        Cavity
```

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 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 Ω)
- **Reverse bias**: High resistance (>10 kΩ)
- **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.

```
   +V
    |

   P    N    Junction

    |
    0V

Capacitance vs Voltage:
C |
  |{    }
  | {   }
  |  {  }
  |\_\_\_{\_\_\_\_}
    0  {-V (reverse bias)}
```

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

```
I{-V Characteristic:}
I |
  |  /{     Negative resistance}
  | /  {   }
  |/    {  }
  |      {\_\_\_}
```

```
  |\_\_\_\_\_\_\_\_\_\_\_\_\_ V
    0  Vp  Vv

Vp = Peak voltage
Vv = Valley voltage
```

Working:

- **Forward bias 0-Vp**: Current increases (tunneling)
- **Vp to Vv**: Negative resistance region
- **Beyond Vv**: 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**: fs (input)
- **Pump frequency**: fp (much higher)
- **Output frequency**: fo = fp + fs
- **Energy transfer**: From pump to signal

Down-conversion:

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

- **Pump frequency**: fp
- **Output frequency**: fo = fp - fs
- **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 {-{-}{} B}
    B {-{-}{} 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	$3 \times 10^8 m/s$	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 = $\sqrt[4]{(P\_t \times G^2 \times {}^2 \times)/(64^3 \times P\_min \times L)}$
Where:

- **P_t: Transmitter power (W)**
- **G: Antenna gain (dimensionless)**
- **: Wavelength (m)**
- **: 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 R**^{2})
1. **Power intercepted:** $\times Powerdensity$
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 P_t^(1/4)**
- **Larger antenna gain: R G^(1/2)**
- **Larger target RCS: R ^(1/4)**
- **Lower system losses: R L^(-1/4)**

Decrease Range:

- **Higher frequency: R ^(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.
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°$around circumference$

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 {-{-}{} D}
    D {-{-}{} 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"