Microwave and Radar Communication (4351103) - Winter 2023 Solution

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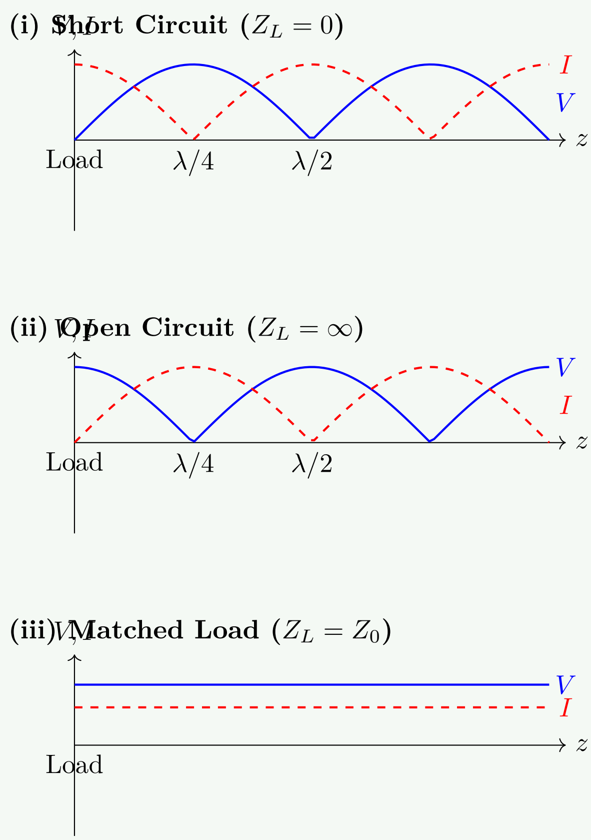
Question 1(a) [3 marks]

Sketch the standing wave pattern for voltage and current along the transmission line when it is terminated with (i) Short Circuit, (ii) Open circuit, and (iii) Matched Load.

Solution

Standing Wave Patterns:

Figure 1. Standing Wave Patterns



- **Short Circuit**: Voltage is zero (minimum) at the load. Current is maximum.
- **Open Circuit**: Voltage is maximum at the load. Current is zero.
- **Matched Load**: No standing waves. Voltage and current are constant (flat line).

Mnemonic

"SOC - Short Opens Current, Open Shorts Current"

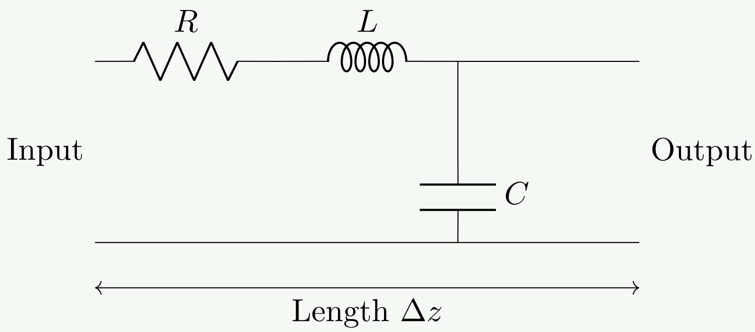
Question 1(b) [4 marks]

Draw and Explain equivalent circuit of two parallel wire transmission line at microwave frequency.

Solution

Equivalent Circuit:

Figure 2. Transmission Line Equivalent Circuit



Primary Constants:

- **R (Resistance)**: Series resistance per unit length due to conductor loss (Ω/m).
- **L (Inductance)**: Series inductance per unit length due to magnetic flux (H/m).
- **G (Conductance)**: Shunt conductance per unit length due to dielectric loss (S/m).
- **C (Capacitance)**: Shunt capacitance per unit length due to electric charge (F/m).

Table of Parameters:

Parameter	**Symbol**	**Unit**	**Effect**
Resistance	R	Ω/m	Power loss in conductors
Inductance	L	H/m	Energy storage (magnetic)
Conductance	G	S/m	Power loss in dielectric
Capacitance	C	F/m	Energy storage (electric)

Mnemonic

"RLGC - Really Large Guide Cables"

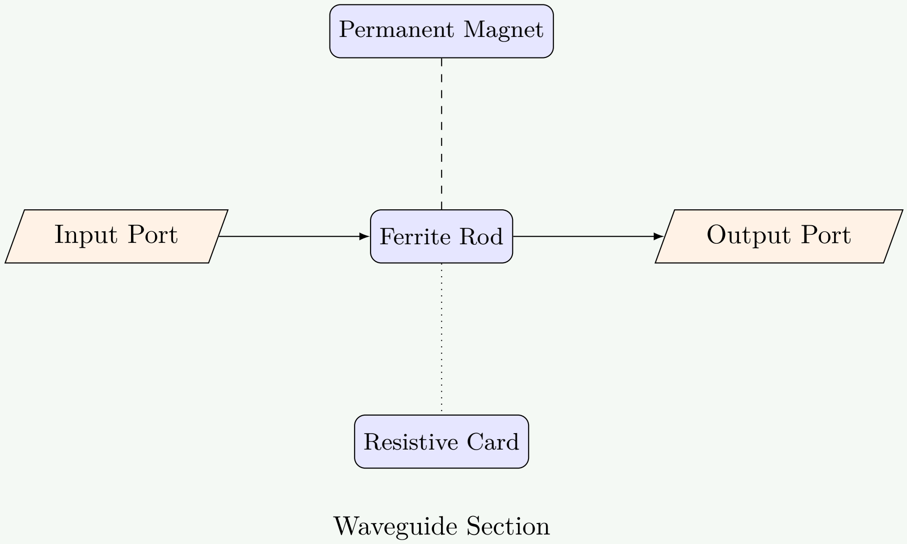
Question 1(c) [7 marks]

Explain Principle, construction and working of Isolator with necessary sketch.

Solution

Principle: An isolator is a non-reciprocal 2-port device that allows microwave signals to pass in the forward direction with minimum attenuation but absorbs signals in the reverse direction. It uses the **Faraday rotation** property of ferrite materials.

Figure 3. Isolator Construction



Working:

- **Forward Direction**: The TE_{10} mode signal enters the input. The ferrite element rotates the polarization by 45°. It passes through the output without attenuation because the resistive card is perpendicular to the E-field.
- **Reverse Direction**: Any reflected signal entering the output is rotated another 45° (total 90°). The E-field becomes parallel to the input resistive card and is **absorbed**.

Applications:

- Protects microwave generators (like Klystrons/Magnetrons) from reflected power.
- Prevents frequency pulling and instability.

Specifications:

Parameter	Typical Value
Isolation	20-30 dB
Insertion Loss	0.5-1 dB
VSWR	< 1.5

Mnemonic

"Isolate Forward, Absorb Reverse"

OR

Question 1(c) [7 marks]

Compare Transmission Line and Waveguide.

Solution

Comparison:

Parameter	Transmission Line	Waveguide
Frequency	DC to Microwave (limited high freq)	Microwave & above (High freq)
Structure	Two conductors (e.g., Coaxial)	Single hollow conductor
Mode	Supports TEM mode	Supports TE and TM modes only
Cutoff	No lower cutoff frequency (passes DC)	Has a cutoff frequency (f_c)
Losses	Higher (I^2R and dielectric)	Lower (Air dielectric, large area)
Power	Moderate power handling	High power handling capability
Interference	Susceptible to EMI (unless shielded)	Self-shielded (closed metal)
Cost/Size	Low cost, Compact, Flexible	Expensive, Bulky, Rigid

Key Differences:

- **Conductors**: Transmission lines need a return path (2 wires). Waveguides use walls for reflection (1 pipe).
- **Modes**: Waveguides cannot support TEM because there is no center conductor.

Mnemonic

"Transmission Travels Two-wire, Waveguide Walks Wide"

Question 2(a) [3 marks]

Define: (i) VSWR, (ii) Reflection Coefficient, and (iii) Skin effect

Solution

Definitions:

1. **VSWR (Voltage Standing Wave Ratio):** The ratio of maximum voltage amplitude to minimum voltage amplitude in a standing wave pattern.

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (1 \leq VSWR \leq \infty)$$

2. **Reflection Coefficient (Γ):** The ratio of the reflected voltage wave amplitude to the incident voltage wave amplitude at the load.

$$\Gamma = \frac{V_{ref}}{V_{inc}} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (0 \leq |\Gamma| \leq 1)$$

3. **Skin Effect:** At high frequencies, alternating current tends to flow only near the surface of the conductor rather than the entire cross-section. The depth where current density drops to $1/e$ is called **Skin Depth (δ)**.

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

Mnemonic

"VSWR Varies, Gamma Guides, Skin Shrinks"

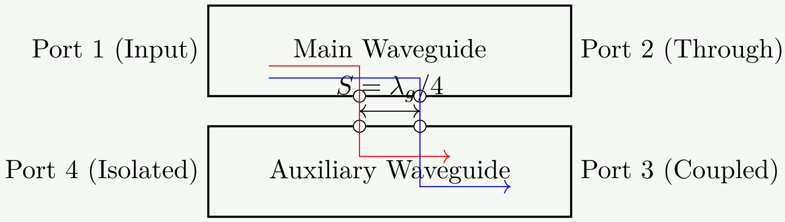
Question 2(b) [4 marks]

Explain working of Two-hole Directional Coupler with Proper sketch.

Solution

Two-Hole Directional Coupler:

Figure 4. Two-Hole Directional Coupler



Working Principle:

- **Spacing**: Two holes are spaced apart by distance $S = \lambda_g/4$.
- **Forward Wave**: Signal travels from Port 1. Part of it couples through hole A and hole B towards Port 3. Path difference is zero (waves travel same distance). They add up **in phase** at Port 3.
- **Reverse Wave**: Waves coupled towards Port 4 have a path difference of $2S = \lambda_g/2$ (180°). They **cancel out** due to destructive interference.

Parameters:

- Coupling Factor (dB) $= 10\log_{10}(P_1/P_3)$
- Directivity (dB) $= 10\log_{10}(P_3/P_4)$

Mnemonic

"Two Holes, Two Directions, Total Control"

Question 2(c) [7 marks]

Describe Propagation of microwaves through waveguide and get the equation of cut off wavelength.

Solution

Wave Propagation: Microwaves propagate in waveguides via reflections from conducting walls. They support TE (Transverse Electric) and TM (Transverse Magnetic) modes.

Cut-off Wavelength Derivation: The wave equation for H_z in a rectangular waveguide (TE mode):

$$\nabla^2 H_z + \omega^2 \mu\epsilon H_z = 0$$

Applying boundary conditions for dimensions $a \times b$:

$$\gamma_{mn}^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2\mu\epsilon$$

For propagation, γ must be imaginary (propagation constant $j\beta$). The transition occurs when $\gamma = 0$:

$$\omega_c^2 \mu\epsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

Since $\omega_c = 2\pi f_c$ and $c = 1/\sqrt{\mu\epsilon}$:

$$\left(\frac{2\pi f_c}{c}\right)^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

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

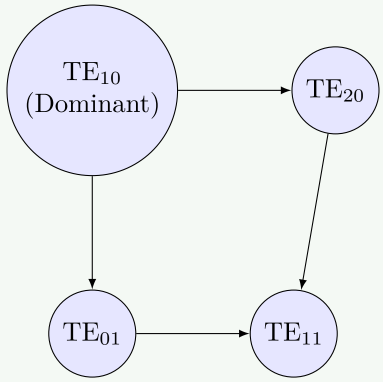
The cut-off wavelength $\lambda_c = c/f_c$:

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$$

For Dominant Mode (TE_{10}): $m = 1, n = 0$:

$$\lambda_c = \frac{2}{\sqrt{(1/a)^2}} = 2a$$

Figure 5. Mode Hierarchy



Mnemonic

"Cut-off Comes, Propagation Proceeds"

OR

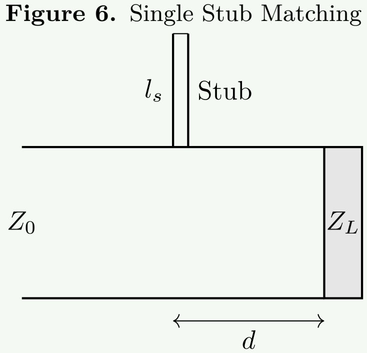
Question 2(a) [3 marks]

Explain Impedance Matching using Single stub.

Solution

Single Stub Matching: A technique to match a load impedance Z_L to the transmission line characteristic impedance Z_0 using a parallel (shunt) stub.

Figure 6. Single Stub Matching



Principle:

1. Move from load Z_L distance d towards source until the real part of admittance is matched: $Y_{in} = Y_0 + jB$.
2. Attach a stub of length l_s at that point with susceptance $-jB$.
3. Total admittance becomes $Y_{total} = (Y_0 + jB) - jB = Y_0$ (Matched).

Mnemonic

"Single Stub Solves Susceptance"

OR

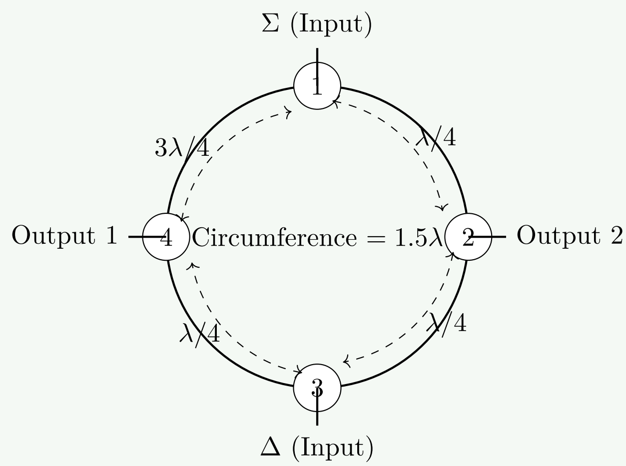
Question 2(b) [4 marks]

Explain Hybrid ring with necessary sketch.

Solution

Hybrid Ring (Rat-Race Coupler): A 4-port directive coupler used for splitting power or combining signals.

Figure 7. Hybrid Ring Structure



Working:

- Input at Port 1 splits equally to Port 2 and Port 4 (in phase). Port 3 is isolated (path diff $\lambda/2$).
- Input at Port 3 splits equally to Port 2 and Port 4 (180° out of phase). Port 1 is isolated.

Mnemonic

"Ring Rotates, Ports Pair-up"

OR

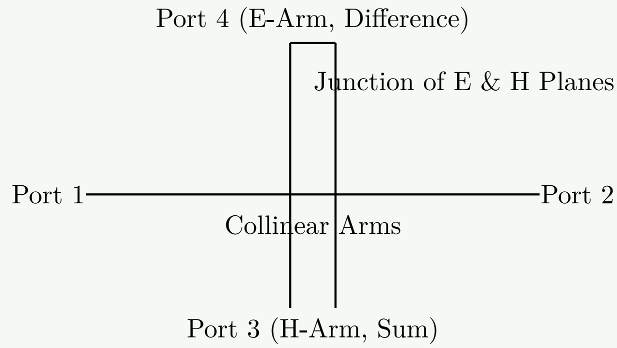
Question 2(c) [7 marks]

Explain construction, working and any one application of Magic Tee with necessary diagram.

Solution

Magic Tee (E-H Plane Tee): A 4-port hybrid waveguide junction that combines the properties of E-plane and H-plane Tees.

Figure 8. Magic Tee Construction



Working Principle:

- **H-Arm Input (Port 3)**: Power splits equally between Port 1 and Port 2 **in phase**. Port 4 is isolated. ($P_1 = P_2 = P_3/2$).
- **E-Arm Input (Port 4)**: Power splits equally between Port 1 and Port 2 but **out of phase** (180°). Port 3 is isolated.
- **Matched**:Ideally, if ports are matched, $S_{34} = S_{43} = 0$ (Isolation).

Application: Radar Duplexer:

- Transmitter connected to H-Arm (Port 3).
- Antenna connected to E-Arm (Port 4).
- Receiver connected to one collinear arm, Matched load to other.
- Allows single antenna for Tx and Rx by utilizing isolation properties.

Mnemonic

"Magic Makes Isolation, Tee Transmits Together"

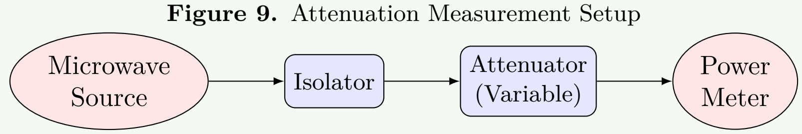
Question 3(a) [3 marks]

Explain Attenuation measurement with the help of block diagram.

Solution

Attenuation Measurement:

Figure 9. Attenuation Measurement Setup



Method:

1. **Reference**: Measure Power P_1 without the device under test (DUT).
2. **Measure**: Insert DUT and measure Power P_2.
3. **Calculate**: Attenuation (dB) $= 10 \log_{10} \frac{P_1}{P_2}$.

Mnemonic

"Attenuation = Power1 / Power2"

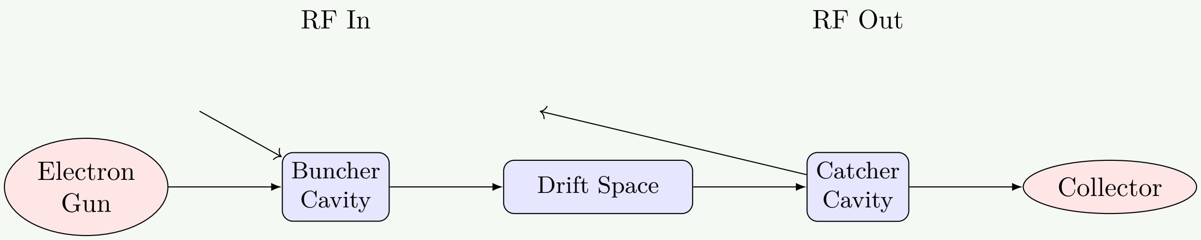
Question 3(b) [4 marks]

Explain velocity modulation in two cavity klystron with the help of Applegate diagram.

Solution

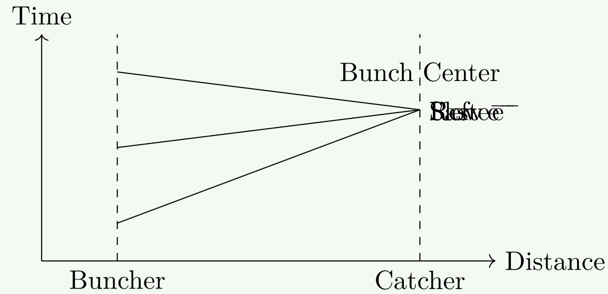
Two Cavity Klystron:

Figure 10. Klystron Structure



Velocity Modulation (Applegate Diagram):

Figure 11. Applegate Diagram



Process:

1. **Modulation**: RF input voltage at buncher cavity accelerates some electrons (fast) and retards others (slow).
2. **Drift**: In the drift space, fast electrons catch up to slow electrons.
3. **Bunching**: Electrons group together into bunches, converting continuous beam into pulsed beam containing RF energy.

Mnemonic

"Velocity Varies, Bunching Builds"

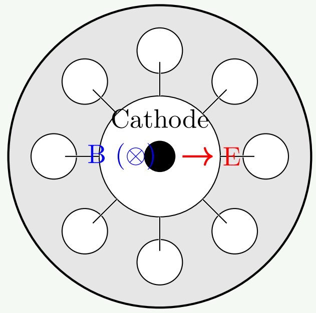
Question 3(c) [7 marks]

Explain the principle, construction and effect of electric and magnetic field in Magnetron.

Solution

Cavity Magnetron: A high-power microwave oscillator utilizing **crossed electric and magnetic fields**.

Figure 12. Magnetron Structure



Anode Block with Resonant Cavities

Effect of Fields:

- **Electric Field (E)**: Radial, from anode (+) to cathode (-). Accelerates electrons outward.
- **Magnetic Field (B)**: Axial (perpendicular to page). Exerts Lorentz force $F = q(v \times B)$, bending electron path.

Electron Motion:

1. **Low B**: Electrons go straight to anode.
2. **Critical B (B_c)**: Electrons graze anode.
3. **Operating B ($> B_c$)**: Electrons spiral in interactions space, forming "spokes", transferring energy to RF fields in cavities before returning to cathode or being collected.

Mnemonic

"Magnetron Makes Microwaves via Magnetic Motion"

OR

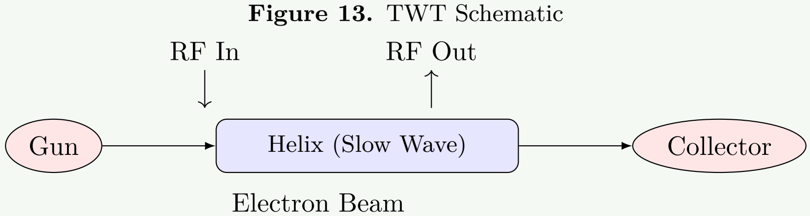
Question 3(a) [3 marks]

Explain working of TWT (Travelling Wave Tube) as an Amplifier.

Solution

Travelling Wave Tube (TWT): A broadband microwave amplifier utilizing a **Slow Wave Structure** (Helix).

Figure 13. TWT Schematic



Working:

- **Slow Wave**: The helix reduces the RF wave velocity (v_p) to match electron beam velocity (v_e).
- **Interaction**: Continuous interaction occurs along the tube. Electrons are bunched by the RF field and transfer kinetic energy to the RF wave, amplifying it.

Mnemonic

"Travelling Wave Transfers Energy"

OR

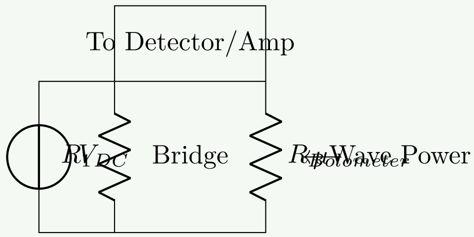
Question 3(b) [4 marks]

Explain Bolometer method for low power measurement at microwave frequency.

Solution

Bolometer Method: Uses a temperature-sensitive resistive element (Barretter or Thermistor) in a bridge circuit.

Figure 14. Bolometer Bridge Circuit



Working:

1. Bridge is initially balanced with DC Power.
2. Microwave power heats the element → Resistance changes → Bridge unbalance.
3. Amount of unbalance or change in DC bias required to re-balance is proportional to RF power.

Mnemonic

"Bolometer Burns, Bridge Balances"

OR

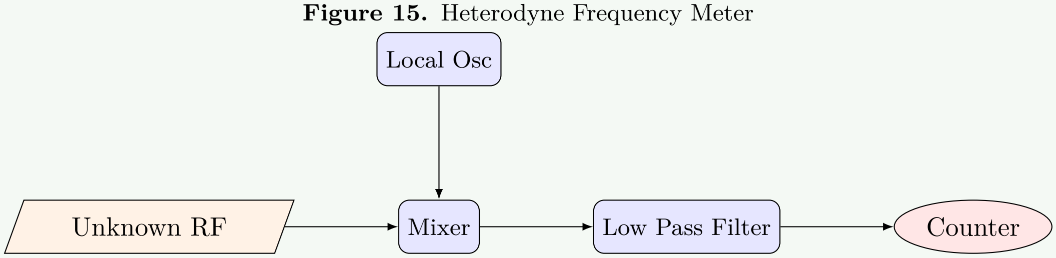
Question 3(c) [7 marks]

Explain frequency and wavelength measurement method with the help of block diagram.

Solution

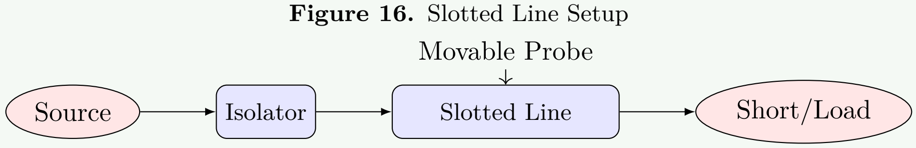
Frequency Measurement (Heterodyne Method):

Figure 15. Heterodyne Frequency Meter



Wavelength Measurement (Slotted Line Method):

Figure 16. Slotted Line Setup



Procedure:

1. **Measure**: Locate two adjacent minima (nodes) on the slotted line. Let locations be d_1 and d_2.

2. **Calculate λ_g**: Distance between minima is $\lambda_g/2$.

$$\lambda_g = 2|d_1 - d_2|$$

3. **Calculate Frequency**:

$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2} \quad \text{and} \quad f = \frac{c}{\lambda_0}$$

Mnemonic

"Frequency First, Wavelength With-measurement"

Question 4(a) [3 marks]

State Frequency limitations of vacuum tubes at microwave frequency.

Solution

Frequency Limitations:

- **Transit time effects**: Electron transit time becomes comparable to RF period, causing phase delay and reducing efficiency.
- **Inter-electrode capacitance**: Reactance ($X_c = 1/2\pi fC$) decreases, shunting the output and reducing gain.
- **Lead inductance**: Parasitic inductance of connecting leads causes resonance and instability.
- **Skin effect**: Current flows only on surface, increasing effective resistance and losses.

Limiting Factors Table:

Factor	Effect
Transit Time	Phase delay ($f < 1/2\pi\tau$)
Capacitance	Gain drop ($\propto 1/f$)
Lead Inductance	Resonance/Instability
Skin Effect	Increased Resistance

Mnemonic

"Transit Time Troubles Traditional Tubes"

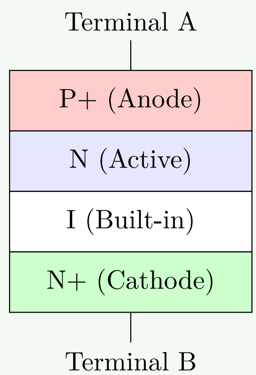
Question 4(b) [4 marks]

Explain working of IMPATT diode with proper sketch.

Solution

IMPATT Diode (Impact Ionization Avalanche Transit Time):

Figure 17. IMPATT Diode Structure

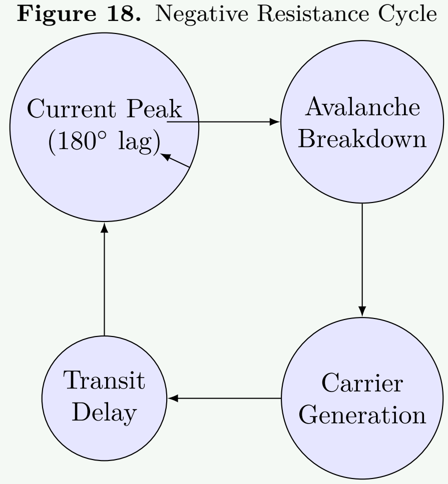


Working Principle: Generates negative resistance using two effects:

1. **Impact Ionization (Avalanche Effect)**: Creates a phase delay of 90° between voltage and current.
2. **Transit Time Effect**: Carriers drifting through the drift region create another 90° delay.

Total Delay: 180° phase shift → Negative Resistance (Current opposes voltage).

Figure 18. Negative Resistance Cycle



Mnemonic

"Impact Ionization, Transit Time = Negative Resistance"

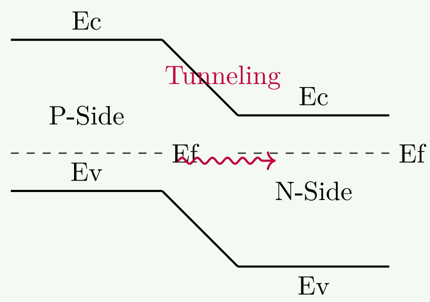
Question 4(c) [7 marks]

Explain Principle, tunneling phenomenon and any one application of Tunnel Diode.

Solution

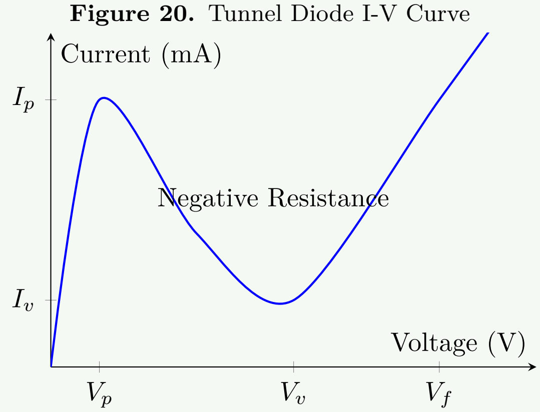
Tunnel Diode Principle: Operates on the **Quantum Mechanical Tunneling** effect across a thin potential barrier in a heavily doped p-n junction (10^{19} to 10^{20} doping).
Energy Band Diagram:

Figure 19. Tunnel Diode Band Diagram (Peak Point)



I-V Characteristics:

Figure 20. Tunnel Diode I-V Curve



Application - Oscillator: Operates in the negative resistance region to generate oscillations.

Mnemonic

"Tunnel Through, Negative Grows, Oscillator Flows"

OR

Question 4(a) [3 marks]

Explain Hazards due to microwave radiation.

Solution

Microwave Hazards:

1. **HERP (Health Hazards to Personnel):**
   - **Thermal**: Tissue heating, cataracts.
   - **Non-thermal**: Cellular damage.
2. **HERO (Hazards to Ordnance):**
   - Premature ignition of explosives.
3. **HERF (Hazards to Fuel):**
   - Ignition of fuel vapors.

Safety Limit: Generally < 10 mW/cm^2.

Mnemonic

"HERP-HERO-HERF = Health-Explosive-Fuel Risks"

OR

Question 4(b) [4 marks]

Explain Degenerate and non-degenerate mode in Parametric Amplifier.

Solution

Parametric Amplifier Modes:

1. **Non-Degenerate Mode:**
   - **Frequencies**: Pump (f_p) $\neq 2 \times$ Signal (f_s). ($f_p = f_s + f_i$).
   - **Idler**: A separate idler frequency f_i exists.
   - **Performance**: Better noise figure, stable gain.
2. **Degenerate Mode:**
   - **Frequencies**: Pump (f_p) $= 2 \times$ Signal (f_s).
   - **Idler**: Idler equals signal frequency ($f_i = f_s$).
   - **Performance**: Output depends on phase of pump.

Mnemonic

"Non-degenerate = Not-single, Degenerate = Doubled-frequency"

OR

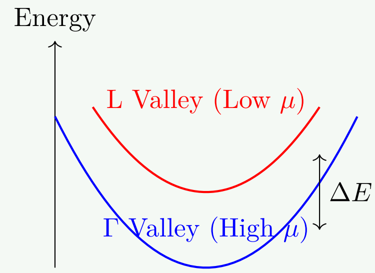
Question 4(c) [7 marks]

Explain principle and Gunn effect in Gunn Diode. Also Explain Gunn Diode as an Oscillator.

Solution

Gunn Effect Principle: Based on the **Transferred Electron Effect**. Electrons transfer from high-mobility central valley (Γ) to low-mobility satellite valley (L).

Figure 21. Gunn Effect Band Structure



Gunn Oscillator:

- Gunn diode in resonant cavity.
- Frequency $f = v_{domain}/L_{eff}$.

Mnemonic

"Gunn Gets Going via Gallium-Arsenide"

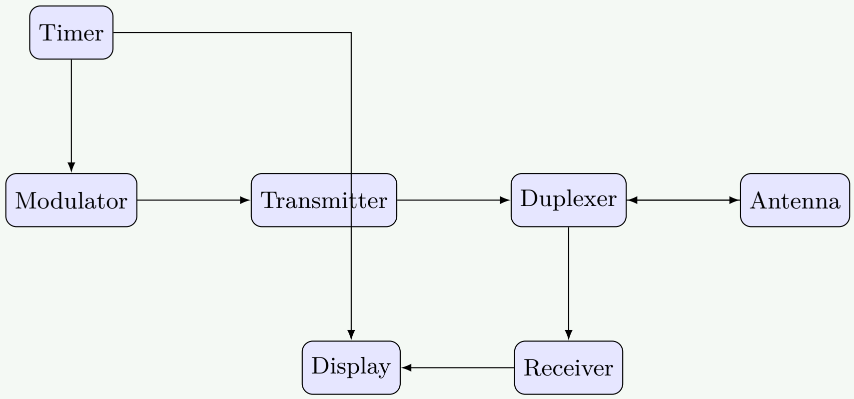
Question 5(a) [3 marks]

Explain working principle of Basic RADAR system with the help of block diagram.

Solution

RADAR Principle: Radio Detection And Ranging. Range $R = (c \times t)/2$.

Figure 22. Basic Radar Block Diagram



Mnemonic

"RADAR Ranges by Round-trip Reflection"

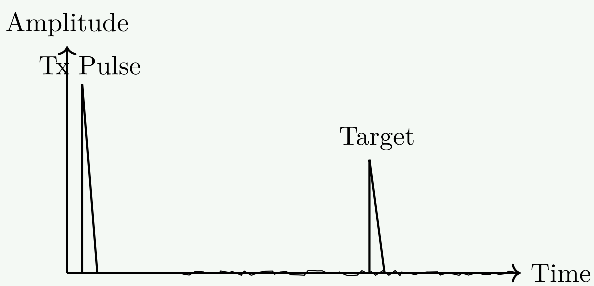
Question 5(b) [4 marks]

Explain A-scope display method with the help of proper figure.

Solution

A-Scope Display: Displays Amplitude vs Time/Range.

Figure 23. A-Scope Presentation



Mnemonic

"A-scope shows Amplitude Along time Axis"

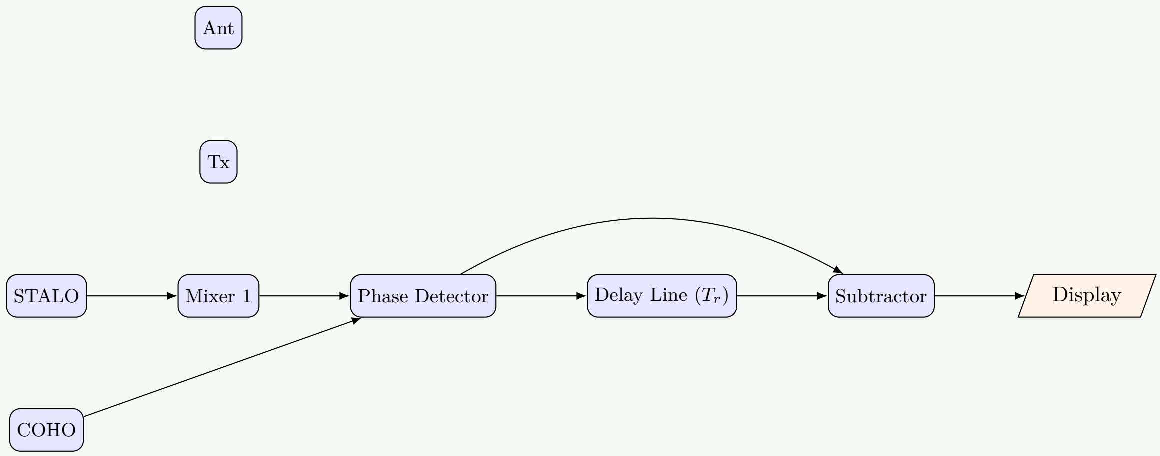
Question 5(c) [7 marks]

Explain Doppler effect and working of MTI (Moving Target Indicator) RADAR system with the help of block diagram.

Solution

Doppler Effect: $f_d = 2v_r/\lambda$.
MTI Radar: Uses Doppler to distinguish moving targets.

Figure 24. MTI Radar Block Diagram



Mnemonic

"MTI Makes Targets Identifiable via Doppler Difference"

OR

Question 5(a) [3 marks]

Define: a) Blind speed, and b) MUR

Solution

Definitions:

- **Blind Speed** (v_b): Target speed where Doppler shift is multiple of PRF. $v_b = \frac{n\lambda f_r}{2}$.
- **MUR**: Maximum Unambiguous Range. $R_{max} = \frac{c}{2f_r}$.

Mnemonic

"Blind speed Blocks, MUR Measures maximum"

OR

Question 5(b) [4 marks]

Explain the factors affecting Maximum RADAR range.

Solution

Radar Range Equation:

$$R_{max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4}$$

Factors:

- P_t: Transmitter Power ($R \propto P_t^{1/4}$).

- G: Antenna Gain ($R \propto \sqrt{G}$).
- λ: Wavelength ($R \propto \sqrt{\lambda}$).
- σ: Target Cross Section.
- S_{min}: Receiver Sensitivity.

Mnemonic

"Power-Gain-Lambda-Sigma determine Range"

OR

Question 5(c) [7 marks]

Compare Pulsed RADAR and CW Doppler RADAR.

Solution

Comparison:

Parameter	Pulsed	CW Doppler
Transmission	Pulses	Continuous
Range	Measurable	Not measurable (normally)
Velocity	Difficult	Easy (Doppler)

Mnemonic

"Pulsed Position gives, CW Continuously Waves"