Microwave and Radar Communication (4351103) - Summer 2025 Solution

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Question 1(a) [3 marks]

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

Solution

Microwave Bands:

Table 1. Frequency Bands

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"

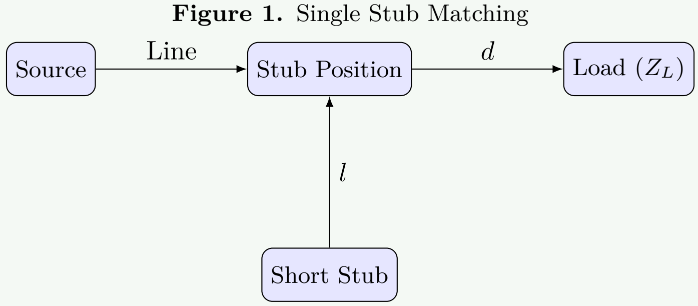
Question 1(b) [4 marks]

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.

Figure 1. Single Stub Matching



Process:

1. **Stub length**: Provides reactive impedance to cancel line reactance.
2. **Stub position**: Point on line where real part of admittance is Y_0.
3. **Matching condition**: Total Admittance $Y = Y_0 + jB_{line} - jB_{stub} = Y_0$.

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.

Solution

Characteristics of Lossless Line:

- **No power loss**: $R = 0, G = 0$.
- **Constant amplitude**: No attenuation ($\alpha = 0$).
- **Phase delay only**: Signal is delayed but not weakened.
- **Standing wave pattern**: Formed due to reflections from mismatched load.

General Equations: For a line with propagation constant $\gamma = \alpha + j\beta$ and characteristic impedance Z_0:

Voltage Equation:

$$V(z) = V^+ e^{-\gamma z} + V^- e^{\gamma z}$$

Current Equation:

$$I(z) = \frac{V^+}{Z_0} e^{-\gamma z} - \frac{V^-}{Z_0} e^{\gamma z}$$

Where:

- $Z_0 = \sqrt{L/C}$ (for lossless line).
- $\gamma = j\beta$ (since $\alpha = 0$).

Mnemonic

"Lossless Lines Love Low Loss"

OR

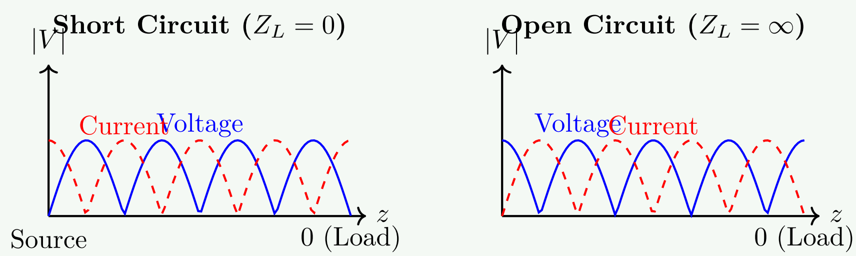
Question 1(c) [7 marks]

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

Solution

Standing Wave: Fixed pattern formed by the interference of **forward** and **reflected waves** traveling in opposite directions.

Figure 2. Standing Wave Patterns



Analysis:

Table 2. Standing Wave Features

Condition	Voltage at Load	Current at Load
Short Circuit	Minimum (0)	Maximum
Open Circuit	Maximum ($2V^+$)	Minimum (0)

Distance between successive maxima or minima is $\lambda/2$.

Mnemonic

"Short Circuits Current, Open Circuits Voltage"

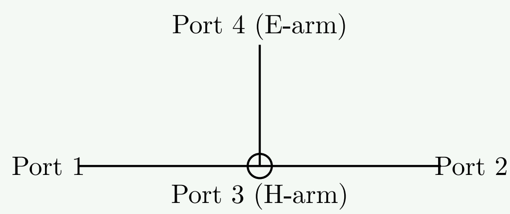
Question 2(a) [3 marks]

Draw and explain the working of Magic TEE.

Solution

Magic TEE: A 4-port hybrid waveguide junction combining E-plane and H-plane Tees.

Figure 3. Magic TEE Structure



Ports 1 & 2: Collinear Arms

Working:

- **Port 3 (H-arm)**: Sum port ($P_3 \propto P_1 + P_2$). Inputs at 1 & 2 appear in phase.
- **Port 4 (E-arm)**: Difference port ($P_4 \propto P_1 - P_2$). Inputs at 1 & 2 appear 180° out of phase.
- **Isolation**: No coupling between E-arm (4) and H-arm (3).

Mnemonic

"Magic Tee Mixes Modes"

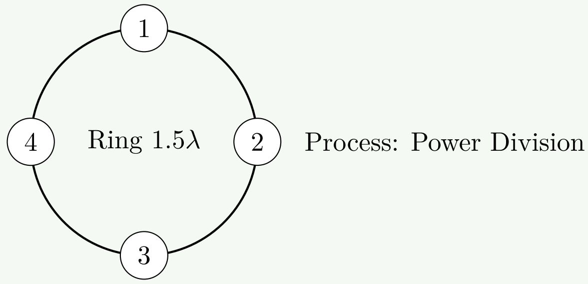
Question 2(b) [4 marks]

Explain the working of Hybrid ring.

Solution

Hybrid Ring (Rat-Race Coupler): A circular waveguide with 4 ports used for power splitting and summing.

Figure 4. Hybrid Ring



Working Parameters:

- **Circumference**: 1.5λ (Total path length).
- **Spacing**: Ports separated by $\lambda/4$, except one $3\lambda/4$ section.
- **Function**: Input at Port 1 splits equally to 2 and 4. Port 3 is isolated.

Mnemonic

"Ring Runs Round for Power Sharing"

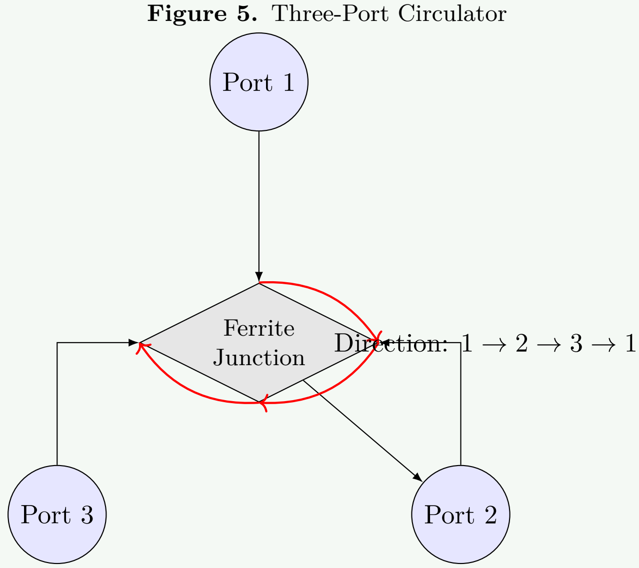
Question 2(c) [7 marks]

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

Solution

Circulator Construction:

Figure 5. Three-Port Circulator



Working Principle:

- Based on **Faraday Rotation** in ferrite material.
- **Non-reciprocal**: A signal entering Port 1 emerges ONLY at Port 2. Port 2 to Port 3, etc.
- Reverse power is blocked (isolated).

Applications:

1. **Duplexer in Radar**: Allows single antenna for Tx and Rx.
2. **Isolator**: By terminating one port with a matched load.
3. **Parametric Amplifiers**: Separation of input and output.

Mnemonic

"Circulator Circles Clockwise Continuously"

OR

Question 2(a) [3 marks]

Compare rectangular waveguide and circular waveguide.

Solution

Comparison:

Table 3. Waveguide Comparison

Parameter	Rectangular Waveguide	Circular Waveguide
Cross-section	Rectangular ($a \times b$)	Circular (radius a)
Dominant Mode	TE_{10}	TE_{11}
Cutoff Freq	$f_c = c/2a$	$f_c = 1.841c/2\pi a$ (Complex)
Power Handling	Lower	Higher
Rotation	Polarization fixed	Supports rotating polarization

Mnemonic

"Rectangles are Regular, Circles are Complex"

OR

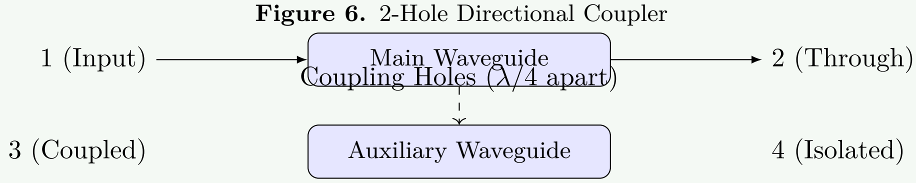
Question 2(b) [4 marks]

Draw and explain the working of a directional coupler.

Solution

Directional Coupler:

Figure 6. 2-Hole Directional Coupler



Working:
- Samples a small fraction of forward power into Port 3.
- Waves traveling backward towards Port 4 cancel out due to $\lambda/2$ path difference (destructive interference).

Parameters:
- **Coupling Factor**: $C = 10\log(P_1/P_3)$ dB.
- **Directivity**: $D = 10\log(P_3/P_4)$ dB.

Mnemonic

"Coupler Couples Carefully in Correct Direction"

OR

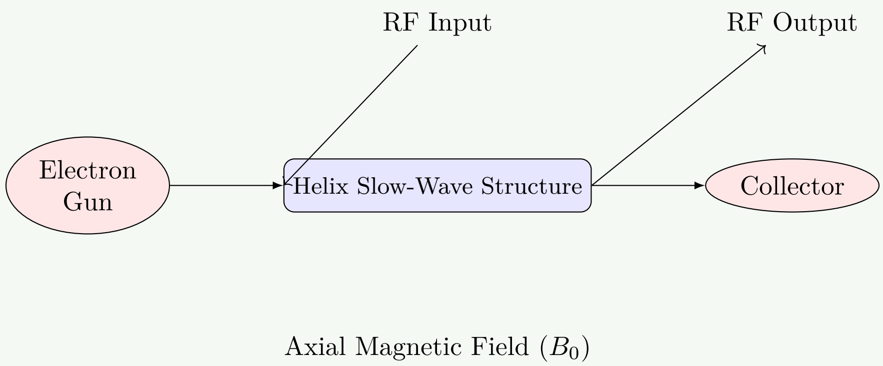
Question 2(c) [7 marks]

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

Solution

Construction:

Figure 7. Helix TWT



Working Principle:

- **Slow Wave Structure**: Helix reduces RF phase velocity to match electron beam velocity ($v_{ph} \approx v_e$).
- **Interaction**: Continuous interaction bunches electrons. Kinetic energy is transferred from electrons to the RF field.
- **Amplification**: Signal grows exponentially along the tube.

Applications:

- Satellite Transponders (High Reliability).
- Radar Systems (Wide Bandwidth).
- Electronic Warfare (Jamming).

Mnemonic

"TWT Transfers Tremendous power Through Travel"

Question 3(a) [3 marks]

Explain the Indirect method for higher VSWR measurement.

Solution

Double Minimum Method (Indirect): Used when VSWR > 10. Direct reading is inaccurate.

Procedure:

1. Find position of voltage minimum (V_{min}).
2. Move probe left and right to points where power is double ($2 \times V_{min}^2$).
3. Measure distance d between these "double power" points.

Formula:

$$VSWR = \frac{\lambda_g}{\pi d}$$

Where λ_g is guide wavelength and d is width of minimum at 3dB points.

Mnemonic

"Indirect method uses Intermediate Attenuation"

Question 3(b) [4 marks]

Write and explain the frequency limitations of conventional tubes.

Solution

Conventional Tube Limitations at Microwave Frequencies:

Table 4. Limitations and Effects

Limitation	Effect
Transit Time	Time for electron to cross gap becomes comparable to RF period. Causes Conductance (G) loading and grid heating.
Lead Inductance	$X_L = 2\pi f L$. High impedance in cathode lead reduces effective gain.
Interelectrode Capacitance	$X_C = 1/2\pi f C$. Shunts RF signal, reducing output impedance and gain.
Skin Effect	Current restricted to surface, increasing resistance and losses.

Result: Gain drops to zero, and noise increases.

Mnemonic

"Transit Time Troubles Traditional Tubes"

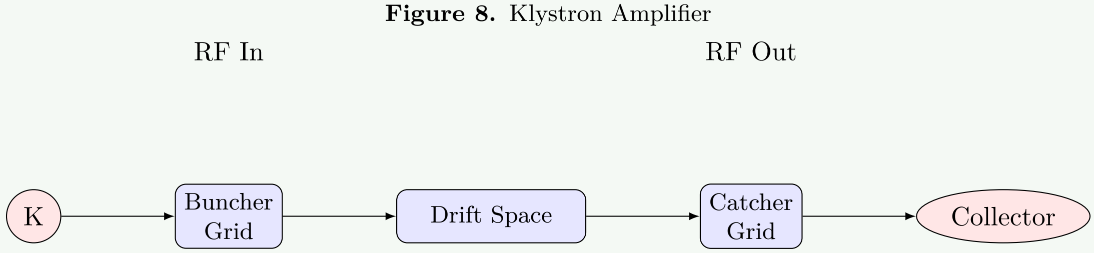
Question 3(c) [7 marks]

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

Solution

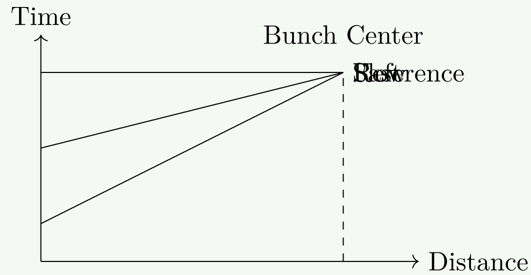
Two Cavity Klystron:

Figure 8. Klystron Amplifier



Applegate Diagram (Bunching):

Figure 9. Applegate Diagram



Working:

1. **Velocity Modulation**: RF input in Buncher cavity accelerates/decelerates electrons.
2. **Bunching**: In drift space, fast electrons catch up to slow ones.
3. **Current Modulation**: Electron bunches induce strong RF current in Catcher cavity.

Advantages: High Gain (>30dB), High Power, Stable.

Mnemonic

"Klystron Kicks with Kinetic Bunching"

OR

Question 3(a) [3 marks]

Explain construction and working of BWO.

Solution

Backward Wave Oscillator (BWO): A TWT-like device where wave travels opposite to electron beam.
Construction: Similar to TWT (Electron gun, Helix), but RF output is taken near the gun end.
Working:

- Beam interacts with **backward space harmonic** of the wave.
- Feedback is internal (wave flows back to input).
- **Voltage Tuning**: Oscillation frequency controlled by beam voltage.

Mnemonic

"BWO goes Backward While Oscillating"

OR

Question 3(b) [4 marks]

Explain hazards due to microwave radiation.

Solution

Microwave Hazards:

- **HERP**: Hazards of EM Radiation to Personnel (Biological damage).
- **HERO**: Hazards to Ordnance (Explosives detonation).
- **HERF**: Hazards to Fuel (Ignition of vapors).

Biological Effects:

- **Thermal**: Heating of water-rich tissues (eyes, brain, stomach). Can cause cataracts.
- **Non-thermal**: Nervous system effects (debated).

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

Mnemonic

"Microwaves Make Multiple Medical Maladies"

OR

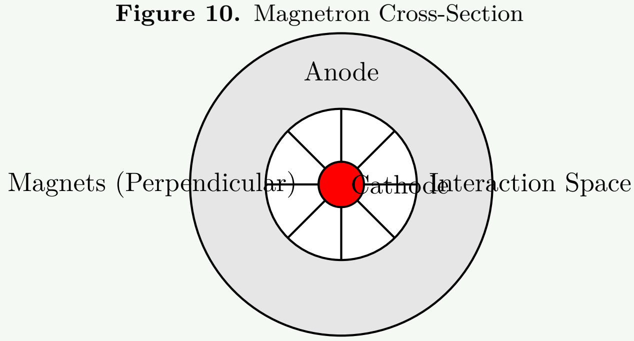
Question 3(c) [7 marks]

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

Solution

Magnetron Construction:

Figure 10. Magnetron Cross-Section



Working Principle:
- **Crossed Fields**: Radial Electric field (E) and Axial Magnetic field (B).
- **Electron Motion**: Electrons spiral outwards in cycloid paths.
- **Phase Focusing**: Electrons transfer energy to RF fields in the cavities ("spokes" of charge).
- **π-mode**: Adjacent cavities are 180° out of phase.

Applications: Microwave Ovens, Radar Transmitters.

Mnemonic

"Magnetron Makes Microwaves Magnificently"

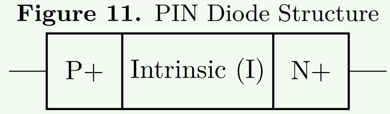
Question 4(a) [3 marks]

Explain working of P-i-N diode.

Solution

P-i-N Diode Working: Has an **Intrinsic (I)** layer between P and N regions.

Figure 11. PIN Diode Structure



States:
1. **Forward Bias**: Injection of carriers lowers resistance ($R \approx 1\Omega$). Acts as **Short**.

2. **Reverse Bias**: Carriers swept out, high resistance ($R > 10k\Omega$). Acts as **Open**.

Applications: RF Switch, Variable Attenuator.

Mnemonic

"PIN controls Power IN Networks"

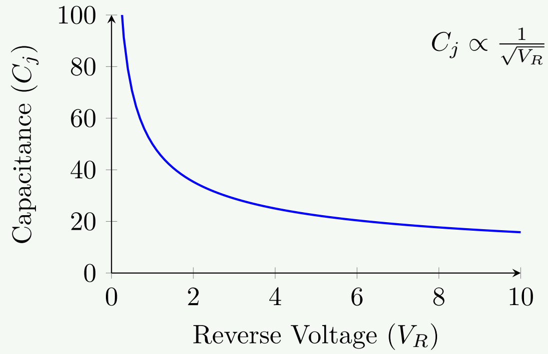
Question 4(b) [4 marks]

Explain the working of Varactor diode with sketch.

Solution

Varactor Diode: Operates as a **voltage-controlled capacitor**.

Figure 12. Varactor C-V Curve



Working:

- **Reverse Bias**: Widens depletion region → Decreases Capacitance.
- **Tuning**: Changing voltage changes C, which changes resonant frequency $f = 1/2\pi\sqrt{LC}$.

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.

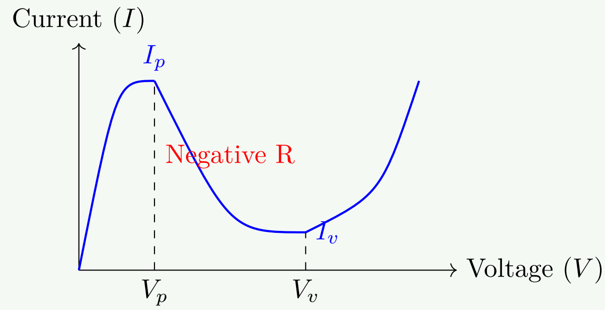
Solution

Tunnel Diode Construction:

- **Heavily Doped**: (10^{19} atoms/cm^3). Degenerate P and N regions.
- **Thin Junction**: Narrow depletion width (100 Å).

Tunneling Phenomenon: Quantum mechanical effect where electrons punch through the potential barrier instead of climbing over it, due to wave-like nature and narrow barrier.

Figure 13. Tunnel Diode I-V



Working Regions:

1. **Peak Point (V_p)**: Max tunneling current.
2. **Negative Resistance (V_p to V_v)**: Current decreases as voltage increases. Used for oscillators.
3. **Valley Point (V_v)**: Tunneling ceases.

Applications: Oscillators, High speed switching.

Mnemonic

"Tunnel Diode Tunnels Through barriers Terrifically"

OR

Question 4(a) [3 marks]

Describe the operation of IMPATT diode.

Solution

IMPATT Diode (Impact Avalanche Transit Time): Generates microwave power using:

1. **Impact Ionization**: Avalanche multiplication creates carriers (90° phase shift).
2. **Transit Time**: Drift of carriers through region adds remaining 90° shift.

Total 180° phase delay results in **Negative Resistance**.
Key Stats: High Power, High Noise, Breakdown voltage 100V.

Mnemonic

"IMPATT Impacts with Avalanche Transit Time"

OR

Question 4(b) [4 marks]

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

Solution

Parametric Amplifier Conversion: Uses a nonlinear reactance (Varactor) pumped at frequency f_p.
Up-Conversion:

- Input: f_s (Signal).
- Output: $f_o = f_p + f_s$ (Sum frequency) or $f_p - f_s$.
- **Gain**: Power gain proportional to frequency ratio (f_o/f_s). Stable with low noise.

Down-Conversion:

- Output: $f_o = f_p - f_s$.

- **Negative Resistance**: Can lead to instability/oscillation.

Mnemonic

"Parametric Pump Provides frequency conversion Plus gain"

OR

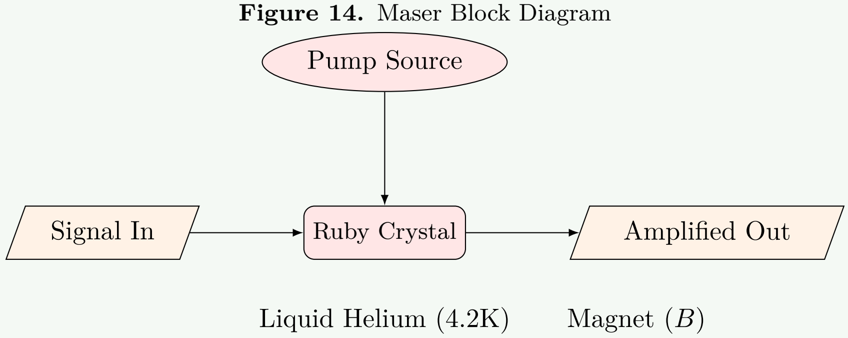
Question 4(c) [7 marks]

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

Solution

Ruby Maser:

Figure 14. Maser Block Diagram



Working Principle (Stimulated Emission):

1. **Population Inversion**: Pump energy raises electrons to unstable higher energy level (E_3).
2. **Stimulated Emission**: Incoming signal photons (E_2) trigger electrons to drop level, releasing coherent photons.
3. **Cooling**: Liquid Helium reduces thermal noise.

Applications: Deep space communication (NASA), Radio Astronomy.

Mnemonic

"RUBY MASER Makes Amazingly Sensitive Electromagnetic Receivers"

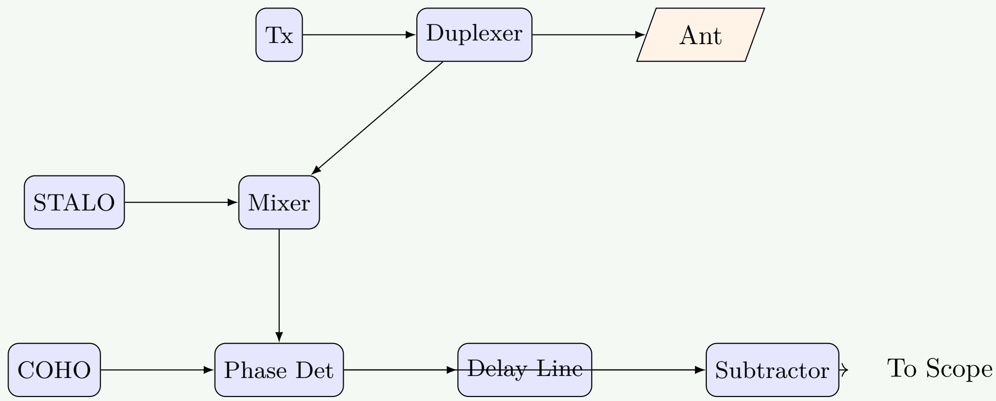
Question 5(a) [3 marks]

Draw and explain the functional block diagram of MTI RADAR.

Solution

MTI (Moving Target Indication) Radar:

Figure 15. MTI Radar



Function: Separates moving targets from clutter (fixed targets) using Doppler phase shift comparison between pulses.

Mnemonic

"MTI Makes Targets Intelligible by Motion"

Question 5(b) [4 marks]

Compare RADAR with SONAR.

Solution

Comparison:

Table 5. Radar vs Sonar

Parameter	RADAR	SONAR
Wave	EM Waves (Microwaves)	Acoustic (Sound) Waves
Speed	3×10^8 m/s	1500 m/s
Medium	Air, Vacuum	Water
Range	Long (Space/Air)	Short (Underwater)
Use	Tracking Aircrafts	Submarines, Fish finding

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:

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

Derivation:

1. Power density at target R: $\frac{P_t G}{4\pi R^2}$.
2. Power reflected by target (σ): $\frac{P_t G \sigma}{4\pi R^2}$.
3. Power density at receiver (return path): $\frac{P_t G \sigma}{(4\pi R^2)^2}$.
4. Effective Area of Antenna $A_e = \frac{G\lambda^2}{4\pi}$.
5. Received Power $P_r = \text{Density} \times A_e = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$.
6. Set $P_r = P_{min}$ and solve for R.

Factors Affecting Range:

- **Transmitter Power (P_t)**: $R \propto P_t^{1/4}$. Need huge power increase for small range gain.
- **Antenna Gain (G) / Area**: Larger antenna improves range.
- **Target RCS (σ)**: Bigger/metallic targets are easier to see.
- **Min Detectable Signal (P_{min})**: Better receiver sensitivity increases range.

OR

Question 5(a) [3 marks]

Describe the Doppler effect in CW Doppler RADAR.

Solution

Doppler Effect: The **frequency shift** observed when a target moves relative to the RADAR.

Formula:

$$f_d = \frac{2V_r f_0}{c} = \frac{2V_r}{\lambda}$$

Where:

- V_r: Radial velocity (m/s).
- f_0: Transmitted frequency.
- c: Speed of light.

Shift Direction:

- **Approaching**: $f_r > f_0$ (Positive shift).
- **Receding**: $f_r < f_0$ (Negative shift).

Mnemonic

"Doppler Detects Direction with Doubled frequency shift"

OR

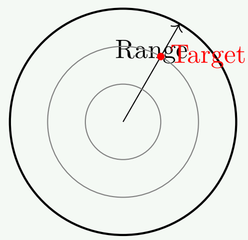
Question 5(b) [4 marks]

Explain PPI Display method for RADAR

Solution

PPI (Plan Position Indicator): Displays a **top-down map view** of the radar coverage.

Figure 16. PPI Display



Features:
1. **Center**: Radar location.
2. **Angle**: Target Azimuth (Bearing).
3. **Radius**: Target Range (Distance).
4. **Sweep**: Rotating trace synchronized with antenna.

Mnemonic

"PPI Provides Position Information Perfectly"

OR

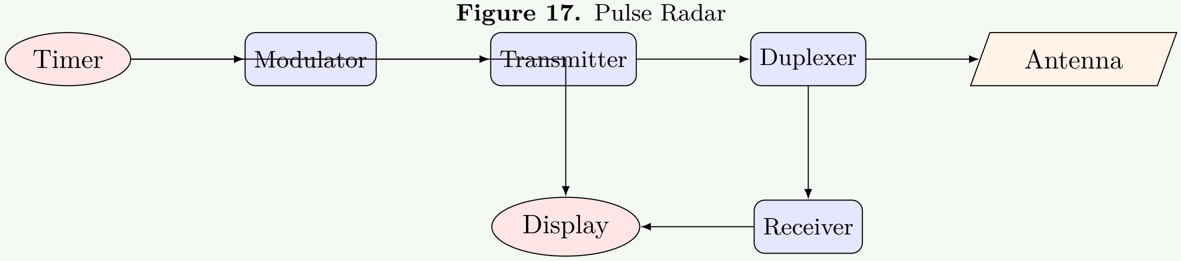
Question 5(c) [7 marks]

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

Solution

Pulse Radar Block Diagram:

Figure 17. Pulse Radar



Working Principle:
- **Transmission**: High power pulses emitted at regular intervals (PRF).
- **Reception**: Echoes received during "listening" time.
- **Duplexer**: Protects receiver during transmission; routes echo to receiver.
- **Timing**: Distance calculated from time delay T: $R = cT/2$.

Mnemonic

"Pulse RADAR Pulses Powerfully for Precise Position"