Microwave and Radar Communication (4351103) - Summer 2024 Solution

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Question 1(a) [3 marks]

List different microwave bands with their frequency range.

Solution

Microwave Frequency Bands:

Table 1. Microwave Frequency Bands

Band	Frequency Range	Wavelength
L Band	1-2 GHz	30-15 cm
S Band	2-4 GHz	15-7.5 cm
C Band	4-8 GHz	7.5-3.75 cm
X Band	8-12 GHz	3.75-2.5 cm
Ku Band	12-18 GHz	2.5-1.67 cm
K Band	18-27 GHz	1.67-1.11 cm
Ka Band	27-40 GHz	1.11-0.75 cm

Mnemonic

"Large Ships Can eXamine Kindly Using Knowledge Always"

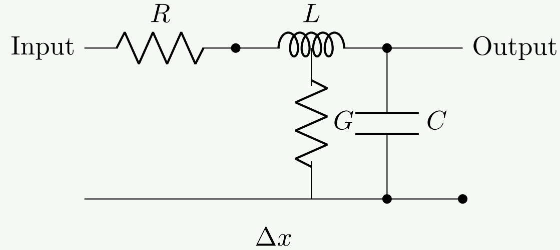
Question 1(b) [4 marks]

Draw the general equivalent circuit of the transmission line. Write the equation for characteristic impedance for a lossless line.

Solution

Transmission Line Equivalent Circuit:

Figure 1. Transmission Line Model



Circuit Elements:

- **R**: Series resistance per unit length
- **L**: Series inductance per unit length
- **C**: Shunt capacitance per unit length
- **G**: Shunt conductance per unit length

For Lossless Line ($R = 0, G = 0$):

$$Z_0 = \sqrt{\frac{L}{C}}$$

Key Points:

- **Lossless condition**: No power loss during transmission.
- **Impedance matching**: Z_0 determines reflection behavior.

Mnemonic

"Lossless Lines Love Constant Impedance"

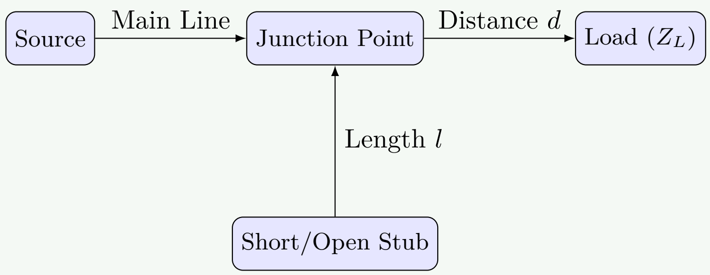
Question 1(c) [7 marks]

Explain the impedance matching process using a single stub.

Solution

Single Stub Matching Process:

Figure 2. Single Stub Matching



Matching Steps:

Table 2. Matching Procedure

Step	Process	Purpose
1	Calculate load admittance	Find $Y_L = 1/Z_L$
2	Move toward generator	Find point where $G = G_0$
3	Add stub susceptance	Cancel reactive part
4	Achieve matching	$Y_{total} = Y_0$

Design Equations:

- **Distance to stub**: $d = (\lambda/2\pi) \times \tan^{-1}(\sqrt{R_L/R_0})$
- **Stub length**: $l = (\lambda/2\pi) \times \tan^{-1}(B_{stub}/Y_0)$

Applications: Antenna matching, Amplifier input/output, Filter design.

Mnemonic

"Single Stubs Stop Standing Waves Successfully"

OR

Question 1(c) [7 marks]

Compare rectangular and circular waveguides.

Solution

Comparison:

Table 3. Rectangular vs Circular Waveguide

Parameter	Rectangular Waveguide	Circular Waveguide
Shape	Rectangular cross-section	Circular cross-section
Dominant Mode	TE_{10}	TE_{11}
Cutoff Frequency	$f_c = c/(2a)$ for TE_{10}	$f_c = 1.841c/(2\pi a)$ for TE_{11}
Power Handling	Lower	Higher
Manufacturing	Easy	Difficult
Mode Separation	Good	Poor
Applications	Radar, microwave ovens	Satellite communication

Key Advantages:

- **Rectangular**: Better mode control, easier fabrication.
- **Circular**: Higher power capacity, rotating polarization.

Mnemonic

"Rectangular is Regular, Circular Carries Current"

Question 2(a) [3 marks]

Define group velocity and phase velocity in relation to them.

Solution

Velocity Definitions:

Table 4. Velocity Types

Velocity Type	Formula	Physical Meaning
Phase Velocity	$v_p = \omega/\beta = c/\sqrt{1-(f_c/f)^2}$	Speed of constant phase
Group Velocity	$v_g = d\omega/d\beta = c\sqrt{1-(f_c/f)^2}$	Speed of signal energy

Relationship: $v_p \times v_g = c^2$

Key Points:

- **Phase velocity**: Always $> c$ (speed of light).
- **Group velocity**: Always $< c$.
- **Signal travels**: At group velocity.

Mnemonic

"Phase is Fast, Group Carries Message"

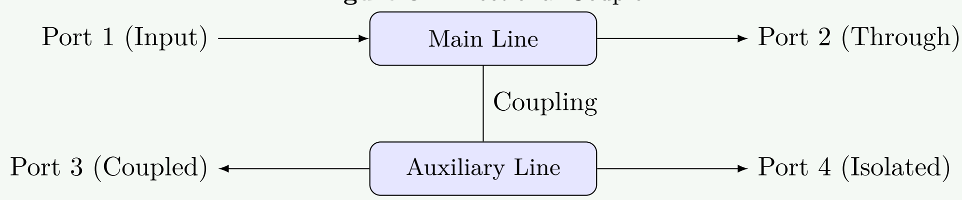
Question 2(b) [4 marks]

Describe the principles and workings of the Directional coupler.

Solution

Directional Coupler Principle:

Figure 3. Directional Coupler



Key Parameters:

- **Coupling Factor**: $C = 10\log(P_1/P_3)$ dB
- **Directivity**: $D = 10\log(P_3/P_4)$ dB
- **Insertion Loss**: $IL = 10\log(P_1/P_2)$ dB

Mnemonic

"Directional Couplers Divide Power Precisely"

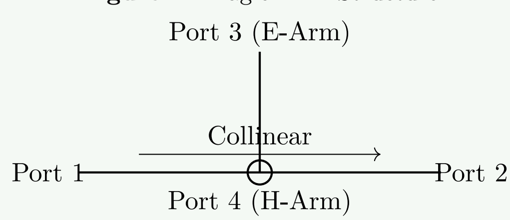
Question 2(c) [7 marks]

Explain Magic TEE with construction, operation and application.

Solution

Magic TEE Construction:

Figure 4. Magic TEE Structure



Operating Principles:

Table 5. Port Functions

Port	Function	Field Pattern
Port 1 & 2	Collinear ports	Symmetric
Port 3 (E-Arm)	E-plane port	Difference port $(P_1 - P_2)$
Port 4 (H-Arm)	H-plane port	Sum port $(P_1 + P_2)$

Properties:

- **Isolation**: Port 3 isolated from Port 4.
- **Power division**: Equal split when matched.

Applications: Mixers, Power combiners, Impedance bridges.

Mnemonic

"Magic TEE Creates Perfect Isolation"

OR

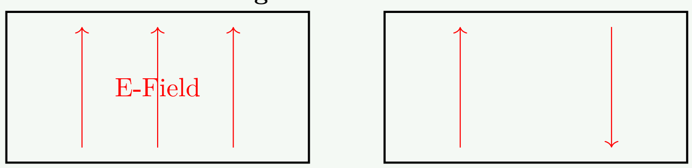
Question 2(a) [3 marks]

Draw TE_{10}, TE_{20} modes for rectangular waveguide.

Solution

TE_{10} Mode (Dominant):

Figure 5. TE Modes



TE_{10}: One half-wave TE_{20}: Two half-waves

Characteristics:

- **TE10**: Single half-wave variation across broad dimension a.
- **TE20**: Two half-wave variations across a.

Mnemonic

"TE modes have Electric Transverse"

OR

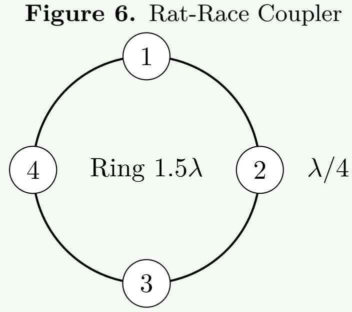
Question 2(b) [4 marks]

Describe the Hybrid Ring with a necessary sketch.

Solution

Hybrid Ring Structure:

Figure 6. Rat-Race Coupler



Operating Principle:

- **Circumference**: $3\lambda/2$ (1.5λ).
- **Port Spacing**: Ports are spaced $\lambda/4$ apart, except one gap is $3\lambda/4$.
- **Isolation**: Specific ports are isolated due to phase cancellation.

Mnemonic

"Hybrid Rings Handle Half-wavelengths"

OR

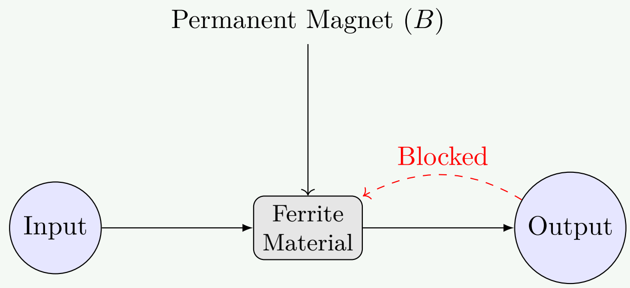
Question 2(c) [7 marks]

Explain the Isolator with principles, construction and operation.

Solution

Isolator Principle:

Figure 7. Isolator



Key Elements:

- **Ferrite**: Non-reciprocal material (e.g., Yttrium Iron Garnet).
- **Magnet**: Provides bias magnetic field.
- **Card**: Absorptive resistive card to kill reverse power.

Operation: Based on **Faraday Rotation**. Forward wave passes with little loss. Reverse wave is rotated such that it is absorbed by the resistive card (Attenuated).

Mnemonic

"Isolators Ignore Reverse Reflections"

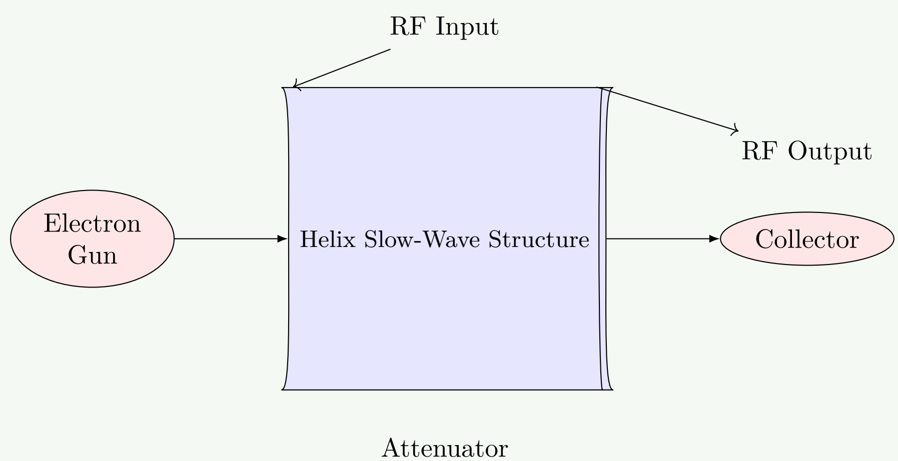
Question 3(a) [3 marks]

Draw a Traveling wave tube amplifier.

Solution

TWT Amplifier:

Figure 8. TWT Structure



Mnemonic

"TWT Transfers Wave Through Helix"

Question 3(b) [4 marks]

Describes various types of hazards due to microwave radiation.

Solution

Microwave Hazards:

Table 6. Radiation Hazards

Hazard Type	Effects	Limit
HERP (Personnel)	Tissue heating, cataracts, burns	10 mW/cm^2
HERO (Ordnance)	Accidental detonation of explosives	Variable
HERF (Fuel)	Fuel ignition/sparks	5 mW/cm^2

Biological Effects:
- **Thermal**: Heating of water-rich tissues (eyes, brain, stomach).
- **Non-thermal**: Potential DNA/cellular effects (debated).

Protection: Shielding, Distance ($1/r^2$ law), Time limits.

Mnemonic

"Heat Energy Requires Proper Protection"

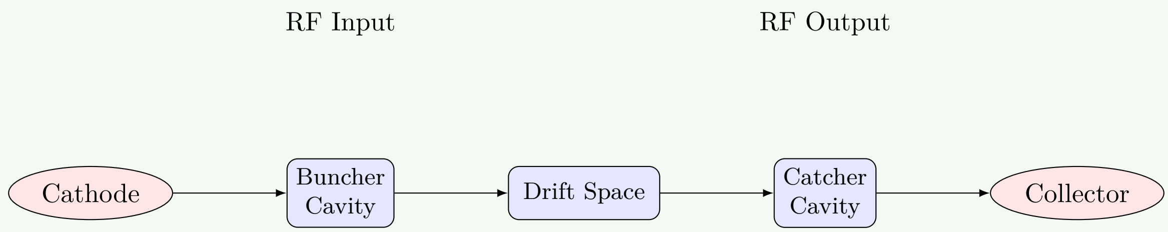
Question 3(c) [7 marks]

Explain two cavity klystrons construction and operation with an Applegate diagram.

Solution

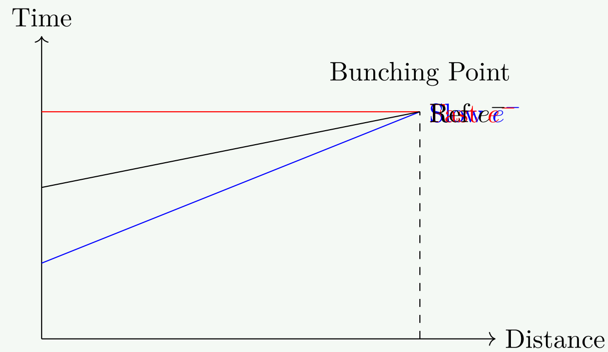
Two-Cavity Klystron Construction:

Figure 9. Klystron Block Diagram



Applegate Diagram (Bunching Process):

Figure 10. Applegate Diagram



Operation Principles:

- **Velocity Modulation**: RF input accelerates/decelerates electrons in Buncher cavity.
- **Drift Space**: Fast electrons catch up to slow ones, forming electron bunches.
- **Energy Extraction**: Bunches induce strong oscillations in Catcher cavity.

Mnemonic

"Klystrons Create Bunches Through Velocity Variation"

OR

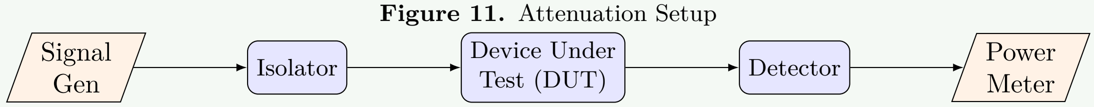
Question 3(a) [3 marks]

Draw the block diagram of the attenuation measurement method for microwave frequency.

Solution

Attenuation Measurement:

Figure 11. Attenuation Setup



Method: Measure power P_1 without DUT, measure power P_2 with DUT. Attenuation (dB) $= 10\log(P_1/P_2)$.

Mnemonic

"Attenuation Appears After Accurate Assessment"

OR

Question 3(b) [4 marks]

Describe the limitation of vacuum tubes at microwave range.

Solution

Limitations of Conventional Tubes:

Table 7. Vacuum Tube Limitations

Limitation	Cause	Effect
Transit Time	Finite electron velocity	Phase shift, reduced gain
Lead Inductance	Wiring inductance ($j\omega L$)	Impedance mismatch
Inter-electrode C	C_{gp}, C_{gk} parasitics	Shunts signal, feedback
Skin Effect	Surface conduction	High resistance, loss

Consequences: At $f > 1$ GHz, conventional tubes become oscillators or stop working entirely due to these parasitics.

Mnemonic

"Vacuum Tubes Fail Fast at High Frequencies"

OR

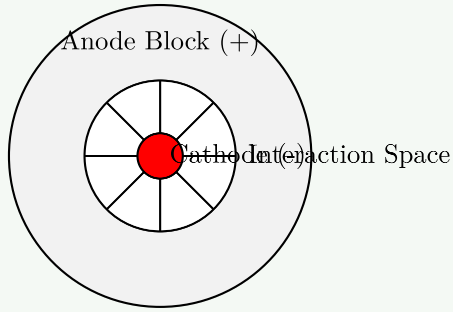
Question 3(c) [7 marks]

Explain the Principle, construction, effect of the electric and magnetic field and operation of the magnetron in detail.

Solution

Magnetron Construction:

Figure 12. Magnetron Cross Section



Principle of Operation:
- **Crossed Fields**: DC Electric field (Radial) and DC Magnetic field (Axial) are perpendicular.
- **Electron Motion**: Electrons emitted from cathode travel in cycloidal paths due to Lorentz force.
- **Interaction**: Electrons transfer potential energy to the RF field in cavities while spiraling outward.

Hull Cutoff:
- If $B < B_c$: Electrons hit anode directly (High current).
- If $B > B_c$: Electrons miss anode and return to cathode (Cutoff).
- Oscillation occurs near the cutoff region.

Mnemonic

"Magnetrons Make Microwaves Through Magnetic Motion"

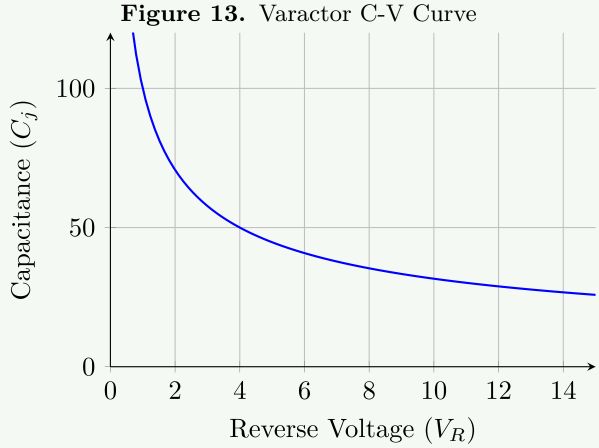
Question 4(a) [3 marks]

Explain the working principle of a varactor diode using a graph.

Solution

Varactor Diode Characteristics:

Figure 13. Varactor C-V Curve



Working Principle:

- **Reverse Bias**: Operated in reverse bias mode.
- **Variable Capacitor**: Depletion layer width increases with reverse voltage.
- **Relation**: $C_j \propto 1/\sqrt{V_R + V_\phi}$. Higher voltage → Lower capacitance.

Applications: VCOs, Parametric Amplifiers, Frequency Multipliers.

Mnemonic

"Varactors Vary Capacitance Via Voltage"

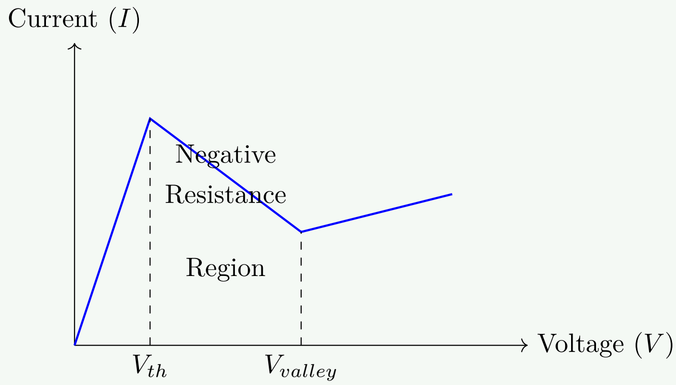
Question 4(b) [4 marks]

Explain the Gunn Effect and negative resistance for Gunn diode.

Solution

Gunn Effect (Transferred Electron Effect):

Figure 14. Gunn Diode I-V Characteristic



Mechanism:

- **Two Valleys**: Conductance band has lower valley (high mobility) and upper valley (low mobility).
- **Threshold**: Above V_{th}, electrons transfer to upper slow valley.
- **Negative Resistance**: Current decreases as voltage increases ($dI/dV < 0$), causing oscillations.

Mnemonic

"Gunn diodes Generate oscillations through Negative resistance"

Question 4(c) [7 marks]

Explain frequency measurement method for microwave frequency.

Mnemonic

"Frequency Found through Careful Cavity Calibration"

OR

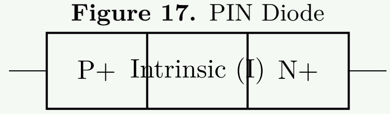
Question 4(a) [3 marks]

Explain the working of a PIN diode as a switch.

Solution

PIN Diode Structure:

Figure 17. PIN Diode



Switching Action:

Table 8. PIN Switch States

Bias	Intrinsic Region	State
Forward Bias	Flooded with carriers (Low R)	**ON** (Pass signal)
Reverse Bias	Depleted (High R, Low C)	**OFF** (Block signal)

Advantages: High power handling, Fast switching (ns), Wide bandwidth.

Mnemonic

"PIN diodes Perform Perfect switching"

OR

Question 4(b) [4 marks]

Explain stripeline and Microstrip circuits.

Solution

Comparison of Planar Transmission Lines:

Figure 18. Stripline vs Microstrip

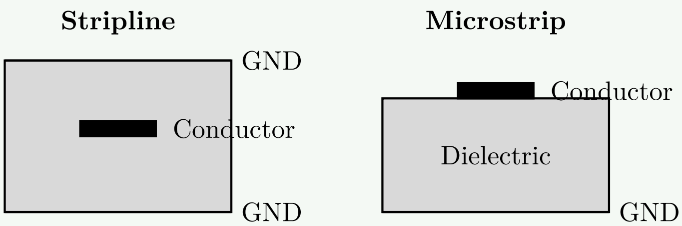


Table 9. Performance Comparison

Parameter	Stripline	Microstrip
Structure	Conductor valid between 2 GNDs	Conductor on top of GND
Radiation	None (Shielded)	Radiates (Open top)
Mode	Pure TEM	Quasi-TEM
Cost	Higher (Complex PCB)	Lower (Simple PCB)

Mnemonic

"Striplines are Sandwiched, Microstrips are Mounted"

OR

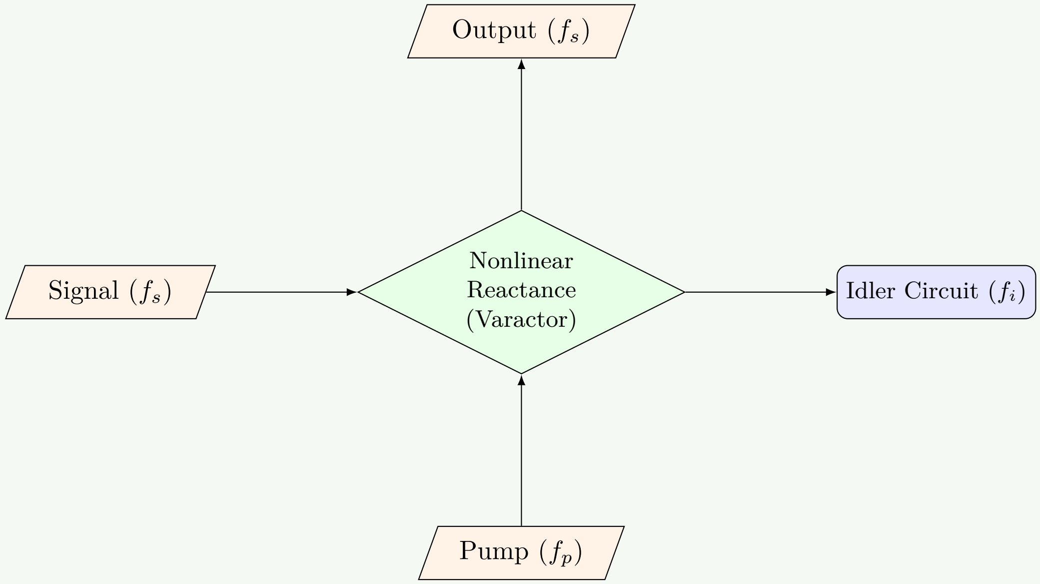
Question 4(c) [7 marks]

Explain the principles and process of amplification for a Parametric amplifier.

Solution

Parametric Amplifier Principle:

Figure 19. Parametric Amplifier Block



Process:

- Uses a nonlinear reactance (Varactor diode) instead of resistance (low noise).
- **Pump Energy**: A high frequency pump (f_p) supplies energy to the system.
- **Mixing**: Interaction creates idler frequency $f_i = f_p - f_s$.
- **Amplification**: Energy is transferred from the Pump to the Signal frequency via the nonlinear capacitance.

Advantages: Extremely low noise figure (used in satellite/radio astronomy).

Mnemonic

"Parametric amplifiers Pump Power into signal Perfectly"

Question 5(a) [3 marks]

Compare RADAR and SONAR.

Solution

Comparison:

Table 10. RADAR vs SONAR

Parameter	RADAR	SONAR
Wave Type	Electromagnetic (Radio)	Acoustic (Sound)
Medium	Air / Vacuum	Water
Speed	3×10^8 m/s	1500 m/s
Range	Long (1000s km)	Short ($<$ 100 km)
Application	Aviation, Weather	Submarine, Fishing

Principle: Both use **Echo Ranging** ($R = vt/2$).

Mnemonic

"RADAR sees Radio waves, SONAR hears Sound waves"

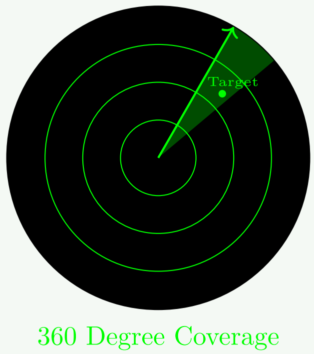
Question 5(b) [4 marks]

Write the name of RADAR display method and explain anyone.

Solution

RADAR Displays: A-Scope, B-Scope, C-Scope, PPI (Plan Position Indicator), RHI.
Plan Position Indicator (PPI):

Figure 20. PPI Display



Features:
- Map-like display in polar coordinates (Range and Azimuth).
- Center of screen = Radar location.
- Sweep rotates in sync with antenna.
- Used in Air Traffic Control and Navigation.

Mnemonic

"PPI Provides Perfect Position Information"

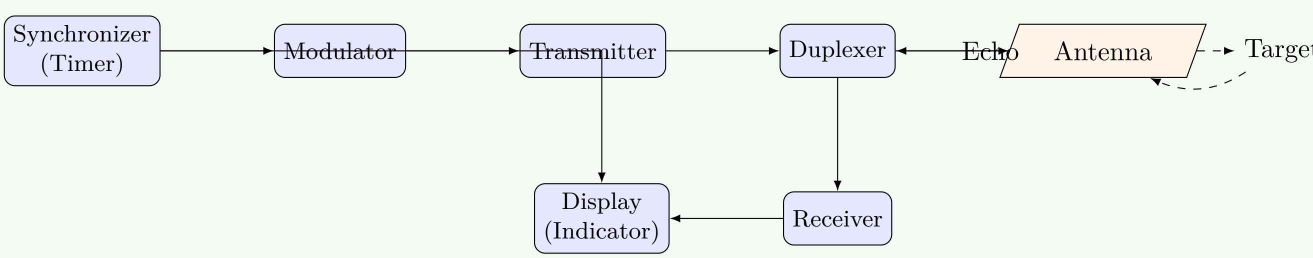
Question 5(c) [7 marks]

Explain the basic pulse radar system with a block diagram.

Solution

Pulse Radar System:

Figure 21. Basic Pulse Radar



Functions:
- **Synchronizer**: Controls timing of pulses.
- **Modulator**: Triggers transmitter.
- **Transmitter**: Generates high power RF pulses.
- **Duplexer**: Switches antenna between Tx and Rx (Protects receiver).

- **Receiver**: Amplifies weak echoes (Superheterodyne).

Range Equation: $R = cT/2$, where T is round trip time.

Mnemonic

"Pulse Radar Properly Processes Reflected signals"

OR

Question 5(a) [3 marks]

List the application of microwave frequency.

Solution

Applications:

Table 11. Microwave Uses

Field	Applications
Communication	Satellite, Mobile, WiFi, Bluetooth
RADAR	Navigation, Weather forecasting, Defense
Industrial	Heating, Drying, Material testing
Medical	Diathermy, Cancer treatment (Hyperthermia)
Domestic	Microwave Ovens (2.45 GHz heating)
Scientific	Radio Astronomy, Particle Accelerators

Mnemonic

"Microwaves Serve Many Applications Perfectly"

OR

Question 5(b) [4 marks]

Compare PULSED RADAR and CW RADAR.

Solution

Comparison:

Table 12. Pulsed vs CW Radar

Parameter	Pulsed RADAR	CW RADAR
Signal	Short pulses	Continuous Wave (Sine)
Range	Measures Range ($ct/2$)	Cannot measure Range (needs FM)
Velocity	Poor velocity measurement	Excellent (Doppler Effect)
Power	High Peak Power	Low Average Power
Complexity	Higher (Duplexer needed)	Simpler (Separate Antennas usually)
Blindness	Blind range (width dependent)	No blind range

Mnemonic

"Pulsed measures Range, CW measures Velocity"

OR

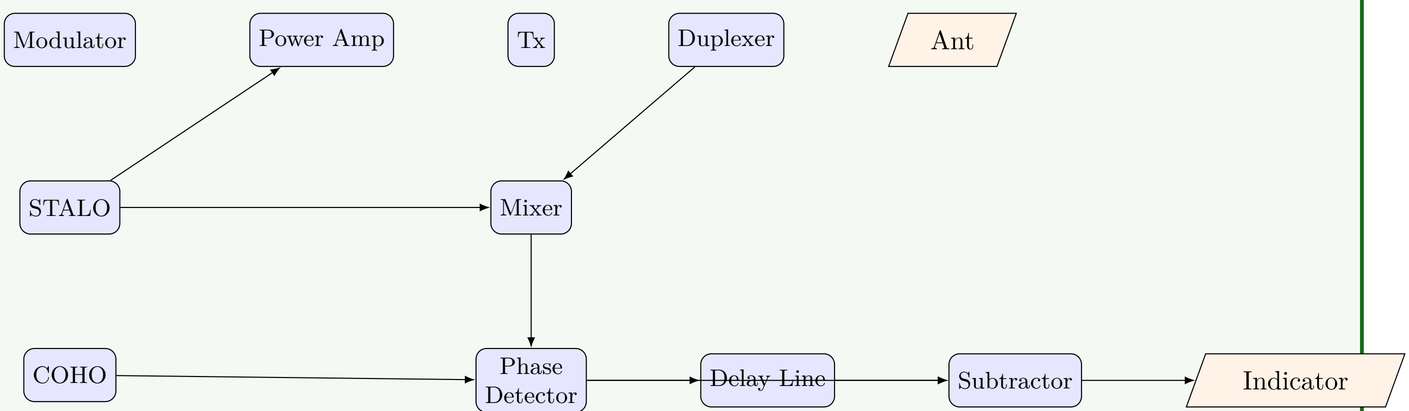
Question 5(c) [7 marks]

Explain MTI Radar with the block diagram.

Solution

Moving Target Indication (MTI) Radar:

Figure 22. MTI Block Diagram



Principle (Doppler Effect):

- **Stationary Targets**: Returns have constant phase pulse-to-pulse.
- **Moving Targets**: Returns have changing phase due to Doppler shift.

Operation:

- **Delay Line Canceler**: Compares current echo with previous echo (delayed by one PRT).
- Subtractor output: $V(t) - V(t-T)$.
- Stationary targets cancel out ($V_{now} = V_{prev}$). Moving targets remains.

Blind Speed: Speeds where phase shift is 360° multiples result in cancellation (Blindness).

Mnemonic

"MTI Makes Targets Identifiable by Movement"