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.

Answer:

Diagram:

```
Short Circuit (Z_L = 0):
     V
     |
     |
     |______|______|______|______ 0V
       λ/4   λ/2   3λ/4    λ

     I
   I_max ---|---|---|---
     |
     |
     0 __________________ 0A

Open Circuit (Z_L = ∞):
   V_max ---|---|---|---
     |
     V
     0 __________________ 0V
       λ/4   λ/2   3λ/4    λ

     I
     |
     |
     |______|______|______|______ 0A
       λ/4   λ/2   3λ/4    λ

Matched Load (Z_L = Z_0):
     V
   ---|---|---|---|--- Constant

     I
   ---|---|---|---|--- Constant
```

- **Short Circuit**: Voltage minimum at load, current maximum at load
- **Open Circuit**: Voltage maximum at load, current minimum at load
- **Matched Load**: Constant voltage and current, no reflections

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.

Answer:

Diagram:

```
      R      L      R      L
   ---|^^^|--|||||---|^^^|--|||||---
   |      |       |      |       |
   |      G       C      G       C
   |     |||     ---    |||     ---
   |     |||     ---    |||     ---
   ---|^^^|--|||||---|^^^|--|||||---
      R      L      R      L

      ←-- Δz --→
```

- **R**: Series resistance per unit length (conductor losses)
- **L**: Series inductance per unit length (magnetic field storage)
- **G**: Shunt conductance per unit length (dielectric losses)
- **C**: Shunt capacitance per unit length (electric field storage)

Primary Constants Table:

Parameter	Symbol	Unit	Effect
Resistance	R	Ω/m	Power loss
Inductance	L	H/m	Magnetic energy
Conductance	G	S/m	Leakage current
Capacitance	C	F/m	Electric energy

Mnemonic: "RLGC - Really Largeガイド Cables"

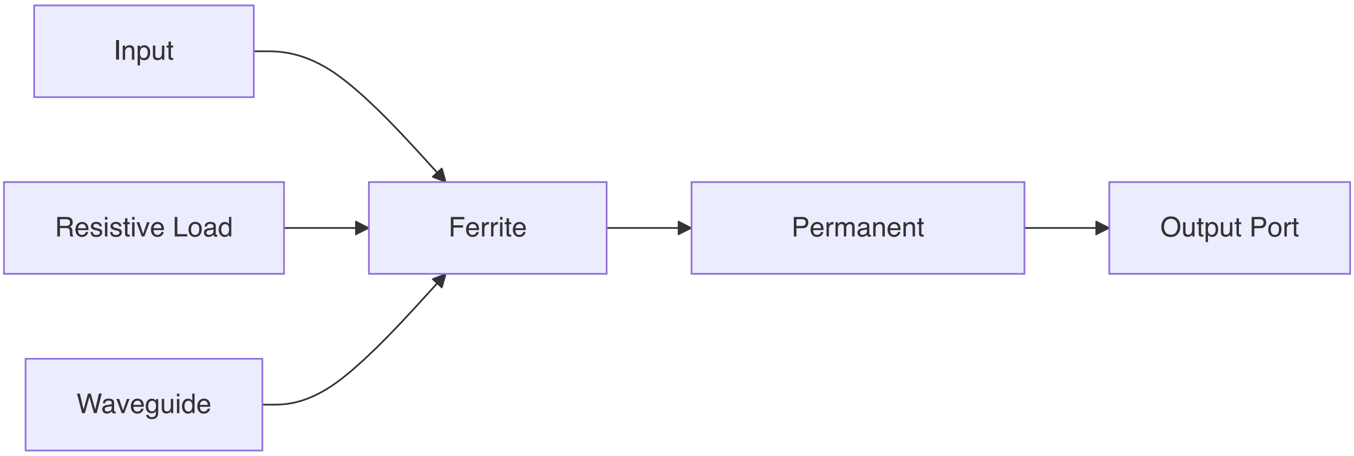
Question 1(c) [7 marks]

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

Answer:

Principle: Isolator allows microwave signal to pass in forward direction only using **ferrite material** and **Faraday rotation effect**.

Construction Diagram:



Working:

- **Forward direction**: Signal passes through ferrite with minimal loss
- **Reverse direction**: Signal is rotated 45° and absorbed by resistive load
- **Magnetic field** biases ferrite material
- **Isolation**: 20-30 dB typical

Applications:

- **Protects** transmitter from reflected power
- **Prevents** oscillations in amplifier circuits
- **Maintains** source impedance matching

Specifications Table:

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

Mnemonic: "Isolate Forward, Absorb Reverse"

Question 1(c OR) [7 marks]

Compare Transmission Line and Waveguide.

Answer:

Comparison Table:

Parameter	Transmission Line	Waveguide
Frequency Range	DC to microwave	Above cutoff frequency
Power Handling	Limited	High power capability
Losses	Higher (I^2R losses)	Lower (no center conductor)
Size	Compact	Bulky at low frequencies
Modes	TEM mode	TE and TM modes
Installation	Easy	Complex mounting
Cost	Lower	Higher
Bandwidth	Wide	Limited by modes

Key Differences:

- **Transmission line**: Uses two conductors, supports TEM mode
- **Waveguide**: Single hollow conductor, supports TE/TM modes
- **Cutoff frequency**: Waveguide has minimum operating frequency
- **Field pattern**: Different electromagnetic field distributions

Applications:

- **Transmission lines**: Low power, broadband applications
- **Waveguides**: High power radar, satellite communication

Mnemonic: "Transmission Travels Two-wire, Waveguide Walks Wide"

Question 2(a) [3 marks]

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

Answer:

Definitions:

- **VSWR (Voltage Standing Wave Ratio)**: Ratio of maximum to minimum voltage amplitudes on transmission line
  - Formula: $VSWR = V_{max}/V_{min} = (1+|\Gamma|)/(1-|\Gamma|)$
- **Reflection Coefficient (Γ)**: Ratio of reflected to incident voltage amplitude
  - Formula: $\Gamma = (Z_L - Z_0)/(Z_L + Z_0)$
- **Skin Effect**: Current flows mainly on conductor surface at high frequencies
  - Skin depth: $\delta = \sqrt{2/\omega\mu\sigma}$

Parameters Table:

Parameter	Range	Ideal Value
VSWR	1 to ∞	1 (matched)
	Γ	
Skin Depth	μm to mm	Frequency dependent

Mnemonic: "VSWR Varies, Gamma Guides, Skin Shrinks"

Question 2(b) [4 marks]

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

Answer:

Construction Diagram:

```
Main Waveguide:
|===============================|
|    →  P1      →  P2           |
|===============================|
         ○    ○  ← Two holes
|===============================|
|    ←  P4      ←  P3           |
|===============================|
Auxiliary Waveguide
```

Working Principle:

- **Two holes** spaced λ/4 apart couple energy between waveguides
- **Forward wave**: Coupled signals add at P3, cancel at P4
- **Reverse wave**: Coupled signals add at P4, cancel at P3
- **Directivity**: Achieved by proper hole spacing and size

Coupling Mechanism:

- **Electric field coupling** through holes
- **Phase difference** creates directional coupling
- **Coupling factor**: C = 10 log(P1/P3) dB

Performance Parameters:

Parameter	Typical Value
Coupling	10-30 dB
Directivity	25-40 dB
VSWR	<1.3

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.

Answer:

Propagation Theory:
Electromagnetic waves propagate through waveguide in **TE and TM modes** with specific field patterns.

Wave Equation:
For rectangular waveguide, the wave equation is:
$\nabla^2 E + \gamma^2 E = 0$

Where $\gamma^2 = \beta^2 - k^2$

Cutoff Wavelength Derivation:

For **TE_{mn} mode** in rectangular waveguide:

- **Cutoff frequency**: $f_c = (c/2)\sqrt{[(m/a)^2 + (n/b)^2]}$
- **Cutoff wavelength**: $\lambda_c = 2/\sqrt{[(m/a)^2 + (n/b)^2]}$

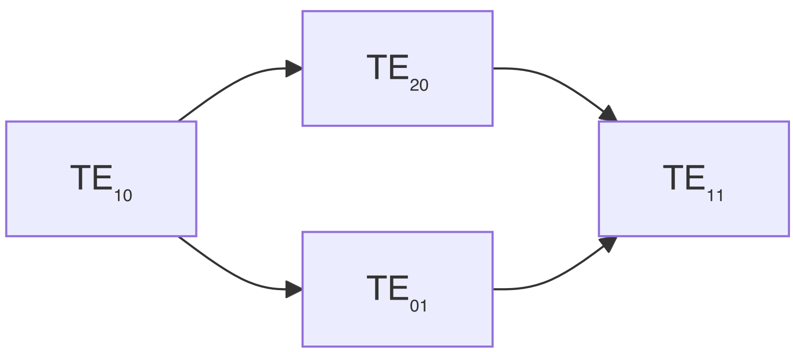
For **dominant TE_{10} mode**:

- $\lambda_c = 2a$ (where a is broad dimension)

Propagation Conditions:

- **Below cutoff** ($f < f_c$): Evanescent wave, exponential decay
- **Above cutoff** ($f > f_c$): Propagating wave
- **Phase velocity**: $v_p = c/\sqrt{[1 - (f_c/f)^2]}$
- **Group velocity**: $v_g = c\sqrt{[1 - (f_c/f)^2]}$

Mode Chart:



Key Relations:

- $v_p \times v_g = c^2$
- $\lambda g = \lambda_0/\sqrt{[1 - (\lambda_0/\lambda c)^2]}$

Mnemonic: "Cut-off Comes, Propagation Proceeds"

Question 2(a OR) [3 marks]

Explain Impedance Matching using Single stub.

Answer:

Principle: Single stub matching uses a **short-circuited** or **open-circuited** stub to cancel reactive component of load impedance.

Stub Diagram:

```
Source ---|---●---|--- Load
  Z₀      |       |    Z_L
          |       |
         ---      |
        Stub      |
         l_s      d
```

Design Steps:

- **Step 1**: Find distance 'd' where normalized conductance = 1
- **Step 2**: Calculate required stub susceptance: B_s = -B_load
- **Step 3**: Determine stub length: l_s from B_s

Smith Chart Method:

- Plot normalized load impedance
- Move toward generator to find matching point
- Add stub susceptance to achieve center point

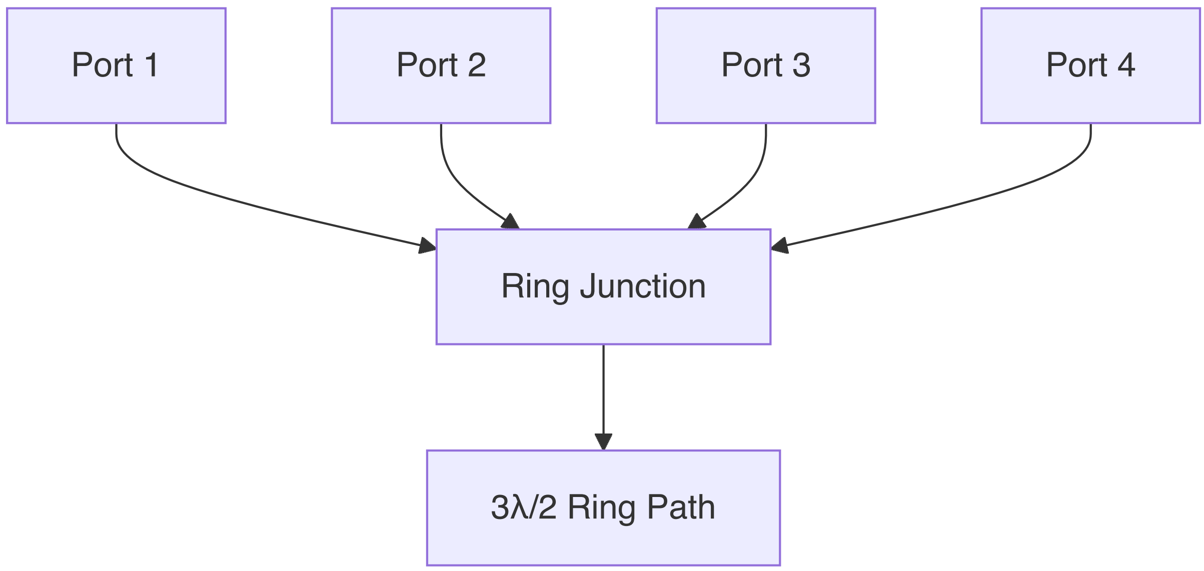
Mnemonic: "Single Stub Solves Susceptance"

Question 2(b OR) [4 marks]

Explain Hybrid ring with necessary sketch.

Answer:

Construction Diagram:



Working Principle:

- **Ring circumference**: 3λ/2 (1.5 wavelengths)
- **Equal path lengths** from each port to opposite port
- **180° phase difference** between adjacent ports

S-Matrix Properties:

- **Isolation**: Ports 1-3 and ports 2-4 are isolated
- **Power division**: Equal split with 180° phase difference
- **Impedance**: All ports matched to Z_0

Applications:

- **Balanced mixers**
- **Push-pull amplifiers**
- **Phase comparison circuits**

Performance Table:

Parameter	Value
Isolation	>25 dB
Return Loss	>20 dB
Phase Balance	±5°

Mnemonic: "Ring Rotates, Ports Pair-up"

Question 2(c OR) [7 marks]

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

Answer:

Construction: Magic Tee is formed by joining **E-plane** and **H-plane** tees at their junction.

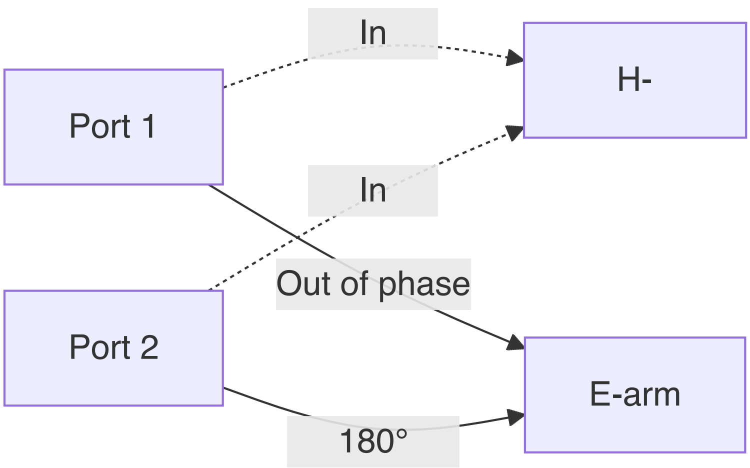
Structure Diagram:

```
         H-arm (Sum port)
              |
              |
      -------●-------
     |               |
  E-arm     Junction  Collinear
  (Diff)              arms
     |               |
      -------●-------
              |
              |
         Matched load
```

Working Principle:

- **Ports 1,2**: Collinear arms (input/output ports)
- **Port 3**: H-arm (sum/Σ port)
- **Port 4**: E-arm (difference/Δ port)
- **Isolation**: Between sum and difference ports

S-Matrix Properties:



Application - Radar Duplexer:

- **Transmit**: Power fed to H-arm, splits equally to ports 1,2
- **Receive**: Received signals combine at E-arm for receiver
- **Isolation**: Protects receiver during transmission
- **Advantage**: Single antenna for transmit/receive

Performance Specifications:

Parameter	Value
Isolation	>30 dB
VSWR	<1.3
Power Split	3 dB
Phase Balance	±5°

Key Features:

- **Symmetric structure** ensures equal power division
- **Orthogonal fields** provide port isolation
- **Broadband operation** over octave bandwidth

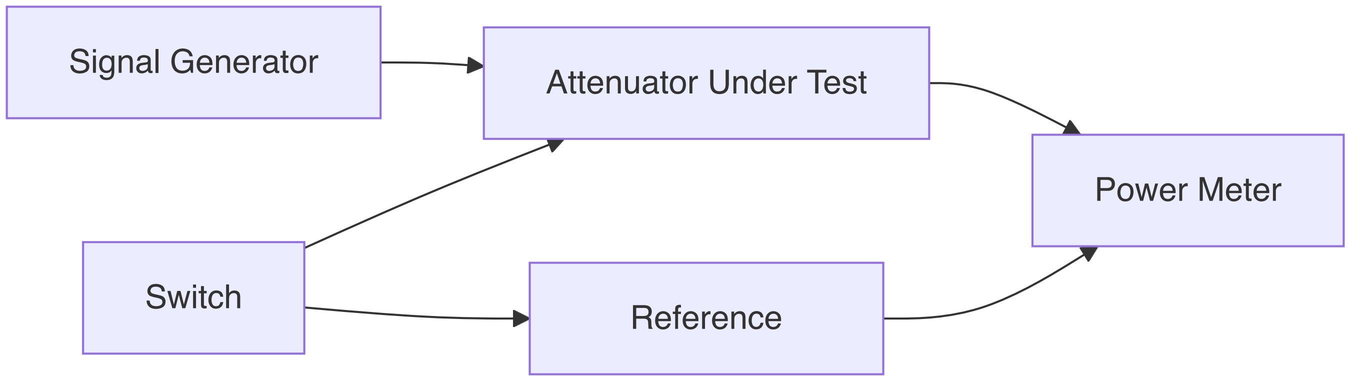
Mnemonic: "Magic Makes Isolation, Tee Transmits Together"

Question 3(a) [3 marks]

Explain Attenuation measurement with the help of block diagram.

Answer:

Block Diagram:



Measurement Procedure:

- **Step 1**: Measure power without attenuator (P_1)
- **Step 2**: Insert attenuator, measure power (P_2)
- **Step 3**: Calculate attenuation = 10 log(P_1/P_2) dB

Methods:

- **Substitution method**: Compare with known attenuator
- **Direct method**: Measure input and output power
- **IF substitution**: Use intermediate frequency

Mnemonic: "Attenuation = $Power_1$/$Power_2$"

Question 3(b) [4 marks]

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

Answer:

Two Cavity Klystron Diagram:

```
Electron -----> ●======● -----> ●======● -----> Collector
Gun             Input    Drift   Output
                Cavity   Space   Cavity
                  |                |
               RF Input         RF Output
```

Applegate Diagram:

```
Distance →
   |
   |  /  \     /  \     /  \
   | /    \   /    \   /    \
   |/      \ /      \ /      \
   |        X        X        X  ← Bunching
Tim|       / \      / \      / \
   ↓      /   \    /   \    /   \
         /     \  /     \  /     \
        /       \/       \/       \
Fast electrons ←→ Slow electrons
```

Velocity Modulation Process:

- **Input cavity**: Electrons gain/lose energy from RF field
- **Drift space**: Fast electrons catch up to slow electrons
- **Bunching**: Electron density varies periodically
- **Output cavity**: Bunched electrons induce RF current

Key Parameters:

- **Transit time**: $\tau = L/v_0$ (where L = drift space length)
- **Bunching parameter**: $X = \beta n/2$
- **Optimum bunching**: $X = 1.84$

Mnemonic: "Velocity Varies, Bunching Builds"

Question 3(c) [7 marks]

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

Answer:

Principle: Magnetron uses **crossed electric and magnetic fields** to generate high-power microwave oscillations through **cyclotron motion** of electrons.

Construction Diagram:

```
    Permanent Magnet (N)
          ↓   ↓   ↓   ↓
      ┌─────────────────┐
      │  ○   ○   ○   ○   ○  │ ← Resonant Cavities
      │○                  ○│
      │  ●─ Cathode ─●  │ ← Central cathode
      │○                  ○│
      │  ○   ○   ○   ○   ○  │
      └─────────────────┘
          ↑   ↑   ↑   ↑
    Permanent Magnet (S)
```

Field Effects:

- **Electric Field (E)**: Radial, from cathode to anode
- **Magnetic Field (B)**: Axial, perpendicular to E-field
- **Crossed fields**: Create cycloidal electron motion

Electron Motion Analysis:

Operating Conditions:

- **Cutoff condition**: $E/B = v_{drift}$
- **Synchronism**: Electron drift velocity matches phase velocity
- **Hull cutoff**: Minimum magnetic field for operation

Resonant Cavities:

- **π-mode operation**: Alternate cavities have opposite phases
- **Frequency**: $f = c/(2\sqrt{LC})$ for cavity resonance
- **Mode separation**: Prevents mode competition

Performance Characteristics:

Parameter	Typical Value
Efficiency	60-80%
Power Output	10 kW - 10 MW
Frequency	1-100 GHz
Pulse/CW	Both modes

Advantages:

- **High efficiency** compared to other tubes
- **High power capability**
- **Compact structure**
- **Good frequency stability**

Applications:

- **Radar transmitters**
- **Microwave ovens**
- **Industrial heating**
- **Electronic warfare**

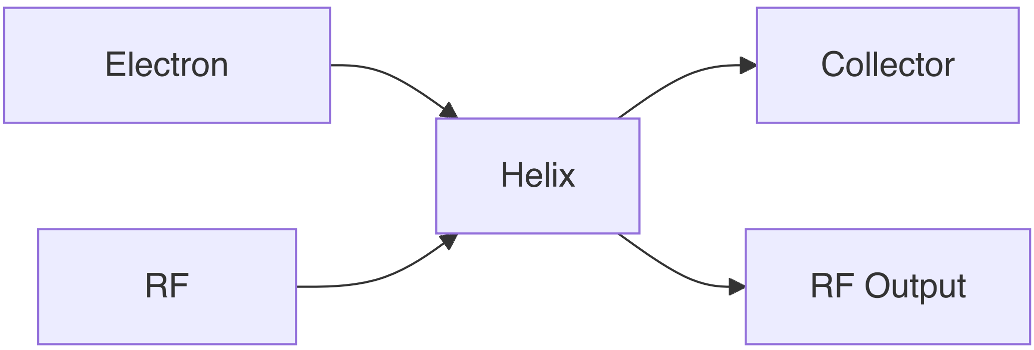
Mnemonic: "Magnetron Makes Microwaves via Magnetic Motion"

Question 3(a OR) [3 marks]

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

Answer:

TWT Structure:



Amplification Process:

- **Electron beam** travels along helix axis
- **RF signal** propagates along helix (slow wave structure)

- **Velocity synchronism**: v_electron ≈ v_RF
- **Energy transfer** from DC beam to RF wave

Gain Mechanism:

- **Bunching**: RF field modulates electron velocity
- **Induced current**: Bunched electrons induce RF current in helix
- **Progressive amplification** along helix length

Mnemonic: "Travelling Wave Transfers Energy"

Question 3(b OR) [4 marks]

Explain Bolometer method for low power measurement at microwave frequency.

Answer:

Principle: Bolometer measures microwave power by detecting **temperature rise** in resistive element.

Bolometer Types:

- **Thermistor**: Negative temperature coefficient
- **Barretter**: Positive temperature coefficient

Circuit Diagram:

```
RF Power -----> [Bolometer] -----> Temperature
     |              |                Change
     |              |                  |
DC Bridge ←---------●---------→ DC Voltmeter
```

Measurement Process:

- **Step 1**: Balance bridge with DC power only
- **Step 2**: Apply RF power, note bridge unbalance
- **Step 3**: Reduce DC power to rebalance bridge
- **Step 4**: RF power = Reduction in DC power

Advantages:

- **High sensitivity** (μW to mW range)
- **Square law response**
- **Broadband operation**

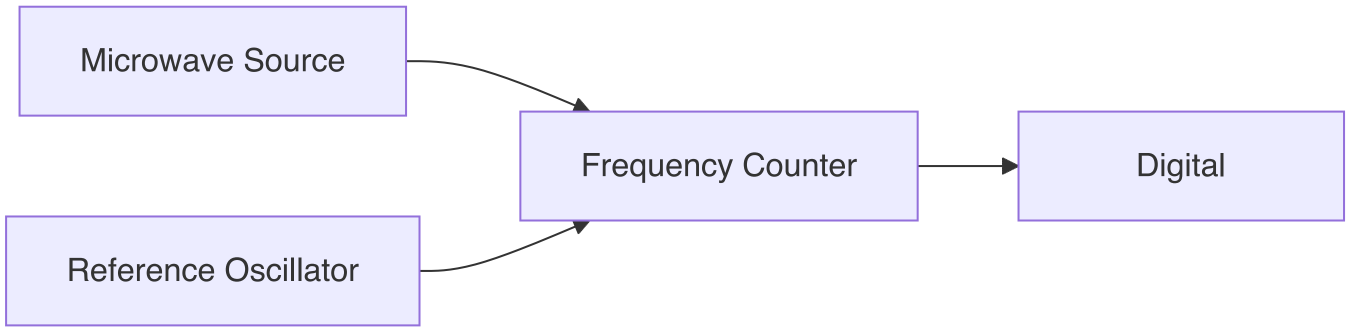
Mnemonic: "Bolometer Burns, Bridge Balances"

Question 3(c OR) [7 marks]

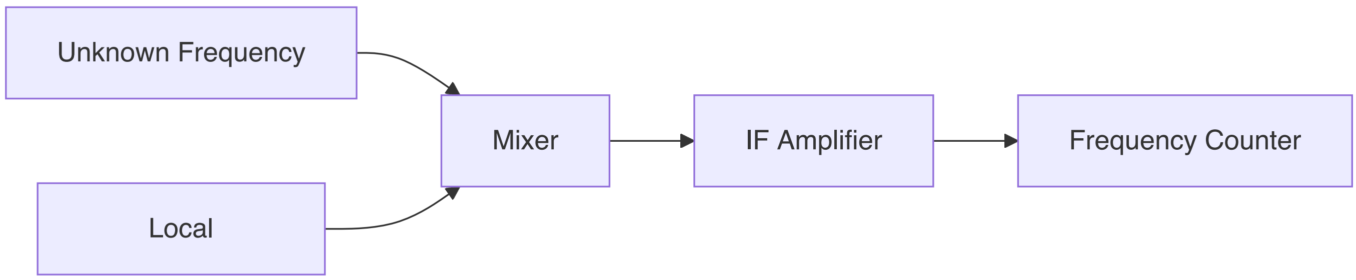
Explain frequency and wavelength measurement method with the help of block diagram.

Answer:

Frequency Measurement - Direct Method:



Frequency Measurement - Heterodyne Method:



Wavelength Measurement - Slotted Line Method:

Setup Diagram:

```
Microwave --|-----|====|-----|-- Slotted Line --|-- Load
Source      |  Isolator  |                      |
            |            |                      |
         Attenuator   Detector               Movable
                                            Probe
```

Measurement Procedure:

Free Space Wavelength (λ_0):

- **Step 1**: Connect matched load, measure frequency
- **Step 2**: Calculate $\lambda_0 = c/f$

Guided Wavelength (λ_g):

- **Step 1**: Connect short circuit, find two consecutive minima
- **Step 2**: λ_g = 2 × distance between minima
- **Step 3**: Verify: $\lambda g = \lambda_0/\sqrt{[1-(\lambda_0/\lambda c)^2]}$

Cut-off Wavelength (λ_c):

- **Method 1**: From waveguide dimensions: λ_c = 2a (for TE_{10})

- **Method 2**: From λ_0 and λg: $\lambda c = \lambda_0/\sqrt{[1-(\lambda_0/\lambda_g)^2]}$

Measurement Table:

Parameter	Method	Accuracy
Frequency	Direct counting	±0.01%
λ_0	Calculate from f	±0.01%
λ_g	Slotted line	±1%
λ_c	Calculation/measurement	±2%

Advantages of Each Method:

- **Direct method**: High accuracy, simple
- **Heterodyne method**: Extended frequency range
- **Slotted line**: Measures guided parameters directly

Error Sources:

- **Probe coupling** variations
- **Temperature effects** on dimensions
- **Detector nonlinearity**
- **Standing wave** disturbances

Applications:

- **Waveguide characterization**
- **Material property measurement**
- **Antenna testing**
- **Component verification**

Mnemonic: "Frequency First, Wavelength With-measurement"

Question 4(a) [3 marks]

State Frequency limitations of vacuum tubes at microwave frequency.

Answer:

Frequency Limitations:

- **Transit time effects**: Electron transit time becomes comparable to RF period
- **Inter-electrode capacitance**: Reduces gain at high frequencies
- **Lead inductance**: Parasitic inductances limit performance
- **Skin effect**: Current concentration reduces effective conductance

Limiting Factors Table:

Factor	Effect	Frequency Impact
Transit Time	Phase delay	$f < 1/(2\pi\tau)$
Capacitance	Reactance loading	Gain $\propto$ 1/f
Inductance	Resonance effects	Stability issues
Skin Effect	Increased resistance	Efficiency ↓

Solutions:

- **Reduce electrode spacing**
- **Use special geometries**
- **Employ microwave tubes** (Klystron, Magnetron)

Mnemonic: "Transit Time Troubles Traditional Tubes"

Question 4(b) [4 marks]

Explain Negative resistance effect in IMPATT Diode.

Answer:

IMPATT Structure:

```
P+ |--| I |--| P |--| N+ |
   ←--|------|------|--→
   Avalanche  Drift
   Region     Region
```

Negative Resistance Mechanism:

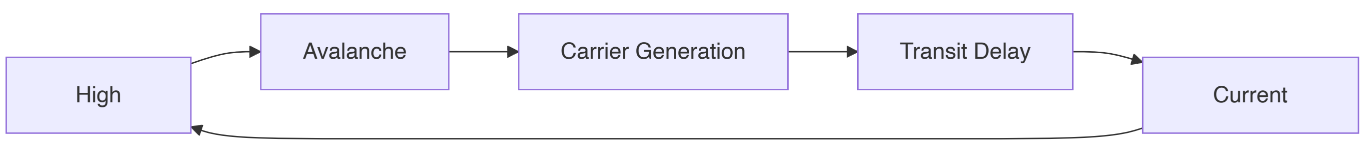
Two-step Process:

1. **Impact Ionization**: High field creates electron-hole pairs
2. **Transit Time Delay**: Carriers drift across depletion region

Phase Relationships:

- **Current**: Lags voltage by 90° (avalanche delay) + 90° (transit delay) = 180°
- **Result**: I = -G*V (negative conductance)

Operating Cycle:



Key Parameters:

- **Avalanche frequency**: f_a = v_s/(2W_a)
- **Transit frequency**: f_t = v_d/(2W_d)
- **Optimum frequency**: f_0 = 1/(2π√L*|C_negative|)

Mnemonic: "Impact Ionization, Transit Time = Negative Resistance"

Question 4(c) [7 marks]

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

Answer:

Principle: Tunnel diode operates on **quantum mechanical tunneling** effect through thin potential barrier in heavily doped p-n junction.

Energy Band Diagram:

```
Forward Bias States:

State 1 (Low bias):    State 2 (Peak):      State 3 (Valley):
   P side | N side        P side | N side        P side | N side
    ___   |  ___           ___   |  ___           ___   |  ___
   |   |  | |   |         |   |  | |   |         |   |  | |   |
   |___|  | |___|         |___| /| |___|         |___| /| |___|
          |               Tunneling              No tunnel
       Tunneling
```

I-V Characteristics:

```
Current ↑
        |
     Ip |●
        | ●
        |  ●  Forward region
        |   ●
        |    ●
     Iv |     ●____
        |         ●
        |          ●
        |________________________→ Voltage
        0   Vp    Vv    Vf

    Peak    Valley  Forward
    point   point   region
```

Tunneling Phenomenon:

Quantum Mechanics: Electrons can penetrate potential barrier even if their energy is less than barrier height.

Tunneling Probability: $T = \exp(-2\sqrt{(2m\phi d^2)}/\hbar)$
Where:

- m = electron mass
- ϕ = barrier height
- d = barrier width
- $\hbar$ = reduced Planck constant

Operating Regions:

- **Tunneling region** (0 to Vp): Current increases with voltage
- **Negative resistance** (Vp to Vv): Current decreases with increasing voltage
- **Forward bias** (>Vv): Normal diode behavior

Key Parameters Table:

Parameter	Symbol	Typical Value
Peak Current	Ip	1-100 mA
Peak Voltage	Vp	50-100 mV
Valley Current	Iv	0.1*Ip
Valley Voltage	Vv	300-500 mV

Application - High Frequency Oscillator:

Circuit Diagram:

```
   +Vcc
     |
     R ← Bias resistor
     |
     ●---L---●---Output
     |       |
   Tunnel    C
   Diode     |
     |       |
   __|__   __|__
    GND     GND
```

Oscillator Operation:

- **Bias point**: Set in negative resistance region
- **Tank circuit**: LC determines oscillation frequency
- **Condition**: |R_negative| > R_positive for oscillation
- **Frequency**: $f = 1/(2\pi\sqrt{LC})$

Advantages:

- **Ultra-high frequency** operation (up to 100 GHz)
- **Low noise** figure
- **Fast switching** (picosecond range)
- **Low power consumption**
- **Temperature stable**

Applications:

- **Microwave oscillators**
- **High-speed switches**
- **Microwave amplifiers**
- **Frequency converters**
- **Computer memory circuits**

Limitations:

- **Low power handling**
- **Critical bias requirements**
- **Limited temperature range**
- **Expensive manufacturing**

Design Considerations:

- **Doping concentration**: $>10^{19}$ cm^{-3} for both sides
- **Junction area**: Small for high frequency operation
- **Parasitic elements**: Minimize package inductance/capacitance
- **Bias stability**: Temperature compensation required

Mnemonic: "Tunnel Through, Negative Grows, Oscillator Flows"

Question 4(a OR) [3 marks]

Explain Hazards due to microwave radiation.

Answer:

Types of Hazards:

HERP (Hazards of Electromagnetic Radiation to Personnel):

- **Thermal effects**: Tissue heating above 41°C
- **Non-thermal effects**: Cellular damage at low power levels
- **Cumulative effects**: Long-term exposure risks

HERO (Hazards of Electromagnetic Radiation to Ordnance):

- **Premature ignition**: RF energy can trigger explosive devices
- **Fuel ignition**: Microwave heating of fuel vapors
- **Electronic interference**: Disruption of control systems

HERF (Hazards of Electromagnetic Radiation to Fuels):

- **Fuel heating**: Dielectric heating of hydrocarbon fuels
- **Static discharge**: RF-induced sparking in fuel systems
- **Vapor ignition**: Heating of fuel-air mixtures

Safety Guidelines Table:

Exposure Level	Power Density	Duration	Effect
Safe	<10 mW/cm²	8 hours	No effect
Caution	10-100 mW/cm²	Limited	Possible heating
Danger	>100 mW/cm²	Avoid	Tissue damage

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

Question 4(b OR) [4 marks]

Explain Degenerate and non-degenerate mode in Parametric Amplifier.

Answer:

Parametric Amplifier Principle: Uses **time-varying reactance** to transfer energy from pump to signal.

Mode Classifications:

Non-degenerate Mode:

- **Three frequencies**: f_s (signal), f_i (idler), f_p (pump)
- **Frequency relation**: $f_p = f_s + f_i$
- **Two separate circuits** for signal and idler
- **Higher gain** but more complex

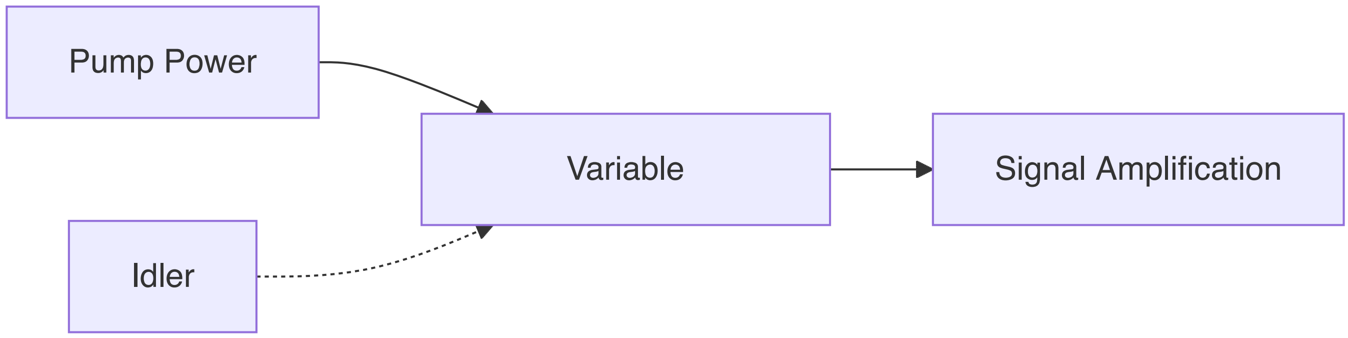
Degenerate Mode:

- **Two frequencies**: f_s (signal), f_p (pump)
- **Frequency relation**: $f_p = 2f_s$
- **Single resonant circuit**
- **Simpler design** but lower gain

Comparison Table:

Parameter	Non-degenerate	Degenerate
Frequencies	3 (fs, fi, fp)	2 (fs, fp)
Circuits	Separate	Combined
Gain	Higher	Lower
Complexity	More	Less
Bandwidth	Narrower	Wider

Energy Transfer:



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

Question 4(c OR) [7 marks]

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

Answer:

Gunn Effect Principle: Based on **transferred electron effect** in compound semiconductors (GaAs, InP).

Energy Band Structure:

```
Energy ↑
       |     Upper valley
       |    /
       |   /  ΔE = 0.36 eV
       |  /
       |_/_______ Lower valley
              |
              |→ k (momentum)
        Γ valley   L valley
```

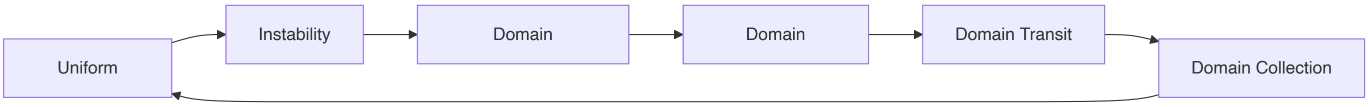
Gunn Effect Mechanism:

Differential Mobility:

- **Low field** (<3 kV/cm): Electrons in Γ valley (high mobility)

- **High field** (>3 kV/cm): Electrons transfer to L valley (low mobility)
- **Result**: Negative differential mobility (NDM)

Domain Formation:



Current-Voltage Characteristics:

```
Current ↑
        |
    I_p |●
        | ●
        |  ●
        |   ●_____ NDM region
        |        ●
        |         ●
        |__________●_________→ Voltage
        0    V_th    V_s

    Threshold  Sustaining
    voltage    voltage
```

Gunn Diode Oscillator:

Basic Configuration:

```
    +V_bias
      |
      R ← Bias resistor
      |
    ──●──── RF Output
      |
   [Gunn]  ← Gunn diode
   Diode
      |
    ──┴──── Ground
     GND
```

Oscillator Modes:

Transit Time Mode:

- **Domain formation** at cathode
- **Domain transit** across active region
- **Current pulse** when domain reaches anode
- **Frequency**: f = v_d/L (where v_d = drift velocity, L = length)

Quenched Domain Mode:

- **Resonant circuit** quenches domain before transit
- **Higher frequency** operation possible
- **Efficiency**: 5-20%

LSA (Limited Space-charge Accumulation) Mode:

- **High frequency** prevents domain formation
- **Uniform field** maintained
- **Higher efficiency**: 10-25%

Performance Parameters:

Parameter	Value	Unit
Frequency Range	1-100	GHz
Power Output	1 mW-10 W	-
Efficiency	5-25	%
Noise Figure	35-50	dB

Advantages:

- **Simple structure -** no external resonator needed
- **Broadband tuning** capability
- **Low noise** at microwave frequencies
- **Reliable operation**

Applications:

- **Local oscillators** in receivers
- **CW radar transmitters**
- **Microwave communication systems**
- **Test equipment signal sources**

Design Considerations:

- **Doping profile**: Uniform n-type doping
- **Length optimization**: L = v_d/f for transit time mode
- **Thermal management**: Heat dissipation critical
- **Circuit design**: Impedance matching important

Comparison with Other Oscillators:

Oscillator	Frequency	Power	Efficiency
Gunn Diode	1-100 GHz	mW-10W	5-25%
IMPATT	1-300 GHz	1W-100W	10-20%
Klystron	1-20 GHz	1kW-1MW	30-60%

Mnemonic: "Gunn Gets Going via Gallium-Arsenide"

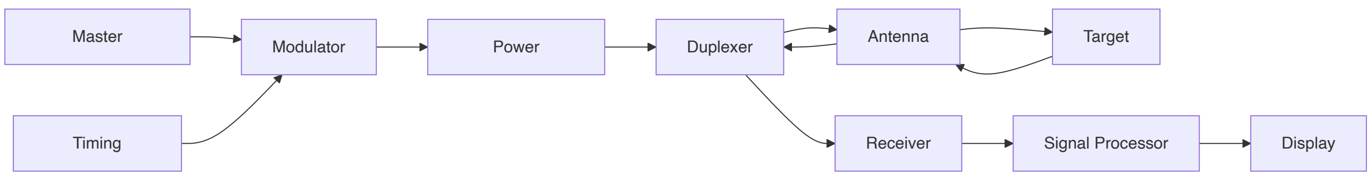
Question 5(a) [3 marks]

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

Answer:

RADAR Principle: **Radio Detection And Ranging** - transmits RF pulses and detects reflected signals from targets.

Basic RADAR Block Diagram:



Working Principle:

- **Transmission**: High power RF pulse transmitted toward target
- **Propagation**: EM wave travels at speed of light (c)
- **Reflection**: Target reflects portion of energy back to radar
- **Reception**: Reflected signal received and processed
- **Range calculation**: $R = (c \times t)/2$

Key Parameters:

- **Pulse width**: $\tau = 0.1$ to $10\ \mu s$
- **Pulse repetition frequency**: PRF = 100 Hz to 10 kHz
- **Peak power**: 1 kW to 10 MW

Mnemonic: "RADAR Ranges by Round-trip Reflection"

Question 5(b) [4 marks]

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

Answer:

A-Scope Display: Shows **amplitude vs time** relationship of received echoes.

A-Scope Presentation:

```
Amplitude ↑
          |
          |    ●  Target echo
          |   /|\
     Main |  / | \
    pulse | /  |  \
          |/   |   \
          |    |    \___
          |____|_________\______→ Time
          0    |
               |
           2R/c (Range)

    ←Ground→←Sea→←Target→←Noise→
     clutter clutter
```

Display Components:

- **Main pulse**: Initial transmitted pulse (reference)
- **Ground clutter**: Reflections from nearby terrain
- **Sea clutter**: Reflections from sea surface
- **Target echo**: Reflection from actual target
- **Noise**: Random background signals

Range Measurement:

- **Horizontal axis**: Time (proportional to range)
- **Vertical axis**: Signal amplitude
- **Range formula**: $R = (c \times t)/2$

Applications:

- **Air traffic control**
- **Height finding radars**
- **Range measurement**
- **Signal analysis**

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.

Answer:

Doppler Effect: Frequency shift occurs when there is relative motion between radar and target.

Doppler Frequency Shift:
$f_d = (2 \times v_r \times f_0)/c$

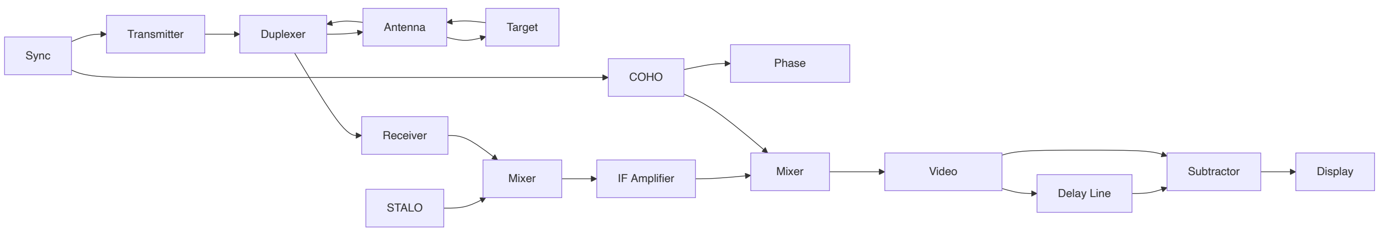
Where:

- f_d = Doppler frequency shift
- v_r = radial velocity of target
- f_0 = transmitted frequency
- c = speed of light

Doppler Shift Cases:

- **Approaching target**: $f_d > 0$ (positive shift)
- **Receding target**: $f_d < 0$ (negative shift)
- **Stationary target**: $f_d = 0$ (no shift)

MTI RADAR Block Diagram:



MTI System Components:

STALO (Stable Local Oscillator):

- **Frequency**: Close to transmitted frequency
- **Stability**: High frequency stability required
- **Function**: First mixer LO

COHO (Coherent Oscillator):

- **Phase reference**: Maintains phase coherence
- **Synchronization**: Locked to transmitter phase
- **Function**: Second mixer LO and phase reference

MTI Processing:

- **Delay line**: Stores previous pulse echo
- **Subtractor**: Subtracts current from previous pulse
- **Result**: Stationary targets cancelled, moving targets enhanced

MTI Transfer Function:

```
|H(f)| ↑
       |
   1.0|     ●●●      ●●●      ●●●
       |   ●    ●   ●    ●   ●    ●
   0.5|  ●      ● ●      ● ●      ●
       | ●       ●        ●        ●
     0 |_●_______●________●________●___→ fd
       0  PRF/4  PRF/2  3PRF/4  PRF

       ← Blind speeds →
```

Blind Speeds: Targets with certain velocities appear stationary:
$v_{blind} = (n \times \lambda \times PRF)/2$ (where n = 1,2,3...)

Performance Improvements:

Multi-pulse MTI:

- **Multiple delay lines** for better clutter rejection
- **Staggered PRF** to reduce blind speeds
- **Weighted coefficients** for optimum response

Clutter Map:

- **Digital memory** stores clutter pattern
- **Adaptive threshold** adjusts to local clutter level
- **Automatic updates** track slow clutter changes

MTI Performance Metrics:

Parameter	Typical Value
Clutter Attenuation	30-60 dB
Minimum Detectable Velocity	1-10 m/s
Blind Speed	$\lambda \times PRF/2$
Improvement Factor	20-40 dB

Advantages:

- **Clutter suppression**: Eliminates stationary clutter
- **Moving target emphasis**: Enhances moving targets
- **Automatic operation**: Reduces operator workload

Limitations:

- **Blind speeds**: Some velocities undetectable
- **Tangential targets**: No radial component

- **Weather effects**: Rain/snow can mask targets

Applications:

- **Air traffic control**: Separates aircraft from ground clutter
- **Weather radar**: Detects precipitation movement
- **Military surveillance**: Detects moving vehicles
- **Marine radar**: Reduces sea clutter

Mnemonic: "MTI Makes Targets Identifiable via Doppler Difference"

Question 5(a OR) [3 marks]

Define: a) Blind speed, and b) MUR

Answer:

Blind Speed:

- **Definition**: Target radial velocities that produce zero Doppler shift in MTI radar
- **Formula**: $v_{blind} = (n \times \lambda \times PRF)/2$
- **Cause**: Target motion synchronized with pulse repetition
- **Result**: Moving target appears stationary

MUR (Maximum Unambiguous Range):

- **Definition**: Maximum range at which targets can be detected without range ambiguity
- **Formula**: $R_{max} = (c \times PRT)/2 = c/(2 \times PRF)$
- **Limitation**: Next pulse transmitted before echo returns
- **Ambiguity**: Targets beyond MUR appear at incorrect range

Relationship Table:

Parameter	Formula	Unit
Blind Speed	$n\lambda PRF/2$	m/s
MUR	$c/(2 \times PRF)$	meters
PRT	$1/PRF$	seconds

Mnemonic: "Blind speed Blocks, MUR Measures maximum"

Question 5(b OR) [4 marks]

Explain the factors affecting Maximum RADAR range.

Answer:

RADAR Range Equation:
$R_{max} = [(P_t \times G^2 \times \lambda^2 \times \sigma)/(64\pi^3 \times P_{min} \times L)]^{(1/4)}$

Factors Affecting Maximum Range:

Transmitted Power (P_t):

- **Higher power** = greater range
- **Relationship**: $R \propto P_t^{(1/4)}$
- **Limitation**: Peak power limited by transmitter

Antenna Gain (G):

- **Directional antenna** concentrates energy
- **Relationship**: $R \propto G^{(1/2)}$
- **Trade-off**: Higher gain = narrower beamwidth

Wavelength (λ):

- **Lower frequency** = better propagation
- **Relationship**: $R \propto \lambda^{(1/2)}$
- **Consideration**: Atmospheric absorption increases with frequency

Target Cross Section (σ):

- **Larger targets** reflect more energy
- **Relationship**: $R \propto \sigma^{(1/4)}$
- **Variation**: Depends on target shape, material, aspect angle

Factors Table:

Factor	Effect on Range	Typical Values
Peak Power	$R \propto Pt^{0.25}$	1 kW - 10 MW
Antenna Gain	$R \propto G^{0.5}$	20 - 50 dB
Frequency	$R \propto \lambda^{0.5}$	1 - 100 GHz
Target RCS	$R \propto \sigma^{0.25}$	0.1 - 1000 m^2

Mnemonic: "Power-Gain-Lambda-Sigma determine Range"

Question 5(c OR) [7 marks]

Compare Pulsed RADAR and CW Doppler RADAR.

Answer:

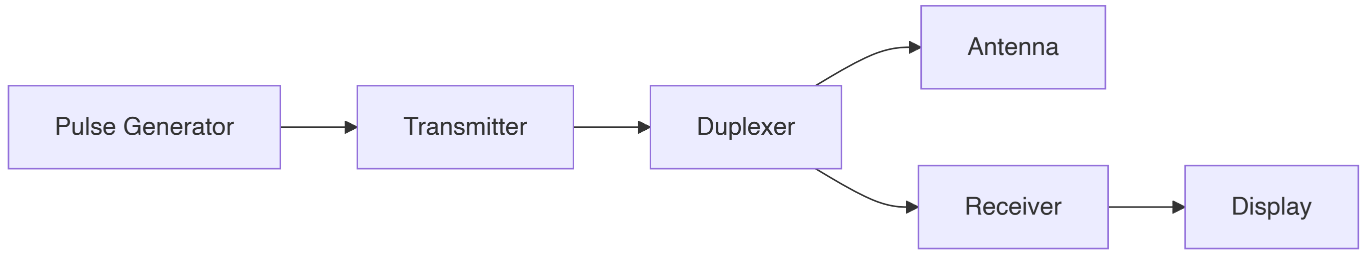
Comprehensive Comparison:

Basic Principle:

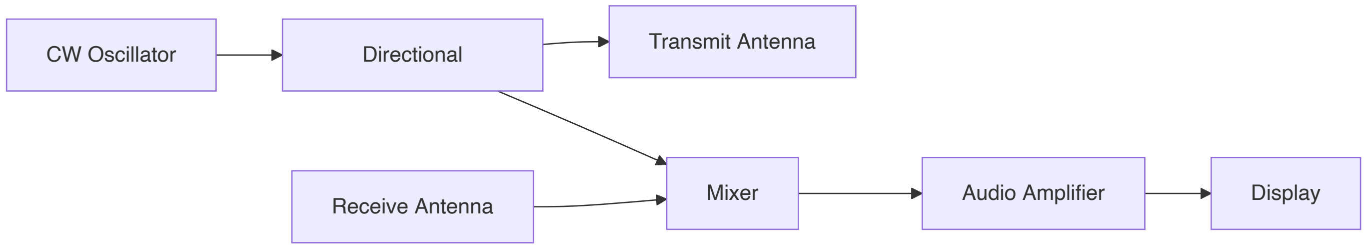
- **Pulsed RADAR**: Transmits high-power pulses, measures round-trip time
- **CW Doppler**: Transmits continuous wave, measures Doppler frequency shift

System Block Diagrams:

Pulsed RADAR:



CW Doppler RADAR:



Detailed Comparison Table:

Parameter	Pulsed RADAR	CW Doppler RADAR
Transmission	High power pulses	Continuous low power
Information	Range + velocity	Velocity only
Antenna	Single (duplexer)	Separate Tx/Rx
Range Capability	Excellent	None (unless FM-CW)
Velocity Resolution	Limited	Excellent
Peak Power	Very high (MW)	Low (mW to W)
Average Power	Low	Moderate
Complexity	High	Simple
Cost	Expensive	Economical
Size	Large	Compact

Performance Characteristics:

Aspect	Pulsed RADAR	CW Doppler RADAR
Range Accuracy	±10-100 m	Not applicable
Velocity Accuracy	±1-10 m/s	±0.1-1 m/s
Minimum Range	Limited by pulse width	Zero
Maximum Range	10-1000 km	1-50 km
Clutter Rejection	Moderate	Excellent
Weather Effects	Significant	Minimal

Advantages & Disadvantages:

Pulsed RADAR Advantages:

- **Range measurement** capability
- **High peak power** for long range
- **Single antenna** system
- **Well-established technology**

Pulsed RADAR Disadvantages:

- **Complex circuitry** (duplexer, timing)
- **High cost** and maintenance
- **Power supply** requirements
- **Blind ranges** due to pulse width

CW Doppler Advantages:

- **Simple design** and low cost
- **Excellent velocity resolution**
- **Continuous monitoring**
- **Low power consumption**
- **Compact size**

CW Doppler Disadvantages:

- **No range information**
- **Separate antennas** required
- **Limited range** capability
- **Vulnerable to interference**

Applications:

Pulsed RADAR Applications:

- **Air traffic control**
- **Weather monitoring**
- **Military surveillance**
- **Maritime navigation**
- **Satellite tracking**

CW Doppler Applications:

- **Traffic speed monitoring**
- **Sports radar guns**
- **Burglar alarms**
- **Automatic door openers**
- **Heart rate monitoring**

Hybrid Systems:

Pulse Doppler RADAR:

- **Combines advantages** of both systems
- **Range and velocity** measurement
- **Higher complexity** but better performance

FM-CW RADAR:

- **Frequency modulated** continuous wave
- **Range capability** added to CW system
- **Used in automotive** radar applications

Selection Criteria:

Requirement	Choose Pulsed	Choose CW Doppler
Range measurement needed	✓	✗
High velocity accuracy	✗	✓
Long range operation	✓	✗
Low cost requirement	✗	✓
Portable application	✗	✓
Weather radar	✓	✗

Future Trends:

- **Digital signal processing** improving both types
- **Software-defined radars** offering flexibility

- **MIMO techniques** enhancing performance
- **Integration** with other sensors

Mnemonic: "Pulsed gives Position, CW gives Continuous-Velocity"