

# Subject Name Solutions

4351103 – Summer 2025

Semester 1 Study Material

*Detailed Solutions and Explanations*

## Question 1(a) [3 marks]

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

### Solution

Band	Frequency Range	Applications
<b>L-band</b>	1-2 GHz	GPS, Mobile communication
<b>S-band</b>	2-4 GHz	WiFi, Bluetooth, Radar
<b>C-band</b>	4-8 GHz	Satellite communication
<b>X-band</b>	8-12 GHz	Military radar, Weather radar

### Mnemonic

“Little Satellites Communicate eXcellently”

## Question 1(b) [4 marks]

Explain the impedance matching process using a single stub.

### Solution

**Single stub matching** removes reflections by adding a **short-circuited stub** at specific distance from load.

**Process:**

- **Stub length:** Provides reactive impedance
- **Stub position:** Calculated from load using Smith chart
- **Matching condition:** Real part =  $Z_0$ , *imaginary part* = 0

### Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Source] --{-}{-}{ B[Transmission Line]}
    B --{-}{-}{ C[Stub Position]}
    C --{-}{-}{ D[Load]}
    C --{-}{-}{ E[Short Stub]}
{Highlighting}
{Shaded}
```

### Mnemonic

“Stub Positioned for Perfect Matching”

## Question 1(c) [7 marks]

State characteristics of lossless transmission line and obtain the general equation for a two-wire transmission line.

### Mnemonic

“Lossless Lines Love Low Loss”

### Question 1(c) OR [7 marks]

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

#### Solution

**Standing Wave:** Fixed pattern formed by **forward and reflected waves** interfering constructively and destructively.

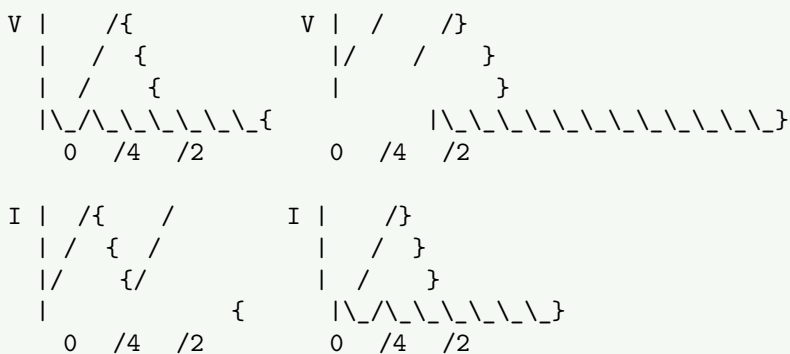
**Short Circuit Line:**

- **Current maximum** at short circuit
- **Voltage minimum** at short circuit
- **Distance between minima:**  $\lambda/2$

**Open Circuit Line:**

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

Short Circuit:      Open Circuit:



### Mnemonic

“Short Circuits Current, Open Circuits Voltage”

### Question 2(a) [3 marks]

Draw and explain the working of Magic TEE.

#### Solution

**Magic TEE** combines E-plane and H-plane tees with **four ports** providing isolation between opposite ports.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Port 1 {- E{-}arm} {-}{-}{-} C[Junction]]
    B[Port 2 {- H{-}arm} {-}{-}{-} C]
    C {-}{-}{-} D[Port 3 {-} Collinear arm]]
    C {-}{-}{-} E[Port 4 {-} Collinear arm]]
{Highlighting}
{Shaded}
```

**Working:**

- **E-arm and H-arm:** Isolated from each other
- **Sum port:** Adds signals from collinear arms
- **Difference port:** Subtracts signals

**Mnemonic**

“Magic Tee Mixes Modes”

**Question 2(b) [4 marks]**

Explain the working of Hybrid ring.

**Solution**

**Hybrid Ring** is a **circular waveguide** with **four ports** spaced at specific intervals for power division and isolation.

**Construction:**

- **Ring circumference:**  $1.5\lambda$
- **Port spacing:**  $\lambda/4$  between adjacent ports
- **Matched impedance:** Each port matched to  $Z_0$

**Working:**

- **Power splitting:** Input splits equally between two output ports
- **Isolation:** Opposite ports are isolated
- **Phase difference:**  $180^\circ$  between output ports

**Mnemonic**

“Ring Runs Round for Power Sharing”

**Question 2(c) [7 marks]**

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

**Solution****Construction:**

- **Three-port device** with **ferrite material**
- **Permanent magnet** creates magnetic field
- **Y-junction waveguide** structure

**Mermaid Diagram (Code)**

```
{Shaded}
{Highlighting}[]
graph LR
    A[Port 1] --{-}{-}{ B[Ferrite Junction]}
    B --{-}{-}{ C[Port 2]}
    C --{-}{-}{ D[Port 3]}
    D --{-}{-}{ A}
    style B fill:\#ff9999
{Highlighting}
{Shaded}
```

**Working Principle:**

- **Faraday rotation:** Magnetic field rotates wave polarization
- **Unidirectional flow:** Power flows in one direction only
- **Non-reciprocal:** Different behavior for opposite directions

**Applications:**

- **Radar systems:** Isolates transmitter from receiver
- **Communication:** Antenna sharing for TX/RX
- **Microwave amplifiers:** Prevents feedback

**Mnemonic**

“Circulator Circles Clockwise Continuously”

**Question 2(a) OR [3 marks]**

Compare rectangular waveguide and circular waveguide.

**Solution**

Parameter	Rectangular	Circular
<b>Cross-section</b>	Rectangle	Circle
<b>Dominant mode</b>	TE <sub>10</sub>	TE <sub>11</sub>
<b>Cutoff frequency</b>	Easy calculation	Complex calculation
<b>Manufacturing</b>	Simple	Moderate
<b>Power handling</b>	Lower	Higher

**Mnemonic**

“Rectangles are Regular, Circles are Complex”

**Question 2(b) OR [4 marks]**

Draw and explain the working of a directional coupler.

**Solution**

**Directional Coupler** samples **forward power** while providing isolation from reflected power.

**Mermaid Diagram (Code)**

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] --> B[Main Line]
    B --> C[Output]
    B --> D[Coupled Port]
    B --> E[Isolated Port]
    style D fill:#99ff99
    style E fill:#ff9999
{Highlighting}
{Shaded}
```

**Working:**

- **Coupling factor:** Determines power extracted (10-20 dB typical)
- **Directivity:** Isolates forward from reverse power
- **Insertion loss:** Minimal loss in main line

**Parameters:**

- $C = 10 \log(P_1/P_3)$  (Coupling factor)
- $D = 10 \log(P_3/P_4)$  (Directivity)

### Mnemonic

“Coupler Couples Carefully in Correct Direction”

### Question 2(c) OR [7 marks]

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

#### Solution

##### Construction:

- **Electron gun:** Emits electron beam
- **Helix structure:** Slows down RF wave
- **Collector:** Collects spent electrons
- **Magnetic focusing:** Keeps beam focused

##### Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Electron Gun] --> B[Helix]
    B --> C[Collector]
    D[RF Input] --> B
    B --> E[RF Output]
    F[Magnetic Field] -. B .-> B
{Highlighting}
{Shaded}
```

##### Working Principle:

- **Velocity synchronization:** Electron velocity  $\approx RF\text{ wave velocity}$
- **Energy transfer:** Electrons give energy to RF wave
- **Continuous interaction:** Along entire helix length

##### Applications:

- **Satellite communication:** High power amplification
- **Radar transmitters:** High gain amplification
- **Electronic warfare:** Jamming systems

### Mnemonic

“TWT Transfers Tremendous power Through Travel”

### Question 3(a) [3 marks]

Explain the Indirect method for higher VSWR measurement.

#### Solution

**Indirect Method** measures **high VSWR** by using **attenuator** to reduce signal level for accurate measurement.

##### Procedure:

- **Insert calibrated attenuator** (10-20 dB)
- **Measure reduced VSWR** ( $VSWR_2$ )
- **Calculate actual VSWR:**  $VSWR_1 = VSWR_2 \times \text{Attenuator ratio}$

**Formula:**  $VSWR_{\text{actual}} = VSWR_{\text{measured}} \times 10^{(\text{Attenuation}/20)}$

### Mnemonic

“Indirect method uses Intermediate Attenuation”

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### Question 3(b) [4 marks]

Write and explain the frequency limitations of conventional tubes.

#### Solution

##### Frequency Limitations:

- **Transit time effect:** Electron transit time becomes significant
- **Interelectrode capacitance:** Limits high frequency response
- **Lead inductance:** Parasitic inductance reduces gain
- **Skin effect:** Current flows on surface only

##### Effects:

- **Reduced gain:** At frequencies above  $f$
- **Increased noise:** Due to shot noise
- **Phase shift:** Delays signal processing

##### Solutions:

- **Reduce electrode spacing**
- **Use special tube designs**
- **Employ cavity resonators**

#### Mnemonic

“Transit Time Troubles Traditional Tubes”

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### Question 3(c) [7 marks]

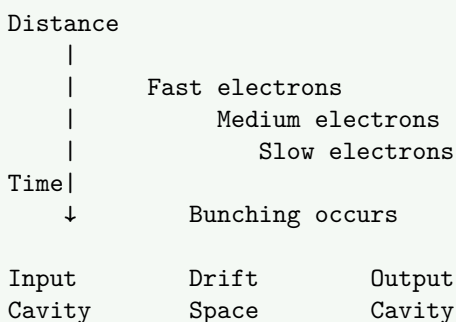
Explain construction and working of Two cavity klystron with applegate diagram. List its advantages.

#### Solution

##### Construction:

- **Electron gun:** Produces electron beam
- **Input cavity:** Velocity modulates beam
- **Drift region:** Beam bunching occurs
- **Output cavity:** Extracts RF energy
- **Collector:** Collects electrons

##### Applegate Diagram:



##### Working:

- **Velocity modulation:** Input cavity varies electron velocity
- **Density modulation:** Electrons bunch in drift space
- **Energy extraction:** Bunched beam transfers energy to output cavity

##### Advantages:

- **High power output:** Several kilowatts
- **High efficiency:** 40-60%
- **Low noise:** Better than semiconductor devices
- **Stable operation:** Excellent frequency stability

### Mnemonic

“Klystron Kicks with Kinetic Bunching”

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### Question 3(a) OR [3 marks]

Explain construction and working of BWO.

#### Solution

**BWO (Backward Wave Oscillator)** uses **backward wave interaction** for oscillation.

##### Construction:

- **Electron gun:** Emits electron beam
- **Slow wave structure:** Helix or coupled cavities
- **Collector:** At input end
- **Output:** From input end

##### Working:

- **Backward wave:** Travels opposite to electron beam
- **Negative resistance:** Beam provides energy to backward wave
- **Oscillation:** When gain > losses

### Mnemonic

“BWO goes Backward While Oscillating”

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### Question 3(b) OR [4 marks]

Explain hazards due to microwave radiation.

#### Solution

##### Types of Hazards:

- **HERP:** Hazards of Electromagnetic Radiation to Personnel
- **HERO:** Hazards of Electromagnetic Radiation to Ordnance
- **HERF:** Hazards of Electromagnetic Radiation to Fuel

##### Effects:

- **Thermal heating:** Tissue heating at high power
- **Eye damage:** Cataract formation
- **Reproductive effects:** Potential fertility issues
- **Pacemaker interference:** Electronic device malfunction

##### Protection:

- **Power density limits:**  $< 10 \text{ mW/cm}^2$
- **Safety distances:** Far field calculations
- **Warning signs:** Radiation hazard markers
- **Personal monitors:** RF exposure meters

### Mnemonic

“Microwaves Make Multiple Medical Maladies”

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### Question 3(c) OR [7 marks]

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

## Solution

### Construction:

- **Circular cathode:** Central hot cathode
- **Cylindrical anode:** With resonant cavities
- **Permanent magnet:** Provides axial magnetic field
- **Output coupling:** Loop or probe

### Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Cathode] --> B[Interaction Space]
    B --> C[Anode Cavities]
    C --> D[Magnetic Field]
    D --> E[Output Coupling]
    style A fill:#ff9999
    style C fill:#99ff99
{Highlighting}
{Shaded}
```

### Working:

- **Electron cloud:** Forms in interaction space
- **Cycloid motion:** Due to E and B fields
- **Resonant cavities:** Determine operating frequency
- **-mode oscillation:** Alternate cavities have opposite phase

### Applications:

- **Microwave ovens:** 2.45 GHz heating
- **Radar systems:** High power pulses
- **Industrial heating:** Material processing
- **Medical diathermy:** Therapeutic heating

## Mnemonic

“Magnetron Makes Microwaves Magnificently”

## Question 4(a) [3 marks]

Explain working of P-i-N diode.

## Solution

**P-i-N Diode** has **intrinsic layer** between P and N regions, acting as **voltage-controlled resistor**.

### Structure:

- **P region:** Heavily doped
- **I region:** Intrinsic (undoped)
- **N region:** Heavily doped

### Working:

- **Forward bias:** Low resistance (1-10  $\Omega$ )
- **Reverse bias:** High resistance ( $>10$  k $\Omega$ )
- **RF switch:** Controls microwave signals
- **Variable attenuator:** Resistance varies with DC bias

## Mnemonic

“PIN controls Power IN Networks”

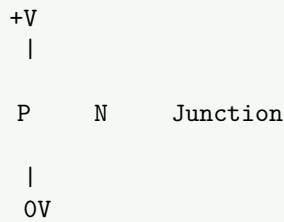


### Question 4(b) [4 marks]

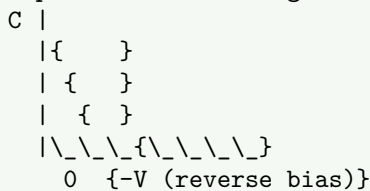
Explain the working of Varactor diode with sketch.

#### Solution

Varactor Diode acts as **voltage-controlled capacitor** using junction capacitance variation.



Capacitance vs Voltage:



Working:

- **Reverse bias:** Depletes junction, reduces capacitance
- **Bias voltage:** Controls capacitance value
- **Capacitance ratio:** Typically 3:1 to 10:1
- **Frequency tuning:** Used in oscillators and filters

Applications:

- **VCO tuning:** Voltage controlled oscillators
- **AFC circuits:** Automatic frequency control
- **Parametric amplifiers:** Low noise amplification

#### Mnemonic

“Varactor Varies Capacitance with Voltage”

### Question 4(c) [7 marks]

Explain construction and working of Tunnel Diode and explain tunneling phenomenon in detail. List its applications.

#### Solution

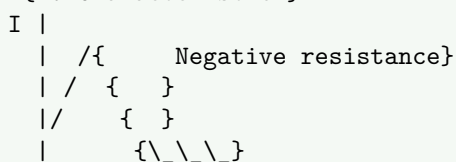
Construction:

- **Heavily doped P-N junction:** Both sides degenerately doped
- **Thin junction:** ~10 nm width
- **Quantum tunneling:** Electrons tunnel through barrier

Tunneling Phenomenon:

- **Quantum effect:** Electrons pass through energy barrier
- **Band overlap:** Conduction band overlaps valence band
- **Probability function:** Tunneling probability depends on barrier width
- **No thermal activation:** Occurs at room temperature

I{-V Characteristic:}



[illegible]

$V_v$  = Valley voltage

- **Forward bias 0-Vp:** Current increases (tunneling)
- **Vp to Vv:** Negative resistance region
- **Beyond Vv:** Normal diode operation

- **High-speed switching:** Picosecond switching
- **Oscillators:** Microwave frequency generation
- **Amplifiers:** Low noise amplification
- **Memory circuits:** Bistable operation

“Tunnel Diode Tunnels Through barriers Terrifically”

**Describe the operation of IMPATT diode.**

**IMPATT (Impact Avalanche Transit Time)** diode uses **avalanche multiplication** and **transit time delay** for oscillation.

- **Avalanche zone:** Impact ionization creates carriers
- **Drift zone:** Carriers drift with constant velocity
- **Transit time:** Provides  $180^\circ$  *phaseshift*
- **Negative resistance:** Due to phase delay

- **Breakdown voltage:** Typically 20-100V
- **Efficiency:** 10-20%
- **Frequency range:** 1-300 GHz

## “IMPATT Impacts with Avalanche Transit Time”

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

**Up-conversion:**

- **Signal frequency:**  $f_s$  (input)
- **Pump frequency:**  $f_p$  (much higher)
- **Output frequency:**  $f_o = f_p + f_s$
- **Energy transfer:** From pump to signal

- **Signal frequency:**  $f_s$  (input)

- **Pump frequency:**  $f_p$
- **Output frequency:**  $f_o = f_p - f_s$
- **Mixer operation:** Frequency translation

**Advantages:**

- **Low noise:** Quantum-limited performance
- **High gain:** 20-30 dB typical
- **Wide bandwidth:** Several GHz

**Mnemonic**

“Parametric Pump Provides frequency conversion Plus gain”

**Question 4(c) OR [7 marks]**

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

**Solution**

**Construction:**

- **Ruby crystal:**  $\text{Cr}^{3+}$  ions in  $\text{Al}_2\text{O}_3$  lattice
- **Magnetic field:** Strong DC magnetic field
- **Microwave cavity:** Resonant at signal frequency
- **Pump source:** High frequency klystron
- **Cryogenic cooling:** Liquid helium temperature

**Mermaid Diagram (Code)**

```
{Shaded}
{Highlighting}[]
graph LR
    A[Ruby Crystal] --{-}{-}{ B[Microwave Cavity]}
    C[Magnetic Field] --{-}{-}{ A}
    D[Pump Source] --{-}{-}{ B}
    E[Liquid Helium] --{-}{-}{ A}
    B --{-}{-}{ F[Amplified Output]}
{Highlighting}
{Shaded}
```

**Working Principle:**

- **Energy levels:**  $\text{Cr}^{3+}$  ions have three energy levels
- **Population inversion:** Pump creates more atoms in upper level
- **Stimulated emission:** Signal photons trigger emission
- **Coherent amplification:** Phase-coherent amplification

**Three-level system:**

- **Ground state:**  $E_1$  (most populated)
- **Intermediate state:**  $E_2$  (signal frequency)
- **Upper state:**  $E_3$  (pump frequency)

**Applications:**

- **Radio astronomy:** Ultra-low noise receivers
- **Satellite communication:** Ground station amplifiers
- **Deep space communication:** NASA tracking stations
- **Research:** Quantum electronics experiments

**Mnemonic**

“RUBY MASER Makes Amazingly Sensitive Electromagnetic Receivers”

Question 5(a) [3 marks]

Draw and explain the functional block diagram of MTI RADAR.

**Solution**

MTI RADAR detects **moving targets** by comparing **successive echoes** and canceling fixed targets.

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Transmitter] --> B[Duplexer]
    B --> C[Antenna]
    C --> B
    B --> D[Receiver]
    D --> E[Phase Detector]
    E --> F[STALO]
    F --> G[COHO]
    G --> E
    E --> H[Canceller]
    H --> I[Display]
```

Components:

- **STALO**: Stable Local Oscillator
- **COHO**: Coherent Oscillator
- **Phase detector**: Compares echo phases
- **Canceller**: Removes fixed target echoes

**Mnemonic**  
“MTI Makes Targets Intelligible by Motion”

Question 5(b) [4 marks]

Compare RADAR with SONAR.

**Solution**

Parameter	RADAR	SONAR
<b>Wave type</b>	Electromagnetic	Acoustic
<b>Medium</b>	Air/vacuum	Water
<b>Speed</b>	$3 \times 10^8 \text{ m/s}$	1500 m/s
<b>Frequency</b>	GHz	kHz
<b>Range</b>	100+ km	10-50 km
<b>Applications</b>	Air/space	Underwater

Common features:

- **Pulse-echo principle**
- **Range measurement**
- **Target detection**

**Mnemonic**  
“RADAR Radiates, SONAR Sounds”

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### Question 5(c) [7 marks]

Obtain the equation of maximum RADAR range. Explain the factors affecting the maximum radar range.

#### Solution

**RADAR Range Equation:**

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

Where:

- $P_t$ : Transmitter power (W)
- $G$ : Antenna gain (dimensionless)
- $\lambda$ : Wavelength (m)
- $\sigma$ : Target cross-section ( $m^2$ )
- $P_{\min}$ : Minimum detectable power (W)
- $L$ : System losses (dimensionless)

Derivation steps:

1. Power density at target:  $P_t / (4\pi R^2)$
1. Power intercepted:  $\sigma \times \text{Power density}$
1. Power at receiver:  $\text{Intercepted power} \times G / (4\pi R^2)$
1. Set equal to  $P_{\min}$  and solve for  $R$

**Factors Affecting Range:**

**Increase Range:**

- Higher transmitter power:  $R \propto P_t^{1/4}$
- Larger antenna gain:  $R \propto G^{1/2}$
- Larger target RCS:  $R \propto \sigma^{1/4}$
- Lower system losses:  $R \propto L^{-1/4}$

**Decrease Range:**

- Higher frequency:  $R \propto \lambda^{1/2}$
- Atmospheric losses: Absorption and scattering
- Ground clutter: Interfering reflections

#### Mnemonic

“RADAR Range Requires Robust Power and Proper Parameters”

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### Question 5(a) OR [3 marks]

Describe the Doppler effect in CW Doppler RADAR.

#### Solution

**Doppler Effect** causes **frequency shift** when target moves relative to RADAR.

**Doppler Frequency:**  $f_d = (2 \times V_r \times f_0) / c$

Where:

- $V_r$ : Radial velocity (m/s)
- $f_0$ : Transmitted frequency (Hz)
- $c$ : Speed of light ( $3 \times 10^8 m/s$ )

**Characteristics:**

- Approaching target:  $f_d$  positive
- Receding target:  $f_d$  negative
- Factor of 2: Due to two-way propagation

#### Mnemonic

“Doppler Detects Direction with Doubled frequency shift”

### Question 5(b) OR [4 marks]

Explain PPI Display method for RADAR

#### Solution

**PPI (Plan Position Indicator)** shows **top view** of RADAR coverage area with range and bearing information.

##### Display Features:

- **Circular screen:** Center represents RADAR location
- **Rotating trace:** Synchronized with antenna rotation
- **Range rings:** Concentric circles for distance
- **Bearing scale:** 0-360° around circumference

##### Operation:

- **Sweep rotation:** Matches antenna rotation
- **Echo intensity:** Controls brightness
- **Persistence:** Afterglow maintains target visibility
- **Range scale:** Selectable range settings

##### Applications:

- **Air traffic control:** Aircraft positioning
- **Marine navigation:** Ship and obstacle detection
- **Weather monitoring:** Storm tracking

#### Mnemonic

“PPI Provides Position Information Perfectly”

### Question 5(c) OR [7 marks]

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

#### Solution

##### Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Master Oscillator] --> B[Modulator]
    B --> C[Power Amplifier]
    C --> D[Duplexer]
    D --> E[Antenna]
    E --> D
    D --> F[RF Amplifier]
    F --> G[Mixer]
    H[Local Oscillator] --> G
    G --> I[IF Amplifier]
    I --> J[Detector]
    J --> K[Video Amplifier]
    K --> L[Display]
    A --> M[Timer]
    M --> B
    M --> L
{Highlighting}
{Shaded}
```

##### Working Principle:

###### Transmission:

- **Master oscillator:** Generates RF carrier
- **Modulator:** Creates short pulses
- **Power amplifier:** Amplifies pulse power
- **Duplexer:** Routes pulse to antenna

**Reception:**

- **Echo reception:** Antenna receives reflected signals
- **RF amplification:** Low noise amplification
- **Mixing:** Converts to intermediate frequency
- **IF amplification:** Further amplification
- **Detection:** Extracts video signal
- **Display:** Shows range vs amplitude

**Key Parameters:**

- **Pulse width:** Determines range resolution
- **PRF:** Pulse repetition frequency
- **Peak power:** Maximum range capability
- **Duty cycle:** Average power consideration

**Advantages:**

- **High peak power:** Long range capability
- **Good range resolution:** Narrow pulses
- **Simple processing:** Direct detection

**Mnemonic**

“Pulse RADAR Pulses Powerfully for Precise Position”

