Microwave and Radar Communication (4351103) - Winter 2024 Solution

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Question 1(a) [3 marks]

Give comparison between transmission line and waveguide.

Solution

Comparison:

Parameter	Transmission Line	Waveguide
Frequency Range	Low to medium frequencies	High frequencies (above 1 GHz)
Structure	Two or more conductors	Single hollow conductor
Propagation Mode	TEM mode	TE and TM modes
Power Handling	Limited power capacity	High power handling capability
Losses	Higher losses at high frequencies	Lower losses at microwave frequencies

Mnemonic

“”WAVES Travel Better” (Waveguides - Advanced Versions Enabling Superior Transmission)”

Question 1(b) [4 marks]

Define the following terms: (1) Lossless Line (2) VSWR (3) STUB (4) Reflection coefficient

Solution

Definitions:

- **Lossless Line**: A transmission line with zero resistance and conductance, having no power loss during signal transmission.
- **VSWR (Voltage Standing Wave Ratio)**: Ratio of maximum voltage to minimum voltage on a transmission line, indicating impedance mismatch.
- **STUB**: Short length of transmission line connected to main line for impedance matching purposes.
- **Reflection Coefficient**: Ratio of reflected wave amplitude to incident wave amplitude at any point on transmission line.

Mnemonic

“”Light Volumes Stay Reflected” (Lossless-VSWR-Stub-Reflection)”

Question 1(c) [7 marks]

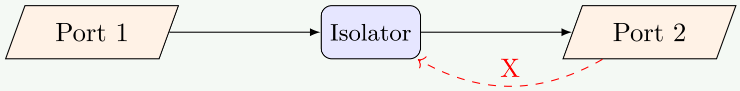
Explain isolator and circulator with the help of sketch.

Solution

Isolator:

1. **Function**: Allows signal flow in one direction only.
2. **Construction**: Uses ferrite material with magnetic bias.
3. **Applications**: Protects sources from reflections.

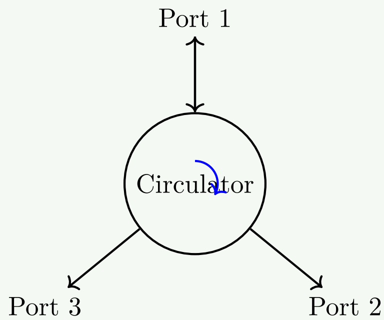
Figure 1. Isolator Symbol



Circulator:

1. **Function**: Routes signals in circular pattern between three or four ports.
2. **Construction**: Y-junction with ferrite material.
3. **Applications**: Duplexers in radar systems.

Figure 2. Circulator Symbol



Mnemonic

“”Isolated Circuits Flow Forward” (Isolator-Circulator-Forward-Flow)”

OR

Question 1(c) [7 marks]

What is dominant mode in a waveguide? What will be the cutoff wavelength for dominant mode, in a rectangular waveguide whose breadth is 10 cm? For a 2.5 GHz signal propagated through it calculate guide wavelength, group velocity and phase velocity and Z .

Solution

Dominant Mode: Lowest order mode that can propagate in a waveguide. For rectangular waveguide, it’s TE_{10} mode.

Given Data:

- Breadth (a) = 10 cm = 0.1 m
- Frequency (f) = 2.5 GHz = 2.5×10^9 Hz
- c = 3×10^8 m/s

Calculations:

Parameter	Formula	Value
Cutoff Wavelength	$\lambda_c = 2a$	$\lambda_c = 2 \times 0.1 = 0.2$ m
Free Space Wavelength	$\lambda_0 = c/f$	$\lambda_0 = 0.12$ m
Guide Wavelength	$\lambda_g = \frac{\lambda_0}{\sqrt{1-(\lambda_0/\lambda_c)^2}}$	$\lambda_g = 0.133$ m
Group Velocity	$v_g = c\sqrt{1-(\lambda_0/\lambda_c)^2}$	$v_g = 2.7 \times 10^8$ m/s
Phase Velocity	$v_p = \frac{c}{\sqrt{1-(\lambda_0/\lambda_c)^2}}$	$v_p = 3.33 \times 10^8$ m/s

Mnemonic

“”Dominant Modes Calculate Guide Parameters””

Question 2(a) [3 marks]

What is single stub impedance matching, and how does it work?

Solution

Single Stub Matching: Technique using one short-circuited or open-circuited stub connected in parallel to transmission line for impedance matching.

Working Principle:

- **Stub acts as reactive element** (inductive or capacitive).
- **Cancels reactive component** of load impedance.
- **Transforms impedance** to characteristic impedance.

Mnemonic

“”Single Stubs Transform Reactance” (Single-Stub-Transform-Reactive)”

Question 2(b) [4 marks]

Differentiate between rectangular and circular waveguide any three points.

Solution

Comparison:

Parameter	Rectangular Waveguide	Circular Waveguide
Cross-section	Rectangular shape	Circular shape
Dominant Mode	TE_{10} mode	TE_{11} mode
Field Pattern	Simple field distribution	Complex field distribution
Manufacturing	Easy to manufacture	Difficult to manufacture

Mnemonic

“”Rectangles Dominate Ten” vs ”Circles Dominate Eleven””

Question 2(c) [7 marks]

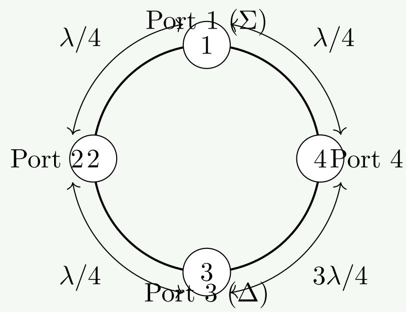
Explain the construction and working of Hybrid Ring with diagram.

Solution

Construction:

- **Ring structure** with four ports.
- **Circumference** = 1.5λ (one and half wavelengths).
- **Adjacent ports** separated by $\lambda/4$.
- **Opposite ports** separated by $3\lambda/4$.

Figure 3. Hybrid Ring (Rat-Race Coupler)



Working:

- **Power division**: Input at one port divides equally between two adjacent ports.
- **Isolation**: Opposite port receives no power.
- **Phase relationship**: 180° phase difference between output ports.

Applications: Balanced mixers, Power combiners/dividers, Antenna feeds.

Mnemonic

“”Hybrid Rings Divide Power Equally””

OR

Question 2(a) [3 marks]

What is Microwave? List out any four applications of microwave.

Solution

Microwave: Electromagnetic waves with frequency range from 1 GHz to 300 GHz.

Applications:

1. **Radar systems**: for detection and ranging.
2. **Satellite communication**: for long-distance transmission.
3. **Microwave ovens**: for heating food.
4. **Mobile communication**: (cellular networks).

Mnemonic

“”Microwaves Reach Space Mobile” (Microwave-Radar-Satellite-Mobile)”

OR

Question 2(b) [4 marks]

Write short note on cavity resonator.

Solution

Cavity Resonator: Closed metallic structure that confines electromagnetic energy at specific resonant frequencies.

Construction:

- **Metallic enclosure** of specific dimensions.
- **High Q factor** (low losses).
- **Resonant frequency** depends on cavity dimensions.

Types: Rectangular cavity, Cylindrical cavity, Spherical cavity.

Applications: Frequency meters, Oscillator circuits, Filter circuits.

Mnemonic

“”Cavities Resonate High Quality” (Cavity-Resonant-High-Q)”

OR

Question 2(c) [7 marks]

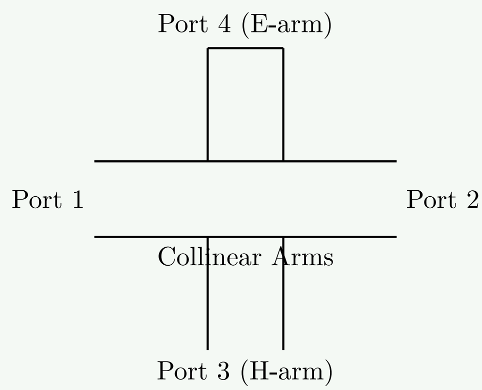
Explain MAGIC TEE with the help of sketch and how it works as an isolator?

Solution

Magic Tee Construction:

- **E-plane Tee** and **H-plane Tee** combined.
- **Four ports**: E-arm, H-arm, and two side arms (Collinear arms).
- **E-arm** perpendicular to H-arm.

Figure 4. Magic Tee



Working as Isolator:

- **Signal at E-arm**: Divides equally between side arms (in-phase).
- **Signal at H-arm**: Divides equally between side arms (out-of-phase).
- **Isolation**: Between E-arm and H-arm.
- **No coupling**: Between perpendicular arms.

Properties: Matched at all ports, Reciprocal device, Power division and isolation.

Mnemonic

“”Magic Isolates Perpendicular Arms””

Question 3(a) [3 marks]

Describe the working principle of MASER.

Solution

MASER (Microwave Amplification by Stimulated Emission of Radiation):

1. **Population Inversion**: Created in active medium.
2. **Stimulated Emission**: Produces coherent microwaves.
3. **Amplification**: Occurs through energy level transitions.

Working Principle: Atoms excited to higher energy levels -> Stimulated photons trigger emission -> Coherent amplification of microwave signals.

Mnemonic

“”Microwaves Amplify Stimulated Emission Radiation””

Question 3(b) [4 marks]

List four microwave diodes and explain any one.

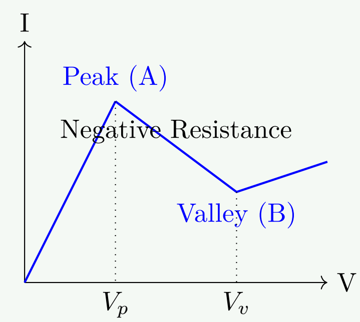
Solution

Four Microwave Diodes: 1. GUNN Diode, 2. IMPATT Diode, 3. TRAPATT Diode, 4. PIN Diode.

GUNN Diode:

- **Principle**: Transferred electron effect in GaAs.
- **Construction**: N-type GaAs with ohmic contacts.
- **Operation**: Negative resistance at microwave frequencies.
- **Applications**: Oscillators, amplifiers.

Figure 5. Gunn Diode I-V Characteristics



Mnemonic

“”GUNN Generates Negative Resistance””

Question 3(c) [7 marks]

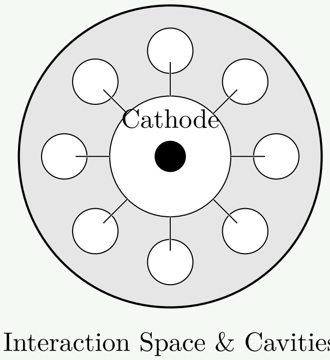
Write a detailed explanation of the Magnetron Oscillator, covering its construction, working principle, and applications?

Solution

Construction:

- **Cylindrical cathode** at center.
- **Anode with resonant cavities** surrounding cathode.
- **Strong magnetic field** perpendicular to electric field.
- **Output coupling** through waveguide.

Figure 6. Magnetron Construction



Working Principle:

- Electrons emitted from heated cathode.
- **Cycloid motion** due to crossed E and B fields.
- **Bunching effect** creates electron clouds.
- Energy transfer from electrons to RF field.
- Oscillation at cavity resonant frequency.

Applications: Radar transmitters, Microwave ovens, Industrial heating.

Mnemonic

“”Magnetrons Make Microwave Oscillations””

OR

Question 3(a) [3 marks]

Describe the working of RUBY MASER.

Solution

Ruby MASER Working:

- **Ruby crystal** (Al_2O_3 with Cr^{3+} ions) as active medium.
- **Three energy levels** in chromium ions.
- **Pump frequency** creates population inversion.
- **Signal amplification** at 2.9 GHz.

Process: Optical pumping excites electrons to higher level -> Stimulated emission produces coherent microwaves -> Low noise amplification achieved.

Mnemonic

“”Ruby Radiates Amplified Microwaves””

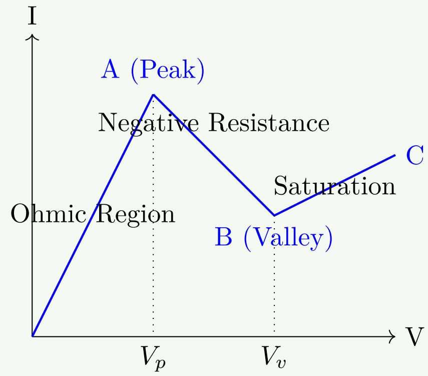
OR

Question 3(b) [4 marks]

Draw and explain the VI characteristic of Gun diode

Solution

Figure 7. Gunn Diode I-V Characteristics



Explanation:

- **Region OA**: Ohmic region (positive resistance).
- **Region AB**: Negative resistance region.
- **Region BC**: Valley current region.
- **Region CD**: Saturation region.

Key Points:

- **Peak voltage**: Maximum voltage before negative resistance.
- **Valley current**: Minimum current in negative resistance region.
- **Negative resistance**: Current decreases with increasing voltage.

Mnemonic

“”Valley Peak Negative Resistance””

OR

Question 3(c) [7 marks]

Explain ”frequency measurement method” as well as ”attenuation measurement method” at microwave frequency.

Solution

Frequency Measurement Methods:

Method	Principle	Accuracy
Cavity Wavemeter	Resonant cavity tuning	High
Direct Reading Meter	Frequency counter	Very High
Heterodyne Method	Beat frequency technique	Medium

Attenuation Measurement Methods:

Method	Description	Applicati
Substitution Method	Replace attenuator with calibrated attenuator	Precision r
Power Ratio Method	Compare input and output power	General pu
RF Bridge Method	Balance bridge circuit	Laboratory

Setup for Measurement:

- **Signal generator** provides test signal.

- **Calibrated attenuator** for reference.
- **Power meter** measures signal levels.
- **VSWR meter** monitors impedance matching.

Mnemonic

“”Frequency Attenuation Measured Precisely””

Question 4(a) [3 marks]

Explain working of P-i-N diode.

Solution

Structure: P-type region (heavily doped), Intrinsic region (undoped, high resistance), N-type region (heavily doped).

Working:

- **Forward bias**: Low resistance, acts as conductor.
- **Reverse bias**: High resistance, acts as insulator.
- **RF switching**: Fast switching due to charge storage.

Applications: RF switches, Attenuators, Phase shifters.

Mnemonic

“”PIN Provides Instant Switching””

Question 4(b) [4 marks]

Explain π mode oscillations for magnetron.

Solution

π Mode Oscillation:

- **Adjacent cavities** oscillate 180° out of phase.
- **Electron bunching** synchronized with RF field.
- **Maximum power transfer** from electrons to RF.
- **Stable oscillation** at designed frequency.

Mode Chart:

Cavity: 1 — 2 — 3 — 4 — 5 — 6 — 7 — 8
Phase: $0 — \pi — 0 — \pi — 0 — \pi — 0 — \pi$

Mnemonic

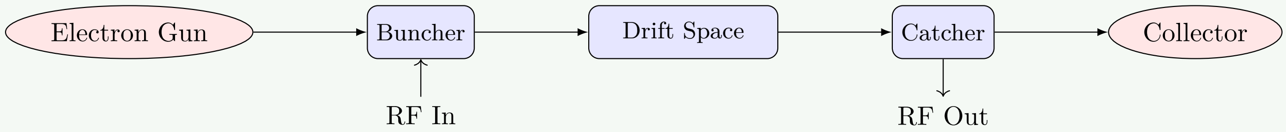
“”Pi Mode Produces Maximum Power””

Question 4(c) [7 marks]

Explain the construction and working of two cavity klystron amplifiers with necessary diagram.

Solution

Figure 8. Two Cavity Klystron



Construction:

- **Electron gun** produces electron beam.
- **Input cavity** (buncher) modulates electron beam.
- **Drift space** allows velocity modulation.
- **Output cavity** (catcher) extracts RF energy.
- **Collector** collects spent electrons.

Working Principle: Velocity modulation in input cavity -> Electron bunching in drift space -> Density modulation creates current variation -> Energy extraction in output cavity -> Amplification.

Mnemonic

“”Klystrons Amplify Through Bunching””

OR

Question 4(a) [3 marks]

Explain parametric amplifier.

Solution

Parametric Amplifier:

- **Variable reactance** device using varactor diode.
- **Pump frequency** modulates diode capacitance.
- **Energy transfer** from pump to signal.
- **Low noise amplification** achieved.

Working: Pump power varies diode reactance -> Signal mixing produces sum and difference frequencies -> Idler frequency $f_p = f_s + f_i$ -> Power gain through nonlinear mixing.

Mnemonic

“”Parametric Amplifiers Pump Low Noise””

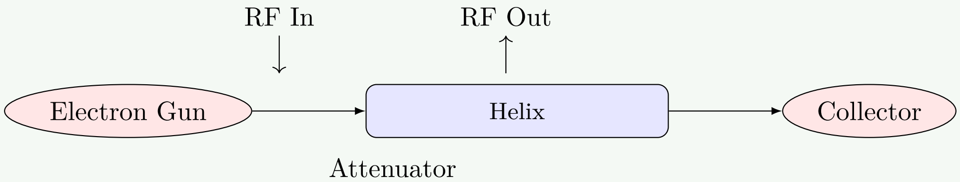
OR

Question 4(b) [4 marks]

Draw and explain schematic diagram of travelling wave tube with necessary notation

Solution

Figure 9. Traveling Wave Tube



Working:

- **Electron beam** travels through helix center.
- **RF signal** propagates along helix.
- **Synchronism** between beam and RF wave.
- **Energy transfer** from beam to RF.
- **Continuous amplification** along helix length.

Mnemonic

“”TWT Travels With Waves””

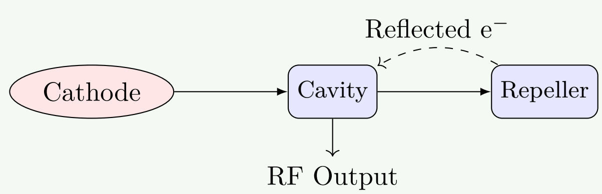
OR

Question 4(c) [7 marks]

Explain the working principle of a reflex klystron in detail with suitable diagram.

Solution

Figure 10. Reflex Klystron Schematic



Working Principle:

1. **Electrons enter cavity** and get velocity modulated.
2. **Electrons drift** toward repeller.
3. **Repeller reflects** electrons back to cavity.
4. **Transit time** determines bunching phase.
5. **Bunched electrons** deliver energy to cavity.
6. **Oscillation maintained** through feedback.

Applications: Local oscillators, Frequency meters, Microwave sources.

Mnemonic

“”Reflex Returns Electron Bunches””

Question 5(a) [3 marks]

”PIN diode acts as a switch and VARACTOR diode acts as a variable capacitor” explain.

Solution

PIN Diode as Switch:

- **Forward bias**: Low resistance ($\sim 1\Omega$), switch ON.
- **Reverse bias**: High resistance ($\sim 10k\Omega$), switch OFF.
- **Fast switching** due to charge storage in I-region.
- **RF isolation** in OFF state.

VARACTOR Diode as Variable Capacitor:

- **Reverse bias voltage** controls junction capacitance.
- **Capacitance decreases** with increasing reverse voltage ($C \propto V^{-n}$).
- **Voltage-controlled reactance** for tuning circuits.
- **Electronic tuning** without mechanical adjustment.

Mnemonic

“”PIN Switches, VARACTOR Varies””

Question 5(b) [4 marks]

List the display methods used in RADAR and explain any one.

Solution

RADAR Display Methods: 1. A-Scope Display, 2. PPI (Plan Position Indicator), 3. B-Scope Display, 4. RHI (Range Height Indicator).

PPI Display Explanation:

- **Circular display** showing target positions.
- **Center represents** radar location.
- **Radial distance** indicates target range.
- **Angular position** shows target bearing.
- **Rotating sweep** synchronized with antenna rotation.

Features: Real-time display, Range and bearing info, Multiple target tracking.

Mnemonic

“”PPI Pictures Position Indicators””

Question 5(c) [7 marks]

What is radar? List out the different types of radar systems? Explain any One of radar in detail?

Solution

RADAR (Radio Detection And Ranging): System using radio waves to detect objects and determine their range, velocity, and characteristics.

Types of RADAR Systems:

Type	Application	Frequency Band
Pulse Radar	Air traffic control	L, S, C bands
CW Doppler Radar	Speed measurement	X, K, Ka bands
MTI Radar	Moving target detection	S, C bands
SAR Radar	Ground mapping	L, C, X bands

Pulse Radar Detailed Explanation:

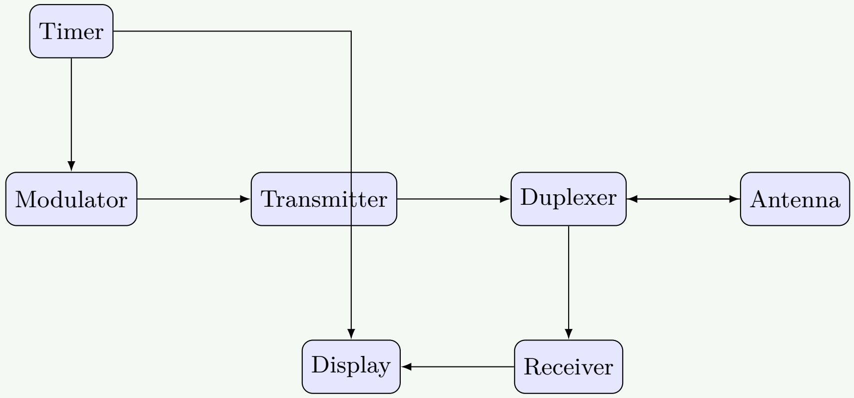


Figure 11. Pulse Radar Block Diagram

Working:
- **Transmits short pulses** of RF energy.
- **Receives echoes** from targets.
- **Measures time delay** for range calculation.
- **Processes signals** for display.

Range Equation: $R = (c \times t)/2$.

OR

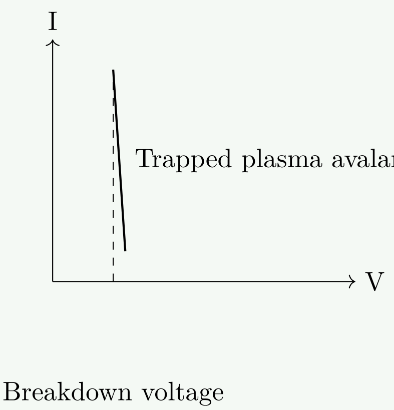
Question 5(a) [3 marks]

Describe the operation of TRAPATT diode with diagram.

Solution

TRAPATT Operation:
- **TRApped Plasma Avalanche Triggered Transit** diode.
- **High field region** creates avalanche breakdown.
- **Plasma formation** traps charge carriers.
- **Transit time effects** create negative resistance.
- **Oscillation frequency** determined by transit time.

Figure 12. TRAPATT Diode Operation



Applications: High power oscillators, Radar transmitters, Communication systems.

Mnemonic

“”TRAPATT Traps Plasma Avalanche””

OR

Question 5(b) [4 marks]

Compare RADAR with SONAR.

Solution

Comparison:

Parameter	RADAR	SONAR
Wave Type	Electromagnetic waves	Sound waves
Medium	Air/vacuum	Water/liquid
Frequency	GHz range	kHz range
Speed	3×10^8 m/s	1500 m/s in water
Range	Very long range	Limited by absorption
Applications	Air/space detection	Underwater detection

Similarities: Echo principle for detection, Range measurement using time delay, Doppler effect for velocity measurement.

Mnemonic

“”RADAR Radiates, SONAR Sounds””

OR

Question 5(c) [7 marks]

Obtain the equation for maximum radar range.

Solution

RADAR Range Equation Derivation:

1. **Power Transmitted:** P_t
2. **Power Density at Target:**

$$P_d = \frac{P_t}{4\pi R^2}$$

3. **Power Intercepted by Target:**

$$P_i = P_d \times \sigma = \frac{P_t \times \sigma}{4\pi R^2}$$

4. **Power Returned to Radar:**

$$P_r = \frac{P_i}{4\pi R^2} = \frac{P_t \times \sigma}{(4\pi R^2)^2}$$

5. **Power Received:**

$$P_r = \frac{P_t \times G^2 \times \lambda^2 \times \sigma}{(4\pi)^3 \times R^4}$$

Maximum Range Equation:

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

Where:

- P_t = Transmitted power
- G = Antenna gain
- λ = Wavelength
- σ = Radar cross section
- $P_{r_{min}}$ = Minimum detectable signal
- R = Range

Factors Affecting Range: Transmitted power, Antenna gain, Target cross-section, Frequency, Receiver sensitivity.

Mnemonic

“”Power Gain Lambda Sigma Range””