Batch 2
SET C

SRM Institute of Science and Technology
College of Engineering and Technology
DEPARTMENT OF ECE

SRM Nagar, Kattankulathur – 603203, Chengalpattu District, Tamilnadu

Academic Year: 2024-2025 (EVEN)

Test: FT III **Date: 07.04.2025**
Course Code & Title: 21ECC304TR Microwave and Optical Communication **Duration: 12.30 pm – 02.15pm**
Year & Sem.: III & VI **Max. Marks: 50**

Course Articulation Matrix:

	21ECC304TR - Microwave & Optical Communication	**Program Outcomes (POs)**														
		Graduate Attributes												**PSO**		
COs	**Course Outcomes (COs)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1	Familiarize the concept of microwave transmission and generation	3	2	-	-	-	-	-	-	-	-	-	-	3	-	-
2	Realize systematic methods to design, analyze S-parameters of microwave devices	3	2	-	-	-	-	-	-	-	-	-	-	3	-	-
3	Identify different measurement techniques for determining various parameters and to gain knowledge on microwave measurements and the techniques with associated equipment	2	-	-	3	-	-	-	-	-	-	-	-	3	-	-
4	Discover complete information on the fundamentals of light transmission through fiber and their characterization and mechanism	3	2	-	-	-	-	-	-	-	-	-	-	3	-	-
5	Recognize the link power budget design considerations of optical communication system	3	-	2	-	-	-	-	-	-	-	-	-	-	2	

Part – A (1x20 = 20 Marks) Answer all the questions					
Q. No.	**Question**	**Marks**	**BL**	**CO**	**PO**
1 (a)	(i)A microwave oven magnetron is modified by increasing its anode voltage significantly. What is the most likely effect of this modification? a) The frequency of oscillation decreases b) The electrons stop following a circular path c) The output power increases but efficiency may reduce d) The magnetron stops oscillating Solution: (c) The output power increases but efficiency may reduce	1	2	1	1
	(ii)A student is testing a semiconductor device and notices that when the voltage is increased beyond a certain point, the current decreases instead of increasing. Which device is the student likely testing? a) Gunn diodeb) Tunnel diodec) Magnetrond) Reflex klystron Solution: (b) Tunnel diode	1	2	1	1
	iii) A microwave amplifier is experiencing unwanted reflections that reduce its efficiency. Which of the following components can be added to solve this issue? a) Directional couplerb) Isolatorc) Attenuatord) Phase shifter Solution: (b) Isolator	1	1	2	1

<table>
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<td>iv) A microwave engineer is analyzing a two-port network with an input at Port 1 and output at Port 2. If S_{21} is close to zero, what does this indicate?
a) The network has high insertion loss
b) The network is reciprocal
c) The network is highly efficient
d) The network is lossless
Solution: (a) The network has high insertion loss</td>
<td>1</td>
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<td>i) A defense research organization is designing a high-power microwave transmitter for a long-range radar system. The chosen microwave source must generate stable, high-power pulses while operating efficiently at high frequencies. The selected device utilizes crossed electric and magnetic fields to produce oscillations without requiring an external resonator.
(a) Explain the working principle of this microwave source and its advantage in high-power radar applications.(5 Marks)
Magnetron: Working Principle
The described microwave source is a magnetron, a vacuum tube that generates high-power microwaves using crossed electric and magnetic fields. Electrons emitted from a central cathode spiral outward under the influence of these fields, interacting with resonant cavities in the anode to produce microwave oscillations. The magnetron operates efficiently at high frequencies without needing an external resonator, making it compact and reliable. Its ability to generate short, high-power pulses with high efficiency makes it ideal for long-range radar systems, ensuring strong signal transmission and target detection. 3 marks

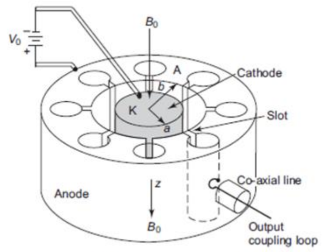
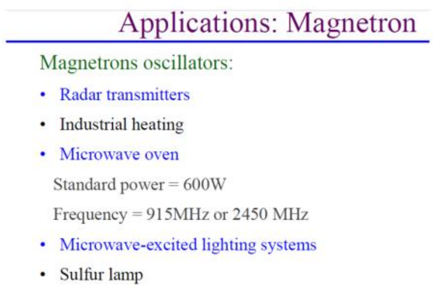


Fig. 9.23 Basic magnetron oscillator

Application


2 marks

(b) If the device operates at 3 GHz with an anode voltage of 40 kV and an efficiency of 70%, determine the output power if the input DC power is 1 MW.(3 Marks)
$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$
(1 mark)

Efficiency=700KW (2marks)</td>
<td>8</td>
<td>3</td>
<td>1</td>
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<td>ii) (a) The input power to the sum arm of an ideal matched magic-T is 1W. Find the output powers from the other arms when matched terminated.. (3 Marks)
Power Distribution:
1. Port 1 (Sum Arm): Input power = 1W
2. Port 2 (Difference Arm): Output power = 0W (due to symmetry)
3. Port 3 (Co-Linear Arm 1): Output power = 0.5W
4. Port 4 (Co-Linear Arm 2): Output power = 0.5W

P1=0.5W;P2=0.5W;P4=0W (each 1mark)</td>
<td>8</td>
<td>3</td>
<td>2</td>
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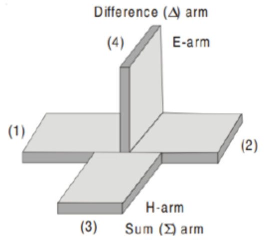
(b) A satellite ground station requires a microwave junction to combine and split signals for efficient transmission and reception. The chosen device must allow for both sum and difference signal processing, ensuring proper signal distribution in a phased-array system. Analyze the device characteristics with suitable diagram (5 Marks)



$$[S] = \begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 & 0 \end{bmatrix}$$

Magic Tee Diagram (2 marks)

Device characteristics

These devices efficiently combine and split signals, supporting both sum and difference processing, which is crucial in phased-array systems for beamforming and signal routing. The magic-T consists of a **sum port**, a **difference port**, and two **side ports**, ensuring that in-phase signals combine at the sum port, while out-of-phase signals combine at the difference port. This enables effective transmission and reception while minimizing interference.(3 marks)

Part – B (2 x 15 = 30 Marks)
Instructions: Answer any two out of three questions

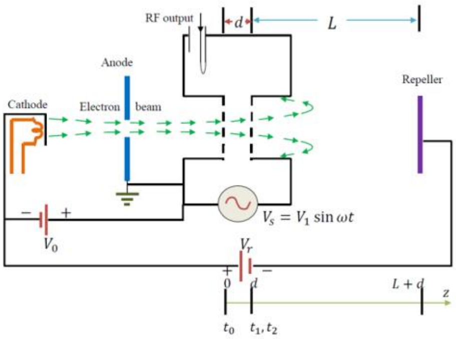
2 (a) A defense research laboratory is developing a compact microwave transmitter for airborne electronic warfare applications. The system requires a stable frequency source capable of producing microwaves through velocity modulation, ensuring efficient signal generation in a lightweight design.

i) Explain the working mechanism of this device and its specific applications. (6 Marks)

Marks	CO	BL	PO
8	3	1	2
7	3	1	2

Klystron mechanism

The ideal microwave source for this application is a **klystron** or a **traveling wave tube (TWT)**, both of which operate based on **velocity modulation** to generate high-power microwaves efficiently. In a **klystron**, an electron beam is emitted from a cathode and accelerated through a series of resonant cavities. The first cavity modulates the velocity of electrons, causing them to bunch together as they travel through drift space. These electron bunches then pass through an output cavity, where their kinetic energy is converted into amplified microwave energy. **TWTs**, on the other hand, use a slow-wave structure to continuously interact with the electron beam, allowing for broadband amplification. These devices are lightweight, stable, and efficient, making them ideal for airborne electronic warfare applications requiring high-power, stable microwave signals.



(4 marks)

	Applications: ## Applications: Klystron Amplifiers **As power output tubes** • In UHF TV transmitters • In troposphere scatter transmitters • In satellite communication ground station • In Radar transmitters • Global Resource Corporation (GRC) - to convert the hydrocarbons in daily materials, coal, automotive waste, diesel fuel, and oil sands into natural gas. • Bio-medical applications 2marks ii) If the repeller voltage is set to -600V, and the electron path length is 1.5 mm, estimate the electron transit time in nanoseconds(3marks) $v = \sqrt{\frac{2e\|V\|}{m}}$ $t = \frac{d}{v}$ $v = \sqrt{\frac{2(1.602 \times 10^{-19}\ \mathrm{C})(600\ \mathrm{V})}{9.109 \times 10^{-31}\ \mathrm{kg}}}$ $d = 1.5 \times 10^{-3}$ m and $v \approx 1.45 \times 10^{7}$ m/s: $t = \frac{1.5 \times 10^{-3}}{1.4527 \times 10^{7}}$ t=d/v=0.103 ns. Formula 1 mark Calculation 2marks				
2 (b)	During an experiment, it is observed that reducing the repeller voltage increases the transit time of electrons. Analyze and explain how this change impacts the operating frequency of the microwave source and its overall performance in radar applications. (7 Marks) **1. Effect of Repeller Voltage on Electron Transit Time** The repeller voltage in a reflex klystron controls the motion of electrons by reflecting them back towards the cavity gap. A more negative repeller voltage increases the electric field strength, leading to faster electron turnaround, thereby reducing transit time. Conversely, a less negative repeller voltage weakens the repulsion, causing longer transit times. (3marks) **2. Impact on Operating Frequency** The frequency of oscillation in a reflex klystron is determined by the bunching condition, which depends on the electron transit time. Since microwave oscillations rely on constructive interference from electron bunches returning to the cavity at the correct phase, increasing the transit time shifts the phase relationship. A longer transit time means electrons take more time to return, reducing the effective resonant frequency of oscillation. $f = \frac{1}{T_{\text{transit}}}$ where T_{transit} is the electron transit time. When transit time increases due to lower repeller voltage, the operating frequency decreases. (3marks) **3. Performance Impact on Radar Applications**				

	Frequency Drift: Lower repeller voltage results in a lower microwave frequency, which may shift the output frequency of the radar transmitter. Reduced Stability: Reflex klystrons are used in some radar systems for local oscillators and signal sources. A frequency shift affects radar signal coherence, reducing target resolution. Tuning Mechanism: In practical applications, controlled repeller voltage tuning is used for frequency modulation (FM) in radar to adjust the transmitted signal. (1 mark)				
3 (a) 3 (b)	i) A satellite communication system requires a power monitoring setup to ensure efficient transmission and reception of signals. The selected device samples a small fraction of the transmitted power for measurement while allowing the main signal to continue with minimal loss Explain the working principle of this device. (5 Marks) **Directional coupler working principle** The ideal device for this application is a **directional coupler**, which samples a small fraction of the transmitted power while allowing the main signal to pass with minimal loss. A directional coupler consists of a main transmission line and a secondary coupled line, positioned close enough to allow electromagnetic coupling. When a signal travels through the main line, a small, proportional amount of power is coupled into the secondary line, which can be measured without significantly affecting the primary signal. This ensures real-time power monitoring for system diagnostics, efficiency optimization, and protection against signal anomalies in satellite communication systems. Additionally, directional couplers provide high isolation between forward and reverse signals, enabling accurate power measurement in both transmission and reception paths. (3 marks) **Port 1 (Input Port)** – The main signal is applied here. **Port 2 (Output Port or Through Port)** – The majority of the signal exits here with minimal loss. **Port 3 (Coupled Port or Auxiliary Port)** – A small fraction of the input power is coupled here. **Port 4 (Isolated Port or Termination Port)** – Ideally receives no power, ensuring high isolation. (2marks) ii) If the input power is 80 W, and the coupling factor is 10 dB, determine the power coupled to the auxiliary port. (3 Marks) $P_{\text{coupled}} = P_{\text{input}} \times 10^{-\frac{\text{Coupling Factor}}{10}}$ =8W Formula 1 mark calculation 2 mark How would you characterize the signal flow and isolation between the input, coupled, and isolated ports of a above microwave device, given its scattering parameters? (7marks)	8 7	3 2	2 2	1 1

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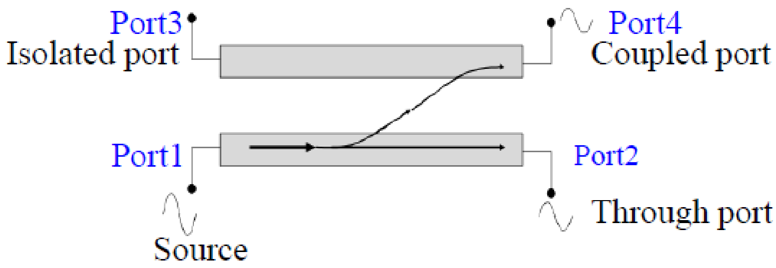

The S matrix of a directional coupler is reduced to

$$S = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jq & 0 & p & 0 \end{bmatrix}$$

The signal flow and isolation in a **directional coupler** can be characterized using its **scattering parameters (S-parameters)**, which describe how power is transmitted and reflected between its four ports with performance parameters:Directivity, coupling factor 4 marks

$$C = 10 \log \frac{P_1}{P_4} = -20 \log |S_{41}|$$

$$D = 10 \log \frac{P_4}{P_3} = 20 \log \frac{|S_{41}|}{|S_{31}|} = 20 \log \frac{|S_{41}|}{|S_{42}|}$$

$$T = 10 \log P_1/P_2 = 20 \log |S_{21}|$$

Scattering matrix 2 marks
Diagram 2 marks
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(a)</td>
<td>
(i)Identify the semiconductor device that exhibits a negative differential resistance region in its current-voltage characteristic. Explain its key characteristics and how this property enables signal oscillation and amplification in microwave applications. (6 Marks)

The **semiconductor device** that exhibits a negative differential resistance region in its current-voltage (I-V) characteristic is the **Tunnel Diode**.

Key Characteristics of the Tunnel Diode:

1. **Very High Doping Levels**: Tunnel diodes have extremely high doping concentrations in both the p-type and n-type regions, leading to a very narrow depletion region. This allows for quantum tunneling, which is the key to their negative resistance behavior.
2. **Negative Differential Resistance**: In the I-V characteristic, after a certain voltage threshold, the current decreases with increasing voltage, which results in a region where the differential resistance is negative. This is due to quantum tunneling where electrons "tunnel" through the potential barrier at low voltages.
3. **Fast Switching**: Tunnel diodes exhibit very fast switching times, typically in the picosecond range, which makes them ideal for high-frequency applications.
4. **High Operating Frequency**: Tunnel diodes are capable of operating at microwave frequencies, making them suitable for high-speed, high-frequency applications.
</td>
<td>8

7</td>
<td>3

3</td>
<td>1

2</td>
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1</td>
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Oscillation: The negative differential resistance region enables **self-sustained oscillations** in oscillator circuits. When used in an appropriate feedback configuration, a tunnel diode can create a continuous oscillation without requiring an external signal source. The device's ability to amplify small signals at high frequencies makes it useful in microwave oscillators.

Amplification: The negative resistance allows for the amplification of signals because the diode can "invert" the input signal, providing the necessary energy to maintain oscillations or amplify signals in microwave circuits. The behavior of the tunnel diode can also be used in mixers and amplifiers, where the negative resistance compensates for losses and amplifies weak signals.(4marks)

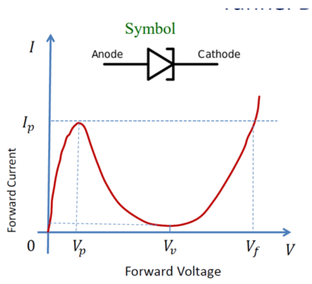


Diagram 2marks

ii) A semiconductor device exhibits a unique current-voltage characteristic, with a peak current of 3 mA at a forward voltage of 0.07 V and a valley current of 0.8 mA at a voltage of 0.2 V. Determine the peak-to-valley current ratio (PVCR) of this device.

$$\text{PVCR} = \frac{3\,\text{mA}}{0.8\,\text{mA}} = 3.75$$

(2 Marks)

4 (b)

A four-port microwave device is required to route signals between different ports in a specific sequence, while isolating them from other ports. Explain the working principle of this device and its applications. (7 Marks)

The device that fits this description is a Circulator.
Working Principle
A circulator is a four-port passive microwave component that routes signals between different ports in a specific sequence, while isolating them from other ports. It works by using a magnetic field to rotate the signal path, ensuring that signals entering one port exit through the next port in sequence.(2marks)

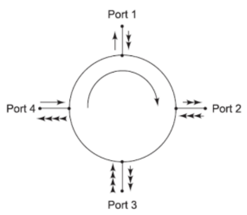
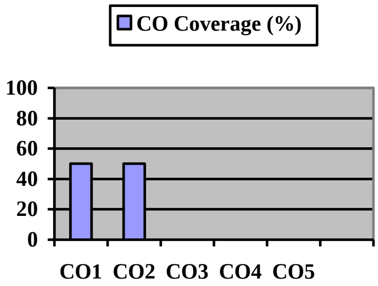
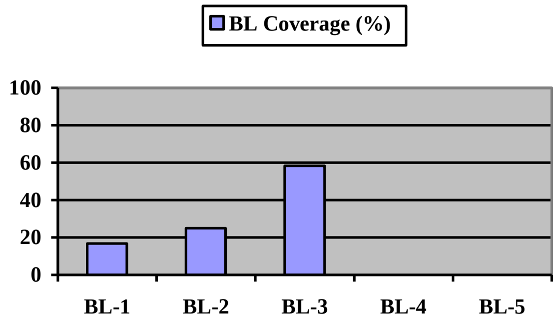


Diagram (2marks)

Applications
Circulators have several applications:
- Duplexing: Circulators are used to separate transmit and receive signals in radar and communication systems.
- Isolation: Circulators provide isolation between ports, preventing signals from interfering with each other.
- Signal routing: Circulators are used to route signals between different ports in a specific sequence.
- Antenna systems: Circulators are used in antenna systems to separate transmit and receive signals.(3marks)

Course Outcome (CO) and Bloom's level (BL) Coverage in Questions





Evaluation Sheet

Name of the Student: **Register No.:**

<table>
<tr><th colspan="7">Part- A (1 x 20= 20 Marks)</th></tr>
<tr><th colspan="2">Q. No.</th><th>CO</th><th>PO</th><th>Maximum Marks</th><th>Marks Obtained</th><th>Total</th></tr>
<tr><td rowspan="4">1(a)</td><td>i</td><td>CO1</td><td>1</td><td>1</td><td></td><td rowspan="6"></td></tr>
<tr><td>ii</td><td>CO1</td><td>1</td><td>1</td><td></td></tr>
<tr><td>iii</td><td>CO2</td><td>1</td><td>1</td><td></td></tr>
<tr><td>iv</td><td>CO2</td><td>1</td><td>1</td><td></td></tr>
<tr><td rowspan="2">1b)</td><td>i</td><td>CO1</td><td>2</td><td>8</td><td></td></tr>
<tr><td>ii</td><td>CO2</td><td>2</td><td>8</td><td></td></tr>
<tr><th colspan="7">Part- B (2 x 15= 30 Marks)</th></tr>
<tr><td colspan="2">2(a)</td><td>CO1</td><td>2</td><td>8</td><td></td><td rowspan="2"></td></tr>
<tr><td colspan="2">2(b)</td><td>CO1</td><td>2</td><td>7</td><td></td></tr>
<tr><td colspan="2">3(a)</td><td>CO2</td><td>1</td><td>8</td><td></td><td rowspan="2"></td></tr>
<tr><td colspan="2">3(b)</td><td>CO2</td><td>1</td><td>7</td><td></td></tr>
<tr><td colspan="2">4(a)</td><td>CO2</td><td>1</td><td>8</td><td></td><td rowspan="2"></td></tr>
<tr><td colspan="2">4(b)</td><td>CO2</td><td>2</td><td>7</td><td></td></tr>
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Consolidated Marks:

CO	Maximum Marks	Marks Obtained
CO1	33	
CO2	32	
Total	65	

PO	Maximum Marks	Marks Obtained
PO1	34	
PO2	31	
Total	65	

Signature of Course Teacher

Signature of the Course Coordinator **Signature of the Academic Advisor**