Batch 1
SET A

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)

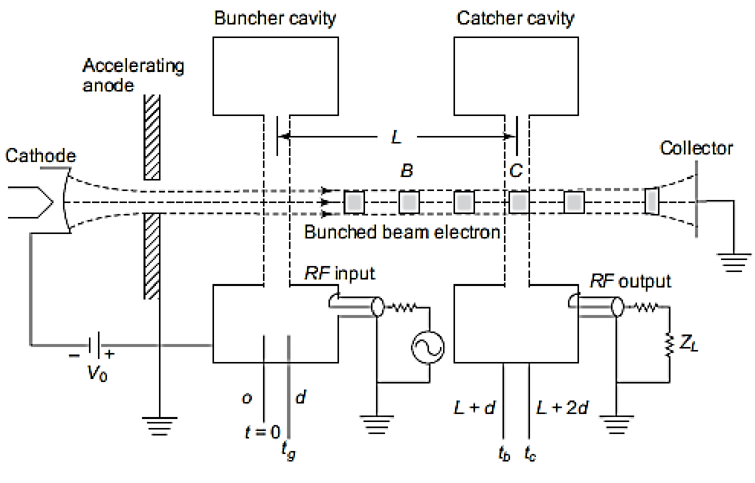
Test: FT III | **Date: 07.04.2025**
Course Code & Title: 21ECC304TR Microwave and Optical Communication | **Duration: 08:00 am – 09:40 am**
Year & Sem.: III & VI | **Max. Marks: 50**

Answer Key

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) TRAPATT diodes differ from IMPATT diodes in that they: **a) Operate at higher efficiency and lower breakdown voltage** b) Operate at lower efficiency and higher breakdown voltage c) Have a lower carrier concentration d) Use quantum well structures for operation	1	2	1	1
	ii) The main principle behind the operation of a tunnel diode is: a) Avalanche Breakdown **b) Negative Differential Resistance due to Quantum Tunneling** c) Thermal Ionization d) Charge Storage Effect	1	2	1	1
	iii) Which material is commonly used in microwave isolators for non-reciprocal behavior? **a) Ferrite** b) Silicon c) GaAs d) Copper	1	1	2	1
	iv) Which type of attenuator provides constant attenuation over a wide frequency range? a) Waveguide variable attenuator **b) Resistive pad attenuator** c) PIN diode attenuator d) Ferrite-based attenuator	1	1	2	1

1 (b)	i) A space agency is developing a deep-space communication system that requires a high-power RF amplifier to enhance weak signals received from a distant probe. The chosen technology relies on velocity modulation to amplify microwave signals efficiently. (a) Explain the working principle behind the amplification process and its significance in space communication. (6 Marks) **<u>Two-cavity Klystron Amplifier</u>** A high velocity electron beam produced by the accelerating anode is successively passed through an input reentrant cavity resonator (buncher cavity) grid, a field free drift space of length L, an output re-entrant cavity resonator (catcher cavity) grid and finally collected by a collector electrode. The electron beam is focused to travel axially without spreading during transit by applying an axial magnetic field produced by an external coil current. The input RF signal to be amplified excites the buncher cavity with a coupling loop. The combination of the anode voltage V0 and the cavity gap width d are such that the transit of electrons through each cavity gap is less than the quarter of the time period T of the input signal cycle. (2 marks)  (1 Mark) The electrons passing through the buncher grids are accelerated/retarded/passed through with unchanged initial dc velocity depending upon when they encounter the RF signal field at the buncher cavity gap at positive/negative/zero crossing phase of the cycle, respectively. Thus, the electron beam is velocity modulated to form bunches or undergoes density modulation in accordance with the input RF signal cycle. While passing through the catcher cavity grid, this density modulated electron beam induces RF current in the output cavity and thereby excites the RF field in the output cavity at input signal cycle. The phase of field in the output cavity is opposite to that of the input cavity so that the bunched electrons are retarded by the output gap voltage. The loss of kinetic energy of the electrons on retardation process transfers RF energy to the output cavity continuously at signal cycle. The amplitude of the signal at output cavity attains a steady large value when the loss of kinetic energy of the bunched electrons compensates the output cavity circuit losses. The amplified signal is coupled out from the catcher cavity through a current loop to the load. (3 marks)	8	3	1	2

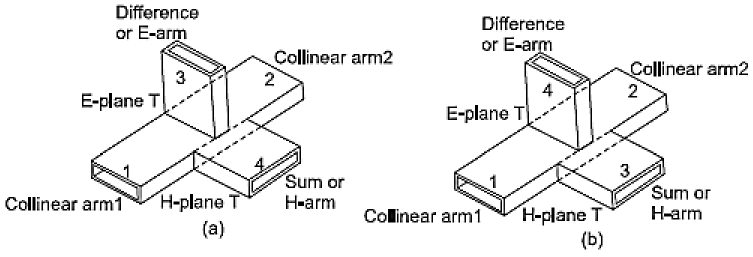
<table>
<tr><td></td><td>(b) The system operates at 9 GHz with an input power of 50 mW and a power gain of 30 dB. Determine the output power. (2 Marks)
$P_{out} = P_{in} \times 10^{G_{dB}/10}$ (1 mark)
P_{out} = 50 Watts (1 mark)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>ii) (a) If an input power of 40 W is applied, and it splits into two outputs maintaining equal phase but different magnitudes (3:1 ratio), determine the power at each output port. (2 Marks)
power Splitter:
power divider
$R = \frac{P1}{P2}$
$Pin = P1 + P2$
$P1 = \frac{R}{R+1} \times Pin$
$P2 = \frac{1}{R+1} \cdot Pin$ (1 mark)
given
$Pin = 40\,W$
Power ratio $R = 3:1$
∴ Substitute the values
$\boxed{P1 = 30W \ \& \ P2 = 10W}$
(1 mark)
(b) A waveguide junction exhibits different power-splitting behavior depending on the orientation of the incident wave. Derive the S parameter of the mentioned device. (6 Marks)
<u>Magic Tee (Hybrid Tee)</u>
A hybrid TEE is formed with the combination of the E-plane and H-plane tees and is called a magic-T.


Fig. 6.49 Magic-T s with ports 3 and 4 interchanged
(1 mark)</td><td>8</td><td>3</td><td>2</td><td>2</td></tr>
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	The magic-T has the following characteristics when all the ports are terminated with a matched loads. • If two waves of equal magnitude and equal phase are fed into ports 1 and 2, the output at Port 3 is subtractive and becomes zero and total output will appear additively at the port 4. Hence, Port 3 is called the difference or E-arm and 4, the sum or H-arm. • A wave incident at Port 3 (E-arm) divides equally between ports 1 and 2 but is opposite in phase with no coupling to Port 4 (H-arm). Thus, S13 = –S23, S43= 0 • A wave incident at Port 4 (H-arm) divides equally between ports 1 and 2 in phase with no coupling to port 3 (E-arm). Thus, • S14 = S41 = 1/ 2 = S24 = S42 and S34 = 0 • A wave fed into one collinear port, 1 or 2, will not appear in the other collinear Ports, 2 or 1, respectively. Hence, two collinear ports 1 and 2 are isolated from each other, making S12 = S21 = 0 A magic-T can be matched by putting tuning screws suitably in the E and H-arms without destroying the symmetry of the junctions. Therefore, for an ideal lossless magic-T matched at ports 3 and 4, S33 = S44 = 0. The procedure of derivation of the S-matrix considers the symmetry property at the junction for which S14 = S41 = S24 = S42, S31 = S13 = –S23 = –S32, S34 = S43 = 0, S12 = S21 = 0. (2 marks) Therefore, the S-matrix for a magic-T, matched at ports 3 and 4 given by $$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix}$$ From the unitary property applied to rows 1 and 2, we get $$\lvert S_{11}\rvert^2 + \lvert S_{12}\rvert^2 + \lvert S_{13}\rvert^2 + \lvert S_{14}\rvert^2 = 1$$ $$\lvert S_{12}\rvert^2 + \lvert S_{22}\rvert^2 + \lvert S_{13}\rvert^2 + \lvert S_{14}\rvert^2 = 1$$ Subtracting these two equations: $$\lvert S_{11}\rvert^2 - \lvert S_{22}\rvert^2 = 0 \quad \text{or,} \quad \lvert S_{11}\rvert = \lvert S_{22}\rvert$$ Form the unitary property applied to rows 3 and 4, $$2\,\lvert S_{13}\rvert^2 = 1, \quad \text{or} \quad \lvert S_{13}\rvert = 1/\sqrt{2}$$ $$2\,\lvert S_{14}\rvert^2 = 1, \quad \text{or} \quad \lvert S_{14}\rvert = 1/\sqrt{2}$$ Substituting these values in Eq. (6.103), $$\lvert S_{11}\rvert^2 + \lvert S_{12}\rvert^2 + 1/2 + 1/2 = 1 \quad \text{or,} \quad \lvert S_{11}\rvert^2 + \lvert S_{12}\rvert^2 = 0$$ which is valid if $S_{11} = S_{12} = 0$ From Eqs (6.105) and (6.109), $S_{22} = 0$ $$\text{Therefore,} \quad [S] = \begin{bmatrix} 0 & 0 & S_{13} & S_{13} \\ 0 & 0 & -S_{13} & S_{13} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{13} & S_{13} & 0 & 0 \end{bmatrix}$$ where $\lvert S_{13}\rvert = 1/\sqrt{2} = \lvert S_{14}\rvert$ (2 marks) By proper choice of reference planes in arms 3 and 4, it is possible to make both S13 and S14 real, resulting in the final form of S-matrix of magic-T.				

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

For the structure (b) where ports 3 and 4 are interchanged, the S-matrix becomes

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

(1 mark)
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Part – B (2 x 15 = 30 Marks)
Instructions: Answer any two out of three questions
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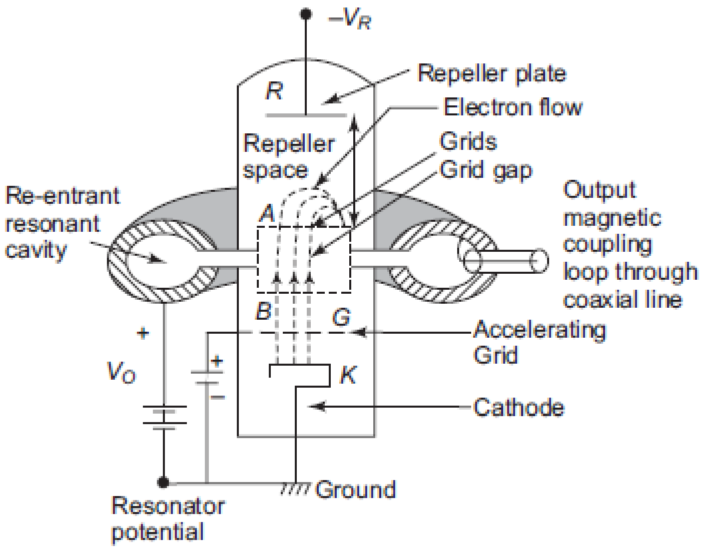
<td>2 (a)</td>
<td>

An aerospace company is designing an airborne radar system where a compact, stable frequency source is required for signal transmission. Due to space constraints, a single-resonator device is selected for generating microwave signals.
i) Explain the working mechanism of this frequency generator and its significance in radar applications. (6 Marks)

<u>**Reflex Klystron Oscillator**</u>

The electron beam emitted from the cathode K is accelerated by the grid G and passes through the cavity anode AB to the repeller space between the cavity anode and the repeller electrode R. The feedback required to maintain oscillations within the cavity is obtained by reversing the electron beam emitted from K towards R and sending it back through the cavity. The electrons in the beam are velocity modulated before the beam passes through the cavity second time and will give up the energy to the cavity to maintain oscillations. This type of a klystron oscillator is called a reflex klystron because of the reflex action of the electron beam.

(2 marks)



(1 mark)

<u>**Mechanism of Oscillation**</u>

Due to dc voltage in the cavity circuit, RF noise is generated in the cavity. This electromagnetic noise field in the cavity becomes pronounced at cavity resonant frequency. The electrons passing through the cavity gap d experience this RF field and are velocity modulated in the following manner. The electrons which encountered the positive half cycle of the RF field in the cavity gap
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<tr><td></td><td>d will be accelerated, those (reference electrons) b which encountered zero RF field will pass with unchanged original velocity, and the electrons c which encountered the negative half cycle will be retarded on entering the repeller space. The RF power is coupled to the output load by means of a small loop which forms the centre conductor of the coaxial line. When the power delivered to the cavity by the electrons becomes equal to the total power loss in the cavity system, a steady microwave oscillation is generated and maintained at resonant frequency of the cavity. (2 marks)

Significance:
• Klystrons play a crucial role in radar applications due to their ability to generate high-power microwave signals with excellent frequency stability and efficiency.
• They provide high gain with minimal noise, making them ideal for detecting weak signals over long distances.
(1 mark)
ii) Given a repeller voltage of -300V and a transit time factor based on an electron path length of 1 mm, estimate the electron transit time. (2 Marks)
given
Repeller Voltage $V_r = -300V$
length $l = 1 mm$
$= 1\times10^{-3} m$
transit time $t = ?$
$$t = \frac{2L}{\sqrt{\frac{2e|V_r|}{m}}}$$
W.k.t $e = 1.6\times10^{-19} C$, $m = 9.1\times10^{-31} kg$
Substitute the values,
$$t = \frac{2\times 1\times10^{-3}}{\sqrt{\frac{2\times1.6\times10^{-19}\times 300}{9.1\times10^{-31}}}}$$
$$\boxed{t = 194.72 ps}$$
Formula: 1 mark, Answer: 1 mark</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2 (b)</td><td>An RF system consists of multiple resonant chambers that determine its operational frequency. If the dimensions of these chambers are altered, how does it affect the output? (7 Marks)
<u>Magnetron Oscillator</u>
Magnetrons are crossed field tubes (M-type) in which the dc magnetic fi eld and the dc electric field are perpendicular to each other. Magnetron consists of a cylindrical cathode K of finite-length-radius a at the centre surrounded by a cylindrical anode A</td><td>7</td><td>3</td><td>1</td><td>2</td></tr>
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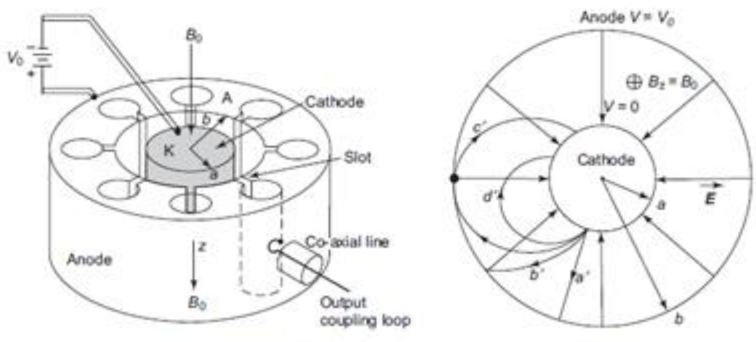
<tr><td></td><td>of radius b. The anode is a slow-wave structure consisting of several re-entrant cavities equispaced around the circumference and coupled together through the anode–cathode space by means of slots. Radial electric field is established by dc voltage V0 in between the cathode and the anode and an axial dc magnetic flux denoted by B0 is maintained in the positive z-direction by means of a permanent magnet or an electromagnet. (2 marks)



Basic magnetron oscillator   Electron trajectory

(1 mark)
Magnetron theory of operation is based on the motion of electrons under the influence of combined electric and magnetic fi elds. The electrons emitted from the cathode try to travel to the anode. But with the influence of crossed fi elds E and H in the space between the anode and the cathode, it experiences resultant force F = – eE – e (v x B), where v is the velocity vector of the electron considered and takes a curved trajectory.
Due to excitation of the anode cavities by RF noise voltage in the biasing circuit, the RF field lines are fringed out of the cavity slot to the space between the anode and cathode. (2 marks)
In a magnetron, altering the dimensions of the resonant cavities changes their resonant frequency, thereby shifting the magnetron’s output frequency. (1 mark)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3 (a)</td><td>i) A three-port non-reciprocal device is used in radar systems to ensure signal flow in a specific direction. Explain its operation and how it achieves isolation between ports.
(5 Marks)
Circulators:
A circulator is a multiport junction in which the wave can travel from one port to the next immediate port in one direction only.
Commonly used circulators are three-port or four-port passive devices although a greater number of ports is possible.
A four-port circulator can be constructed from two magic-T’s and a nonreciprocal 180° phase shifter or a combination of two 3 dB side hole directional couplers with two non-reciprocal phase shifters.
A perfectly matched, lossless, and non-reciprocal four-port circulator has S-matrix: (1 Mark)</td><td>8</td><td>3</td><td>2</td><td>1</td></tr>
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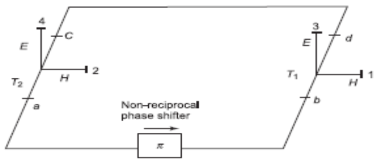
$$[S] = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

(1 mark)

- An input signal at Port 1 is split into two in-phase and equal amplitude waves in the collinear arms b and d of the magic-tee, T_1 and added up to emerge from Port 2 in the magic tee, T_2.



(b)

(1 mark)

- On the other hand, a signal at Port 2 will split into two equal amplitude and equiphase waves in the collinear arms of the magic-tee, T_2 and appears at point b and d out of phase due to presence of the non-reciprocal 180° phase shifter.
- These out-of-phase waves add up and appear from Port 3 in the magic-tee, T_1.
- In a similar manner, an input signal at Port 3 will emerge from 4, an input at Port 4 will appear at Port 1. Thus, the circulator property is exhibited. (2 marks)

ii) If an input power of 100 W is applied and the insertion loss is 0.5 dB, determine the output power at the desired port.
(3 Marks)

$$P_{\text{out}} = P_{\text{in}} \times 10^{-\frac{L}{10}}$$

(1 mark)

Given:

- Pin=100W
- L=0.5 dB

$$P_{\text{out}} = 100 \times 10^{-0.5/10} = 100 \times 10^{-0.05}$$

$$10^{-0.05} \approx 0.8913$$

$$P_{\text{out}} \approx 100 \times 0.8913 = 89.13\,\text{W}$$

(2 marks)

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<td>3 (b)</td>
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i) A device is designed to protect microwave sources from unwanted reflections by providing high isolation in one direction. Explain its working principle and mention two key applications. (5 Marks)

<u>**Isolator**</u>

- An isolator is a two-port, non-reciprocal device which produces a minimum attenuation to wave propagation in one direction and very high attenuation in the opposite direction.
- Thus, when inserted between a signal source and load, almost all the signal power can be transmitted to the load

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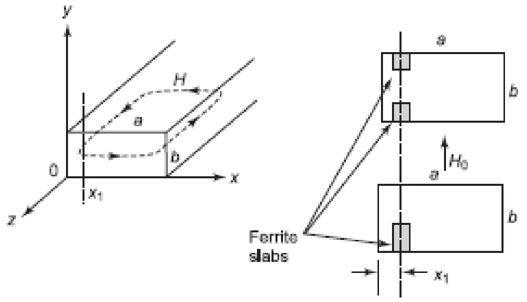
	and any reflected power from the load is not fed back to the generator output port. • This eliminates variations of source power output and frequency pulling due to changing loads. (1 mark)  Waveguide isolator (1 mark) • An isolator can be constructed in a rectangular waveguide operating in dominant mode. • The non-reciprocal characteristics are obtained by establishing a steady magnetic field H_0 in the y direction and placing a ferrite slab at any of the longitudinal plane's $x = x_1$ near and parallel to the narrow waveguide wall, where the magnetic field exhibits circular polarization. • This occurs at $x_1 = a/4$ or, $3a/4$. • The required steady state magnetic field H_0 in the y-direction is established by placing permanent magnetic poles between the two broad walls. • It is known that the attenuation in ferrite for negative/clockwise circular polarization is very small whereas for positive/counter clockwise circular polarization is very large at and near the resonance frequency f_0. • Therefore, the ferrite slab is placed in such a way that while transmission it encounters negative circular polarization in the reverse direction. (2 marks) **<u>Applications</u>** 1. Protection of microwave sources 2. Used in network Analyzer and Signal generators to protect the source during device testing (1 mark) **ii) If the isolation is 20 dB and the reflected power is 5 W, calculate the power reaching the source. (2 Marks)** **Given:** Isolator Protects microwave sources from reflected power. • Isolation = 20 dB • Reflected power, $P_{reflected}$=5 W $$\text{Isolation (dB)} = 10\log_{10}\left(\frac{P_{\text{reflected}}}{P_{\text{source}}}\right)$$ (1 mark) Power reaching the source is = 0.05 Watt (1 mark)				
4 (a)	**A city's traffic enforcement department is deploying speed-detection radar systems that operate at 35 GHz to measure vehicle speeds. The system uses a solid-state semiconductor device that exhibits bulk negative differential resistance for signal generation.**	8	3	1	1

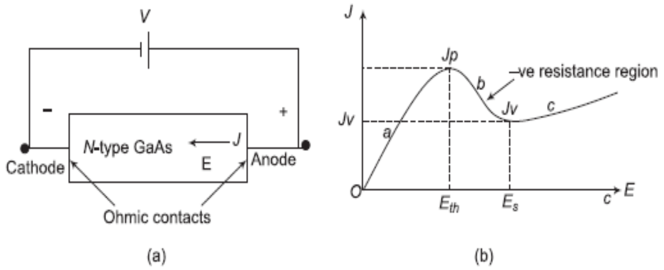
i) Describe the principle enabling the generation of microwave signals in this system. (6 Marks)

<u>Gunn Diode</u>

- There are two principle modes of operation that result in microwave oscillations in a Gunn diode. These are the Gunn mode or the transit-time (TT) mode and the limited-space-charge (LSA) mode.

I-V Characteristics and Basic Operation

- When the GaAs sample is biased with a dc source of voltage V, an electric fi eld is generated inside the sample with electric current I. The typical characteristic of current density J vs. electric fi eld E in the semiconductor is shown in Fig. below.



Gunn diode biasing and *I-V* characteristics

(2 marks)

- It is seen that when the electric fi eld in the sample is less than a critical value Eth, called the threshold field, the sample obeys Ohm's law. When E exceeds Eth but is less than a sustaining value Es, the slope of J-E curve is negative, i.e. the differential resistance of the device is negative.
- This differential negative resistance (usually stated as the "negative resistance") of the device is utilized for making microwave Gunn oscillators.
- When the negative resistance of the device is compensated by the positive resistance of the external resonance circuit, sustained oscillations take place.
- The value of the threshold field varies with the type of the semiconductor materials used. (2 marks)

Microwave Generation

- The high field domain moves through the sample with uniform velocity and gets collected at the anode. A new domain is again formed at the cathode and the process repeats itself.
- Thus, a pulse current output is obtained with the intrinsic period T equal to the transit time of the domain through the effective length l_{eff} of the sample:

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$$T = \frac{l_{eff}}{v_d}$$

The intrinsic frequency of oscillation is given by

$$f = \frac{1}{T} = \frac{v_d}{l_{eff}}$$

- where v_d is the domain velocity (approximately the drift velocity of electrons) and the effective length that the domain travels $l_{eff} = l$, the sample length.
- Since the drift velocity is very high and the semiconductor length is very small, the current fluctuation occurs at microwave frequencies to produce an output signal in the low impedance external RF circuit. (2 marks)

ii) If the radar operates with a bias voltage of 10V and a current of 200 mA, calculate the power dissipated. (2 Marks)
given:
Voltage (V) = 10 V
Current (I) = 200 mA = 0.2 A
P = Vx I (1 mark)
P =10 x 0.2= 2 Watts (1 mark)

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<td>4 (b)</td>
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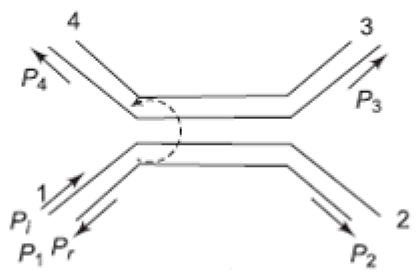
A four-port device is designed to extract a portion of an input signal while maintaining most of the power in the main path. Explain its working principle and the factors affecting its coupling efficiency. (7 Marks)

<u>Directional Coupler</u>

- A directional coupler is a four-port passive device commonly used for coupling a known fraction of the microwave power to a port (coupled port) in the auxiliary line while flowing from the input port to the output port in the main line.
- The remaining port is an ideally isolated port and matched terminated.
- The performance of a directional coupler is measured in terms of four basic parameters, i.e., coupling (C), transmission loss (T), directivity (D), and the return loss (R) when all the ports are matched.

$$C\,(\text{dB}) = 10 \log (\text{Input power/Coupled output power}) = 10 \log(P_1/P_4)$$

(2 marks)



(1 mark)

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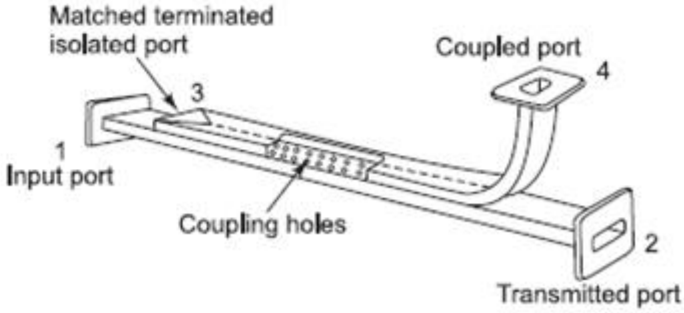


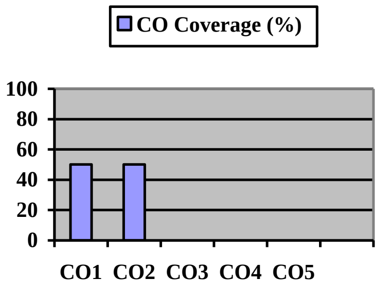
(2 marks)

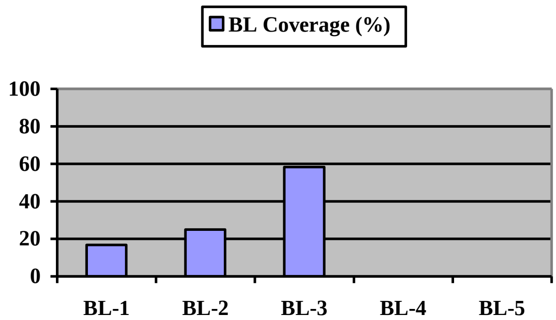
- The structure of a multihole coupler is symmetrical with respect to a transverse plane. For an input at Port 1 of the main guide, a fraction of input power is coupled into the auxiliary guide in a forward direction at Port 4.
- The successive openings are spaced quarter wavelength apart at a designed frequency so that the coupled waves travelling back towards Port 3 will be out of phase and cancelled; whereas the forward-coupled waves are in phase and thus, reinforce each other.
- Thus, Port 3 is an ideally isolated port and matched terminated for absorbing any coupled power flows in practical situation. Such a coupler is called a forward coupler.
- For an input to Port 2, coupled power gets absorbed at Port 3 and Port 4 is isolated. (2 marks)

Factors Affecting Coupling Efficiency:

1. Coupling Coefficient
2. Frequency
3. Physical Dimensions and Design
4. Load Impedance Matching
5. Isolation and Directivity (1 mark)

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





Signature of Course Teacher

Approved by the Course Coordinator

Approved by the Academic Advisor