SRM Institute of Science and Technology
Faculty of Engineering and Technology

SET-B

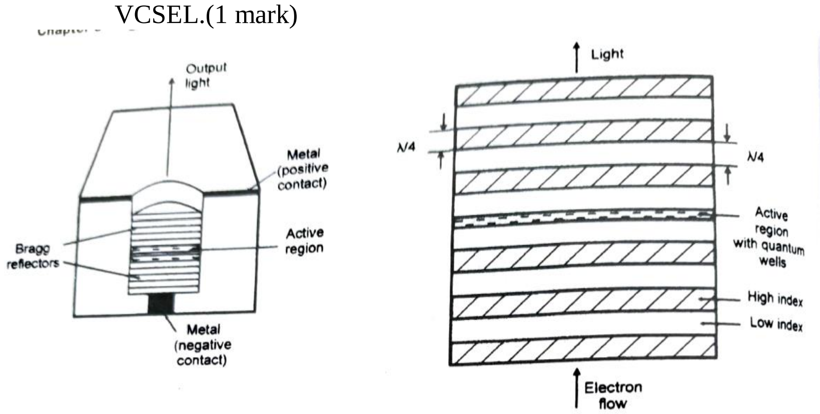
DEPARTMENT OF ECE

SRM Nagar, Kattankulathur – 603203, Chengalpattu District, Tamilnadu

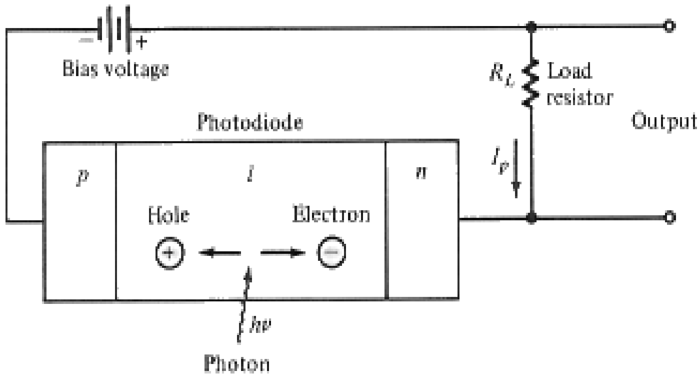
Academic Year: 2022-2023 (EVEN)

Test: CLAT-3 **Date: 04/05/23**
Course Code & Title: 18ECC302J–Microwave and Optical Communication **Duration: 10:30-12:10 PM**
Year & Sem: III /VI **Max. Marks: 50**

	18ECC302J - Microwave & Optical Communications	**Program Outcomes (POs)**														
		Graduate Attributes												**PSO**		
S. No.	**Course Outcomes (COs)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
1	Demonstrate the knowledge on the theory of microwave transmission, microwave generators and associated components.	3	-	-	3	-	-	-	-	-	-	-	-	-	-	1
2	Analyse the microwave passive devices and components.	-	2	-	3	-	-	-	-	-	-	-	-	2	-	-
3	Incorporate microwave measurements and associated techniques with equipment	-	-	3	2	-	-	-	-	-	-	-	-	-	-	3
4	Gain knowledge of the fundamentals on light transmission through fiber	-	3	-	2	-	-	-	-	-	-	-	-	-	-	1
5	Develop a basic optical communication system.	-	3	-	-	3	-	-	-	-	-	-	-	2	-	-
6	Implement the working principle of microwave components, microwave measurements, optical sources, detector and fibers	-	-	3	-	3	-	-	-	-	-	-	-	-	-	3

Q. No	**Answer**	**Marks**	**BL**	**CO**	**PO**
	Part – A **(5 × 10 = 50 Marks)** **Instructions: Answer any FIVE Questions.**				
1	i) a) 0.344	**1**	**4**	**4**	**2**
	ii) The identified source is Vertical Cavity Surface Emitting Laser-VCSEL.(1 mark)  (3 marks) Vertical cavity means the structure (cavity) providing laser feedback is arrange in the vertical direction. Surface emitting means the laser beam is emitted perpendicular to the wafer. Semiconductor heterostructure forms an active region. Several quantum wells are made within this active region to enhance light gain. This region is placed between Bragg reflectors- the stacks of layers with alternate high and low refractive index material. Each layer is λ/4 thick	**9**	**3**	**4**	**2**

	and made from GaAs (n=3.6) and AlAs (n=2.9). These layer work like high reflective mirror providing positive feedback (2 marks)
	Advantages
	• Size of the resonant cavity is very small resulting in huge spacing between two adjacent longitudinal modes
	    • Only one mode can be within gain curve
	    • Operates in single mode regime
	• Very small dimensions (cavity and diameter of active region is about 1 to 5μm and thickness is 25nm)
	    • Can fabricate many diodes on one substrate
	• Low power consumption and high switching speed
	• High current density at low current value
	• Short lifetime leading to high modulation bandwidth
	• VCSEL diode radiates a circular output beam in contrast to that radiated by edge emitting lasers
	• Fabrication technology is very similar to that for electronic chips (3 marks)				

2	i) d) 32 ii) PIN diode (1 mark) **Construction (3 marks)** The PIN photodiode is structured with p and n regions separated by a lightly n-doped intrinsic (i) region. Incident photon with energy ≥ band-gap energy of the photodiode will generate free electron-hole pairs, known as photo-carriers. The high electric field present in the depletion region causes the carriers to separate and be collected across the reverse-biased junction. This gives rise to a photo-current flow in an external circuit, with one electron flowing for every carrier pair generated. In the absence of light, PIN photodiodes behave electrically just like an ordinary rectifier diode. If forward biased, they conduct large amount of current.  **Operating Modes (2 marks)** PIN detectors can be operated in two modes 1. **Photovoltaic Mode** 2. **Photoconductive Mode** **1. Photovoltaic Mode:** • No bias is applied to the detector. • In this case, the detector works very slow and output is approximately logarithmic to the input light level. • Real world fiber optic receivers never use the photovoltaic mode. **2. Photoconductive Mode:** • The detector is reversed biased. • The output in this case is a current that is very linear with the input light power. • The intrinsic region somewhat improves the sensitivity of the device. It does not provide internal gain. The combination of different semiconductors operating at different wavelengths allow the selection of material capable of responding to the desired operating wavelength.	**1** **9**	**4** **3**	**4** **4**	**2** **2**

<table>
<tr>
<td></td>
<td>

Characteristic Parameters (3 marks)

Diffusion Length:

As the charge carriers flow through the material, some electron-hole pairs will recombine and disappear.

On the average, the charge carriers move a *diffusion length* L_n or L_p for electrons and holes, respectively.

Carrier Life time:

The time it takes for an electron or hole to recombine is known as the *carrier lifetime* and is represented by τ_n and τ_p, respectively.

The lifetimes and the diffusion lengths are related by

$$\boldsymbol{L_n = (D_n\tau_n)^{1/2}} \quad \text{and} \quad \boldsymbol{L_p = (D_p\tau_p)^{1/2}}$$

where D_n and D_p are the electron and hole diffusion coefficients, expressed in units of cm^2/sec.

Optical power absorbed

Optical radiation is absorbed in the semiconductor material according to the exponential law

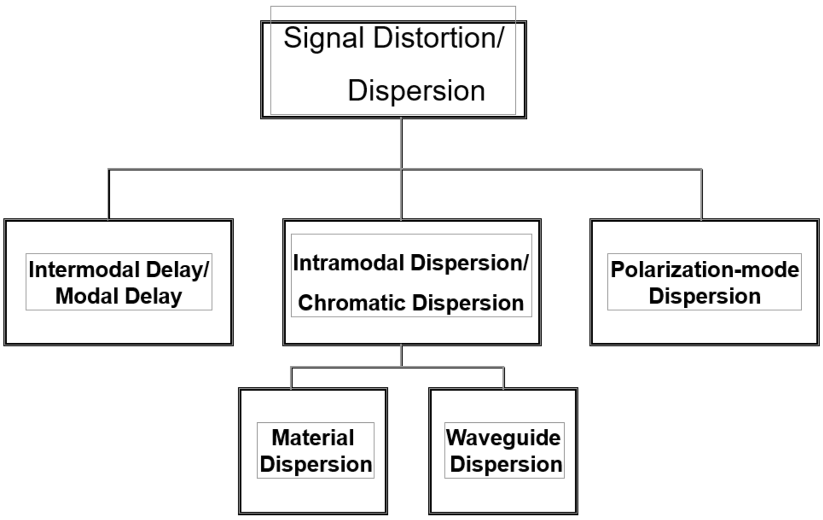
$$P(x) = P_o[1 - \exp(-\alpha_s(\lambda)x)]$$

Here, $\alpha_s(\lambda)$ is the *absorption coefficient* at wavelength λ,
P_o is the incident optical power level, and
$P(x)$ is the optical power absorbed in a distance x.

</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>

i) a) 820 nm

ii) The phenomenon where signal distortion happens due to broadening of the pulse is called dispersion (1 mark)



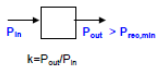
(3 marks)

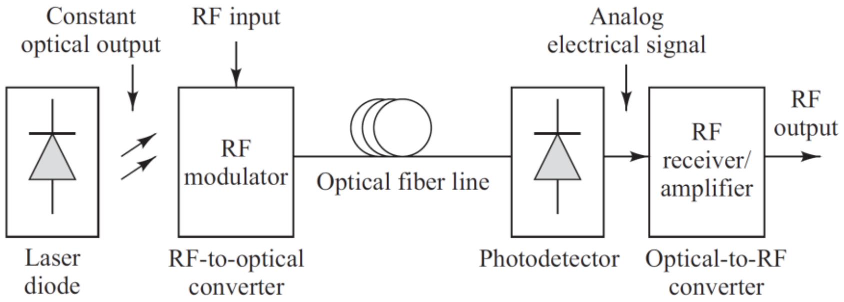
Intramodal Dispersion or Chromatic Dispersion takes place within a single mode. It depends on the wavelength, its effect on signal distortion increases with the spectral width of the light source. Spectral width is approximately 4 to 9 percent of a central wavelength.Two main causes of intramodal dispersion are as:

Material Dispersion

This refractive index property causes a wavelength dependence of the group velocity of a given mode; that is, Pulse spreading occurs even when different wavelength follow the same path. Material dispersion can be reduced: Either by choosing sources with narrower spectral output widths or by operating at longer wavelengths.

</td>
<td>1
9</td>
<td>4
3</td>
<td>4
4</td>
<td>2
2</td>
</tr>
</table>

	Waveguide Dispersion It causes pulse spreading because only part of the optical power propagation along a fiber is confined to core. Dispersion arises because the fraction of light power propagating in the cladding travels faster than the light confined to core. Single mode fiber confines only 80 percent of the power in the core for V values around 2. The amount of waveguide dispersion depends on the fiber design**.** (5 marks)				
4	i) b) Rise time budget ii) The link power budget is an "accounting" procedure in which one calculates how much power can be lost between the transmitter and the receiver for a given receiver sensitivity (which depends on the bit rate) and transmitter power output. The resulting budget is allocated to connector losses, splice losses, fibre losses and a safety margin (system margin).dB and dBm units are used in the link power budget (2 marks) Considering a simple point-to-point-link (without amplifier), we find the following **component power losses k=P_{out}/P_{in}:** - **Attenuation losses** of the fiber (proportional to the fiber length L, $k_{faser}=e^{-\alpha L}$) - **Coupling losses (input)** Laser-Fiber (k_{LF}) - **Insertion loss** of an external modulator (k_{MOD}) (optional) - **Total Fiber-Splice losses** (k_{SPLICE} , mostly proportional to L) - **Coupling losses (output)** Fiber-Photodetector (k_{PD})  - **Amplification** in optical amplifiers (G_{tot}) - **Responsivity of the photodiode** (R) $P_{s,in}$ is the modulated optical power emitted by the source. We determine the power on the receiving photodiode as P_{out}: $P_{out}=P_{s,in}(0)\,k_{faser}(L)k_{LF}k_{MOD}k_{SPLICE}k_{PD}\,G_{tot}=P_{rec}(L)>P_{rec,min}(BER,B_{ch})$ *with* $P_{out}=P_{S,in}\,e^{-\alpha_{faser}L}e^{-\alpha_{loss}L}\quad with\ \ \alpha_{loss}=\frac{1}{L}ln\left(k_{LF}k_{MOD}k_{SPLICE}k_{PD}G_{tot}\right)\quad (equivalent\ loss\ per\ unit\ length)$ α_{loss} are local losses, represented formally as distributed losses over the distance L. Depending on 1) the requested BER 2) the necessary signal bandwidth B_{ch} 3) and the noise properties of the receiver the receiver is characterized by its **sensitivity , resp. a minimal optical power $P_{rec,min}$** required at its input (P_{out}> $P_{rec,min}$). (3 marks) iii) $T_{syst}=1.1(T_S^2+T_n^2+T_c^2+T_D^2)^{\frac{1}{2}}$ $=1.1(8^2+(8\times 5)^2+(8\times 1)^2+6^2)^{\frac{1}{2}}$ $=46.2$ ns Hence the maximum bit rate for the link using an NRZ format is given by Eq. (12.51) where: $B_T(\max)=\frac{0.7}{T_{syst}}=\frac{0.7}{46.2\times 10^{-9}}\simeq 15.2\ \text{Mbit s}^{-1}$	**1** **5** **4**	**1** **3** **2**	**5** **5** **5**	**2** **2** **2**
5	i) **b) 31** ii)Radio frequency (RF) signals at microwave and millimetre-wave frequencies are used in applications such as radars, satellite links, broadband terrestrial radios, and cable television networks. Traditionally these RF systems used wireless or coaxial cable links for transporting the microwave signals from a receiving element (Ex. an antenna) to a signal processing centre, which could be located hundreds of meters away. The methods for transmitting microwave analog signals over an optical fiber link have become known as **RF-over-fiber techniques. (1 mark)** **Architecture (4 marks)**	**1** **5**	**4** **3**	**5** **5**	**2** **2**

<table>
<tr>
<td></td>
<td>


- An RF-to-optical signal converting device at the transmitting end,
- An optical-to-RF signal converting device at the receiving end, and
- An optical fiber that joins these two modules.

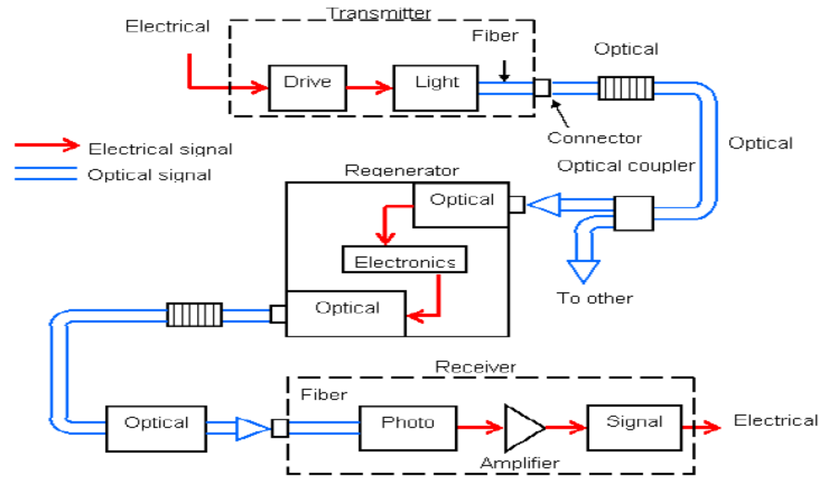
Characteristic parameter

The Link Gain (G) is defined as the ratio of the RF power P_{out} generated in the photodetector load resistor to the RF power input P_{in} to the laser transmitter

$$G = \frac{P_{out}}{P_{in}} = S_M^2 \eta_{LF}^2 T_F^2 \eta_{FD}^2 \Re^2 \frac{R_{load}}{R_M}$$

The Noise Figure (NF) represents a measure of the degradation in the signal-to-noise ratio (SNR) between the input and the output of the link. It is usually defined in decibels.

$$NF = 10\log\frac{SNR_{in}}{SNR_{out}} = 10\log\frac{\bar{N}_{out}/B_e}{k_B TG} = 10\log\frac{N_{out}}{k_B TG}$$

iii)


</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>
i) c) Interferometer

ii) Capacity upgrade of existing fiber networks by sending different data streams at different frequencies over a single optical fiber – WDM (1 mark)

Passive/active devices are needed to combine, distribute, isolate and amplify optical power at different wavelengths. WDM technology uses multiple wavelengths to transmit information over a single fiber
Coarse WDM (CWDM) has wider channel spacing (20 nm) – low cost
Dense WDM (DWDM) has dense channel spacing (0.8 nm) which allows simultaneous transmission of 16+ wavelengths – high capacity (1 mark)

Passive Optical Components
➢ Wavelength Selective Splitters
➢ Wavelength Selective Couplers
Active Optical Components
➢ Tunable Optical Filter
➢ Tunable Source
</td>
<td>1

5</td>
<td>1

2</td>
<td>5

5</td>
<td>2

2</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>
➢ Optical amplifier
➢ Add-drop Multiplexer and De-multiplexer (3 marks)

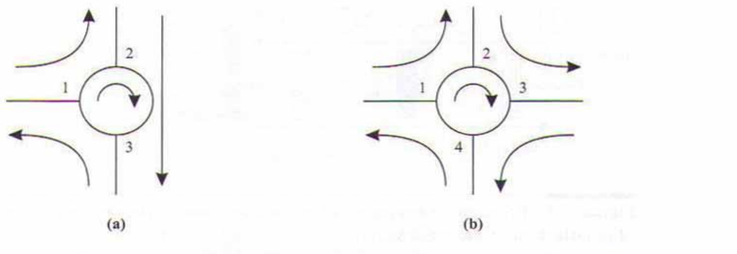
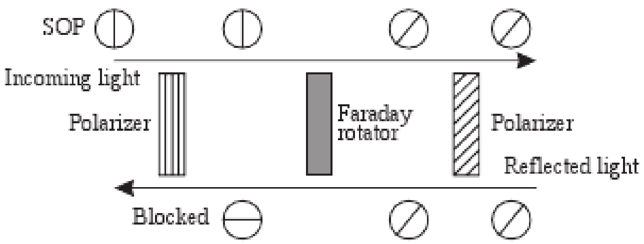
iii)
– Isolators , Faraday Rotators and Circulators (1 mark)
Isolators are for transmitter, circulators are for add and drop or others. The insertion loss should be small ~ 1dB. A circulator is similar to an isolator except it has multiple ports.


Figure 3.3 Functional representation of circulators: (a) three-port and (b) four-port. The arrows represent the direction of signal flow.

(2 marks)
Transmit in one direction only. Avoid reflection of laser – or any reflection. One input, one output or multiple ports. Key parameters are insertion loss and excess loss


(1 mark)
</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>
i) b) 1310 nm

ii) $\tau = \tau_r \tau_{nr} / (\tau_r + \tau_{nr})$=37.5 ns (1 mark)

$\eta_{int} = \frac{\tau}{\tau_r} = \frac{37.5}{60}$=0.625 (1 mark)

$p_{int} = \eta_{int}\frac{hcI}{q\lambda} = 0.625 * \frac{6.6256 * 10^{-34} * 3 * 10^{8} * 40 * 10^{-3}}{1.602 * 10^{-19} * 0.82 * 10^{-6}} = 0.03782 = 37.8mA$

(2 marks)

iii) Pi − Po = (α_{fc} + α_j)L + α_{cr} + M_a dB (1 Mark)

−3 dBm − (−55 dBm) = (α_{fc} + α_j)L + α_{cr} + M_a

Hence: (α_{fc} + α_j)L = 52 − α_{cr} − M_a

0.5L = 52 − 2 − 7 (2 Marks)

L = = 86 km (2 Marks)
</td>
<td>1

4

5</td>
<td>1

4

4</td>
<td>4

4

5</td>
<td>2

4

2</td>
</tr>
</table>

Signature of the Course Teacher **Signature of the Course Co-ordinator**

Signature of the Academic Advisor