PVP 23

Code: 23EC4601B

III B.Tech - II Semester - Regular Examinations – APRIL 2026

OPTICAL COMMUNICATIONS
(ELECTRONICS & COMMUNICATION ENGINEERING)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	What is Numerical Aperture of an optical fiber? Why is it important?	L2	CO1
1.b)	What are skew rays in an optical fiber? Explain briefly.	L2	CO1
1.c)	List any two advantages of optical fiber communication over copper cables.	L2	CO1
1.d)	Define Material Dispersion in optical fibers.	L2	CO2
1.e)	What is meant by bending loss in an optical fiber?	L2	CO2
1.f)	What are fiber splices? Mention any two types.	L2	CO3
1.g)	Define Wavelength Division Multiplexing (WDM).	L2	CO3
1.h)	What is the function of a Laser Diode in an optical communication system?	L2	CO4

1.i)	What is shot noise?	L2	CO5
1.j)	What is modal noise in optical communication receivers?	L2	CO5

PART – B

			BL	CO	Max. Marks
UNIT-I					
2	a)	Define refractive index and Numerical aperture.	L2	CO1	5 M
	b)	A silica optical fiber with a core diameter large enough to be considered by ray theory analysis has a core refractive index of 1.50 and a cladding refractive index of 1.47. Determine: i. the critical angle at the core–cladding interface ii. the NA for the fiber iii. the acceptance angle in air for the fiber.	L2	CO1	5 M
OR					
3	a)	Draw the block diagram of optical fiber communication and explain each block.	L2	CO1	5 M
	b)	What is Total Internal Reflection and how to determine critical angle pictorially?	L2	CO1	5 M

<table>
<tr><td colspan="6">UNIT-II</td></tr>
<tr><td>4</td><td colspan="2">Explain the different types of fiber materials used in optical fiber communication.</td><td>L3</td><td>CO2</td><td>10 M</td></tr>
<tr><td colspan="6">OR</td></tr>
<tr><td>5</td><td>a)</td><td>Discuss about core and cladding losses in optical fibers.</td><td>L3</td><td>CO2</td><td>5 M</td></tr>
<tr><td></td><td>b)</td><td>Write a short note on intermodal dispersion.</td><td>L2</td><td>CO2</td><td>5 M</td></tr>
<tr><td colspan="6">UNIT-III</td></tr>
<tr><td>6</td><td>a)</td><td>Explain star couplers with a neat diagram.</td><td>L3</td><td>CO3</td><td>5 M</td></tr>
<tr><td></td><td>b)</td><td>A 32 × 32 port multimode fiber transmissive star coupler has 1 mW of optical power launched into a single input port. The average measured optical power at each output port is 14 μW. Calculate the total loss incurred by the star coupler and the average insertion loss through the device.</td><td>L3</td><td>CO3</td><td>5 M</td></tr>
<tr><td colspan="6">OR</td></tr>
<tr><td>7</td><td colspan="2">Explain the architecture of a WDM in optical communication system.</td><td>L4</td><td>CO3</td><td>10 M</td></tr>
<tr><td colspan="6">UNIT-IV</td></tr>
<tr><td>8</td><td colspan="2">Explain the working principle of a Surface-Emitting LED (Light Emitting Diode) and explain any two LED characteristics.</td><td>L4</td><td>CO4</td><td>10 M</td></tr>
<tr><td colspan="6">OR</td></tr>
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9	a)	Explain the laser diode characteristics and its operation.	L4	CO4	5 M
	b)	Explain the concept of carrier pair multiplication in Avalanche Photodiode.	L4	CO4	5 M
UNIT-V					
10	a)	Explain about Signal to Noise Ratio.	L4	CO5	5 M
	b)	Explain about thermal noise and laser noise.	L4	CO5	5 M
OR					
11	Explain Analog System Design parameters.		L4	CO5	10 M

Code: 23EC4601B

III B.Tech II Sem Regular Examinations April-2026
Optical communications
scheme of valuation

PART A

1a

2M

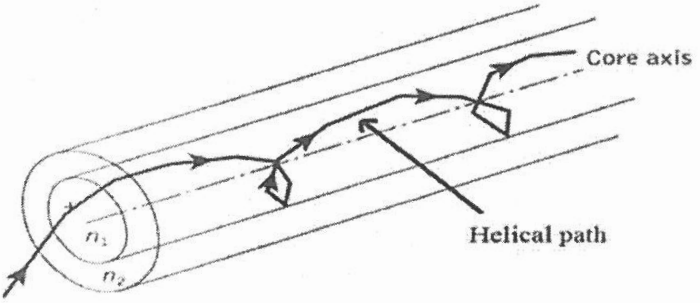
- **Numerical Aperture**:
- Is defined as Sine of acceptance angle
  $NA = \sin \Theta_a = (n_1^2 - n_2^2)^{1/2}$
- It indicates the light collecting efficiency of an optical fiber (or) ability of optical fiber to capture light.
- Value ranges from 0.15 to 0.3 for communication application
- NA= 0.5 for other application
- Dimensionless Quantity
- If NA is large ,then acceptance angle is high then it leads to no of modes in the fiber
- If NA is small then it is advantageous

b.

2M

Skew Rays : The rays which never intersect the axis of the fiber, giving low optical intensity at the center and high intensity towards the rim of the fiber.

✓ Skew rays are the rays following the helical path around the fiber axis when they travel through the fiber and they would not cross the fiber axis at any time.



c.

2M

Advantages of Optical Communication

- Enormous potential bandwidth
- Small size and weight
- Electrical isolation
- Low EMI
- Immunity to interference and crosstalk
- Signal security
- Low Transmission Loss
- Ruggedness and flexibility
- System Reliability and ease of maintenance
- Potential low cost

2M

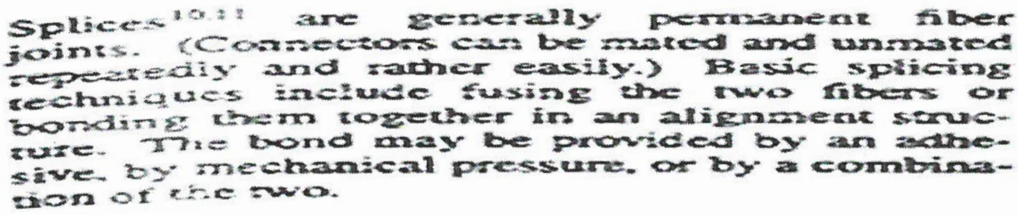
d. Material dispersion occurs because the refractive index of the fiber core varies with wavelength, causing different spectral components of a light pulse to travel at slightly different velocities through the fiber. Since most light sources, such as lasers or LEDs, emit light with a range of wavelengths, each component of the pulse arrives at the receiver at different times, leading to pulse broadening. This broadening can cause intersymbol interference (ISI), where adjacent pulses overlap, potentially resulting in bit errors and reduced data integrity.

2M

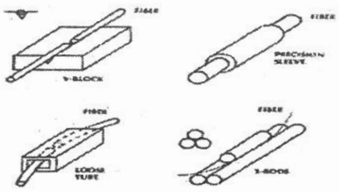
e. Bending losses occur when an optical fiber is curved, causing some of the light to escape from the core into the cladding or outside the fiber, reducing signal strength and overall performance. Optical fibers rely on total internal reflection to confine light within the core, and bending can alter the incident angle at the core-cladding interface, leading to leakage. Smaller cores are more sensitive to bending losses. Uneven forces can induce micro-bends, increasing attenuation.

2M

f.

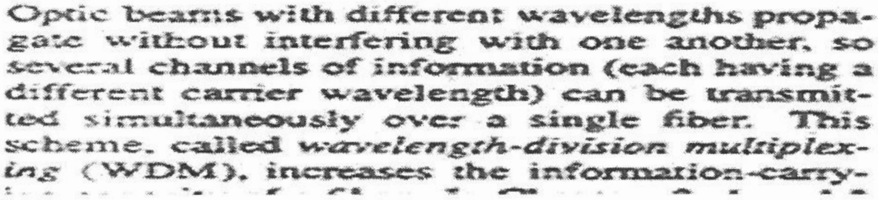


Splices[10,11] are generally permanent fiber joints. (Connectors can be mated and unmated repeatedly and rather easily.) Basic splicing techniques include fusing the two fibers or bonding them together in an alignment structure. The bond may be provided by an adhesive, by mechanical pressure, or by a combination of the two.



g.

2M



Optic beams with different wavelengths propagate without interfering with one another, so several channels of information (each having a different carrier wavelength) can be transmitted simultaneously over a single fiber. This scheme, called *wavelength-division multiplexing* (WDM), increases the information-carry-

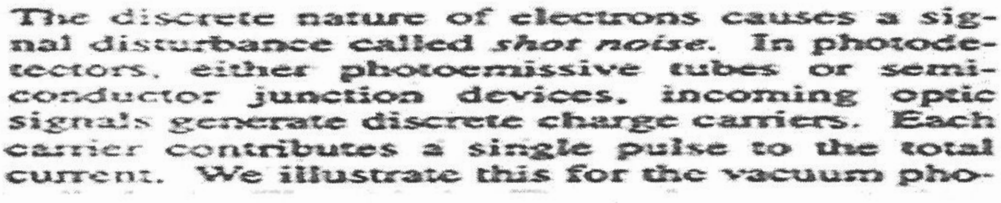
h.

2M

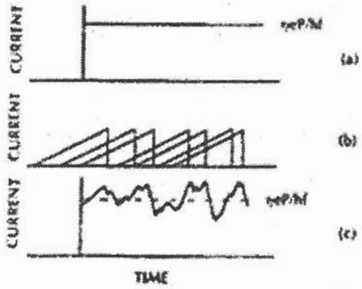
The laser diode plays a crucial role in optical communication by generating the optical carrier, which is the light signal that carries data. The laser diode modulates the power or intensity of this carrier with the information to be transmitted, a process known as Intensity Modulation (IM). This modulation is essential for establishing an optical communication link, as it allows for the transmission of data over long distances with minimal loss. The coherent and monochromatic nature of laser diodes ensures that the light emitted is focused and precise, making them ideal for high-speed data transmission in fiber-optic communication systems.

i.

2M



The discrete nature of electrons causes a signal disturbance called *shot noise*. In photodetectors, either photoemissive tubes or semiconductor junction devices, incoming optic signals generate discrete charge carriers. Each carrier contributes a single pulse to the total current. We illustrate this for the vacuum pho-



J.

J. 2M

Modal noise[9] is a random variation in optic power occurring in multimode fibers. If the light source is highly coherent (say, a good laser diode), then the fiber modes interfere with one another and form a speckle pattern consisting of bright and dark spots. Figure 11-

Figure 11-14 Speckle patter

2a. UNIT 1

The refractive index(n) of a medium is defined as the ratio of velocity of light in a vacuum(c) to the velocity of light in the medium(v)

$n = c/v$

$n = 1$ (air)

$n = 1.2$ (water)

$n = 1.5$ (glass)

$n = 2.419$ (diamond)

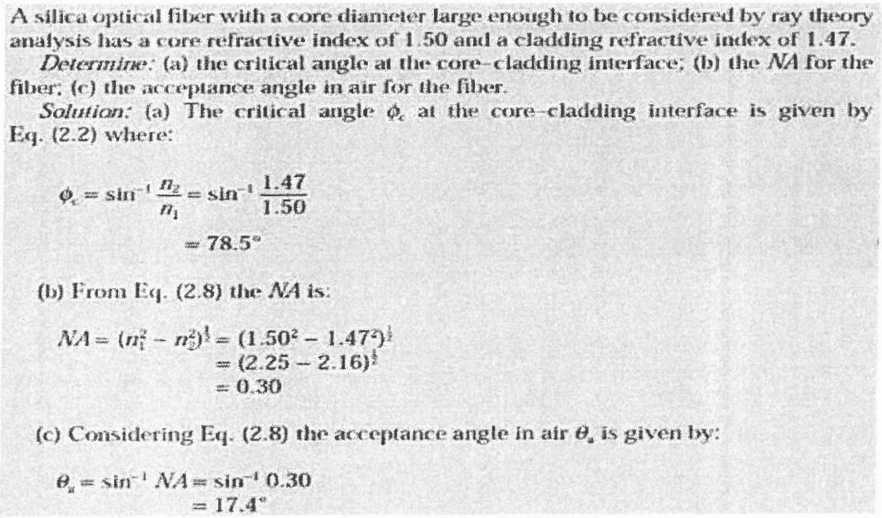
2M

- **Numerical Aperture**:
- Is defined as Sine of acceptance angle

  $NA = \sin \Theta_a = (n_1^2 - n_2^2)^{1/2}$
- It indicates the light collecting efficiency of an optical fiber (or) ability of optical fiber to capture light.
- Value ranges from 0.15 to 0.3 for communication application
- NA= 0.5 for other application
- Dimensionless Quantity
- If NA is large ,then acceptance angle is high then it leads to no of modes in the fiber
- If NA is small then it is advantageous

3M

2b.



A silica optical fiber with a core diameter large enough to be considered by ray theory analysis has a core refractive index of 1.50 and a cladding refractive index of 1.47.

Determine: (a) the critical angle at the core–cladding interface; (b) the *NA* for the fiber; (c) the acceptance angle in air for the fiber.

Solution: (a) The critical angle ϕ_c at the core–cladding interface is given by Eq. (2.2) where:

$$\phi_c = \sin^{-1}\frac{n_2}{n_1} = \sin^{-1}\frac{1.47}{1.50} = 78.5^\circ$$

(b) From Eq. (2.8) the *NA* is:

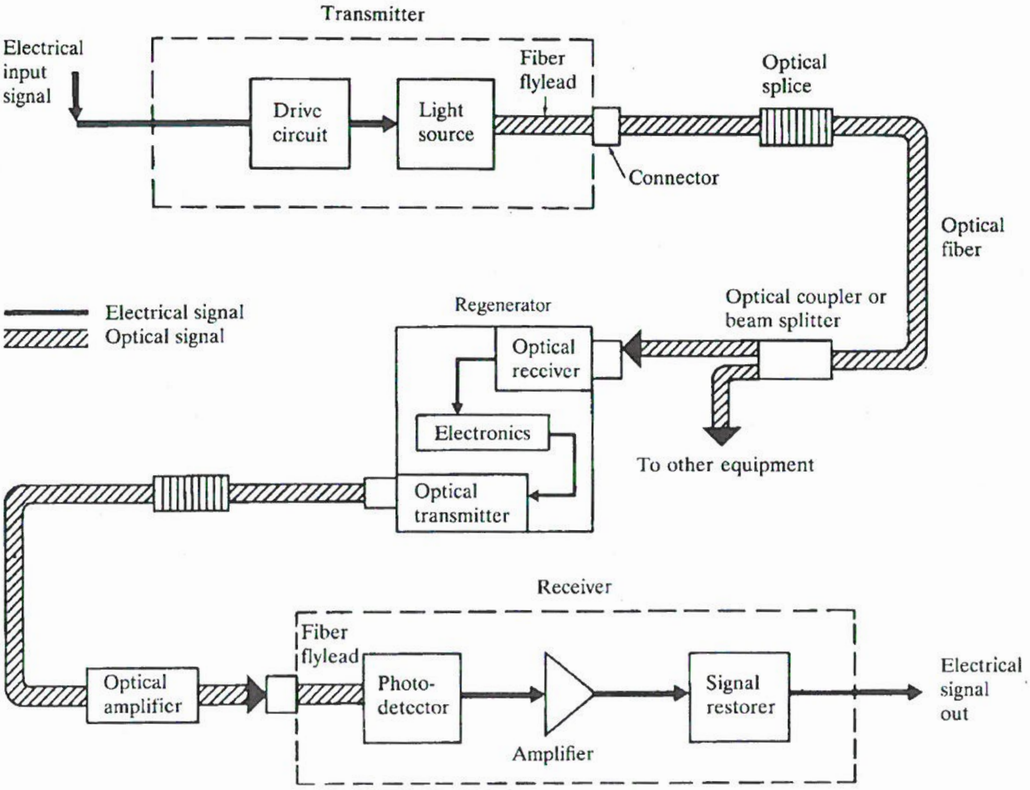
$$NA = (n_1^2 - n_2^2)^{\frac{1}{2}} = (1.50^2 - 1.47^2)^{\frac{1}{2}} = (2.25 - 2.16)^{\frac{1}{2}} = 0.30$$

(c) Considering Eq. (2.8) the acceptance angle in air θ_a is given by:

$$\theta_a = \sin^{-1} NA = \sin^{-1} 0.30 = 17.4^\circ$$

5M

3a. BLOCK DIAGRAM 3M

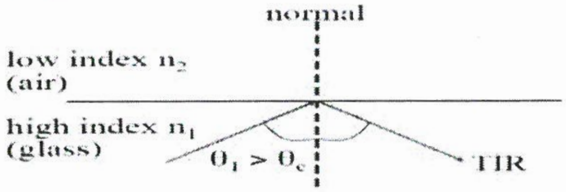


Explanation about each block 2M

3b.

Total internal reflection

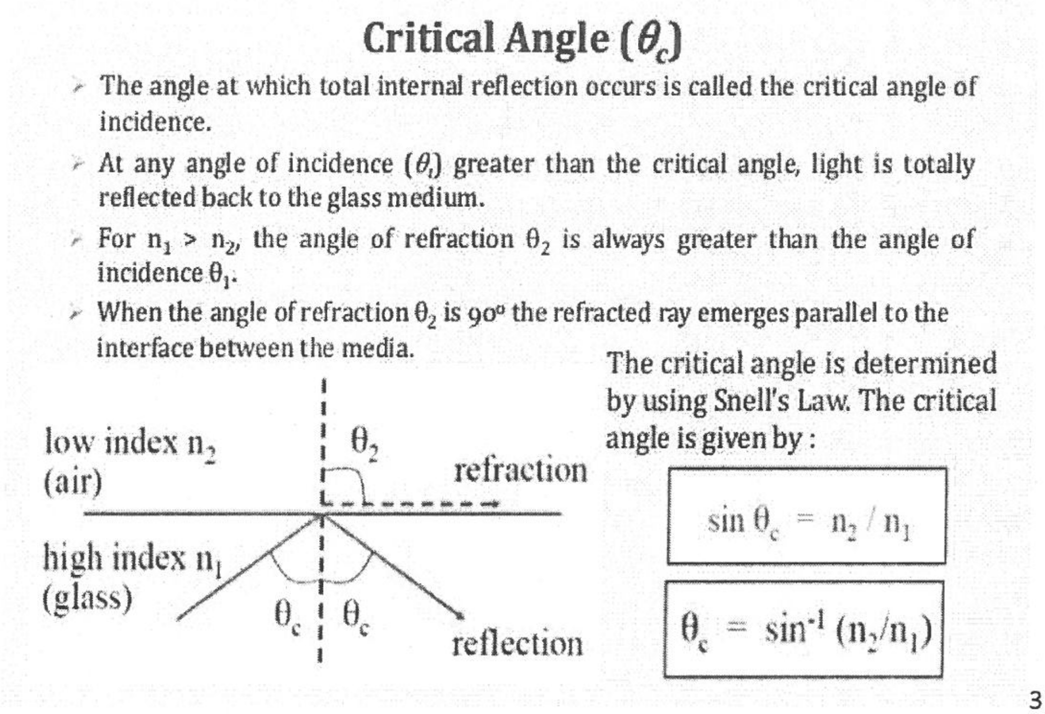
- At angles of incidence $\theta_1 > \theta_c$ the light is totally reflected back into the incidence higher refractive index medium. This is known as **total internal reflection.**



e.g. $n_1 = 1.44$, $n_2 = 1$, then $\theta_c = \sin^{-1}(1/1.44) = 44°$

Total internal reflection: $\theta_1 > \theta_c$

2M



Critical Angle (θ_c)

- The angle at which total internal reflection occurs is called the critical angle of incidence.
- At any angle of incidence (θ_i) greater than the critical angle, light is totally reflected back to the glass medium.
- For $n_1 > n_2$, the angle of refraction θ_2 is always greater than the angle of incidence θ_1.
- When the angle of refraction θ_2 is 90° the refracted ray emerges parallel to the interface between the media.

The critical angle is determined by using Snell's Law. The critical angle is given by :

$$\boxed{\sin\theta_c = n_2 / n_1}$$

$$\boxed{\theta_c = \sin^{-1}(n_2/n_1)}$$

3M

4)

GLASS FIBERS -

3M

: How glass is made ?

↳ It is made by fusing mixtures of metal oxides, sulfides, or selenides.

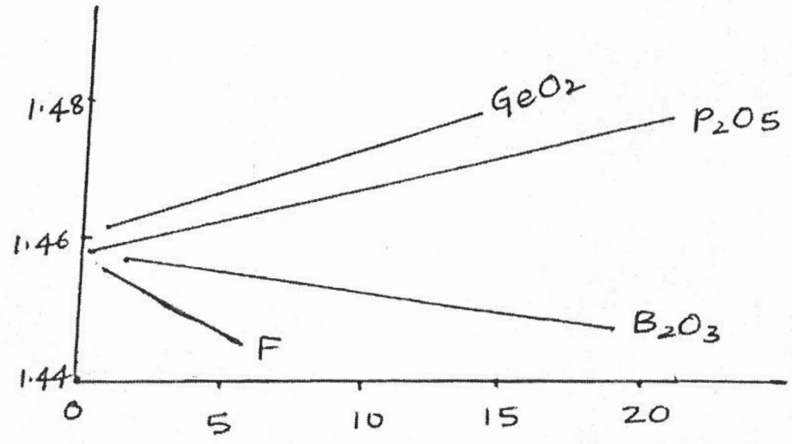
↳ The resultant material is a randomly connected molecular network rather than well-defined structure.

↳ Consequence of this random order – glass does not have well-defined melting points

↳ Upto several hundred ~~ge~~ degrees centigrade glass remains as a solid, when temperature increases further it becomes soft and when at ~~to~~ very high temperature it becomes viscious liquid

* Glasses from which optical fibers are made consists of oxide glasses which are

- Silica Oxide (SiO_2) - refractive index of 1·458 at 850nm
- Flourine and various oxides such as B_2O_3, GeO_2 or P_2O_5 are added to silica.
- Here,
  - ↳ Addition of GeO_2 or P_2O_5 increases refractive index
  - ↳ Addition of B_2O_3 or Flourine ~~oxide~~ decreases refractive index



NOTE - CLADDING MUST HAVE LOWER INDEX THAN CORE

Examples of fiber compositions-

1. $GeO_2 - SiO_2$ core ; SiO_2 cladding
2. $P_2O_5 - SiO_2$ core ; SiO_2 cladding
3. SiO_2 core; $B_2O_3 - SiO_2$ cladding

→ Raw material for silica is sand

→ Glass composed of pure silica is referred as silica glass/ fused ~~glass~~ silica / vitreous silica

DISADVANTAGE-

- High melting temperature
  - ↳This is avoided ~~when~~ by ~~use~~ using vapor depostion techniques.

ADVANTAGE-

- Low thermal expansion
- Good chemical durability
- High transparancy

FIBERS

2M ③

→ Incorporating rare-earth elements into a normally passive glass gives the resulting material new optical and magnetic Properties

→ These new properties allow the material to perform amplification, attenuation and phase retardation.

→ Doping can be carried out for Both silica and halide glasses

→ erbium and neodymium are commonly used materials for fiber lasers

→ To avoid clustering effects the ionic concentration of the rare-earth elements are low

→ One can use an optical source which Emits at an absorption wavelength to excite electrons to higher energy levels in the rare-earth dopants

→ When these excited electrons drop to lower energy levels, they emit light in a narrow optical spectrum at the fluorescence wavelength.

HALIDE GLASS FIBERS - 3M ②

↳ In 1975 researchers at the Université de Rennes discovered flouride glasses that have extremely low transmission losses at mid-infrared wavelengths.

↳ Fluoride glasses belong to a general family of halide glasses in which anions are from elements in group VII

↳ A Heavy metal fluoride glass, which uses ZrF_4 as major component and glass network former.

↳ Other constituents need to be added to make a glass that has moderate resistance to crystallization.

↳ ZBLAN (ZrF_4, BaF_2, LaF_3, AlF_3 and NaF) - this material forsms the core of glass fiber.

↳ To make a lower-refractive-index glass, one partially replaces ZrF_4 by HaF_4 to get a ZHBLAN cladding.

↳ First, ultrapure materials must be used to reach this low loss level

↳ Second, flouride glass is prone to devitrification.

→ Fiber-making techniques are used to avoid the formation of microcrystallites which have drastic effect on scattering losses

2M

④

Chalgenide Glass fibers -

(i) The nonlinear properties of glass fibers can be used in other applications like all-optical switches and fiber lasers.

(ii) Chalgenide Glass fibers is the one for such applications because of its high optical nonlinearity and long interaction length.

(iii) These glasses contain atleast one chalcogen element (S, Se, Te) and one other element such as P, Cl, Br, Cd.

(iv) These particular elements are used for improving the thermal, mechanical and optical properties of the glass.

(v) As_2S_3 is the most well-known material for a chalgenide glass.

(vi) Single-mode fibers are made using $As_{40}S_{58}Se_2$ and As_2S_3 for core and cladding materials.

(vii) Losses in these glasses range around 1 dB/m.

The students can also write plastic optical fibers
any four of five types shall be discussed,

5a) Core and cladding Losses

— 5M

- ∵ the core and cladding have different indices of refraction and therefore differ in composition,
- The core and cladding generally have different attenuation coefficients denoted α_1 & α_2 respectively
- The loss for a mode/path of order (ν, m) for SI waveguide is

$$\alpha_{\nu m} = \alpha_1 \frac{P_{core}}{P} + \alpha_2 \frac{P_{clad}}{P} \quad -①$$

where $\frac{P_{core}}{P}$ & $\frac{P_{clad}}{P}$ are fractional powers for several low order modes

using eq $\frac{P_{clad}}{P} = 1 - \frac{P_{core}}{P}$ / $\frac{P_{core}}{P} = 1 - \frac{P_{clad}}{P}$

$$\alpha_{\nu m} = \alpha_1 + (\alpha_2 - \alpha_1) \frac{P_{clad}}{P}$$

- The total loss of the waveguide can be found by summing over all modes weighted by the fractional power in that mode.
- for the case of graded index fiber the situation is much more complicated. It is generally observed that the loss increases with increasing mode number.

—✓ +b —

5b. — 5M

Intermodal dispersion is the spreading of light pulses in a multimode optical fiber caused by different propagation speeds of the fiber's multiple modes.Intermodal dispersion, also called modal dispersion, occurs in multimode optical fibers where light can propagate through multiple modes or paths. Each mode travels at a slightly different group velocity, so when a pulse of light is launched into the fiber, the components corresponding to different modes arrive at the output at different times, causing the pulse to broaden over distance. Thefastest mode, usually the fundamental mode, arrives first, while higher-order modes arrive later, creating a temporal spread in the signal.

Mitigation Strategies

Use of single-mode fibers to completely avoid intermodal dispersion. Graded-index multimode fibers to minimize differential mode delays.

Understanding and managing intermodal dispersion is crucial for designing high-speed fiber-optic networks, especially for multimode fiber links used in shortdistance applications like campus or building networks

UNIT 3

6a. — 3M

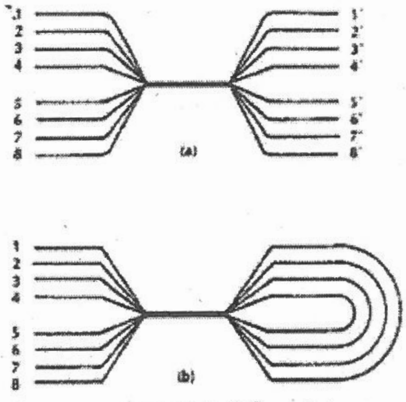


Figure 9-23 Star couplers. (a) Transmission star. (b) Reflection star.

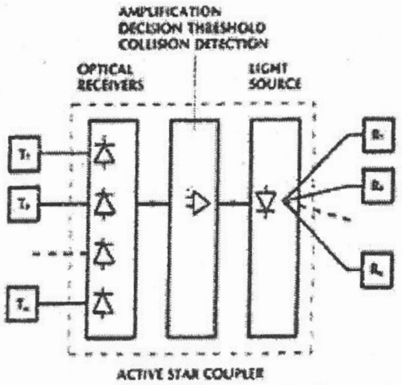


Figure 9-25 Active star network.

The fused biconically tapered technique can be extended to produce multimode fiber couplers having more than four ports.[9] An 8 × 8

2m

transmission star coupler and an eight-port *reflection star coupler* are illustrated in Fig. 9-23. Individual multimode fibers are wound around one another and fused while under tension.

For the transmission star, power put into any port on one side of the coupler emerges from all the ports on the other side, divided equally. Ideally, ports on the same side of the coupler are isolated from each other. Figure

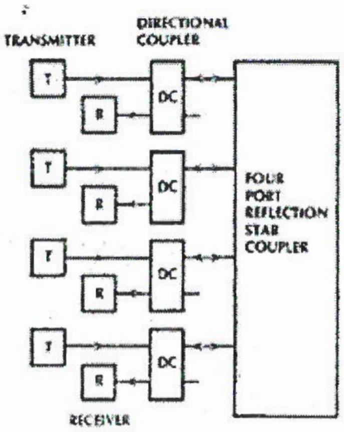


Figure 9-24 Reflection star coupler network.

The reflection star couples light from any one port to all the ports. It interconnects terminals as shown in Fig. 9-24. Because every fiber connected to the star carries both transmitted and received data, a directional coupler is needed to separate the two signals at each terminal.

Fusion of more than two single-mode fibers to produce multiterminal star couplers does not work well because of the need to couple between the individual evanescent fields of the many fibers. For single-mode systems, star couplers are made by cascading 1 × 2 port fused couplers. The scheme, illustrated in

The active star can include provisions for detecting collisions between data packets transmitted simultaneously by different terminals. If collisions occur, then the repeater signals the stations to take corrective actions. Active stars add flexibility to a distribution network because of their regenerating and collision detecting properties.

6b.

Given data

Input power $P_{in} = 1\,\mathrm{mW} = 1000\,\mu W$
Number of output ports $N = 32$
Power per output port $P_{out} = 14\,\mu W$

1. Total output power

$$P_{total,out} = 32 \times 14 = 448\,\mu W$$ — 1M

2. Total loss (Excess loss)

This compares input power to **sum of all outputs:**

$L_{total} = 10\log_{10}\left(\frac{P_{in}}{P_{total,out}}\right)$

$$L_{total} = 10\log_{10}\left(\frac{1000}{448}\right) = 10\log_{10}(2.232) \approx 10 \times 0.349 \approx 3.49\ \mathrm{dB}$$

Total loss ≈ 3.5 dB — 2M

3. Average insertion loss (per port)

This compares input power to **one output port:**

— 2M

$L_{ins} = 10\log_{10}\left(\frac{P_{in}}{P_{out}}\right)$

$$L_{ins} = 10\log_{10}\left(\frac{1000}{14}\right) = 10\log_{10}(71.43) \approx 10 \times 1.854 \approx 18.54\ \mathrm{dB}$$

Average insertion loss ≈ 18.5 dB

7.

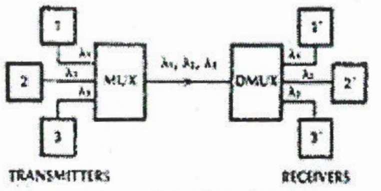


Figure 9-37 Three-channel wavelength-division-multiplexed network. MUX, multiplexer; DMUX, demultiplexer.

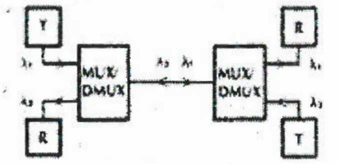


Figure 9-38 Full-duplex network. T, transmitter; R, receiver; MUX/DMUX, bidirectional multiplexer.

— 4M

Figure 9-37 illustrates a three-channel WDM system. In its simplest form this network is unidirectional. It can, however, operate in both directions if the wavelength-separation devices are bidirectional. Later in this section we will see how such devices can be

constructed. When operating bidirectionally, directional couplers must be included at each terminal to separate the transmitted and received waves.

Previously installed systems, designed to operate with a single carrier, can be upgraded by WDM. Only the terminal equipment need be changed. The original fibers can remain in place.

A particularly attractive combination for WDM operates with one channel at 1.3 μm and one at 1.55 μm. The large wavelength spacing simplifies the design of the multiplexer. The similarity in fiber characteristics (attenuation and bandwidth) at these two wavelengths makes the system practical. An

4M

Wavelength division can be used to produce a fully duplexed network, as shown in Fig. 9-38.

Figure 9-36 illustrates loss curves for an eight-channel multiplexer/demultiplexer. The eight curves represent the transmission loss associated with each of the eight channels. For example, the first channel is centered at 1530 nm, the second at 1534 nm, and so forth, up to the eighth channel at 1558 nm. The channel spacing is 4 nm and the individual channel bandwidth appears to be about 2 nm. In this example the insertion loss is about 1 dB and the adjacent-channel isolation (crosstalk) is low (more than 35 dB if the source wave-

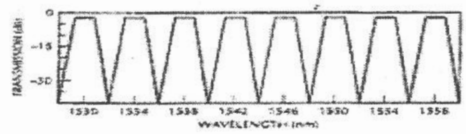


Figure 9-36 Transmission loss (in dB) of an eight-channel multiplexer/demultiplexer.

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UNIT 4

8.

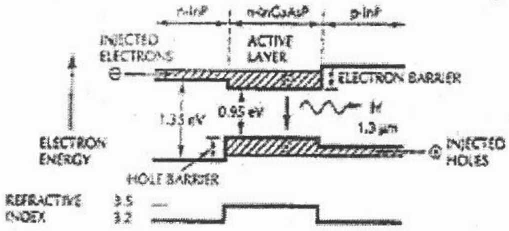


Figure 6-2 Double-heterojunction emitter. The crosshatched regions represent the energy levels of the free charges. The junction on the right forms an energy barrier that prohibits electrons from crossing into the *p* region; the junction on the left prohibits holes from crossing into the InP *n* region. Recombination occurs only in the active InGaAsP layer. This LED emits at wavelengths around 1.3 μm.

— 3M

The LED pictured in Fig. 6-2 actually contains two heterojunctions and is thus a *double-heterojunction* emitter. The two materials have different bandgap energies and different refractive indices. The changes in bandgap energies create potential barriers for both holes and electrons. The free charges can meet and recombine only in the narrow, well-defined active layer. Because the active region has a higher refractive index than the materials on either side, an optic waveguide is formed.

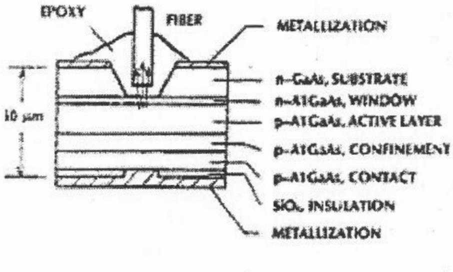


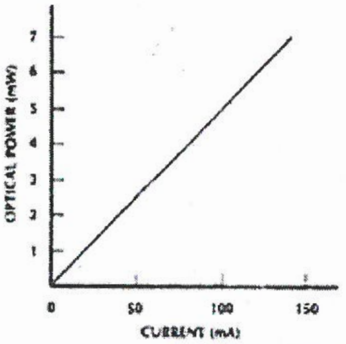
Figure 6-3 Etched-well, surface-emitting LED.

— 3M

Power can be coupled to a fiber from the planar surface of an emitting layer or from its edge. The most efficient surface coupler is the Burrus, or *etched-well*, construction, shown in Fig. 6-3. The AlGaAs diode pictured typically emits at 0.82 μm, where glass fibers have low attenuation. Note the insulating SiO_2 layer and the metal coating at the bottom of the diode. The metal contact is circular, extending through a hole in the SiO_2 layer. This construction confines injected charges to a small central portion of the diode. Fibers as small as 50 μm can be attached with relatively efficient coupling because of the restricted emitting area. Most of the emitted radiation will at least strike the fiber core. The power will not be entirely collected by the fiber because of its limited numerical aperture.

LED Characteristics

As a sample listed two characteristics. The students can write any two



2M

Figure 6-5 Power-current relationship for an LED.

The optic power generated by an LED is linearly proportional to the forward driving current. A typical power-current curve is drawn in Fig. 6-5. The linear relationship can be understood by the following argument: The current i is the injected charge per second. The number of charges per second is then $N = i/e$, where e is the magnitude of the charge on each electron. If η is the fraction of these charges that will recombine and produce photons, the optic power output will be

$$P = \eta N W_g = \frac{\eta W_g}{e} i \qquad (6\text{-}3)$$

proving the linear relationship between optic power and current. In this result, the gap energy is in joules. If it is in electron volts, then the equation simplifies to

$$P = \eta i W_g \qquad (6\text{-}4)$$

Analog modulation (Fig. 6-7) requires a dc bias to keep the total current in the forward direction at all times. Without the dc current, a negative swing in the signal current would reverse bias the diode, shutting it off.

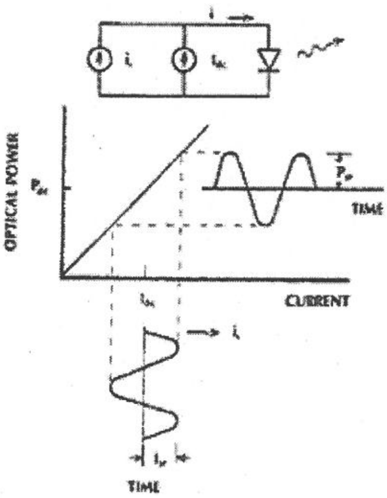
The total diode current is

$$i = I_{dc} + I_{SP} \sin \omega t \qquad (6\text{-}5)$$

and the corresponding optic output power is

$$P = P_{dc} + P_{SP} \sin \omega t \qquad (6\text{-}6)$$

P_{SP} is the peak signal power. We will call it the ac power. Note how the shape of the input-current variation is replicated by the optic power waveform because of the linear power-current relationship. Deviations from linearity distort the signal. When very low distortion is required, the linearity of the proposed source must be evaluated.



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9a.

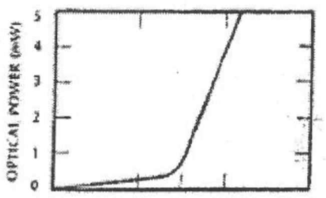

Figure 6-21 Power-current relationship for a laser diode.

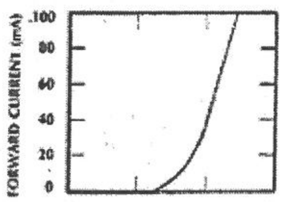

Figure 6-22 Typical voltage-current characteristic for a laser diode.

— 1M

The output optic power versus forward input current characteristic is plotted in Fig. 6-21 for a typical laser diode. The threshold current is 75 mA for this diode. Below this level there is a small increase in optic power with drive current. This is noncoherent radiation caused by spontaneous emission in the recombination layer. Spectral measurements would show a sharp decrease in the output linewidth when the current exceeds the threshold value. Threshold currents run from 5 to 250 mA for

most diodes. The voltages are of the order of 1.2 – 2 V at threshold. The forward current increases rapidly with voltage for a diode, as demonstrated in Fig. 6-22, so that only a small

increase in voltage beyond the threshold value will bring the current to its operating point. Output powers for continuously running lasers (CW, or *continuous wave*) are typically 1 – 10 mW. Pulsed lasers operating at low duty cycles can safely produce larger peak powers, but CW lasers that can be turned on and off at high rates are more useful for communications. The operating current is generally about 20 – 40 mA above the threshold current. Running at currents higher than those suggested by the manufacturer will shorten the lifetime of the diode.

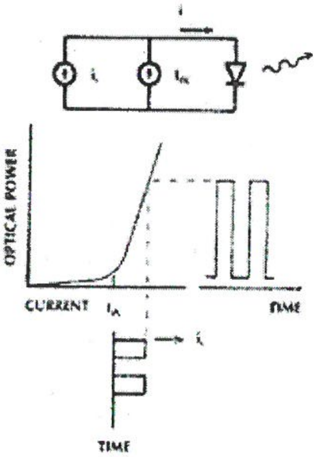

Figure 6-23 Digital modulation of a laser diode.

— 2M

Digital modulation of a laser diode, demonstrated in Fig. 6-23, differs from digital modulation of an LED. A dc bias current I_{dc} is added to place the current at threshold when the signal current I_s is zero. A binary 1 is generated when the signal current contains a positive pulse, as sketched in the figure. When biased near threshold, the diode will turn on quicker and the signal current can be smaller than without the bias.

For analog modulation, Fig. 6-24, the dc bias is moved beyond threshold, so that operation will be along the linear portion of the power-current characteristic curve. The linearity of the laser diode should be carefully checked if the analog signal must be reproduced with low harmonic distortion.

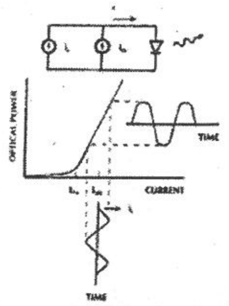

Figure 6-24 Analog modulation of a laser diode.

— 2M

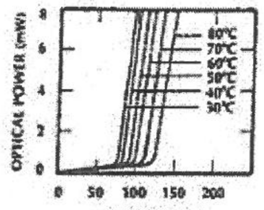

Figure 6-25 Temperature dependence of a laser diode.

Any Three diode characteristics in detail Explanation needed.

Laser diodes are much more temperature sensitive than LEDs, as Fig. 6-25 illustrates for a representative diode. As the temperature increases, the diode's gain decreases so that more current is required before oscillation can begin. That is, the threshold current becomes greater (increasing about 1.5%/°C). This occurs because of thermal generation of holes in the n layer and electrons in the p layer. These free charges recombine with free electrons and holes outside the active layer, reducing the number of charges reaching that layer and, consequently, reducing the number of charges available for the production of gain and stimulated emission. In addition, thermally generated holes and electrons in the active layer itself recombine nonradiatively, reducing the population inversion. Again, a reduction in gain and an increase in threshold current results.

9b.

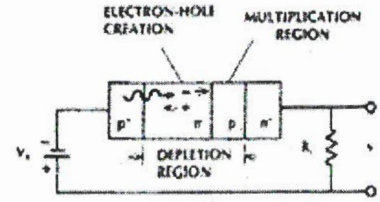

Figure 7-13 Reach-through avalanche photodiode.

— 3M

Avalanche current multiplication comes about in the following way: A photon is absorbed in the depletion region, creating a free electron and a free hole. The large electrical forces in the depletion region cause these

charges to accelerate, gaining kinetic energy. When fast charges collide with neutral atoms, they create additional electron-hole pairs by using part of their kinetic energy to raise electrons across the energy bandgap. One accelerating charge can generate several new secondary charges. The secondary charges, themselves, can accelerate and create even more electron-hole pairs. This, then, is the process of avalanche multiplication.

—2M

photoelectrons move to the p region, which has been depleted of free charge by the large reverse voltage. In essence, the depletion region at the p-n^+ junction has "reached through" to the π layer. The voltage drop is mostly across the p-n^+ junction, where the resulting large electrical forces cause avalanche multiplication. In this device, multiplication is initiated by electrons. Holes gen-

UNIT 5

10a.

signal-to-noise ratio can be computed from the circuit for a variety of circumstances. We will compute the SNR for the following situations:

1. *Constant incident optic power.* This corresponds to reception of a 1 in a binary PCM system. We will first consider use of a detector with no internal gain (such as a *pn* or PIN diode) and then show the improvement by using a detector with internal gain (such as an avalanche photodiode) or by using heterodyne detection.
2. *Sinusoidally varying optic power.* This corresponds to an intensity-modulated analog signal.

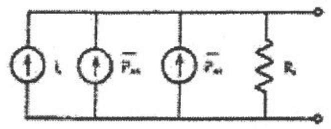

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Figure 11-8 Photodetector receiving circuit, including the equivalent sources of thermal and shot noise.

Constant Power

In this case, the signal photocurrent has the constant value

$$i_s = \frac{\eta e P}{hf} \qquad (11\text{-}4)$$

where P is the incident optic power. The diode delivers average electrical signal power

$$\overline{P}_{ES} = i_s^2 R_L = \left(\frac{\eta e P}{hf}\right)^2 R_L \qquad (11\text{-}5)$$

to the load resistor.

The average shot-noise power delivered to the load is $\overline{i^2_{NS}} R_L$, which, using Eqs. (11-3) and (11-4), becomes

$$\overline{P}_{NS} = 2e\,\Delta f\left(\frac{\eta e P}{hf} + I_D\right) R_L \qquad (11\text{-}6)$$

We made the substitution $\overline{i}_s = \eta e P/hf$, because the current's instantaneous and average values are the same for the case of constant optic power.

The thermal-noise power delivered to the load is $\overline{i^2_{NT}} R_L$, which can be written as

$$\overline{P}_{NT} = 4kT\,\Delta f \qquad (11\text{-}7)$$

by using Eq. (11-1) for the current.

The signal-to-noise ratio is the average *signal* power divided by the average power owing to all noise sources. Combining Eqs. (11-5), (11-6), and (11-7), we obtain

$$\frac{S}{N} = \frac{(\eta e P/hf)^2 R_L}{2eR_L\,\Delta f\,(I_D + \eta e P/hf) + 4kT\,\Delta f} \tag{11-8}$$

Let us investigate some special cases. Suppose that the average signal current $(\eta e P/hf)$ is much larger than the dark current. Then I_D can be dropped from Eq. (11-8). This situation occurs if the dark current is small and the optic power is not too low. Suppose also that the shot-noise power far exceeds the thermal power. Then the term $4kT\Delta f$ can be ignored.

this to happen. The signal-to-noise ratio then simplifies to

$$\frac{S}{N} = \frac{\eta P}{2hf\,\Delta f} \tag{11-9}$$

ited signal-to-noise ratio can be rewritten in terms of the signal photocurrent by combining Eqs. (11-4) and (11-9) to obtain

$$\frac{S}{N} = \frac{i_s}{2e\,\Delta f} \tag{11-10}$$

Unfortunately, we do not always have unlimited power. When the power is low, thermal noise usually dominates over shot noise. Then, Eq. (11-8) reduces to

$$\frac{S}{N} = \frac{R_L(\eta e P/hf)^2}{4kT\,\Delta f} \tag{11-11}$$

This is the *thermal-noise-limited* result. It is

SNR increases as the square of the incident optic power. We conclude that relatively small changes in system efficiency produce significant changes in the quality of the received signal in thermal-noise-limited systems. — 4M

10b.

Thermal Noise — 3M

Thermal noise (also called *Johnson noise* and *Nyquist noise*) originates within the photode-

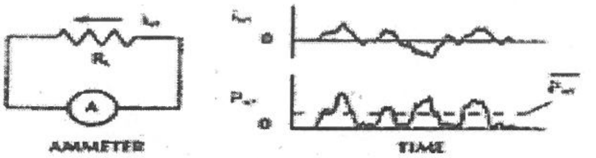

Figure 11-1 Thermal noise current.

tector's load resistor R_L. Electrons within any resistor never remain stationary. Because of their thermal energy, they continually move, even with no voltage applied. The electron motion is random, so the net flow of charge could be toward one electrode or the other at any instant. Thus, a randomly varying current exists in the resistor, as pictured in Fig. 11-1. This is the thermal noise current i_{NT}. Its average value is zero. The average noise power generated within the resistor is $R_L \overline{i_{NT}^2}$, where $\overline{i_{NT}^2}$ is the mean-square value of the thermal noise current. (The bar indicates average

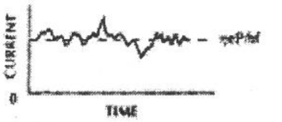

Figure 11-2 Receiver current when the optic power is constant, showing the signal degradation caused by thermal noise.

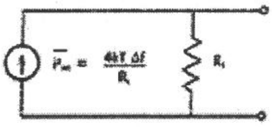

Figure 11-3 Thermal noise equivalent circuit.

Figure 11-2 shows the results when constant optic power P illuminates the photodetector. Instead of remaining fixed at $i = \eta e P/hf$, the load current varies randomly around this value. When the incident power is

The presence of thermal noise can be modeled by the equivalent circuit drawn in Fig. 11-3.[1] In this circuit, R_L is an ideal noiseless resistor. The noise is produced by a current source generating mean-square current

$$\overline{i_{NT}^2} = \frac{4kT\Delta f}{R_L} \qquad (11\text{-}1)$$

where k is the Boltzmann constant (given in Table 1-2), T is the absolute temperature (K), and Δf is the receiver's electrical bandwidth.

Laser Noise

2M

Laser noise[11] is an undesirable random fluctuation in the output of a laser diode that occurs even when the driving current is constant. It is a characteristic associated with poor lasers but is present to some extent in all of them. Laser noise reaches a peak when modulating a diode at its resonant frequency (typically a few gigahertz). For this reason, laser noise is more significant for high-frequency links than for lower-frequency ones. Well-constructed laser

The *relative-intensity noise* (RIN) describes the amount of noise emitted by the laser. We will introduce it in the following way: A laser emits an average power P. A photodetector having responsivity ρ, connected to a receiver whose bandwidth is Δf, measures the laser output. The average detected current is ρP, but the average value of the square of the noise current (i.e., the noise fluctuations) is[12]

$$\overline{i_{NL}^2} = \text{RIN}\,(\rho P)^2\,\Delta f \qquad (11\text{-}44)$$

The average noise power generated by the laser must be

$$\sqrt{\overline{P_{NL}^2}} = \sqrt{\overline{i_{NL}^2}}/\rho \qquad (11\text{-}45)$$

Combining these last two equations yields the RIN.

$$\text{RIN} = \frac{\overline{P_{NL}^2}}{P^2\,\Delta f} \qquad (11\text{-}46)$$

Its units are $(\text{Hz})^{-1}$. Often the RIN is expressed in dB/Hz, which is just,

$$(\text{RIN})_{\text{dB/Hz}} = 10\log\left(\frac{\overline{P_{NL}^2}}{P^2\,\Delta f}\right) \qquad (11\text{-}47)$$

11.

Analog System Design

- Analog system design is the process of transmitting continuous signals, like TV or radio waves, over optical fiber. It ensures that the transmitted signal maintains its shape and quality while minimizing noise and distortion. Key factors include power budget, bandwidth, and signal-to-noise ratio (SNR).
- **Example**: Cable TV transmission over fiber networks.
  Key Focus: Clear signal transmission with minimal loss.

System Specifications

System Specification refers to design a simple point-to-point optical communication system. The key aspects are:

– 3M

1.Purpose of the System

- The system transmits TV signals from a studio to a remote transmitter.
- It can also be used for security camera feeds or other video transmissions.

2.Bandwidth Requirement

- The signals cover a bandwidth of 6 MHz
- A signal-to-noise ratio (S/N) of 50 dB is required for a clear picture.

3.Transmission Medium

- The system uses optical fibers to carry the signals.
- Fiber length is estimated to be around 500 meters to a few kilometers.

Load Resistance:

•$RL=(2\pi Cdf-3dB)-1$

•$RL=[2\pi(5\times10-12)(6\times10\wedge6)]-1=5305\ \Omega$

Where "f–3dB" is the cut-off frequency, "Cd" is the capacitance of the PIN diode

Power Budget

- As we are using PIN diode ,we expect a Thermal-Noise limited System .
- We will proceed on this assumption and calculate received power,

$$\frac{S}{N} = \frac{0.5R_L(\rho P)^2}{4kT_e\,\Delta f}$$

4M

Where,

S/N => Signal-to-Noise Ratio

RL => Load Resistance [Ω]

ρ => PIN diode Responsivity [A/W]

P => Received Optical Power [W]

k => Boltzmann's Constant [1.38×10^−23 J/K]

Te => Equivalent Noise Temperature [K]

Δf=> Bandwidth) [Hz]

- The amount of light energy required to transmit signals successfully over distance through a fiber optic communication is known as Power Budget.

Bandwidth Budget

The **bandwidth budget** is the allocation of available bandwidth across system components to ensure proper signal transmission while minimizing losses and distortions. It considers the combined bandwidths of **source, fiber, and detector** to optimize system performance.

Rise Time Relationship:

3M ·

The total system rise time ts is given by the equation:

$$t_S^2 = t_{LS}^2 + t_F^2 + t_{PD}^2$$

where ,

tLS= rise time of the light source,

ts = rise time of the fiber,

tPD = rise time of the photodetector.