FIRST TERM EXAMINATION [SEPT. 2015]
SEVENTH SEMESTER [B.TECH]
OPTICAL COMMUNICATION [ETEC-403]

Time : 1.5 hrs. **M.M. : 30**

Note: *Attempt Question. No.1, which is compulsory and any two more questions from remaining.*

Q.1.(a) Discuss channel capacity theorem (2)

Ans. Refer Q.No.1 of Question Bank .

Q.1. (*b*) Discuss step index and graded index fiber. **(2)**

Ans. Step Index fiber: A cylindrical core of radius, 'a' and refractive index n_1 surrounded by a cladding of slightly lower refractive index gives a step-index fiber the refractive index profile is defined as

$$n(r) = \begin{cases} n_1 & r < a(\text{core}) \\ n_2 & r \geq a\,(\text{cladding}) \end{cases}$$

Where a = core radius.

Graded Index Fiber: The refractive index in the core of a graded index fiber is not constant. It decrases continuously with increasing radial distance 'r' from the centre of the fiber. However, refractive index is generally constant in the cladding. The refractive index profile in the core is giving by.

$$n(r) = n_1\left[1-2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]^{1/2} \quad r < a\,(\text{core})$$

$$n_1(1-2\Delta)^{1/2} \simeq n_1(1-\Delta) = n_2,\ r \geq a\,(\text{cladding})$$

Q.1. (*c*) Value of Normalised frequency parameter for single mode graded index fiber is.....(1)

Ans.

$$V_c = 2.405\left(1+\frac{2}{\alpha}\right)^{1/2}$$

where α = Index profile

Q.1. (*d*) 6Km optical link consists of multimode step index fiber with a core refractive index of 1.5 and refractive index difference is 1%. Find the rms pulse broadening due to intermodel dispersion. **(3)**

Ans. The rms pulse broadening

$$\sigma_s = \frac{Ln_1\Delta}{2\sqrt{3}c} = \frac{1}{2\sqrt{3}} \times \frac{6\times10^3\times1.5\times0.01}{2.998\times10^8}$$

$$= 86.7 \text{ ns}$$

Q.1. (*e*) What are the advantages of optical fibers over copper cables. **(2)**

Ans. Advantages of optical fiber communication are:

(*a*) Enormous potential Bandwidth: The optical carrier frequency in the range 10^{13} to 10^{16} Hz yields a far greater potential transmission bandwidth than metallic cable system upto around 500 MHz.

(*b*) **Small size and weight:** Optical fibers have very small diameters which are often no greater than the diameter of a human hair.

(*c*) **Electrical isolation:** Optical fiber's are fabricated from glass, or plastic polymers, are insulators they do not exhibit earth loop & interface problem like metallic cables.

(*d*) **Immunity to interference and crosstalk:** Optical fibers form a dielectric waveguide & are therefore free from EMI, RFI or EMP.

(*e*) **Signal Security:** The light from optical fibers does not radiate significantly and therefore they provide a high degree of signal secuirty.

(*f*) **Low transmission loss:** Optical fibers have very low attenuation or transmission loss (0.2dB/km) in comparision with copper cables.

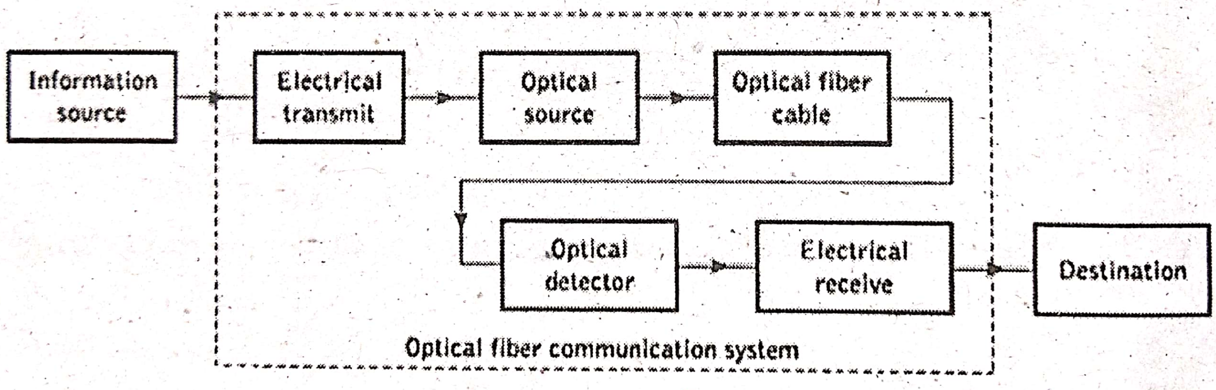
(*g*) **Ruggedness and flexibility:** Due to small size & weight optical fiber cables are superior than conventional cable in terms of storage, transportation, handling and installation.

(*h*) **System reliability and ease of maintenance:** Low loss property of optical fiber cables reduce the requirements of intermediate repeaters in comparision with conventional electrical conductor systems.

(*i*) **Potential low cost:** The glass which generally provides the optical fiber transmission medium is made from sand-not a scarce resource. So in comparison with copper conductors, optical fibers offer the potential for low cost line communication.

Q.2. (*a*) Explain the basic architecture of analog optical fiber communication system along with the LED drive circuit used. Also draw the block diagram (3)

Ans. The basic architecture of analog optical fiber communication system is shown below:



In this case the information source provides an electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the light wave carrier. The optical source which provides the electrical–optical conversion may be either a semiconductor laser or light-emitting diode (LED). The transmission medium consists of an optical fiber cable and the receiver consists of an optical detector which drives a further electrical stage and hence provides demodulation of the optical carrier. Photodiodes (*p–n*, *p–i–n* or avalanche) and, in some instances, phototransistors and photoconductors are utilized for the detection of the opticalsignal and the optical–electrical conversion. Thus there is a requirement for electrical interfacing at either end of the optical link and at present the signal processing is usually performed electrically.

Q.2. (*b*) On the basis of ray theory explain numerical aperture and acceptance angle. Find the numerical aperture in terms of refractive index difference. (3)

Ans. A light ray incident on the fiber core at an angle θ_1 to the fiber axis which is less than the acceptance angle for the fiber θ_2. The ray enters the fiber from a medium (air) of refractive index n_0, and the fiber core has a refractive index n_1, which is slightly greater than the cladding refractive index n_2.

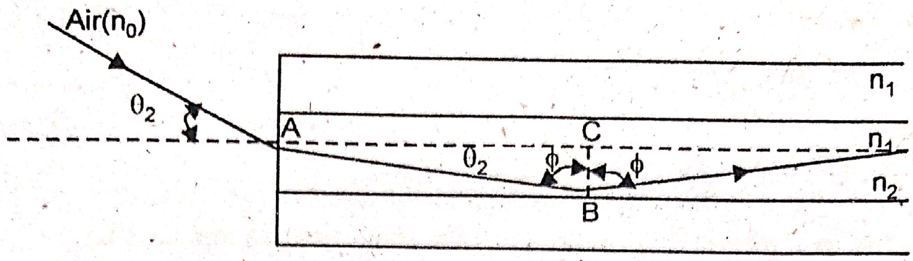


Fig.1

Assuming the entrance face at the fiber core to be normal to the axis, then considering the refraction at the air–core interface and Using Snell's law,

$$n_0 \sin\theta_1 = n_1 \sin\theta_2 \quad \text{...(1)}$$

Considering the right-angled triangle ABC indicated in Figure 1, then:

$$\phi = \frac{\pi}{2} - \theta_2 \quad \text{...(2)}$$

where ϕ is greater than the critical angle at the core–cladding interface. Hence Eq. (1) becomes:

$$n_0 \sin\theta_1 = n_1 \cos\phi \quad \text{...(3)}$$

Using the trigonometrical relationship $\sin^2\phi + \cos^2\phi = 1$, Eq. (3) may be written in the form:

$$n_0 \sin\theta_1 = n_1{}^{C1} - \sin^2\phi)^{\frac{1}{2}} \quad \text{...(4)}$$

When the limiting case for total internal reflection is considered, ϕ becomes equal to thecritical angle for the core–cladding interface, also in this limiting case $\theta 1$ becomes the acceptance angle for the fiber θa. Combining these limiting cases into Eq. (4) gives:

$$n_0 \sin\theta_a = \left(n_1^2 - n_2^2\right)^{\frac{1}{2}} \quad \text{...(5)}$$

Equation (5), apart from relating the acceptance angle to the refractive indices, serves as the basis for the definition of the important optical fiber parameter, the numerical aperture(NA). Hence the NA is defined as:

$$NA = n_0 \sin\theta_a = (n_1^2 - n_2^2)^{\frac{1}{2}} \quad \text{...(6)}$$

The NA may also be given in terms of the relative refractive index difference Δ between the core and the cladding which is defined as:

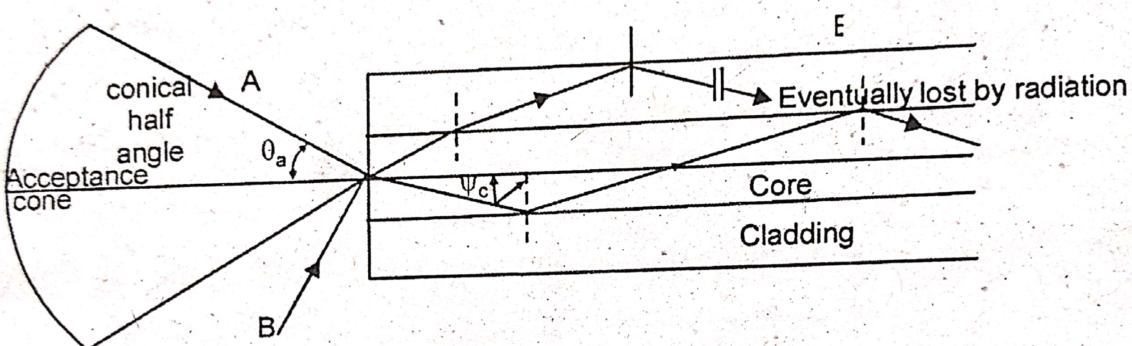
$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

$$= \frac{n_1 - n_2}{n_1} \text{ for } \Delta << 1 \quad \text{...(7)}$$

Combining (6) and (7)

$$\text{NA} = n_1(2\Delta)^{\frac{1}{2}}$$

Acceptance angle: The geometry concerned with launching a light ray into an optical fiber is shown in Figure 2, which illustrates a meridional ray *A* at the critical angle ψc within the fiber at the core–cladding interface. It may be observed that this ray enters the fiber core at an angle θa to the fiber axis and is refracted at the air–core interface before transmission to the core–cladding interface at the critical angle. Hence, any rays which are incident into the fiber core at an angle greater than θa will be transmitted to the core–cladding interface atan angle less than ψc, and will not be totally internally reflected. This situation is also illustrated in Figure 2, where the incident ray *B* at an angle greater than θa is refracted in to the cladding and eventually lost by radiation. Thus for rays to be transmitted by total internalreflection within the fiber core they must be incident on the fiber core within an acceptance cone defined by the conical half angle θa. Hence θa is the maximum angle to the axis at which light may enter the fiber in order to be propagated, and is often referred to as the acceptance angle for the fiber.



Q.2. (c) A step index multimode optical fiber in air has a numerical aperture of 0.17 and core diameter of 45 micrometer and core refractive index 1.46. Find: (*a*). Normalized frequency for the fiber at a wavelength of 0.85micrometer. (*b*). Number of guided modes. **(4)**

Ans. Given that

$$NA = 0.17 \text{ and core diameter} = 45\ \mu m$$

$$\lambda = 0.85\ \mu m$$

(*a*) Normalized frequency

$$V = \frac{2\pi}{\lambda}a(NA) = \frac{2\times3.14\times22.5\times10^{-6}\times0.17}{0.85\times10^{-6}}$$

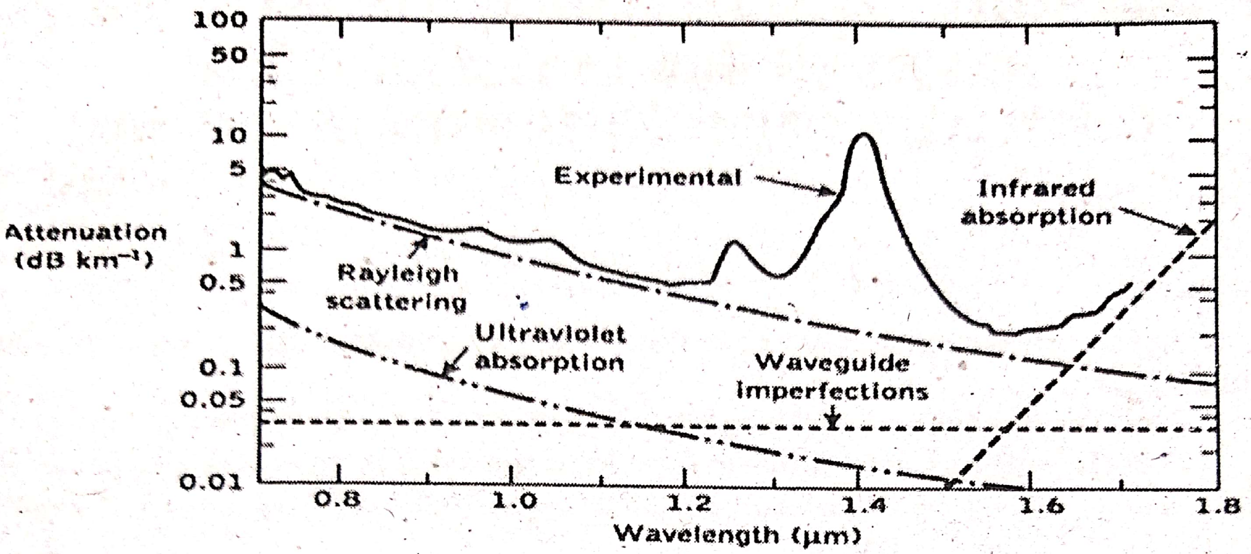
$$= 28.26$$

(*b*) No. of guided mode

$$M_s = \frac{V^2}{2} = 399.31 \approx 400$$

Q.3. (*a*) Explain the main cause of attenuation in optical fibers, with reference to losses. Show the wavelength for minimum losses in attenuation spectrum for single mode fiber. **(5)**

Ans. A number of mechanisms are responsible for the signal attenuation within optical fibers. These mechanisms are influenced by the material composition, the preparation and purification technique, and the waveguide structure. They may be categorized within several major areas which include material absorption, material scattering (linear and nonlinear scattering), curve and micro-bending losses, mode coupling radiation losses and losses due to leaky modes. The wavelength for minimum lossess in attenuation spectrum for single mode fiber is shown below



Q.3. (*b*) The mean power launched in a fiber link is 1.5 m W and fiber has an attenuation of 0.5d/km. Determine the maximum possible link length when the minimum mean power optical level at the detector is 2 micrometers. (5)

Ans. Given that: $p_i = 1.5\text{mW}, p_o = 2\ \mu\text{W}, \alpha_{\text{dB}} = 0.5$ dB/km

The attenuation expressed in decibels per unit length is given by

$$\alpha_{dB}L = 10\log_{10}\left(\frac{p_i}{p_o}\right) = 10\log_{10}\left(\frac{1.5\times10^{-3}}{2\times10^{-6}}\right)$$

$$= 28.75$$

$$L = \frac{28.75}{0.5dB/km} = 57.5km$$

Q.4. (*a*) What is meant by ZMD. At which wavelength zero dispersion occurs. With reference to ZMD point discuss dispersion shifted single mode fibers. (4)

Ans. ZMD stands for zero material dispersion . The ZMD point occurs at a wavelength of1.276 μm for pure silica, but that the influence of waveguide dispersion shifts the total dispersion minimum towards the longer wavelength giving a λ0 of 1.32 μm.

At wavelengths longer than the ZMD point in most common fiber designs, the *DM* and *DW* components are of opposite sign and can therefore be made to cancel at some longer wavelength. Hence the wavelength of zero first-order chromatic dispersion can be shifted to the lowest loss wavelength for silicate glass fibers at 1.55 μm to provide both low dispersion and low-loss fiber. This may be achieved by such mechanisms as a reduction in the fiber core diameter with an accompanying increase in the relative or fractional index difference to create so-called dispersion-shifted single-mode fibers (DSFs). However, the design flexibility required to obtain particular dispersion, attenuation, mode-field diameterand bend loss characteristics has resulted in specific, different refractive index profiles forthese dispersion-modified fibers.

Q.4. (*b*) Derive the r.m.s pulse broadening due to intermodal dispersion for multimode stepindex fiber. (6)

Ans.4 (b) Refer Q.No.2 of Question Bank

SECOND TERM EXAMINATION [NOV. 2015]
SEVENTH SEMESTER [B.TECH]
OPTICAL COMMUNICATION [ETEC–403]

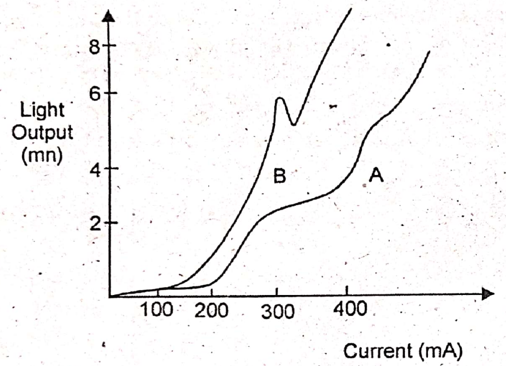
Time : 1½ hrs. **M.M. : 30**

Note: *Attempt Question. No.1, which is compulsory and any two more questions from remaining.*

Q.1. (a) Draw a graph between the driving current and optical output power of an ILD. (1)

Ans. The light output power against the current of an ILD is shown below:

ILD (Injection Laser diode): Stimulated emission by the recombination of the injected carriers by the provision of an optical cavity in the crystal structure in order to provide the feedback of photons.



Q.1. (b) Compare the 3dB optical bandwidth with the electrical 3dB bandwidth. Also find the optical bandwidth if the electrical BW is 50MHz. (3)

Ans. Electrical bandwidth: The ratio of the electrical output power to the electrical input power in decibels RE_{dB} is given by:

$$RE_{dB} = 10\log_{10}\frac{\text{electrical power out (at the detector)}}{\text{electircal power in (at the source)}}$$

$$= 10\log_{10}\frac{I^2_{out}/R_{out}}{I^2_{in}/R_{in}} \alpha 10\log_{10}\left[\frac{I_{out}}{I_{in}}\right]^2$$

Optical bandwidth: The ratio of the optical output power to the optical input power in decibels RO_{db} is given by,

$$RO_{db} = 10\log_{10}\frac{\text{optical power out (received at detector)}}{\text{optical power in (transmitted at source)}}$$

$$= 10\log_{10}\frac{I_{out}}{I_{in}}$$

Hence the optical 3dB points occur when the ratio of the ratio of the currents is

Thus from above disucussion. Electrical bandwidth is defined by the frequency when the output current has dropped to 0.707 of the input current output current has dropped to 0.707 of the input current optical bandwidth is defined by the frequencies at which the output current has dropped to 0.5 of the input current.

Q.1. (c) Give the advantages of LED OVER Laser. (2)

Ans. Advantages of LEDs.

(*i*) Simpler fabrication.

(*ii*) Cost is less due to simpler construction.

(*iii*) Reliability: LEd does not exhibit catastrophic degradation and also immune to self pulsation and modal noise problems.

(*iv*) Less temperature dependence.

(*v*) Simpler drive circuitry

(*vi*) Linearity

Q.1. (d) What are the merits of Heterojunction over homojunction. (2)

Ans. Merits of hetrojunctions are

(*i*) It has sufficiently large bandgap differences to improve the injection efficiency of either electron or holes.

(*ii*) It is widely used for the fabrication of injection lasers and high-radiance LEDs.

(*iii*) It is used to provide potential barriers in injection lasers.

Q.1. (e) Calculate the external power efficiency of a injection laser having 18% of total efficiency and the bandgap energy is 1.43eV. The voltage applied to the device is 2.5 V. (2)

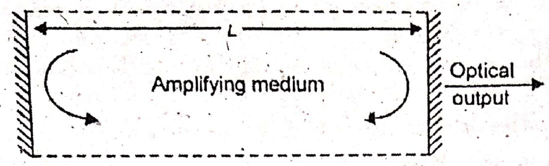
Ans. The external power efficiency is given by

$$\eta_{ep} = \eta_T\left(\frac{Eg}{V}\right)\times 100\%$$

$$= 0.18\left(\frac{1.43}{2.5}\right)\times 100 \cong 10\%$$

Q.2. (a) Explain the working of Fabry-Perot resonator. Also derive the spectral distance between the two adjancent axial modes. (5)

Ans. Light amplification in the laser occurs when a photon colliding with an atom in the excited energy state causes the stimulated emission of a second photon and then both these photons release two more. Continuation of this process effectively creates avalanche multiplication, and when the electromagnetic waves associated with these photons are in phase, amplified coherent emission is obtained. To achieve this laser action it is necessary to contain photons within the laser medium and maintain the conditions for coherence. This is accomplished by placing or forming mirrors' (plane or curved) at either end of the amplifying medium. The optical cavity formed is more analogous to an oscillator than an amplifier as it provides positive feedback of the photons by reflection at the mirrors at either end of the cavity. Hence the optical signal is fed back many time whilst receiving amplification as it passes through the medium. The structure therefore acts as a Fabry-Petrot resonator. Although the amplification of the signal from a single pass through the medium is quite small, after multiple passes the net gain can be large. Furthermore, if one mirror is made partially transmitung, useful radiation may escape from the cavity.



Thus when the optical spacing between the mirrors is L the resonance condition along the axis of the cavity is given by

$$L = \frac{\lambda q}{2n}$$

where λ is the emission wavelength, n is the refractive index of the amplifying medium and q is an integer. Alternatively, discrete emission frequencies f *are* defined by

$$f = \frac{qc}{2nL} \qquad ...(2)$$

where c is the velocity of light. The different frequencies of oscillation within the laser cavity are determined by the various integer values of q and each constitutes a resonance or mode. Since Equations. (1) and (2) apply for the case when L *is* along the longitudinal axis of the structure the (frequencies given by Equation. (2) are known as the longitudinal or axial modes. Furthermore, from Equation (2) it may be observed that these modes are separated by a frequency interval δf where.

$$\delta f = \frac{c}{2nL} \qquad ...(3)$$

The mode separation in terms of the free space wavelength; assuming $\delta f < f$ *and as* $f = c / \lambda$, is given by:

$$\delta\lambda = \frac{\lambda \delta f}{f} = \frac{\lambda^2}{c}\delta f \qquad ...(4)$$

Hence substituting for δf from Equation (3) gives:

$$\delta\lambda = \frac{\lambda^2}{2nL} \qquad ...(5)$$

Q.2. (*b*) The radioactive and non-radioactive recombination lifetime of minority carriers in the active region of a LED are 60ns and 100ns. Find the total recombination time period and power generated internally at a wavelength of 0.87 micrometer and at drive current of 40mA. **(5)**

Ans. The total carrier recombination lifetime is given by

$$\tau = \frac{\tau_r \tau_{nr}}{\tau_r + \tau_{nr}} = \frac{60 \times 100ns}{(60+100)} = 37.5ns$$

Internal quantum efficiency

$$\eta_{int} = \frac{\tau}{\tau_r} = \frac{37.5}{60} = 0.625$$

The power internally generated is,

$$P_{int} = \eta_{int}\frac{hci}{e\lambda} = \frac{0.625 \times 6{,}626 \times 10^{-34} \times 2.998 \times 10^{8} \times 40 \times 10^{-3}}{1.6 \times 10^{-19} \times 0.87 \times 10^{-6}}$$

$$= 35.6 \text{ mW}$$

Q.3. (*a*) Derive the expression for responsitivity of an intrinsic Photodiode in terms of Quantum efficiency of device and the wavelength of incident radiation. Also draw a graph between responsitivity vs wavelength. **(5)**

Ans. The photodiode has a p-n junction or PIN structure. The *P-N* junction is made up of a light sensitive semiconductor. When the photon energy excites the p-n junction, the electrons will be mobilized and the holes are produced. This process occurs in the depletion region of the *p-n* junction. The holes then move towards the anode and the electrons towards the cathode. This generates the photocurrent in the photodiode.

The quantum efficiency n is defined as the fraction of incident photons which are absorbed by the photodetector and generate electrons which are collected at the detector terminals:

$$n = \frac{\text{number of electrons collected}}{\text{number of incident photons}} \qquad ...(i)$$

Hence,

$$\eta = \frac{r_e}{r_p} \qquad ...(ii)$$

Where r_p is the incident photon rate and r_e is the corresponding electron rate.

The expression for quantum efficiency does not involve photon energy and therefore the responsivity R is often of more use when characterizing the performance of a photodetector. It is defined as:

$$R = \frac{I_p}{P_0}(AW^{-1}) \qquad ...(iii)$$

Where I_p is the output photocurrent in amperes and P_0 is the incident optical power in watts. The responsivity is a useful parameter as it gives the transfer characteristic of the detector (i.e., photo current per unit incident optical power)

Considering the energy of a photon $E = hf$. The incident photon rate r_p may be written in terms of incident optical power and photon energy as:

$$r_p = \frac{P_0}{hf} \qquad ...(iv)$$

in Eq. (ii) the electron rate is given by

$$r_e = \eta r_p \qquad ...(v)$$

Subsitituting from Eq. (u) we obtain

$$r_e = \frac{\eta P_0}{hf} \qquad ...(vi)$$

Therefore, the output photocurrent is

$$I_p = \frac{\eta P_0 e}{hf} \qquad ...(vii)$$

Where e is the charge on an electron. Thus from Eq. (iii) the responsivity may be written as:

$$R = \frac{\eta e}{hf} \quad ...(viii)$$

E.q (viii) is a useful relationship for responsivity which may be developed a stage further to include the wavelength of the incident light.

The frequency f of the incident photons is related of their wavelength and the velocity of light in air c, by:

$$f = \frac{c}{\lambda} \quad ...(ix)$$

Substituting into Eq. (*viii*), a final expression for the responsivity is given by:

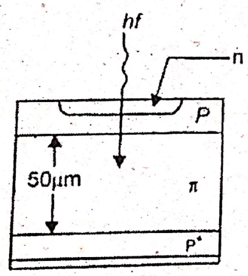
$$R = \frac{\eta e \lambda}{hc} \quad ...(x)$$

OR

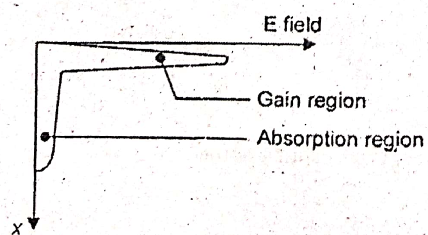
Q. 3(*b*) Eplain the working of silicon reach through avalanche phatadiode.

Ans. To ensure carrier multiplication without excess noise for a specific thickness of multiplication region wiithin the APD it is necessary to reduce the ratio of the ionization coefficients for electrons and holes k. In silicon this ratio is a strong function of the electric field varying from around 0.1 at 3×10^5 Vm^{-1} to 0. 5 at 6×10^5 Vm^{-1}. Hence for minimum noise, the electric field at avalanche breakdown must be as low as possible and the impact ionization should be initiated by electrons. To this end a 'reach through' structure has been implemented with the silicon avalanche photodiode. The silicon reach through APD (RAPD) consists of $p^+ - \pi - p - n^+$ layers as shown in Figure.(a). As may be seen from the corresponding field plot in Figure *(b)*, the high field region where the avalanche multiplication takes place is relatively narrow and centred on the $p - n^+$ junction. Thus under low reverse bias most of the voltage is dropped across the $p - n^+$ junction.

When the reverse bias voltage is increased the deplection layer widens across the p region until it 'reaches through' to the nearly intrinsic (lightly doped) π region. Since the π region is much wider than the p region the field in the π region is much lower than that at the $p - n^+$ junction. This has the effect of removing some of the excess applied voltage from the multiplication region to the π region giving a relatively show increase in multiplication region it is high enough (2×10^4 Vcm^{-1}) when the photodiode is operating to sweep the carriers through to the multiplication region at their scattering limited velocity (10^7 cm S^{-1}). This limits the transit time and ensures a fast response (as short as 0.5 ns).



(a)



(b)

Q.3. (*b*) A P-I-N photodiode generates one electron hole pair per two incident photons at wavelength of 0.85 micrometer. Calculate the Quantum efficiency and the mean output photocurrent when the incident optical power is 10 microwatt. (5)

Ans. Quantum efficiency

$$\eta = \frac{\text{number of electrons collected}}{\text{number of incident photons}}$$

$$= \frac{1}{2} = 0.5$$

i.e. 50%

Output photocurrent is

$$I_p = \frac{\eta p_o e}{hf} = \frac{\eta p_o e \lambda}{hc}$$

$$= \frac{0.5 \times 10 \times 10^{-6} \times 1.6 \times 10^{-19} \times 0.85 \times 10^{-6}}{6.626 \times 10^{-34} \times 2.998 \times 10^8}$$

$$I_p = 3.427 \ \mu A$$

Q.4. (*a*) Explain different multiplexing techniques used for optical fiber communication. (6)

Ans. Multiplexing techniques used for optical fiber communication are

(*i*) Optical time division multiplexing (OTDM)

(*ii*) Subcarrier multiplexing (SCM).

(*iii*) Orthogonal frequency division multiplexing (OFDM).

(*iv*) Wavelength division multiplexing (WDM).

(*v*) Optical code division multiplexing (OCDM).

(*vi*) Hybrid multiplexing

Optical time division multiplexing: For increasing the bit rate of digital optical fiber system beyond the bandwidth capabilites of the drive electronics is know as OTDM. The optical multiplexing and demultiplexing ratio is 1:4.

Subcarrier multiplexing (SCM): In SCM, the microwave frequency or RF electrical subcarriers are modulated with an optical carrier and than are transmitted using s single-wavelength signal.

Orthogonal Frequency division multiplexing: It employs several subcarrier frequencies orthogonal to each other and therefore they do not overlap. Hence this technique can squeeze multiple modulated carriers tightly together at a reduced bandwidth.

Wavelength division multiplexing: It involves the transmission of a number of different peak wavelength optical signals in parallel on an single optical fiber.

Optical code division multiplexing: It is a digital technique where, instead of each channel occupying a given wavelength frequency or time slot, the information is transmitted using a coded sequence of pulses. Each channel employs a specific code to transmit and recover the original signal.

Hybrid multiplexing: When two (or more) different multiplexing techniques are combined to allow optical signal multiplexing for several optical signals, the resultant is referred to as hybrid multiplexing Hybrid WDM/TDM systems can support terabit per second transmission rates when several WDM channels are combined with OTDM technology.

Q.4. (*b*) Give the difference between first, second, and third generation digital optical fiber communication system. **(4)**

Ans. First generation-system: This system was designed primarily for inter office use in metropolitan areas. This was introduced into 3rd level of digtal hierarchy DS3 at 44.7 Mb/s and was called as FT3 lightwave digital transmission system. It used 50/125 graded index fiber. The optical power of about 0.5 mW and operating at 0.826 μm. The detector used was Si-APD.

2nd generation system: It was based on the use of monomode fibers. They usually operate at the wavelength of 1.3 μm. Compared to the 1st generation system, the repeater spacings are significantly longaer in this case. There are three possible systems that can be considered.

(*a*) Systems operating with minimum material dispersion at 1300 μm.

(*b*) Systems with minimum attenuation at 1550 nm.

(*c*) System using a fiber in which material and waveguide dispersion minimum is shifted so as to get attenuation minimum.

3rd generation system: In this case optical amplification, external modulation and hetrodyne detection is used. The system operated at 1550 nm. There is an increased use of opto-electronic integrated circuits and integrated optical components. The 3rd generation system is basically an intensity modulated system, where the dispersion limit can be raised in three ways:

(1) Use of dispersion shifted fiber.

(2) Use of an external modulator rather than direct modulation.

(3) Use of solition propagation.

END TERM EXAMINATION [DEC. 2015]
SEVENTH SEMESTER [B.TECH]
OPTICAL COMMUNICATION [ETEC–403]

Time : 3 hrs. **M.M. :75**

Note: *Attempt any five question including Q.No.1 which is compulsory.*

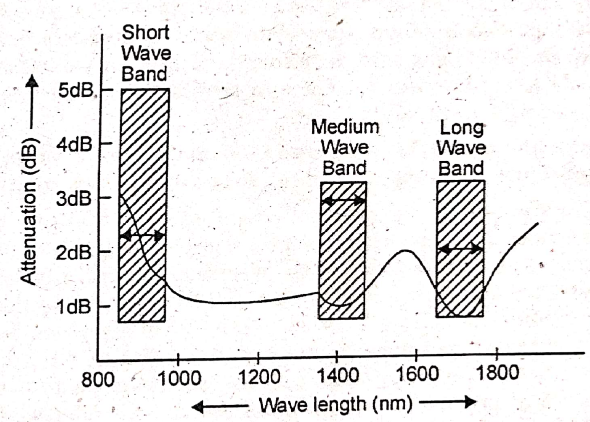
Q.1. (*a*) Describe the function of the core and cladding in optical fiber. Why their refractive are indexes different. **(2)**

Ans. Optical fiber has two layers inner and outer with three basic elements such as core, cladding and coating. Core is nothing but a light transmission area made up of either glass or a plastic. Cladding provides a lower refractive index at the core interface to cause reflection within the core and light are transmitted through the fiber.

Their refractive indexes are different to cover complete reflection of light within the fiber without any distortion

Q.1. (*b*) What does the transparent windows means? Specify three peak wavelength for the transparent window in modern opticasl fibers. **(3)**

Ans. Optical window can be understood by considering the attenuation that would be expected for a particular wavelength. The figure given below of optical window with respect to the wavelength.



Q.1. (*c*) What are the primary features of designing of an optical source? **(3)**

Ans. Features of designing of an optical source are:

1. A size and configuration compatible with launching light into an optical fiber.Ideally, the light output should be highly directional.

2. Must accurately track the electrical input signal to minimize distortion and noise.Ideally, the source should be linear.

3. Should emit light at wavelengths where the fiber has low losses and low dispersion and where the detectors are efficient.

4. Preferably capable of simple signal modulation over a wide bandwidth extending from audio frequencies to beyond the gigahertz range.

5. Must couple sufficient optical power to overcome attenuation in the fiber plus additional connector losses and leave adequate power to drive the detector.

6. Should have a very narrow spectral bandwidth (line-width) in order to minimize dispersion in the fiber.

7. Must be capable of maintaining a stable optical output which is largely unaffected by changes in ambient conditions (e.g. temperature).

8. It is essential that the source is comparatively cheap and highly reliable in order to compete with conventional transmission techniques.

Q.1. (*d*) Explain the Optical Access Network. (3)

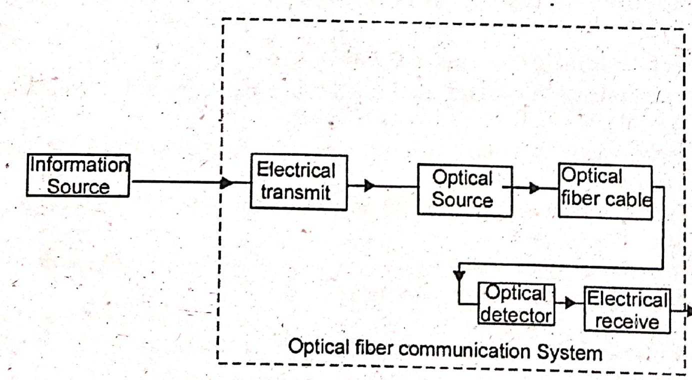
Ans. The access network is an element of a public telecommunications network that connects access nodes to either individual users (i.e. business, residential) or MANs. Therefore itcan be considered as the last link in a network between the customer's premises and the first point of connection to the network infrastructure (i.e. local exchange/switching centeror local office).Access networks based on hybrid fiber coaxial (HFC) are a combination of two technologies employing both optical fiber and coaxial cable as the media. Originally, HFC was a cable TV (CATV) concept to provide TV broadcasting and reception in rural areas.

Q.1. (*e*) How linear scattering does contributes to increase in BER? (3)

Ans. Linear scattering mechanisms occurs when some or all of the optical power is transferred linearly (i.e., proportionally to the input optical power injected into the dominant mode) from the dominant propagating, node to adjacent modes. This process results in attenuation of the transmitted light as the transfer may be to a leaky or radiation mode which may not continue to propagate within the fiber core, and is readiated from the fiber. But being a linear process no change of frequency on scattering takes place. This optical energy transfer promotes intersymbol interference [ISI] which contributes to an increase in the BER.

Q.2. (*a*) Draw a block diagram of an optical communication system showing its various components. Explain in brief the function of each component. (8)

Ans. The information source provides an electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the light wave carrier. The optical source which provides the electrical - optical conversion may be either a semiconductor later or light emitting diode (LED). The transmission medium consists of an optical fiber cable and the receiver consists of an optical detector which drives a further electrical stage and hence provides demodulation of the optical carrier. Photodiodes (*p-n, p-i-n* or avalanche) and, in some instances, photo transistors and photo conductors are utilized for the detection of the optical signal and the optical-electrical conversion.



Description of each component is given below:

(*i*) Information Source: An information source is a source of information for somebody, *i.e.* anything that might inform a person about something or provide knowledge about it. Information sources may be observations, people, speeches, documents, pictures, organizations, websites, etc.

(*ii*) Electrical transmit: In electronics & telecommunications a transmitter or radio to the optical input radio transmitter is an electronic device which, with the aid of an antenna produces io waves. The transmitter itself generates a radio frequency altering current, which pplied to the antenna. ,

(*iii*) Optical Source: The optical source in a fiber optic transmitter is usually an LED or laser diode.

(*iv*) Optical fiber cable: Optical fiber consists of a core and a cladding layer, it is a cable containing one or more optical fibers. The optical fiber elements are typically individually coated with plastic layers and contained in a protective tube suitable for the environment where the cable will be deployed.

(*v*) Optical detector: Its function is to convert the received optical signal into an electrical signal, which is then amplified before further processing, therefore when considering signal attenuation along the link, the system performance is determined at the detector.

(*vi*) Electrical Recive: It is the part in a complete circuit that receives the elecrical energy.

Q.2. (*b*) Determine the number of modes for a multimode fiber if core radius (a = 20 μm), wavelength (λ = 0.85 μm), n_1 = 1.475 and n_2 = 1.472. How many modes will propagate if λ is changed to 1.3 μm? (7)

Ans. Given that (a core radius) = 20 μm = 20×10^{-6} m

$$n_1 = 1.475 \text{ and } n_2 = 1.472$$

$$\lambda = 0.85\ \mu m = 0.85\times10^{-6}\ m$$

We have

$$NA = \left(n_1^2 - n_2^2\right)^{1/2} = \sqrt{(1.475)^2 - (1.472)^2}$$

$$NA = 0.094$$

Also

$$V = \frac{2\pi}{\lambda} a(NA) = \frac{2\times3.14}{0.85\times10^{-6}}\times20\times10^{-6}(0.094)$$

$$= 13.89$$

Hence

$$M = \frac{V^2}{2} = \frac{(13.89)^2}{2} \cong 96$$

If λ is changed to 1.3 μm then

$$V = \frac{2\pi}{\lambda} a(NA) = \frac{2\times3.14}{1.3\times10^{-6}}\times20\times10^{-6}(0.094) \cong 9$$

Hence

$$M = \frac{V^2}{2} = \frac{(9)^2}{2} \cong 41$$

Q.3 (a) What is polarization in optical fibre. Explain. (7)

Ans. Refer Q.No.3. of Question Bank

Q.3. (b) Discuss the LED emission pattern for surface emitting LED and edge emitting LED. (8)

Ans. Surface emitting LED has been widely used with DH structure for increasing efficiency and less absorption. The structure of a high-radiance etched well DH surface emitter for the 0.8 to 0.9 μm wavelength. The internal absorption in this device is very low due to the larger bandgap-confining layers, and the reflection coefficient at the back crystal face is high giving good forward radiance. The emission from the active layer is essentially isotropic, although the external emission distribution may be considered Lambertian with a beam width of 120° due to refraction from a high to a low refractive index at the GaAs–fiber interface. The power coupled P_c into a multimode step index fiber may be estimated from the relationship

$$P_c = \pi(1-r)AR_D(NA)^2$$

However, the power coupled into the fiber is also dependent on many other factors including the distance and alignment between the emission area and the fiber, the SLED emission pattern and the medium between the emitting area and the fiber. For instance, the addition of epoxy resin in the etched well tends to reduce the refractive index mismatch and increase the external power efficiency of the device.

Another basic high-radiance structure currently used in optical communications is the stripe geometry DH edge emitter LED (ELED). This device has a similar geometry to a conventional contact stripe injection laser.It takes advantage of transparent guiding layers with a very thin active layer (50 to 100 μm) in order that the light produced in the active layer spreads into the transparent guiding layers, reducing self-absorption in the active layer. The consequent wave-guiding narrows the beam divergence to a half-power width of around 30° in the plane perpendicular to the junction.However, the lack of wave-guiding in the plane of the junction gives a Lambertian output with a half-power width of around 120°.

Most of the propagating light is emitted at one end face only due to a reflector on the other end face and an antireflection coating on the emitting end face. The effective radianceat the emitting end face can be very high giving an increased coupling efficiency in to small-*NA* fiber compared with the surface emitter. However, surface emitters generally radiate more power into air (2.5 to 3 times) than edge emitters since the emitted light isless affected by reabsorption and interfacial recombination.

Q.4. (a) Differentiate between intermodal and intramodal dispersion. Explain the concept of dispersion shifted fiber. (7)

Ans. In optical fiber communication if transmission involves digital modulation i.e. transmission of pulses through optical fiber cable then broadening of the transmitted pulses if they travel along the channel is called dispersion.

In dispersion, the transmitted pulse broadens and overlap with its neighbours and eventually indistinguishable at the receiver. For no overlapping of light pulses, the digital bit rate B_T must be less than the the resiprocal of the pulse duration (2τ). *i.e.*

$$\boxed{B_T \leq \frac{1}{2\tau}}$$

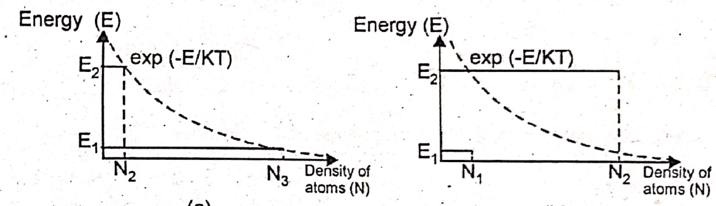
Dispersion can be divided into two categories:

(i) Intermodal dispersion: The different modes travelling within a multimode fiber introduces a multimode fiber introduces a propagation delay difference between the modes giving rise to dispersion. This is called intermodal dispersion.

(ii) Intramodal dispersion: Optical sources used fibers emit not just a signal frequency but a band of frequencies. Each transmitted mode therefore gives a different component. This causes the propagation delay difference between different spectral components of the transmitted signal. This leads to the broadening of each transmitted mode, thereby giving rise to intramodal dispersion.

Q.4. (b) What is population inversion? What is meant by optical and electrical commement in LASER? How is it achieved? Explain. (8)

Ans. Under the conditions of thermal equilibrium given by the Boltzmann distribution the lower energy level E_1 of the two-level atomic system contains more atoms than the upper energy level E_2. This situation, which is normal for structures at room temperature, is illustrated in Fig.(a). However, to achieve optical amplification it is necessary to create a non-equilibrium distribution of atoms such that the population of the upper energy level is greater than that of the lower energy level (i.e. $N_2 > N_1$). This condition, which is known as population inversion, is illustrated in Fig.(b).



(a) (b)

In order to achieve population inversion it is necessary to excite atoms into the upper energy level E_2 and hence obtain a non-equilibrium distribution. This process is achieved using an external energy source and is referred to as 'pumping'. A common method used for pumping involves the application of intense radiation (e.g. from an optical flash tube or high-frequency radio field). In the former case atoms are excited into the higher energy state through stimulated absorption.

Q.5. (a) Why does an optical transmission section (Amplifier) layer exist at each WDM node and not just at the amplifier node? (7)

Hint: Optical transmission section exist at each WDM node and not at amplifier node because optical transmission is required at receiving end not on an amplification node.

Since in wavelength division multiplescing (WDM) the wavelength of the signal is divided into blocks.

Q.5. (b)In a p-n photodiode: (7)

(i) Can we increase the bandwidth by varying the thickness of the depletion region.

Ans. Yes

(ii) Can we increase the bandwidth by varying its load resistance.

Ans. Yes

(iii) What is the role of the active area of ~~a~~ photodiode?

Ans. Active area of a photodiode is used for the detection of light at the receiving end in optical communication.

Q.6. (a) Define Numerical Aperture and derive its expression for the step index fiber. A multimode step index fiber has a refractive index difference of 1% and a core refractive index of 1.5. The number of modes propagating at a wavelength of 1.3 μm is 1600. Calculate the acceptance angle, numerical aperture and the diameter of the fiber core. (8)

Ans. Given that $M_s = \frac{V^2}{2}$

or $V = \sqrt{2M_s} = \sqrt{3200} = 56.56$

We have $V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{1/2}$

Since NA (Numerical Aperture) $= n_1 (2\Delta)^{1/2}$

Hence $x_1 (2\Delta)^{1/2} = \frac{V\lambda}{2\pi a} = \frac{56.56 \times 1.3 \times 10^{-6}}{2 \times 3.14 \times 9}$

Also given that, refractive index difference of 1%. Hence

$$\Delta = 0.01 = \frac{n_1 - n_2}{n_1} = 1 - \frac{n_2}{n_1}$$

Hence $\frac{n_2}{n_1} = 1 - \Delta = 1 - 0.01 = 0.99$

$\therefore$ $n_2 = 0.99 n_1 = 0.99 \times 1.5 = 1.485$ (given that $n_1 = 1.5$)

Hence $NA = \left(n_1^2 - n_2^2\right) = [(1.5)^2 - (1.48)^2] = [2.25 - 2.20]$

$$\boxed{NA = 0.05}$$

From equation (1) $NA = \frac{56.56 \times 1.3 \times 10^{-6}}{2 \times 3.14 \times 9}$

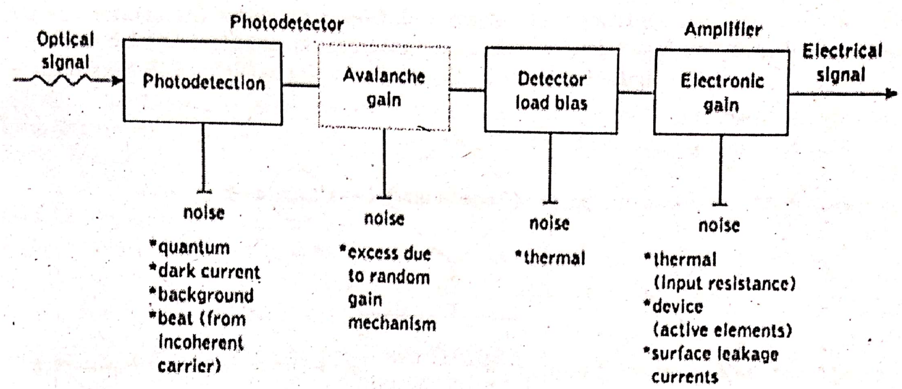
Hence a (diameter of the giber) $= \frac{56.56 \times 1.3 \times 10^{-6}}{2 \times 3.14 \times 0.05}$

$$\alpha = \frac{73.528 \times 10^{-6}}{0.314} = 234.16 \mu m$$

Acceptance angle $(\theta_a) = \sin^{-1}(NA) = \sin^{-1}(0.5) = 2.86°$

Q.6. (b) Briefly discuss the possible source of noise in optical recivers. (7)

Ans. Figure shows a block schematic of the front end of an optical receiver and the various noise sources associated with it. The majority of the noise sources shown apply to both main types of optical detector (*p–i–n* and avalanche photodiode).



The noise generated from background radiation, which is important in atmospheric propagation and some copper-based systems, is negligible in both types of optical fiber receiver, and thus is often ignored. Also the beat noise generated from the various spectral components of the incoherent optical carrier can be shown to be insignificant with multimode propagation and hence will not be considered.

Q.7. (a) The quantum efficiency of a photo detector is 80% at a wavelength of 0.85 μm. When the incident optical power is 0.6 μW, output current after avalanche gain is 12 μA. Calculate the multiplication factor. (7)

Ans. Given that efficiency is 80% *i.e,* $\eta = 0.8$

$$\lambda = 0.85 \mu m = 0.85 \times 10^{-6} m.$$

$$P_0 = 0.6 \mu W = 0.6 \times 10^{-6} W.$$

and $I = 12 \mu A = 12 \times 10^{-6} A.$

We know that the responsivity

$$R = \frac{\eta e \lambda}{hc} = \frac{0.8 \times 1.6 \times 10^{-19} \times 0.85 \times 10^{-6}}{6.626 \times 10^{-34} \times 3 \times 10^8} = 0.547 AW^{-1}$$

the photocurrent

$$I_p = P_0 R = 0.6 \times 10^{-6} \times 0.547 = 0.328 \mu A$$

The multiplication factor

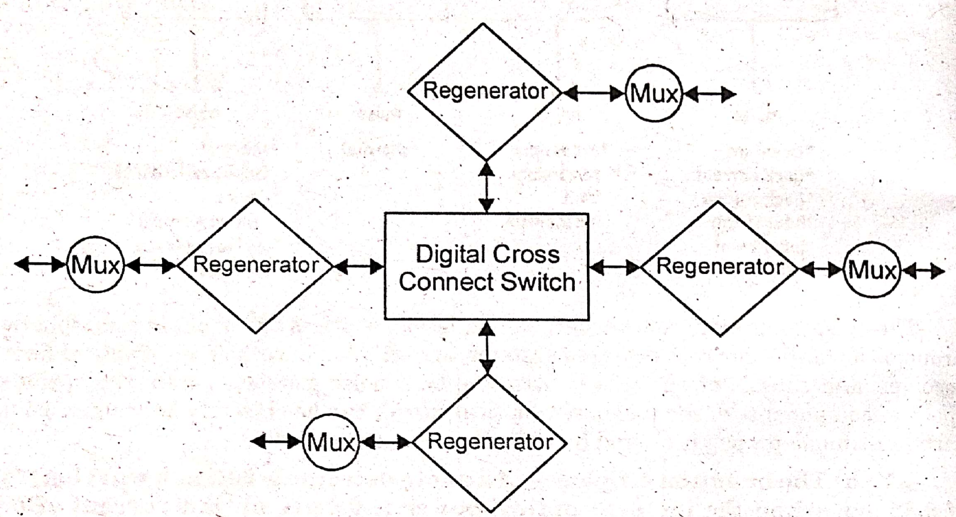
$$M = \frac{I}{I_p} = \frac{12 \times 10^{-6}}{0.328 \times 10^{-6}} = 36.58$$

The multiplication factor of the photodiode is approximately 37.

Q.7. (b) Write detail note on Synchronous optical fiber network (SONET). (8)

Ans. SONET is the American National Standard Institute (ANSI) standard for synchronous data transmission on optical media. SONET provdies standards for a number of line rates upto the maximum line rate of 39.808 giga bits per second and is considered to be foundation for the physical layer of the broadband ISDN. Optical carrier levels are defined for their electrical equivalents, called synchronous transport signals for the optic fiber.

The basic network element consist of a terminal multiplexer (PTE), a regenerator (needed for long distance transmission), an add drop multiplexer (ADM) (for use pn point-to-multipoint configuration),w ide band digital cross-connects (w – DCs), broadband cross connects, and the digital loop carrier. Figure shows the SONET HUB Network.



SHD (Synchronous Digital Hierarchy): It is defined by:

1. G.707: This gives transmission bit rates.
2. G.708: Indicates the network node interference (NNI).
3. G.709: Gives the multiplexing structure and configuration for the NNI.

SDH is applied in all application sectors like the local loop, inter-exchange network and the long haul link. Multiplexing is done with ease from a lower to higher signal hierarchy or demodulation from higher to lower hierarchy.

Q.8. (*a*) Discuss the use of access couplers in fiber optics data communication and LANs. Compare the properties of Tree and Star coupler. (7)

Ans. The bus configuration utilizes three port fiber couplers to act as both beam splitter/combiner devices for the transmit and receive paths at each node, as well as passive fiber access couplers or taps along the buslink.

The loss per kilometer exhibited by the fiber cable αfc enables the total fiber cable loss between the two terminals to be written as$(N-1)\ \alpha_{fc}L_{bu}$ where L_{bu} is equal to the fiber length between each of the access couplers.

Furthermore, the total loss incurred by the signal in passing through the access couplersor taps between nodes 1 and $N-1$ (excepting the final access coupler at which the signal to node $N-1$ is tapped off) is given by $(2\ \alpha_{cr} + L_{ac})$ (N– 3) where L_{ac} is the insertion loss of the access coupler. At the final access coupler before node $N-1$ the loss obtained is $(2\sigma_{cr} + L_{tr})$ where L_{tr} is the loss due to the tap ratio of the device.

Star couplers distribute an optical signal from a single-input fiber to multiple-**outputfibers. In an ideal star coupler** the optical power from any input fiber is evenly **distributed** among the output fibers. The total loss associated with the star coupler **comprises** its theoretical splitting loss together with the excess loss.

A tree coupler would be used to supply optical signals to a bus type network of in-line terminals. It is also reffered to as an optical tap, due to nature of the device. A majority of the power continues forward, but a portion of the signal is tapped to be used for an output port.

Q.8. (*b*) List and explain the recent developments in the field of optical communication. How the nonlinear effects are restricting the data rates? Explain. (8)

Ans. At the dawn of optical communications, optical Time-division Multiplexing: OTDM helped improve communication speed. This was primarily achieved by speed improvement of electronic circuits in transmitters and receivers.

Recent developments and reserch in optical communication are:

(*i*) Space-Division Multiplexing (SDM)
(*ii*) Optical-Time Division Multiplexing (OTDM)
(*iii*) Wind Profile Redar (WPR)
(*iv*) Range Imaging Observation
(*v*) Satellite/Terrestrial Integrated mobile Communication System
(*vi*) Satellite sensor system
(*vii*) Wireless image Transmission System.

Optical fibers exhibit a variety of nonlinear effects. Fiber nonlineraities are feared by telcome system designers because they can affect system performance adversely. Nonlinear effects are useful for many device and system application:

(*i*) Optical switching
(*ii*) Soliton formation
(*iii*) Wavelength conversion
(*iv*) Broadband amplification
(*v*) Demultiplexing.