UNIT - 6

OPTICAL SYSTEM DESIGN

Design Considerations: The user specifies the distance over which the information is sent and the data rate to be transmitted. The designer then as to define the specifications of system component.

The design criteria are given in the following

1. Primary design criteria
   - Data rate
   - link length
2. Additional design parameter
   a) Modulation format : Analog | Digital

It depends upon the type of signals user want to transmit. for example, if it is TV signal, then analog transmission may be more suited. since, it requires less bandwidth and better linearity. If data & sampled voice is to be transmit then digital transmission may be more appropriate. For long distance, repeaters are neccessary. Digital repeaters are simpler than analog receivers and digital transmission gives higher quantity received signals. A disadvantage of digital form is the increased bandwidth required for its transmission.

b) System Fidelity :- The System fidelity defines the correctness of data received at the receiver. For digital transmission it is measured by the bit-error-rate (BER). It is defined as,

$$BER = \frac{\text{No: of bits in error}}{\text{Total no: of bits transmitted}}$$

In optical system, the BER has to be $< 10^{-9}$

For analog transmission, the Quantity parameter is the signal to noise ratio (SNR)

c) Cost : Components, installation, maintainence.

The Component and the installation Costs are initial Cost.

Generally, the installation cost is much higher than the Components cost for longer link. The optical link is supposed to work for long time. Hence, the maintainance. Cost is also important.

d) Upgradability : The optical fiber technology is changing rapidly and the data rates are increasing steadily. The system should be able to adopt new technology and should be able to accommodate higher data rates with least possible changes.

e) Commercial availability : The availability of the components is also important.

Point-to-point optical link : A single point-to-point link is shown in fig 1.

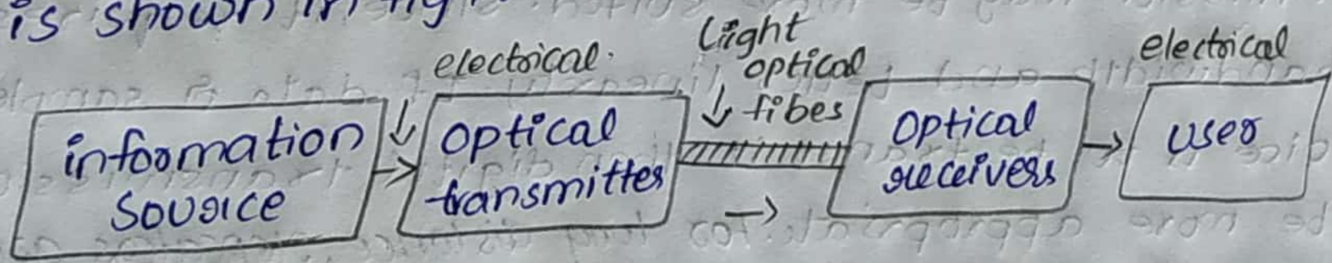


FIG 1

The link has mainly three Components to design
1. optical transmitter
2. optical fiber.
3. optical receiver

Component NO.	Component name	Characteristics
1.	(Transmitter Parameters) light source (LED, laser DIODE)	1. Emission wavelength (λ) 2. Radiance. 3. Effecting emitting arrow. 4. Emission pattern. 5. Spectral line width ($\Delta\lambda$)
2.	(channel parameters) optical fibes (singlemode, multimode).	1. core size (2a) 2. Core refractive index (n_1) 3. NA 4. Relative refractive index difference (Δ) 5. Bandwidth. 6. Attenuation (& dB/cm)
3.	(Receiver parameters) optical detector (PIN, APD)	1. Responsivity. 2. operating wavelength 3. speed. 4. Senstivity.

Analysis of fiber link: Two important analysis for deciding the performance of any fiber link are

1. Link power budget analysis (power budget)
2. Rise time budget analysis [Bandwidth budget]

Link power budget Analysis:

- The power budget means the amount of loss that a data link {Tx to Rx} can tolerate inorder to operate properly.
- The optical power received at the receiver depends on the amount of light coupled into the fiber and losses ocurring in the fiber.
- The power at the receiver is equal to the Transmitted power − link losses. linklosses should not exceed the allowed loss. If it exceeds the allowed loss signal cannot be received properly.
- An optical power loss model for a point to point link is shown in figure 2.

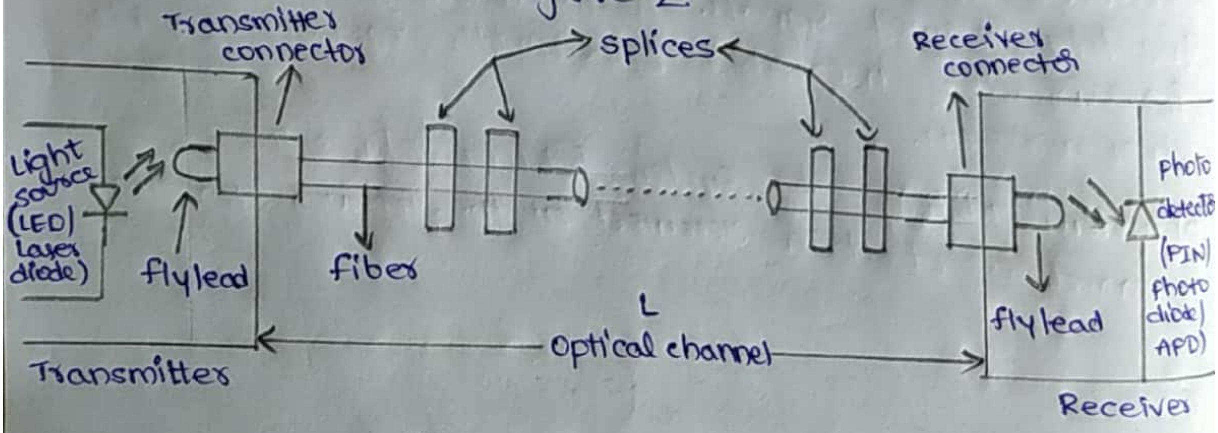


Figure 2

Lsp → losses due to single splice

number of splices, $n = \frac{L}{l} - 1$

L is length of fiber in kilometers

l is distance between two splices

$L_c \rightarrow$ Loss due to connector

$\alpha \rightarrow$ attenuation of fiber (dB/km)

$\therefore$ Total loss is given by - $P_T = \underbrace{2L_c}_{\text{Connector loss}} + \underbrace{n \cdot L_{sp}}_{\text{splice loss}} + \underbrace{\alpha L}_{\text{attenuation}} + \text{system margin}$

$P_T = 2L_c + nL_{sp} + \alpha L + \underbrace{\text{system margin}}$

other losses due to component aging and temperature fluctuations.

It is generally 6dB to 8dB.

This loss should not cross the allowed loss. If it exceeds the allowed loss, signal can not be received properly.

Q. Determine the optical power received in dBm and watts for a 20km optical fiber link with the following parameters, LED output power of 30mW.

Four 5km sections of optical cable each with a loss of 0.5dB/km.

Three cable to cable connectors with a loss of 2dB each

No cable splices, Light source to fiber interface loss of 1.9 dB, fiber to light detector loss of 2.1 dB.

No losses due to cable bends.

Sol: length of fiber, $L = 20km$

LED output power, $P_{out} = 30mW = 14.8dBm$

$$dBm = 10\log\frac{P}{1mW}$$

Attenuation, $\alpha = 10dB$ $[0.5 \times 20km = 10dB]$

connector loss $= 3 \times 2dB = 6dB$

Light source to fiber interface loss $= 1.9dB$

fiber to light detector loss $= 2.1dB$

Total loss $= 10 + 6 + 1.9 + 2.1$

$= 20dB$

Received optical power $P_T = P_{TX} - P_{RX}$

$$= [14.8 - 20]\,dBm$$

$$= -5.2\,dBm$$

$$dBm = 10\log\frac{P}{1mw}$$

$$-5.2 = 10\log\frac{P}{1mw}$$

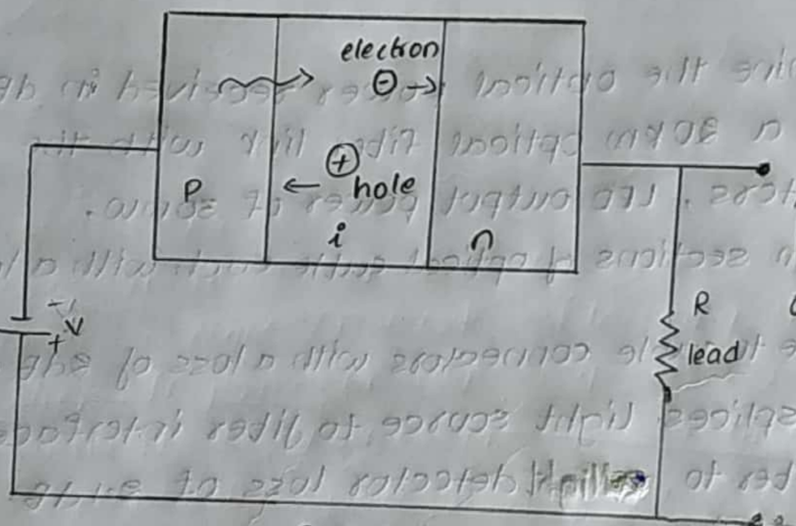
$$-0.52 = \log\frac{P}{1mw}$$

$$\frac{P}{1mw} = 10^{(-0.52)}$$

$$\boxed{P = 0.301\,mw}$$

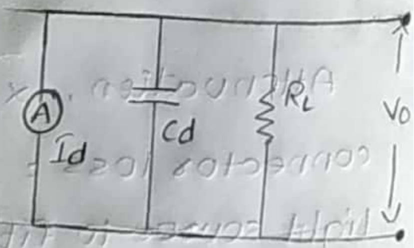
PIN-PHOTO Diode Equivalent circuit :

The structure of PIN-photo diode is shown in fig(a)



Fig(a)

The equivalence circuit of PIN photo-diode is shown in fig(b)
Cd is junction capacitance formed by the P type and n-type Semi Conductor Seperated by the intrinsic layers.
Analysis of the Circuit use the rise time as, $t_r = \boxed{2.19\, R_2 \cdot Cd}$



Fig(b)

The 3dB band width is given by:

$$f_{3dB} = \frac{1}{2\pi R_2 Cd}$$

Photo diode designed for high speed applications have

Capacitances of an few pico-farads. To obtain low capacitance. The diode Surface area must be Small. However, for efficient coupling the area cannot be reduced below the area of attached optical fibers Core.

MECHANICAL PROPERTIES OF OPTICAL FIBERS :-

1. In Sensing technology, the mechanical properties of optical fibers are important for the sensors characterization
2. Most of the optical fibers based Sensors rely on deformation of optical fibers to determine the external Parameters of intrest.
3. The expression for Critical radius of Curvatures is given by

$$R_{cm} = \frac{3\pi n_1^2 \lambda}{4\pi (n_1^2 - n_2^2)^{3/2}}$$

where, n_1 = refractive index of Core

n_2 = refractive index of cladding

λ = operating wavelength

4. The fiber Bragg (FBG) concept is useful to know the mechanical properties optical fibers.
5. If an optical fiber is protected mechanical, it will Suffer a deformation proportional to the amplitude of perturlation force-

The Hooke's law is given by the following expression along the longitudinal axis of the fiber: $k = \frac{|F|}{|\Delta l|}$

where k is elastic constant and Δl is the relative deformation impost by the pertubing force (F).

The fiber young modules, (E_G) is the proporinality constant between $F = E_G \cdot A \cdot \frac{\Delta l}{l}$ the pertubation force per unit area and relative deformation: $F = E_G \cdot A \cdot \frac{\Delta l}{l}$

where, A is area and l is length of optical fibers Under Pertubation.

From the above 2 expressions, we can write as, $|k| = \frac{E_G \cdot A}{l}$

Mode Delay Factor :-

The transit time (or) group delay (T_g) for a light pulse Propagating along unit length of fiber is $T_g = \frac{1}{v_g}$ where v_g - group velocity.

The group index of a uniform plane was propagating in a homogeneous medium is $N_g = \frac{c}{v_g}$, where c is speed of light in Vaccum = 3×10^8 m/sec

Let Ng_1 & Ng_2 are the group indices for the fiber Core Cladding regions respectively, then the expression for the group delay is given by,

$$\Rightarrow \tau g = \frac{1}{c}\left[Ng_2 + n_2 \Delta \frac{d(vb)}{dv}\right]$$

where, Δ is relative refractive index difference

b is normalised frequency.

v is normalised propagating Constant.

The term $\frac{d(vb)}{dv}$ is called modes delay factor.

Absorption, Spontaneous emission & Stimulated emission :- The basic Concepts associated with LASER are absorption, Spontaneous emission & stimulated emission.

Consider an isolated atom, it can exist either in the ground State (E_0) (or) in excited State (E_x)

Initially, the atom is in ground state when external energy (in the form of light) is supplied, the atom absorbs the energy and passes on the excited state. we call this Process as Absorption

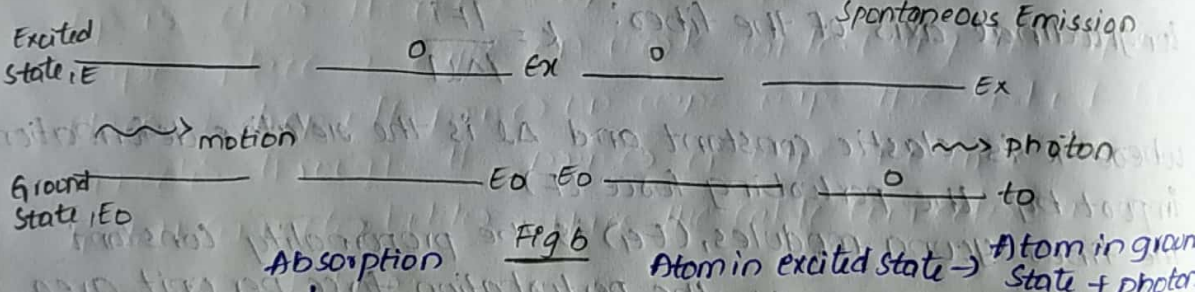


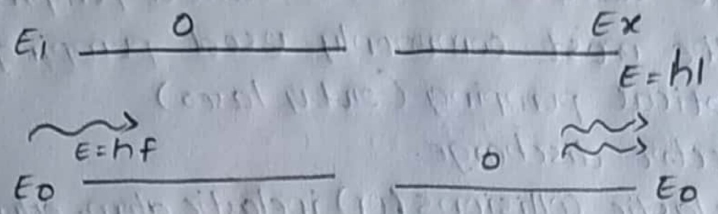
Fig b

Atom is ground state + photon ⟶ Atom in excited state

An Atom is always stable in the ground state with its lowest Possibles energy. The atom in the excited State is unstable. The tendency of the atom is to Come back to ground State. The life time of the atom in the excited state is very small. and is order of 10^{-8} sec. when the atom is the excited state emitted back to ground state, it emitts exactly the some amount of energy it absorbs, when moving from ground state to excited state, we call as Spontaneous emission.

(Fig(b))

when the atom is in excited state, if the photon is passed by the atom, it can stimulate the atom to move to its ground state, the atom returns to the ground state, we call this process as stimulated emission. In stimulated emission, 2-photons are emitted. The 2-photons will have similar energy, similar direction of propagation, stimulated emission is principle of laser.



Atom is excited state + photon ⟶ Atom in ground state + 2 photon

* Explain population inversion:-

Consider a collection of atom. Let 'N_x' be the no. of atoms in the excited state and (N_0) be the no. of atoms in the ground state.

From Boltzman's law., $N_x = N_0 \cdot e^{-\frac{(E_x \cdot E_0)}{kT}}$

where, E_x - Energy of excited state.

E_0 - Energy of ground state.

$E_x \to E_0 \Rightarrow \frac{E_x}{kT} > \frac{E_0}{kT}$

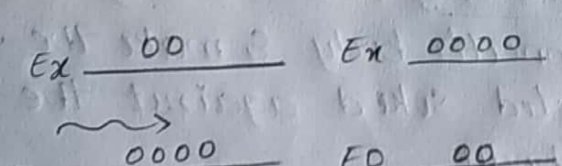
$\Rightarrow \frac{\frac{E_x}{kT}}{\frac{E_0}{kT}} > 1 \Rightarrow$ i.e., $\frac{E_x \cdot E_0}{kT} > 1$

$e^{-\left(\frac{E_x \cdot E_0}{kT}\right)} < 1$

$N_x = N_0 (<1)$

$\Rightarrow N_x < N_0$

This means the ground state is more populated than the excited state (fig a). when the ground state is more populated if a photon is



Fig(a) Fig(b)

Only for stimulated emission, we will have more (populated) no:of stimulated emission, if there is no more atoms in the excited state there is ground state, i.e we need population inversion (fig b)

In order to acheive population inossion, we need to supply energy to laser medium. The sources that supplies energy in the laser medium is called pumping source.

Some of the most commonly used pumping source are as follows optical pumping (ruby laser)
electric discharge.
Treelastic collisions (or) inelastic atom-atom collision
Thermal pumping.
chemical reactions.

* Explain the procedure of installing fiber connectors in optical fibers

Ans: Connector installation:

1. Apply the primer fiber to fiber buffer: Using syringe with prime unique apply primer to 0.25 inches of fiber buffer. Avoid getting primer on fiber.
2. Prepare connector tip: Make sure that the hole in the connector tip is clear. It necessary clear the hole with a thin wipe place a wipe on work table. Using the syringe place a drop off primer on wipe. wipe the end of fiber connector through the primer on wipe one time.
3. Install connector holder: place the cable connector: a
a. connector holder.
4. Inject adhesive into connector: Gently invert the syringe on adhesive through the qubing in the back off the body until the battons against Inject adhesive into until a layer of adhesive forms on tip of the
5. Insert fiber into connector body: Immediately insert the fiber through the connector body & make the sure that the buffer is completed suked against the ceramic inside the connector body.
6. Install buffer support: Apply a drop of actile super border to be large & small grooves at the back of the

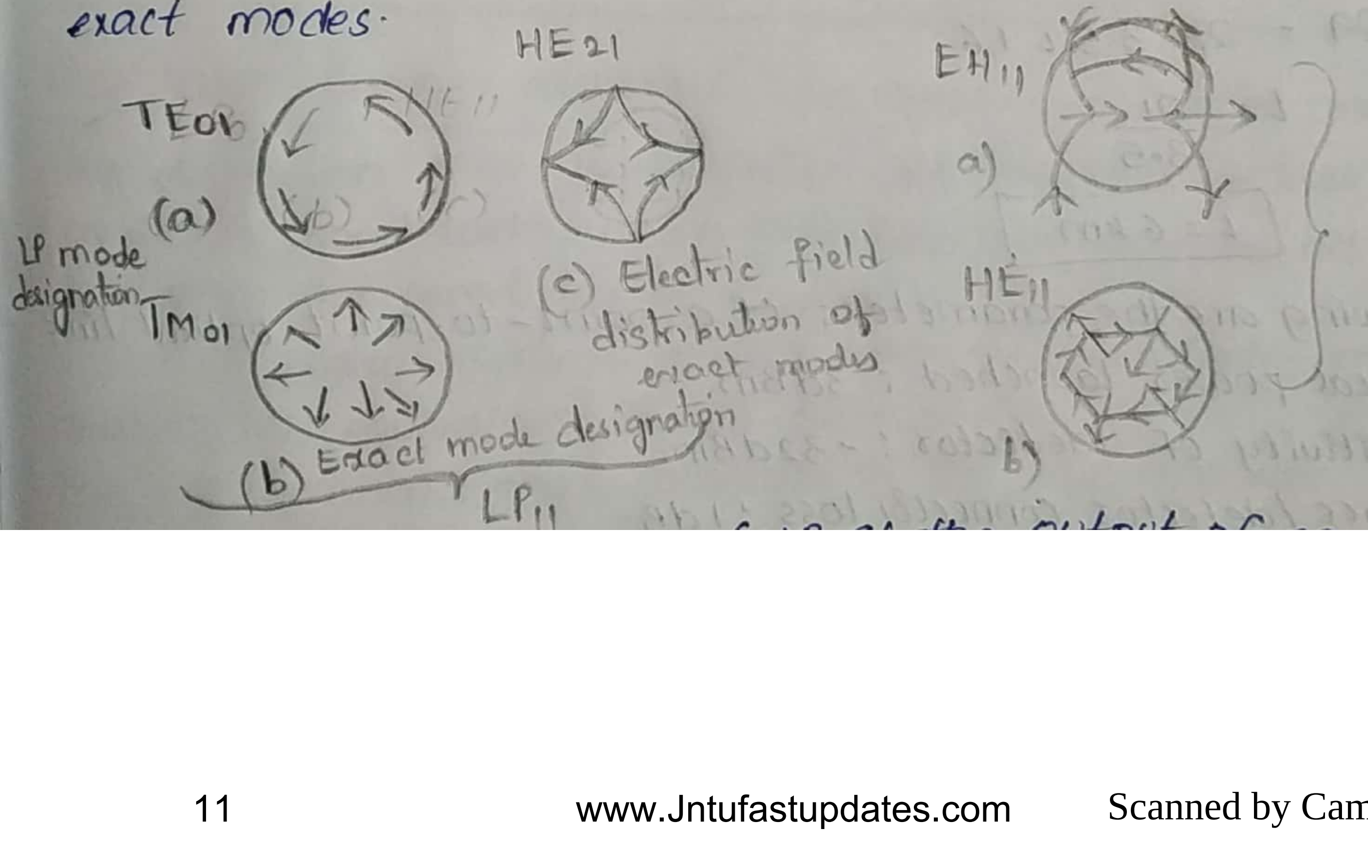
Connector body. Allow adhesive to Gueiv atleast one minute

* Explain linearly polarised (LP) modes ?

In an optical fiber, there can be infinite no.'of paths of propagation but in practice, only a limited no.'of paths of propagation are possible, there allowed paths are called modes in optical fibers.

A mode for which the filled components ~~(perpendicular to the direction~~ is called linearly polarised (LP) mode) in the direction. If propagation are small compared to components perpendicular to the direction is called linearly polarised (LP) mode. The LP mode is represented by LPin. The mode are splite subscripts cm are related to the electric field intensity profile for a particular (LP) mode.

The electric field configurations for 3 lowest s LP modes is shown blow in terms of this constituent exact modes.



Problems

2. Design an optical link for a data rate of 20mbps and a bit error rate of 10^{-9}. The link attenuation is 3.5 db/km. The following assumptions can be made

a) The light source is Ga·As LED that can couple −13 dBm optical power level into a fiber.

b) The detector is a silicon thin photo-diode operated at 850nm. The received input signal is −42dBm.

c) The connector loss is 1dB/connector.

d) The power margin is 6dB.

Sol:- The transmitted power = −13dB

Received power = −42dB.

Power loss = −13 − (−42) = 29dBm

Power loss = Connector loss + fiber attenuation + power margin (Tx + Rx)

$$29 = 2 + 3.5L + 6$$

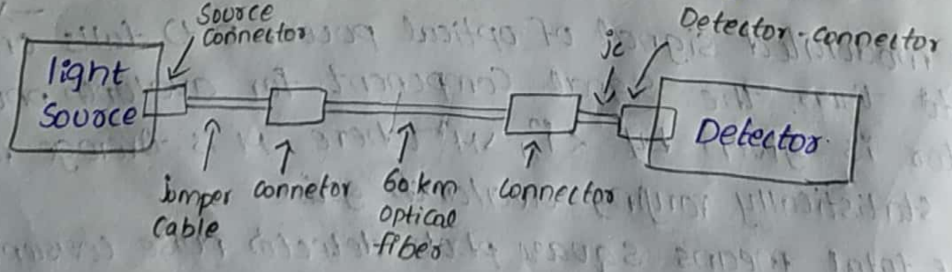
$$L = \frac{21}{3.5}$$

$$\boxed{L = 6\text{ km}}$$

3. Following are the parameters of a point-to-point optical link

1. Optical power launched : 3dBm.
2. Sensitivity of idetector : −32dBm.
3. Source/detector connector loss : 1dB.
4. length of optical cable : 60km
5. Cable attenuation : 0.3dB/km
6. Jumper cable loss : 3dB
7. Connector loss at each fiber joint : 1dB. (Two at each Tx & Rx end bcoz of the jumper cables)

Compute the power margin of the link using spreadsheet method



Ans:- Spread sheet for calculating an optical-link power budget is given below

Component/loss Parameter	output/Sensitivity/loss	Power Margin (dB)
1. LED output	3dBm	
2. Sensitivity of detector	-32dBm	-
3. Allowed loss	35dBm	-
4. Source Connector loss	1dBm	34 dB
5. Jmper cable loss + Connector loss (Tx)	4 dB (3+1)	30 dB
6. Cable attenuation	(60x0.3) 18dB	12 dB
7. Connector + Jumper Cable loss (Rx)	(3+1) 4 dB	8 dB
8. Detector Connector loss	1 dB	7dB (final margin)

RISE TIME BUDGET ANALYSIS :- In link power budget analysis, the dispersion effect is neglected. The dispersion reduces the available band width which may limit not only the bit rate but also the sensitivity of the receiver.

In digital systems, the dispersion analysis (pulse spreading analysis) is equivalent to riso-time analysis.

Four basic elements that contribute to the rise time are

1. Transmitter rise-time (t_{tx})
2. Group Velocity dispersion (GVD) rise time (t_{GVD})
3. Model dispersion rise-time (t_{mod}).
4. Receiver rise-time (t_{rx}).

Total rise-time of a fiber link is

$$t_{sys} = \sqrt{t_{tx}^2 + t_{GVD}^2 + t_{mod}^2 + t_{rx}^2}$$

1. Transmitter rise-time (t_{tx}) :- In transmitter dispersion is contributed by the light source and it driving circuit. Rise-time of LED is greater than LASER. For long-distance communication, laser diode is used. Tx rise time is represented by., 't_{tx}'

This value is Generally known to designer.

Rise time due to group Velocity dispersion is,

$t_{GVD} = D \sigma_\lambda L$ Spectral width of light Source

where, D is dispersion (n sec/nm-km)

L length of optical fiber

Pulse Spreading

σ_λ is half power spectral width of light source.

L is length of optical fiber.

Rise time due to model dispersion is,

$$\Rightarrow t_{mod} = \frac{440}{B_M} = \frac{440 \cdot L^q}{B_0}$$

where, B_M is bandwidth (MHz)

L is length of fiber (km)

q is a parameter ranging 0.5 & 1

B_0 is bandwidth of 1km length fiber.

Receiver front-end rise time is.,

$$\Rightarrow t_{rx} = \frac{350}{B_{rx}}$$

where B_{rx} is 3dB bandwidth of receiver (MHz)

∴ Total rise-time of a fiber link is,

$$\Rightarrow t_{sys} = \left[t_{tx}^2 + \left(\frac{440 \cdot L^q}{B_0} \right)^2 + D^2 \sigma_\lambda^2 L^2 + \left(\frac{350}{B_{rx}} \right)^2 \right]^{1/2}$$

All times are in nano-seconds (nsec)

The system band-width is

$$\Rightarrow \boxed{B_w = \frac{0.35}{t_{sys}}}$$

Problems :-

1. For a multi-mode fiber link following parameters are recorded.
   1, LED with drive Circuit has rise-time of 15 nsec
   2, LED Spectral width = 40nm.
   3, Material dispersion related rise-time degradation = 21 nsec over 6 km link.
   4, Receiver band width = 25 MHz.
   5, Modal dispersion rise time = 3.9 nsec

   Calculate System rise-time ?

Sol:- Transmitter rise-time, $(t_{tx}) = 15$ n sec

Modal dispersion rise-time, $(t_{mod}) = 3.9$ n sec

Material dispersion rise time $(t_{mat}) = 21\,nsec$

Receiver band width, $(B_{rx}) = 25\,MHz$

Receiver rise-time, $(t_{rx}) = \frac{350}{B_{rx}} = \frac{350}{25} = 14\,nsec$

∴ System rise-time,

$$t_{sys} = \left[(15)^2 + (3.9)^2 + (21)^2 + (14)^2\right]^{1/2}$$

$$\Rightarrow \boxed{t_{sys} = 29.61\,nsec}$$

2. A fiber link has the following data.

Component	Bandwidth	Rise-time (t_r)
1. Transmitter	200 MHz	1.75 nsec
2. LED (wave length = 850nm)	100 MHz	3.5 nsec
3. Fiber cable	90 MHz	3.89 nsec
4. Pin-detector	350 MHz	1 nsec
5. Receiver	180 MHz	1.94 nsec

Compute system rise time & Bandwidth ?

Sol: $t_{sys} = \left[(1.75)^2 + (3.5)^2 + (3.89)^2 + (1)^2 + (1.94)^2\right]^{1/2}$

$$\Rightarrow \boxed{t_{sys} = 5.932\,nsec}$$

$$B.w = \frac{0.35}{t_{sys}} = \frac{0.35}{5.932} = 0.058\,Hz$$

$$\boxed{B.w = 59\,MHz}$$

3. A 2km length of multi-mode fiber is attached to apparatus for Spectral loss measurement. The measured output voltage from the photo-receiver using the full, 2km fiber length is 2.1V at a wavelength of 0.85mm when the fiber is then cut-back to leave a 2kmts length, the output voltage increases to 10.7 volts. Determine the attenuation (per km) for the fiber with a wavelength of 0.85mm and estimate the accuracy of the result?

Sol: length of multi-mode fiber attached to apparatus, $(L_1) = 2km$

Measured output voltage from photo-receiver using 2km fiber length, $(V_1) = 2.1V$

wavelength, $(\lambda) = 0.85\ \mu m$

Cut-back fiber length, $(L_2) = 2m$

Measured output voltage using cut-back fiber length, $(V_2) = 10.7V$

Attenuation per km, $(\alpha)_{dB} = \frac{10}{L_1 - L_2} \log \frac{V_2}{V_1}$

$$\alpha = \frac{10}{2000 \cdot 2} \log \left(\frac{10.7}{2.1}\right)$$

$$\boxed{\alpha = 3.5\ dB/km}$$

The accuracy of the result obtained in this method depends on optical launch conditions.

4. Design optical fiber link & for transmitting 15Mbits of data for a distance of 4km with BER of 10^{-9}.

Sol: Transmitting data rate = 15Mbps.

Distance of transmission, $L = 4km$

Bit error rate, $BER = 10^{-9}$

Designing of optical fiber link :

Design of the optical fiber link is as follows.

1. Selection of light source :-

The distance of transmission is 4 km. For short distance applications, LED is preferred. Its operating wavelength is 820nm. It generates -10dBm optical power.

2. Selection of optical detector :-

For low optical power, pin-photo diode is used. The Sensitivity is -50dBm.

3. Selection of optical fiber cable :

The bandwidth & distance product is equal to $15 \times 4 = 60$ Mbps-km upto 100Mbps-km, a step-index multi-mode fiber is used.

4. Link power budget :-

For step-index multi-mode fibers, the standard values of losses are

Splicing loss = 0.5 dB/splice.

Connector loss = 1.5 dB/ connector

Pass margin = 8dB

Fiber attenuation = 6 dB/km

$\therefore$ Actual loss $= (2 \times 1.5) + (6 \times 4) + 8 = 35dB$

Maximum permitted loss = -10dBm - (-50dBm) = 40dBm

Hence actual loss is less than permitted loss. Hence the System will function well.

5. Estimate the receiver front-end rise-time, if the 3dB electrical B.W is 5MHz

Sol:- The 3dB electrical bandwidth, $B_{rx} = 5MHz$

Receiver front end rise time $(t_{rx}) = \frac{350}{B_{rx}} = \frac{350}{5} = 70nsec$

6. Calculate the system rise time of the 6km fiber optic link with the following specifications.

Rise time of the LED & its drive electronic Circuit = 12nsec

Material dispersion related rise time = 24nsec

Bandwidth of the optical receiver = 20MHz

Bandwidth distance product of fiber = 400MHz-km

Mode mixing factor, q over 6km fiber = 1

Sol:- Length of fiber, $(L) = 6km$

Rise-time of LED $(t_{tx}) = 12nsec$.

material dispersion related rise time $(t_{mat}) = 24nsec$

Bandwidth of optical receiver, $(B_{rx}) = 20MHz$

Bandwidth distance product of receiver, $(B_0) = 400MHz-km$

Mode mixing factor, $q=1$

System rise time, $t_{sys} = \left[(t_{tx})^2 + (t_{mat})^2 + (t_{mod})^2 + (t_{rx})^2\right]^{1/2}$

$$t_{mod} = \frac{440L^q}{B_0} = \frac{(440)(6)}{400} = 6$$

$$t_{rx} = \frac{350}{B_{rx}} = \frac{350}{20} = 17.5$$

$$t_{sys} = \left[(12)^2 + (24)^2 + 6^2 + (17.5)^2\right]$$

$$\Rightarrow \boxed{t_{sys} = 32.7\,nsec}$$

7. Calculate the rise time limit for the optical fiber system working at 1.3μm wavelength and 1 Gbps bit rate are a single mode fiber with a link length of 50km. The rise time of Tx & Rx are 0.25ns and 0.35ns respectively. The source spectral width is 3nm & the dispersion parameter is 2psec/km-nm ?

Sol:- wavelength, $\lambda = 1.3\mu m$

Bit rate, BER = 1 Gbps

fiber Length = 50km

Transmitter resistance $(t_{tx}) = 0.25ns$
Receiver rise time $(t_{rx}) = 0.35nsec$
Source spectral width $(\sigma_\lambda) = 3nm$
dispersion parameter, $(D) = 2ps/km\text{-}nm$

Rise time limit for optical fiber, $T_r = 1.1(t_{tx}^2 + t_{mod}^2 + t_{GVD}^2 + t_{rx}^2)$

$$\therefore T_r = 1.1\left[(0.25)^2 + 0 + (0.3)^2 + (0.35)^2\right]^{1/2}$$

let $t_{mod} = 0$; $t_{GVD} = D\sigma_\lambda L = \frac{(2)(3)\times10^{-12}\times10^{-9}(50\times10^{3})}{10^3\times10^{-9}}$

$$\Rightarrow t_{GVD} = 0.3nsec$$

$$\Rightarrow \boxed{T_r = 0.576nsec}$$

8. An optical fiber System is to be designed to operate Over 8km length without repeaters. The rise-time of the choosen components are; i) source (LED) = 8ns; ii) fiber intermodal (Pulse breadening) = 5ns/km iii) Intra-modal = 1ns/km; iv) Detector (pin photo diode) = 6nsec estimate the maximum bit rate that may be acheived in the link when using NRZ format.

Sol: length of optical fiber, $(L) = 8km$
Source rise time, $(t_{tx}) = 8nsec$
Inter modal rise time $(t_{inter}) = 5nsec/km$
Intra modal rise time $(t_{intra}) = 1ns/km$
Detector rise time $(t_{rx}) = 6nsec$
Maximum bit rate for NRZ format $= \frac{0.7}{T_r}$

$$\text{But, } T_r = 1.1\left[(t_{tx})^2 + (t_{inter})^2 + (t_{intra})^2 + (t_{rx})^2\right]^{1/2}$$

$$= 1.1\left[64 + (5\times6)^2 + (1\times8)^2 + 6^2\right]^{1/2}$$

$$\Rightarrow T_r = 46.2\ nsec$$

$$\therefore \text{Max. bit rate} = \frac{0.7}{T_r} = \frac{0.7}{46.2} = 0.015\times10^9 = 15Mbps$$

LINE CODING - NRZ, RZ & MAN CHESTER SINGAL FORMATS :-

In designing a Communication link for Sending digital information an important consideration is the format of the transmitted digital signal. The signal format is important because, the receiver must be able to extract precise tiny information from the incoming signal. The three main uses of timing are 1. To indicate the start end of each timing interval
2. To maintain a proper Spacing between pulses.
3. To allow the signal to be sampled by the receiver

at the time the SNR is maximum.

For this, the data (System) Stream is encoded. This process is Called channel Coding & line Coding. The following figure Shows the Signal formats.

NRZ (Non-return to zero)

The NRZ format derives it name from the fact that the Signal level does not return to zero during the bit Period. The Signal amplitude remains Constant throughout the bit period.

'1' Forces a high level & '0' forces a low level.

RZ (Return to zero):

'1' goes high for half the bit period.

'0' does nothing.

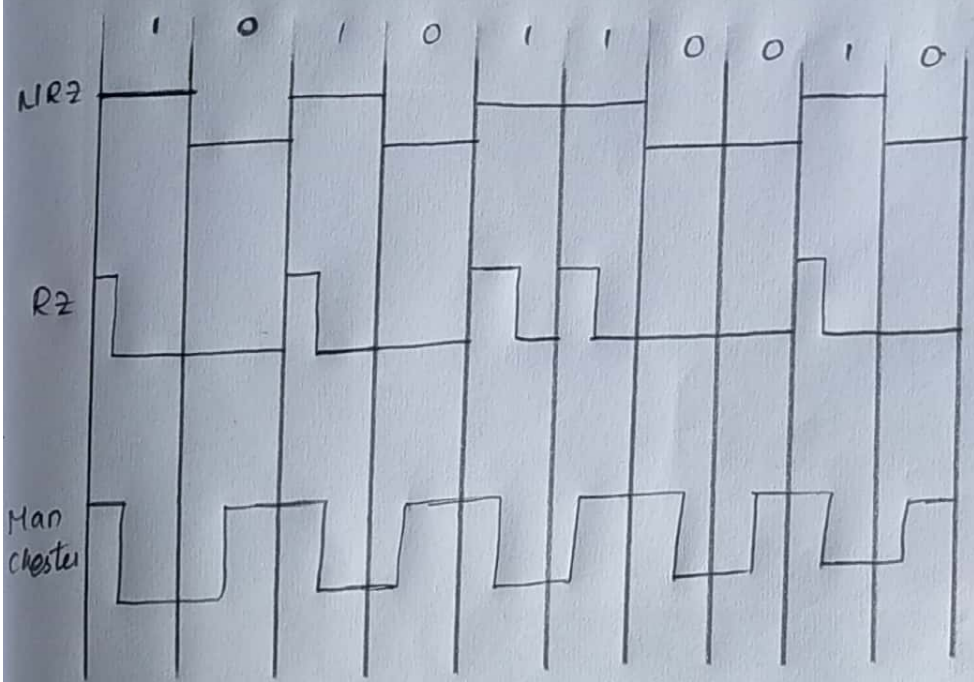
MANCHESTER format:-

Two Consecutive bits of same type forces a transmisson at the begining of the bit period.

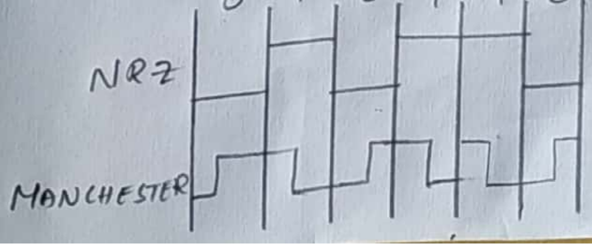
'1' forces a negative transition in the middle of the bit

'0' forces a positive transition in the middle of the bit

The formats are represented below.



1. Draw the waveforms of given data 010110 in NRZ & manchester coding.



→ Write expressions for SNR at the output of an APD based analog receiver and explain? (MAY 2014, 6M)

A. The signal-to-noise ratio (SNR) at output of optical receiver is defined by;

$$SNR = \frac{S}{N} = \frac{\text{Signal power from photo Current}}{\text{Photo detector noise power} + \text{Amplifier noise Power}} \longrightarrow (1)$$

If a modulated signal of optical power, $P(t)$ falls on detector, then the signal component for avalanche photo detectors is given by, $\langle i_D^2 \rangle M^2$, where 'M' is average value of the statistically varying avalanche gain.

The total mean square photo detector noise current can be written as,

$$\langle i_N^2 \rangle = \sigma_N^2 = \langle i_{shot}^2 \rangle + \langle i_{DB}^2 \rangle + \langle i_{DS}^2 \rangle = \sigma_{shot}^2 + \sigma_{DB}^2 + \sigma_{DS}^2.$$

The shot noise current as a mean square value given by,

$$\langle i_{shot}^2 \rangle = \sigma_{shot}^2 = 2q\, I_p\, B_e\, M^2 F(M),$$

where, q is charge of an electron

I_p is photo current.

B_e is receiver bandwidth

$F(M)$ is a noise figure related to the random nature of random process.

From experimental results, it has been found that,

$F(M) \approx M^x$.

where, x depends on material.

For PIN photo diodes, M and F(M) are equal to '1'. The photo-diode dark current is the current that flows in the device when no light is incident. This is combination of bulk and surface current. The bulk dark current (i_{DB}) is due to electrons & holes that are thermally generated in the photo-diode. The mean square value of this current is given by,

$$\langle i_{DB}^2 \rangle = \sigma_{DB}^2 = 2q \, I_D \cdot M^2 \cdot F(M) \cdot B_e$$

where I_D photo detector primary bulk dark current.

The surface dark current is also called surface leakage current or simply leak current. The means square value of surface dark current is given by,

$$\langle i_{DS}^2 \rangle = \sigma_{DS}^2 = 2 q \cdot I_L \cdot B_e$$

where, I_L is surface leakage current.

The photo-detector load resistor contribute a mean-square thermal noise current given by,

$$\langle i_T^2 \rangle = \sigma_T^2 = \frac{L_1 \cdot K \cdot T}{R_L} \cdot B_e$$

where, K is Boltzmann's constant

T is absolute temperature.

∴ This signal-to-noise ratio at the input of the amplifier is,

$$\Rightarrow \frac{S}{N} = \frac{\langle i_p^2 \rangle M^2}{2 \cdot q \cdot I_p \cdot B_e \cdot M^2 \cdot F(M) + 2q I_D M^2 F(M) \cdot B_e + \frac{4KT}{R_L} B_e + 2q I_L B_e}$$

$$\Rightarrow \frac{S}{N} = \frac{\langle i_p^2 \rangle M^2}{2q (I_p + I_D) M^2 F(M) B_e + 2q I_L B_e + \frac{4KT B_e}{R_L}}$$

In general, we can ignore negligible leakage current, we can also neglect the term involving (I_D) when the average signal current is much larger than the dark current. The signal-to-noise ratio then becomes,

$$\frac{S}{N} = \frac{\langle i_p^2 \rangle M^2}{2q I_p M^2 F(M) B_e + \frac{4KT B_e}{R_L}}$$

To achieve high SNR, the following conditions should be kept as low as possible.

1. The photo detector must have a high quantum efficiency to generate large signal power.
2. The photo detector of an amplifier noise should be kept as low as possible.

→ Explain frequency chirping in optical fibers.

Ans: 1. The DC modulation of a single longitudinal mode semiconductor laser can cause a dynamic shift of the peak wavelength emitted from device. This phenomenon is called frequency chirping. Frequency chirping produces dynamic line width broadening

2. Frequency chirping due to strong coupling between the free carrier density and the refractive index which is present in any semiconductor structure.

3. The frequency chirping (or) laser linewidth broadening combined with the chromatic dispersion characteristics of single mode fibers can cause a significant performance degradation with in high transmission rate system. It may result in a shift in operating wavelengths of the fiber which can finally effects the system performance.

4. For example, the wavelength shift that may occur in an Indium Gallium Arsenade Phosphorous (InGaAsP) laser around 0.05nm.

5. A number of techniques can be used to reduce the frequency chirping. One method is to bias the laser sufficiently above threshold so that the modulation current doesnot drive the device below the threshold. Another method is sharpening the electric drive pulses. certain device structures provide the improved performance in relation to frequency chirping. But the fabrication of structures is complex.

6. A line width enhancement factor {also called as α-parameter} is defined. α-value for semiconductor lasers range from 2-8. some laser structures (has 0 or negative chirp) have α-value less than 1 or even negative.

A light signal which has 0 or negative chirp is generally required to achieve very high tx rate when using standard single mode fiber operating wavelength of 1.55µm.

Link Power Budget:

It is used to ensure that the enough power will reach the receiver to maintain reliable performance during entire system life time.

The receiver sensitivity is the minimum average power required by the receiver. It takes simple form in decibel units with optical power expressed in dBm units.

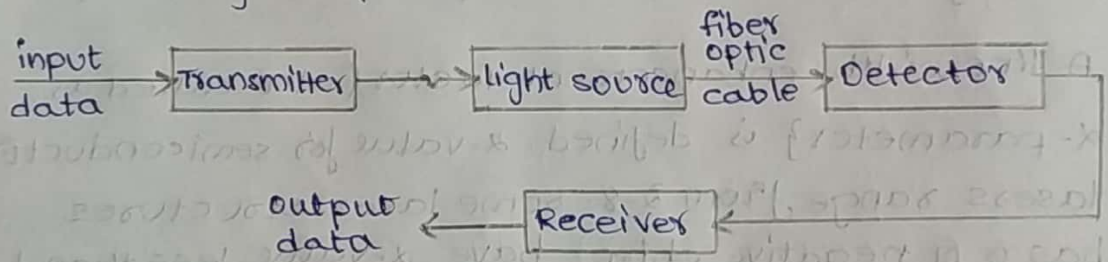
Rise Time Budget:

It is used to ensure that the system is able to operate properly at designed bit rate.

The bandwidth of individual system components exceeds the bit rate, then the total system may not be able to operate at that bit rate.

→ Explain Analog and Digital Optical communication systems.

Ans: The optical fiber communication system consists of following components.



The input data is in the form of electrical signal. The transmitter converts the electrical input signal into light signal with the help of light source. Two components are used as light sources: LEDs and LASER diodes. LEDs are used for short distances and slow data rate applications due to low bandwidth and the power capabilities. Two such LEDs structures are surface & edge emitting systems. for long distance and high data rate applications, laser diodes are preferred.

The fiber optic cable is made up of high quality glass or plastic that is flexible. the diameter of the fiber optic cable is in between 0.25 to 0.5mm (slightly thicker than a human hair). Light travels through the optical fiber by making the use of the principle of total internal reflection.

The receiver circuit consists of photodetector along with appropriate electronic circuit. The purpose of photo detector is to convert light signal back to an electrical signal. Two types of photo detectors are mainly used are PIN photo diode and Avalanche photo diode.

In Transmitter circuit, the process of varying the irradiance of light source as a function of time is called modulation.

Analog modulation consists of changing the light level in a continuous manner. the performance of the system using analog modulation is limited by the random noise in the system. Noise determines the smallest signals that can be transmitted and how faithful the reproduce signal is to the original signal.

In a system using digital modulation, information is enclosed into a series of pulses. separated by spaces. The absence & presence of light at some point in the data stream represents one bit of information. performance in digital system is given in terms of bit error rate. A system should have bit error less than 10^{-9}. In a digital modulation, faithful reproduction of signal intensity is not required. Pulses must only transmitted with sufficient power for detector to determine the presence & absence of pulse. This makes a system making digital modulation superior when sources of the noise are present.

LED Vs LASER

characteristic	LED	LASER
Output power	Lower	Higher
spectral width	wide	Narrow
Numerical Aperture	larger	smaller
Speed	slower	Faster
cost	less	More
Sense of operation	Easier	More difficult