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25th BATCH

COMPUTER AND COMMUNICATION ENGINEERING

International Islamic University Chittagong

COURSE CODE: CCE-4801

COURSE TITLE: Fiber Optic Communication

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Optical Fibre & Communication

~~Fibre optic Specificat~~ion :-

Fibre optic: ~~Cable Types~~:-

→ Composed of one or more transparent fibers enclosed

→ protects the glass.

→ The glass helps ~~glass~~ light to pass long distances.

→ Glass is coated into two layers:-

→ Plastic gives equivalent mirror ~~reflect~~ effect & creates total internal reflection.

→ Light travels using reflection. This happens when the light hits the interface at angle larger than the critical angle.

Fibre optic Cable Types:-

⇒ Simplex:-

→ A single optical fiber.

→ One way data transfer

→ Available in singlemode & multimode

→ Ex- TV broadcasting.

Duplex:-

- ⇒ Fibere optic cables with two optical ~~Fibres~~. Fibers.
- → Set up side-by-side
- → Requires simultaneous, bi-directional data transfer.
- → Duplex Fiber is available in singlemode & multimode.
- → Two types:-
  - ⇒ Half Duplex:- Data Flows both direction but not simultaneously. Ex:- Walkie-Talkie.
  - ⇒ Full-Duplex:- Data Flows both direction simultaneously.

    Ex:- phone calls.

Multimode v/s Singlemode Fiber types:-

Multimode	Singlemode
① Multimode Fiber	① Singlemode Fiber
② 62.5+ Mm in core diagram.	② 8.3 um in Core diagram.
③ cheap- Light emitting diode	③ Expensive laser light.
④ multiple path used by light.	④ uses single path
⑤ short distances, <5 miles.	⑤ Long distances > 5 miles
⑥ power distribution 100%	⑥ power in the center OF the Fiber.

Multimode:-

Step-Index:

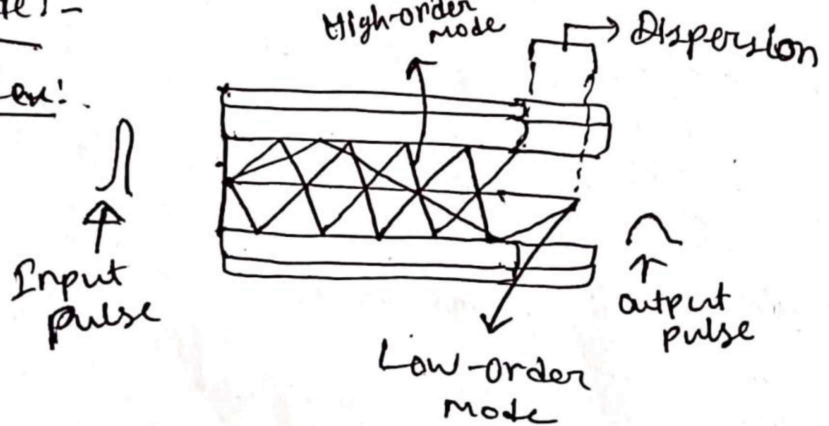
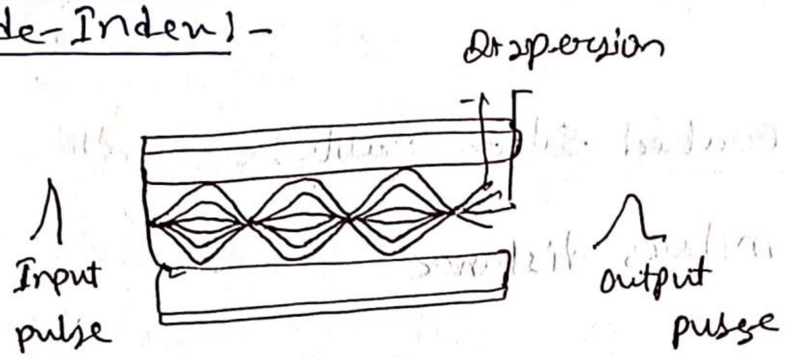
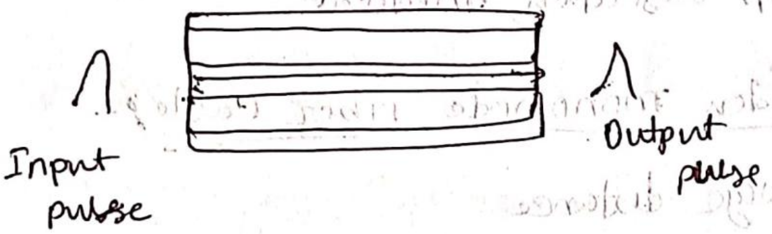


Fig:- Step-Indew .

Grade-Index)-



Singlemode StepIndex:-



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Types of ~~Fibre~~ Fiber optic cables :-

① plastic ~~a~~ cables :-

→ Travels a few meters
↳ 1 mm Core diagram.

→ Inexpensive & works with inexpensive Components.

→ Low bandwidth. Can carry about 200 Mbit/s for a 50 m link.

→ Example:- Industrial drives & generators; automotive.

~~e~~ Types

2| plastic-coated silica cable:-

→ A few meters distance

→ 1 mm

→ Better than plastic cables

→ Expensive

→ Ex:- used for research, medical

3| ~~plas~~ Single-Index monomode fiber cable:-

→ Extremely large distance

→ very narrow core

→ Highest BW.

→ Most expensive & most difficult to handle.

→ Allow for one data stream or mode.

4| Step-Index Multimode cable:-

→ Short distances.

→ Larger diameter core

→ Can carry encoded data

→ Don't support high BW.

→ Design for LAN & light is generated with a LED.

5] Graded-index Multimode Cable:-

-> Long distance than step-index

-> Larger diameter

-> Reduced mode dispersion & BW

-> Higher cost than step-index.

-> Multiple layers of glasses contain dispersion enough ~~to provide~~ that increases cable distances

6] Application of Fiber Optic Cables:-

-> Used by Telecom companies

-> Telephone signals, Internet, TV signals used this.

-> Used for long distance.

-> Used for full transmission capacity.

-> Higher Bandwidth & Low ~~cost low~~ loss transmission.

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⑦ ⇒ ~~Hughe~~

⇒ Huge Cost

-> Hard to install

-> Doesn't use electricity.

-> The glass or plastic core make it more fragile & less ~~Flexible~~ Flexibl

☐ Feature & Fiber optic cable maintanance

→ ~~Plorizat~~ polarize of light that enters

→ Operating temperature

→ Metallized fibers helps in increased temperature.

→ Can break any time.

→ Two types of Fiber optic connector applications.

(i) Free connectors on a Fiber optic patch cable.

(ii) Connectors plugged in patch panels.

Cleaning method:-

→ Dry Cleaning

→ wet cleaning (with Isopropyl Alcohol),

→ Non Abrasive cleaning

→ Abrasive "

Fiber optic ~~Connect~~ Construction & Specification :-

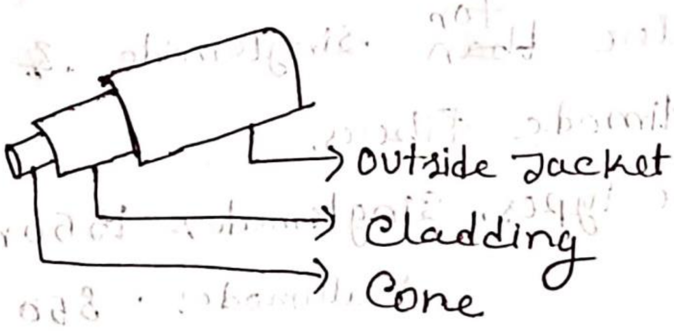

Fig:- Fiber optic

Cone :-

-> Inner part of Fiber.

-> Guides the light & has higher refreective index than cladding & Jacket.

-> ~~Hi~~ light hits at an angle & reflects back.

-> The core is made from a transparent glass or plastic.

-> Distance upto 100 miles.

-> ~~Ase the~~

Cladding:-

- → Outside portion of core.
- → Smaller ~~than~~ for singlemode & larger for multimode fibers.
- → Fiber types. Singlemode:- 1550nm
  Multimode: 850 or 1300 nm.
- → Diameter:- 8 to 62.5 μm.
- → Most common:- 125 μm.

Buffer coating:-

- → Protects inner part.
- → Diameter 250 to 900 μm.
- → Provide mechanical protection.
- → Flexibility.
- → Made of soft, hard plastic.
- → Single mode: yellow jacket.
  multimode:- Orange "
- → Cables used for outside application uses black jacket.

Laser Diode :-

→ Continuous operation.

→ Modulate over a wide range of modulating Freq.

optical Fiber Function :-

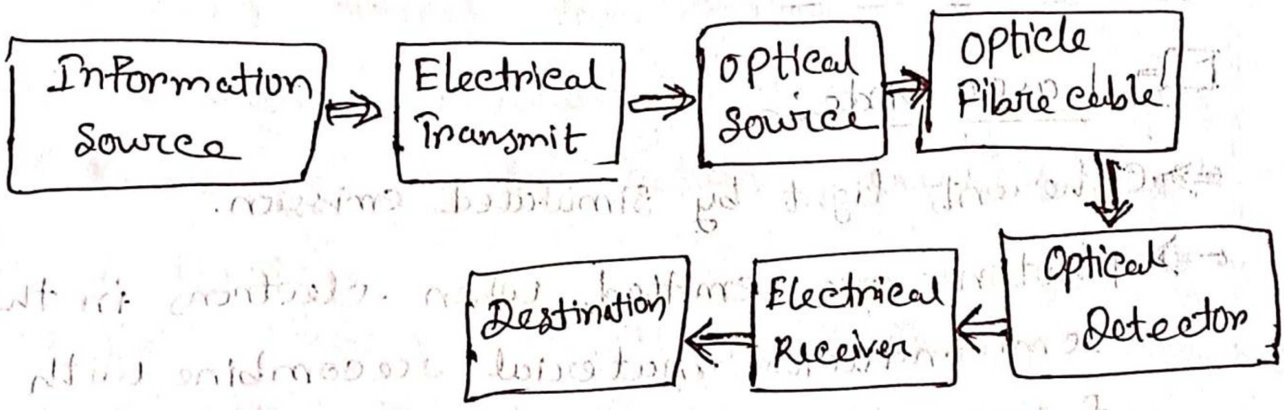

Fig 1- optical Fiber Function

Information Source :- provides the input electrical signal

Electrical Transmitter :- Gives modulation OF light wave Carrier.

optical Sources :- provide electrical to optical Conversion.

Optical Fibre cable :- Used as a transmission medium to compensate for losses during transmission repeaters.

Optical Detectors:- Detects & converts optical to electrical signal. Ex:- photo diode, photo transistors.

Electrical receiver:- Receives electrical signal

Destination:- The receiver.

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1) **Laser Diode:-**

⇒ Coherent light by simulated emission.

⇒ Photons are emitted when electrons in the semiconductor material recombine with holes.

⇒ Laser diode produce intense, monochromatic light with narrow spectral BW.

2) **LED (Light Emitting Diode):-**

→ Emit incoherent light

→ Electrons recombine with holes in the semiconductor material.

→ ~~p~~ Maintain principles of electroluminescene.

→ They ~~an~~ are energy efficient.

→ Longer lifespan ~~on~~

→ Have various colors.

→ Less expensive than laser diodes.

Avalanche photodiode :-

→ High gain.

→ Convert light signals into electrical signals.

→ Used in optical com. system.

→ Carriers generated by incoming photons, undergo multiplication through impact ionization.

→ Offer higher sensitivity & faster response.

→ Capable of detecting weak optical signals.

Photo diode :-

→ ~~It~~ converts light into electrical current.

→ Principles based on internal photoelectric effect.

→ ~~[illegible]~~ offers linear response to light.

Q) Attenuation & ~~the~~ its class:-

Attenuation:-

Refers to the reduction in the intensity or magnitude of a signal as it propagates through medium.

a) Absorption:-

→ Energy of light absorbed by the material.

⇒ When light interact with matter, certain wavelengths of light are absorbed by the atoms or molecules in the material.

(i) Intrinsic Absorption:-

→ Occurs within the material itself.

→ This happens when light with photons of specific energies interacts with the material.

Ex:- Semiconductors.

(ii) Extrinsic Absorption:-

→ Occurs due to impurities.

→ Ex:- In doped materials.

(b) Scattering:- Refers to the process by which light or electromagnetic waves are redirected in different direction.

(i) Rayleigh Scattering:-

-) When the size of the scattering particles is much smaller than the wavelength.

(ii) Mie Scattering:- occurs when the size of the scattering particles is comparable.

Snell's law

Refrective Index,

Air = 1

water = 1.3

Glass = 1.5

Snell's Law:- $n_1 \sin \theta_1 = n_2 \sin \theta_2$

n_1 = refrective index of 1st medium

n_2 " " " 2nd "

θ_1 = Angle of incidence

θ_2 = " " refraction.

critical

Critiele Angle:-

→ Minimum angle of incidence (θ_1) is progressively increased, there will be progressive increase of refractive angle (θ_2). At some condition of θ_1 the θ_2 becomes 90°. And this is called critical angle.

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) \quad [\sin 90° = 1]$$

Acceptance Angle:-

যতটুকু light accept করতে পারবে।

The angle at which the light ray first encounters the core of an optical fiber is called acceptance angle.

Numerical Aperture:- The ability of the optical system to collect all of the light incident on it, in one area.

Attenuation, $\alpha_{dB/Km} = 10 \cdot \frac{1}{z} \log \left[\frac{P(0)}{P(z)} \right]$

Math

① A low loss Fiber has average loss of $\underset{\alpha}{\underline{3 dB/Km}}$ at 900 nm. power decreased by 75%

Compute the $\underset{z}{\underline{\text{length}}}$.

=> $\frac{P(0)}{P(z)} = \cancel{75\%} \; 25\% = 0.25$ since power decrease 75%

$$3 = 10 \times \frac{1}{z} \log(0.25)$$

$$\cancel{z} \; 0.3 = \frac{1}{z} \log(0.25)$$

$= 2$ Km.

② For a $\underset{z}{\underline{30 \text{ Km}}}$ long Fiber attenuation $\underset{\alpha}{\underline{0.8 dB/Km}}$ at $\underset{\lambda}{\underline{1300 \text{ nm}}}$. If a $\underset{P(0)}{\underline{200 \mu \text{watt}}}$ power is launched into the Fiber, Find the $\underset{P(z)}{\underline{\text{output}}}$ power.

=> we know,

$$\alpha = 10 \cdot \frac{1}{z} \cdot \log \left[\frac{P(0)}{P(z)} \right]$$

$$\Rightarrow 0.8 = 10 \cdot \frac{1}{30} \log \cdot \left[\frac{200 \mu W}{P(z)} \right]$$

$$\Rightarrow \cancel{(10)^{0.8}} = \frac{1}{30} \left[\frac{200 \mu W}{P(z)} \right] \cancel{\Rightarrow P(z) = \frac{1}{10^{0.8}}}$$

$$\Rightarrow \cancel{0.412} = \frac{200}{P(z)}$$

$$\Rightarrow 30 \times 0.8 = 10 \log\left[\frac{200}{P(z)}\right]$$

$$\Rightarrow (10)^{2.4} = \frac{200}{P(z)}$$

$\Rightarrow P(z) = 0.796$ Mw (Ans, sure না)

2| When a mean optical power ~~loss~~ launched into an $\underset{z}{\underline{8\text{ Km}}}$ length of fiber is $\underset{P(0)}{\underline{120\text{ Mw}}}$, the mean optical power at fiber output is $\underset{P(z)}{\underline{3\text{ Mw}}}$.

$\Rightarrow$ Determine,

Overall signal attenuation in dB. [Extended question টুকু তোলা হয়নি]

$$\Rightarrow \alpha = 10 \cdot \frac{1}{z} \log\left(\frac{P(0)}{P(z)}\right)$$

$$= 10 \times \frac{1}{8} \log \frac{12}{3}$$

$$= \cancel{0.752}\ 16.02 \times \frac{1}{8}$$

$$= 2.00$$

$\therefore$ Attenuation per Km $= 2 \times 10$

$= 20$ dB

Here, [Extended part]

$$P(z) = P(0) \cdot e^{-\alpha \cdot p^{2}}$$

In 10 k.m link there will be 9 splices at 1 k.m interval

So, total attenuation = 20 + 9 = 29 dB

③ Optical power launched into fiber at transmitter end is $\underset{P(0)}{\underline{150\ \mu W}}$. The power at the end of $\underset{z}{\underline{10\ k.m}}$ length of the link working in (First $\underset{\boxed{1st}}{\text{windows}}$ is $\underset{\alpha}{\underline{-38.2\ dBm}}$) (Another system of same length working in second $\underset{\boxed{2nd}}{\text{window}}$ is $\underline{47.5\ \mu W}$) (Same $\underset{\boxed{3rd}}{\text{length}}$ system working in third window has 50% launched power)

Calculate fiber attenuation for each case & mention wavelength of operation.

⇒ Given,

$P(0) = 150\ \mu W$ [Input]

$z = 10\ k.m.$

$\alpha = -38.2\ dBM$

$$P(0)\alpha = 10 \frac{1}{z} \log\left[\frac{P(0)}{P(z)}\right]$$

$$\Rightarrow \cancel{-38.2 = 10 \frac{1}{10} \log\left[\frac{150}{P(z)}\right]}$$

$$\Rightarrow \cancel{-38.2 = \log\left(\frac{150}{P(z)}\right)}$$

$$\Rightarrow -38.2 = 10 \log \frac{P(z)}{1\ mW} = 0.151\ \mu W$$

~~100%~~

·151 — 100

2·1 → $\frac{\cdot 15\cancel{5}\times 100}{50}$

1st window:-

$$\alpha_1 = 10\times \frac{1}{10} \log \left[\frac{150}{0.151}\right] = 2.99 \text{ dB/Km}$$

2nd window:-

$$\alpha_2 = 10\times \frac{1}{10} \log \left[\frac{150}{47.5}\right] = 0.499 \text{ dB/km}$$

3rd ~~with~~ window:-

$$\alpha_3 = 10\times \frac{1}{10} \log \left[\frac{150}{75}\right] = 0.30 \text{ dB/Km}$$

4) In rare medium incidence angle is ~~30~~ 30°, & denser medium angle is 19.5°. Calculate reflective inden.

→ θ_1 in rarer medium = 30°

θ_2 " " " = ·19.5°

Assuming, air as the rarer medium, $n_1 = 1$

we know,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\Rightarrow n_2 = \frac{n_1 \sin(\theta_1)}{\sin(\theta_2)} = \frac{1\times \cancel{30}}{\cancel{19.5}} = \frac{1\times \sin(30°)}{\sin(19.5°)}$$

Refractive Indent

Air = 1

Water = 1.3

Glass = 1.5

$$= \frac{\text{[illegible]}}{\quad}$$

$= 1.497$

$\cong 1.50$

(Ans.)

[P] Light passes from air into glass at an angle of 50°, find the angle of refraction.

$\overset{1}{\text{air}}$ $\overset{1.5}{\text{glass}}$ $\underset{n_2}{\text{refraction}}$ $\underset{n_1 \theta_1}{50°}$

$\Rightarrow$ Here,

$n_1 = 1$

$n_2 = 1.5$

$\theta_1 = 50°$

θ_2 ~~n_2~~ $= ?$

We know,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\Rightarrow \theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

FINAL EXAM

(FIBER OPTICAL)

4] Error Sources in Fiber optical:-

In fiber optic communication systems, errors can arise from various sources. Identifying & understanding these sources is crucial for optimizing performance & maintaining signal integrity.

b) There are couple of error sources. These are:-

1) Shot Noise:-

→ Discrete nature of current flow in electric device.

→ Results from the random arrival rate of signal photons at the photodetector.

2) Thermal Noise:-

→ Originates from the random motion of electrons in a conductor

→ Affects applications with low signal-to noise ratios when using a PIN photodiode.

3) Quantum Noise:-

→ Form of shot noise, depended on the signal level

→ Significant for PIN receivers with large optical input levels, & for APD receiver due to the statistical nature of APDs.

4) Intersymbol Interference (ISI):-

→ Caused by pulse spreading in the optical Fiber

5) Avalanche Multiplication Noise:-

→ Occurs in APD receivers

→ Arises from the statistical nature of the avalanche multiplication process.

6) Poisson Noise:-

→ Related to the primary photocurrent generated by the photodiode.

→ The number of electron hole pairs generated fluctuates according to a poisson distribution.

7) Excess Noise Factor:-

→ It varies with the photodiode material & gain.

8) Amplifier Noise:

⊛

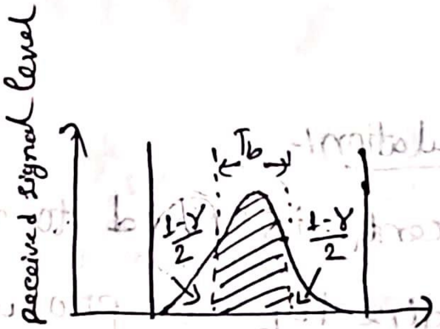


Fig:- pulse spreading in an optical signal that leads to ISI.

⊛

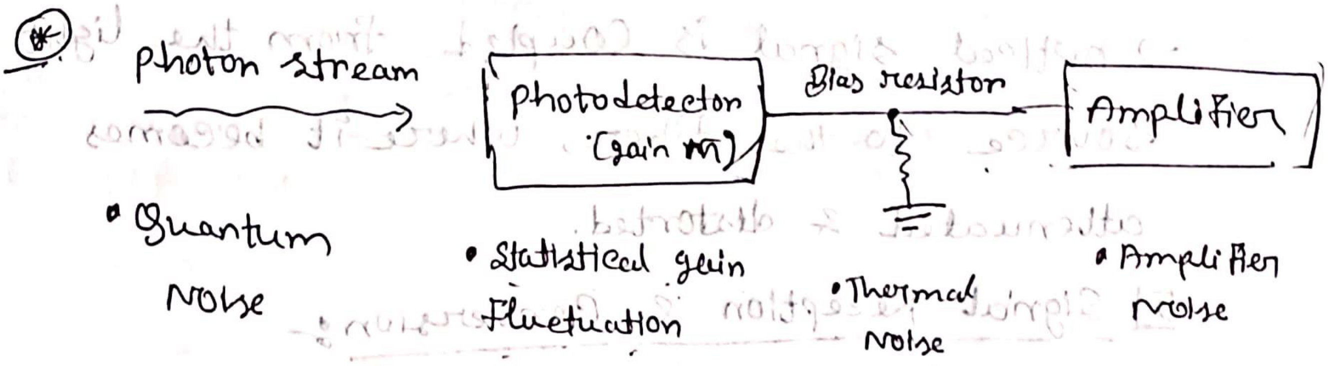


Fig:- Noise sources & disturbances in optical pulse.

▢ Digital Signal Transmission:-

1| Binary Data Stream:-

Transmitted signal is a two level binary data stream. 0 or a 1

2| Amplitude Shift Keying (ASK):-

-) simplest technique to send binary data.

↳ A voltage level is switched between on=1 or OFF=0.

3) Optical Source Modulation:-

→ An electric current is used to modulate an optical source directly to produce an optical output power.

4) Propogation & Attenuation:-

→ optical signal is coupled from the light source to the fiber, where it becomes attenuated & distorted.

5) Signal Reception & Conversion:-

→ Upon reaching the receiver, either a PIN photodiode or an avalanche photodiode (APD) converts the optical signal back to an electrical format.

6) Decision Circuity

→ A decision circuit compares the amplified signal in each time slot with a thresold level.

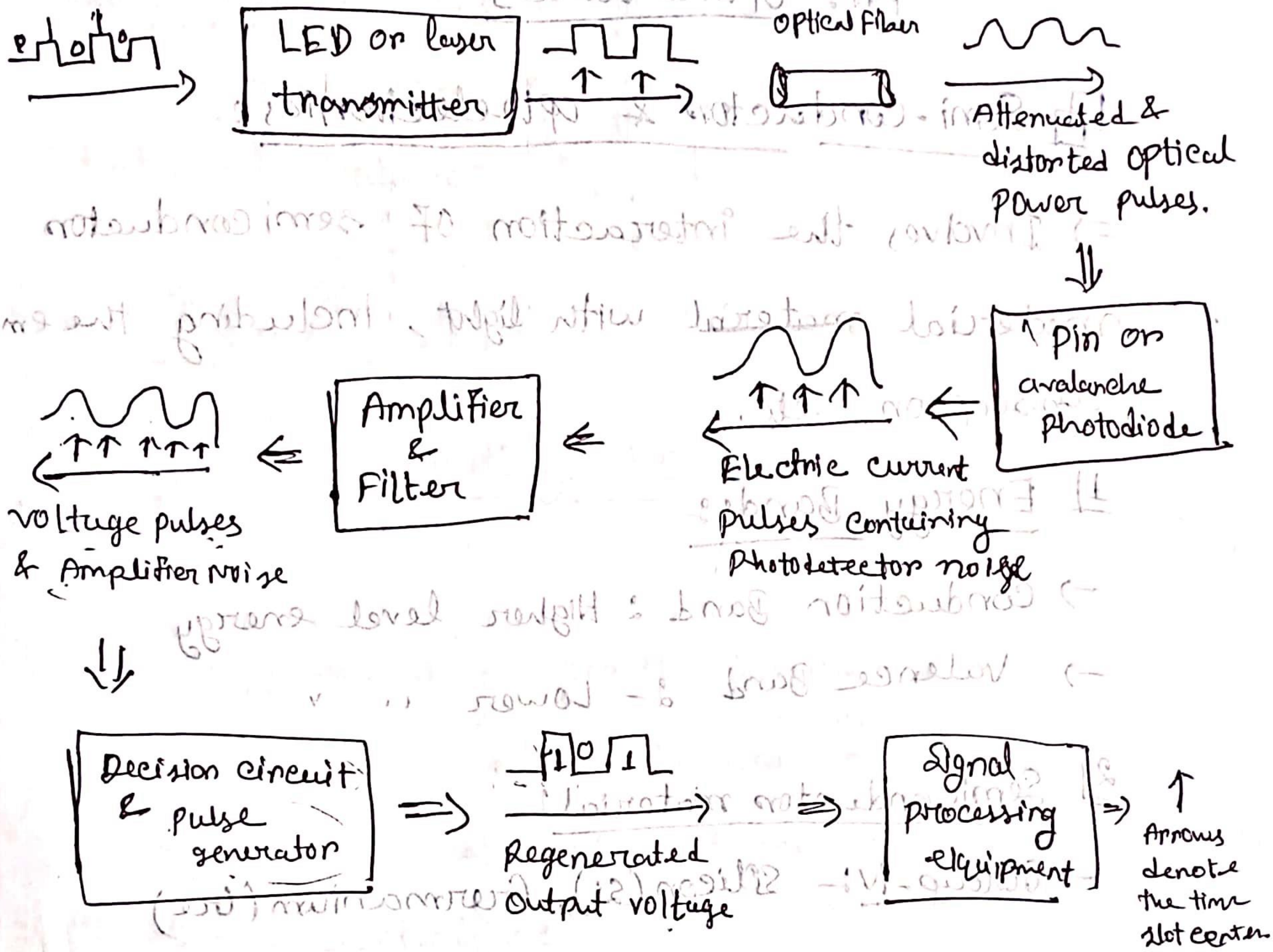


Fig:- Digital Signal Transmission

~~PAF: Chapt~~

PAF:- Optical Sources

[4] Semi-Conductor & opto-electronics:-

=) Involves the interaction of semi conductor material ~~material~~ with light, Including the emission, absorption etc.

1) Energy Bands:-

-> Conduction Band : Higher level energy

-> Valence Band :- Lower " "

2) Semiconductor material:-

-> Group-IV:- Silicon (Si), Germanium (Ge)

-> Group III-V:- Gallium-Arsenide (GaAs)

3) optical Sources:-

- LED (Light Emitting Diode):-

-> Emit coherent light

-> Broad spectral width

-> Commonly used in multimode system

- LD (Laser Diodes):-

->

4) Modulation of optical sources:-

→ Direct modulation:-

→ External modulation

SLEDs & ELEDs:-

SLEDs (Surface Emitting LEDs):-

① Structure:-

→ Primary region is small circular area

→ Active region has a diameter of 20-50 μm & thickness ~~of~~ up to 2.5 μm.

② Emission characteristic:-

→ ~~Em~~ Isotropic emission. It radiates light in all directions.

③ Coupling to optical Fiber:-

→ A well is etched in the substrate.

⇒ Emission area of the substrate is perpendicular to the axis of the optical Fiber

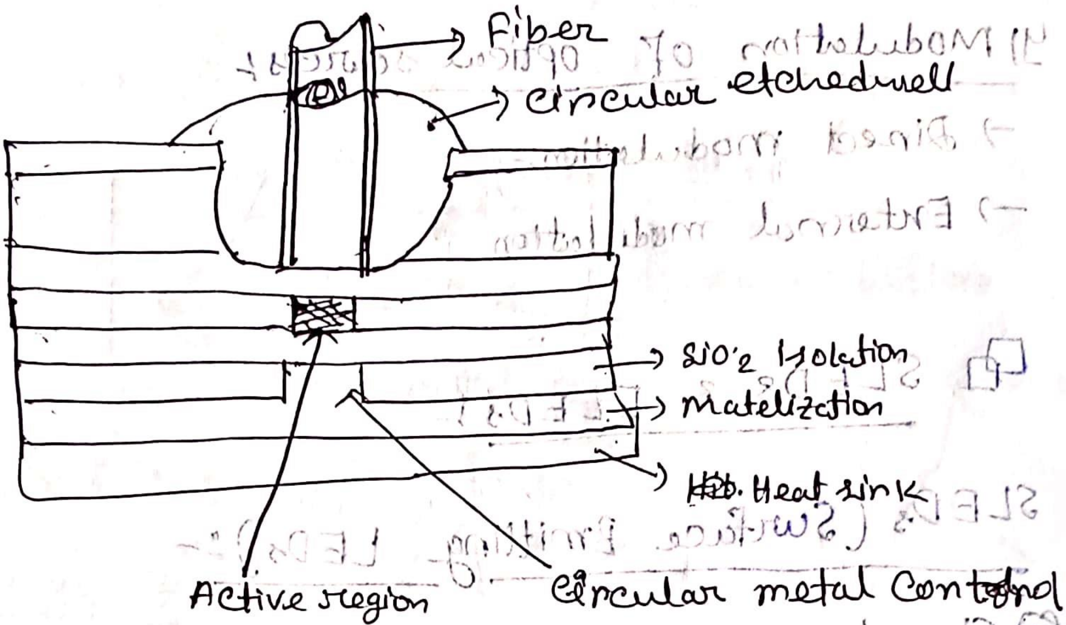


Fig:- SLEDs.

Edge Emitting ~~Diode~~ LEDs (ELEDs):-

① Structure:-

→ The semi conductor is cut & polished so the emission strip region runs between the Front & back OF the device.

② Emission characteristic:-

→ rear Face OF the semiconductor is polished

→ Front Face is coated with anti reflective material, allowing light to reflect from the rear Face.

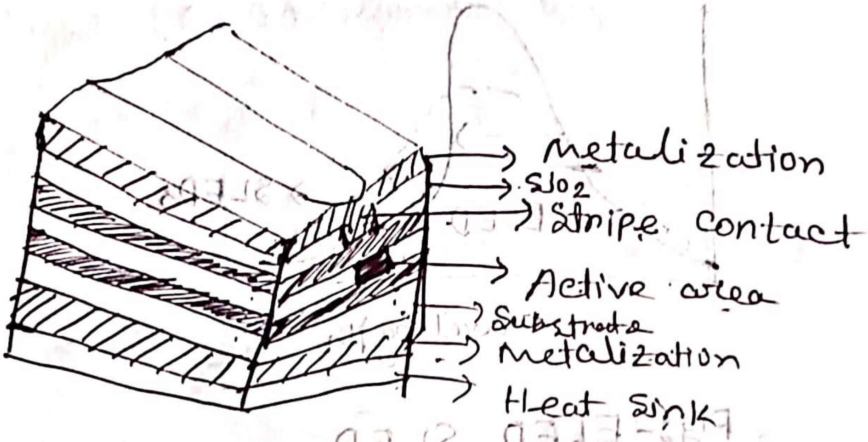


Fig:- ELEDs

Comparison:-

① Emission Pattern:-

→ SLEDs emit light in Lambertial pattern.

→ ELDs " " in narrower angle.

② Coupling Efficiency:-

→ SLEDs directly binding the fiber to the substrate with an epoxy resin.

→ ELEDs are designed with a reflective rear face & anti-reflective front face.

③ Applications:-

→ SLEDs are suitable for application requiring broad, uniform light distribution

→ ELEDs for needing high efficiency.

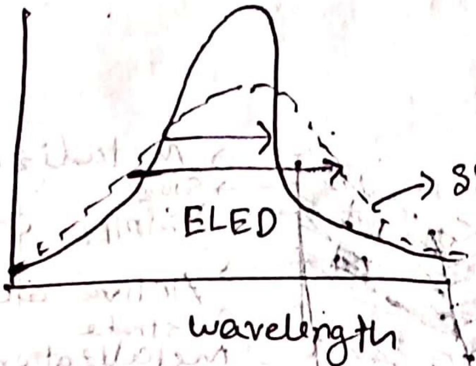


Fig:- ELED, SLED

4 Photon Emission Type:-

① Spontaneous Emission:-

स्वाभाविक

- → When an electron in an excided state spontaneously.
- → Emitted photons are random in phase & direction.
- → Type of emission is dominant in LED.

② Stimulate Emission:-

उत्तेजित

Q

- → Happens when an incoming photon causes an electron to fall to a lower energy state, emitting a second photon.
- → Fundamental to the operation of laser diode (LDs).

$\boxed{4}$ Basic Light Emission process.

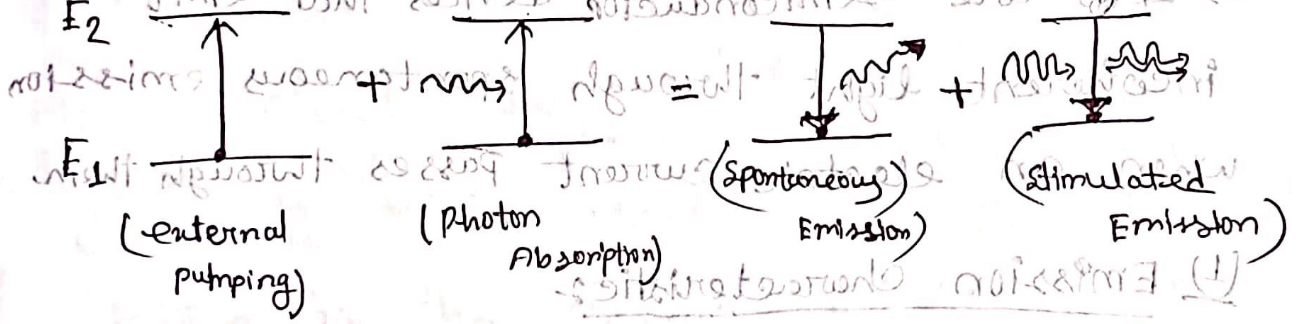
i) Pumping:-

→ Creating more electron hole-pairs
↳ Can be done electrically or optically.

ii) Emission:-

→ Recombination of electron-hole pairs.

→ Includes both spontaneous & stimulated emission



$\boxed{5}$ Direct & Indirect Material:-

(i) Direct material:-

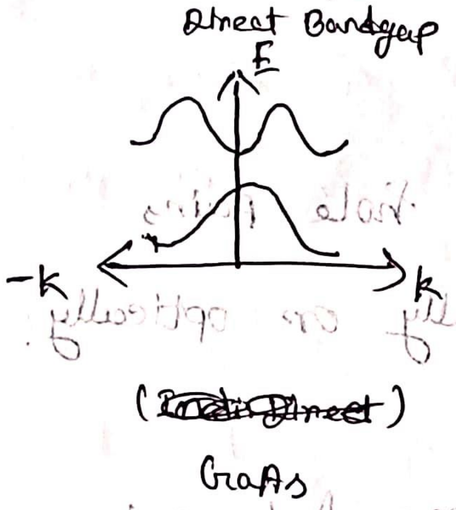
→ Minimum of the conduction band is directly above the maximum of the valence band.

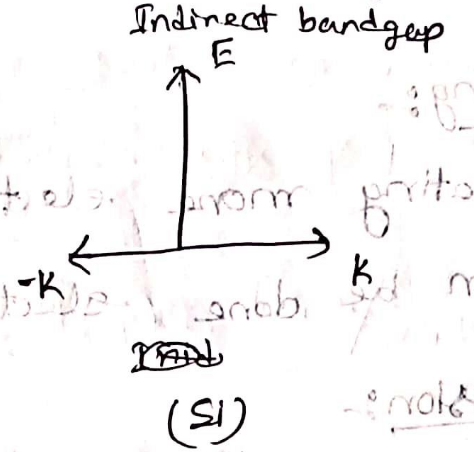
→ Photon emission occurs without a change in momentum. Ex: → GaAs, InP

(ii) Indirect material:-

→ Require a change in momentum for electron-hole recombination.

→ Silicon (Si), Germanium (Ge).





⊡ Light Emitting Diodes

⇒ LEDs are semiconductor devices that emit incoherent light through spontaneous emission when an electric current passes through them

(1) Emission characteristics

→ Emits incoherent light
→ used in multimode system with data rates of 100-200 Mb/s.
→ Has broad spectral width & a wide output pattern.

(2) Material & wavelengths :-

① 850 nm region :- materials like GaAs & AlGaAs.

② 1300 - 1550 nm :- materials like InGaAsP & InP.

3) Types of LED:- (i) SLEDs,
(ii) ELEDs

(4) Performance requirement:-

→ For fiber optic LEDs should have high radiance.

→ Devices can be double or single hetero-structure

5) HeteroJunction [LED Structure):-

→ Advanced design to reduce diffraction loss in optical cavity.

→ It is lightly doped with p-type material, which has the highest index of refraction, creating a light pipe effect that confines the laser light to the active region.

6) Quantum Efficiency:-

(i) Internal efficiency:- Ratio between the radiative recombination rate & the sum of radiative & non radiative recombination rates.

$$\eta_{int} = R_r / (R_r + R_{nr})$$

(ii) External efficiency:-

Depends on the Fresnel Transmission Coefficient for air & specific design of LED.

Freshnel Coefficient: $T(\phi) = 4n_1n_2/(n_1+n_2)^2$

External efficiency for air:-

$n_2 = 1, \; n_1 = n.$

$n_{ext} = 1/n(n+1)^2$

[4] Lasing operation:-

→ Lasing operation in lasers involves several key concepts & processes that are crucial for the generation & amplification of light.

(i) Population Inversion:-

⇒ In thermal equilibrium, the density of electrons in the excited state is very small.

But for lassing to occur the excited state electrons must exceed that of the ground state, a condition known as population inversion.

$N_E > G.N_h$

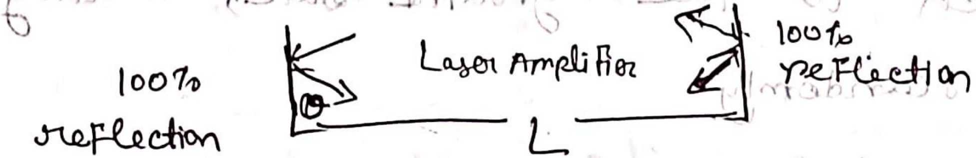
Heterojunction Devices are made by joining two semiconductors with different energy band structures.

(2) Laser Diode Mode & Thresold conditions:-

→ Most laser diode are multilayered heterojunction devices where stimulated emission arises from optical transitions between energy states in the valanche & conduction bands.

→ The radiation in the laser diode is generated within a Febry-perot resonator cavity.

→ A pair of flat, partially reflected mirrors are directed toward each other to enclose the cavity.

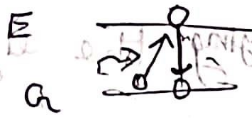


(3) Stimulated Emission:-

- Absorption
- Spontaneous Emission
- Stimulated Emission

(4) Lasing condition:- Happens when gain of one or several guided modes exceeds the optical loss during one roundtrip.

(5)



How a laser works?

→ A laser (Light Amplification by stimulated Emission of Radiation) operates based on the principles of stimulated emission & population inversion within a resonant, optical cavity.

Steps of laser operation:-

(1) Pumping:- Energy is supplied to the laser medium to excite electrons. ~~From the~~

(2) Spontaneous Emission:-

Some excited electrons will spontaneously fall back to the ground state, emitting photons randomly.

(3) Stimulated emission:-

→ Photons emitted from spontaneous emission or from external sources stimulate other excited electrons.

(4) Photon amplification:- The emitted photons are reflected back & forth between the mirrors of the optical resonator, stimulating more emissions & amplifying the light.

(5) Laser output:-

the partially reflected mirror allows some of the amplified light to escape.

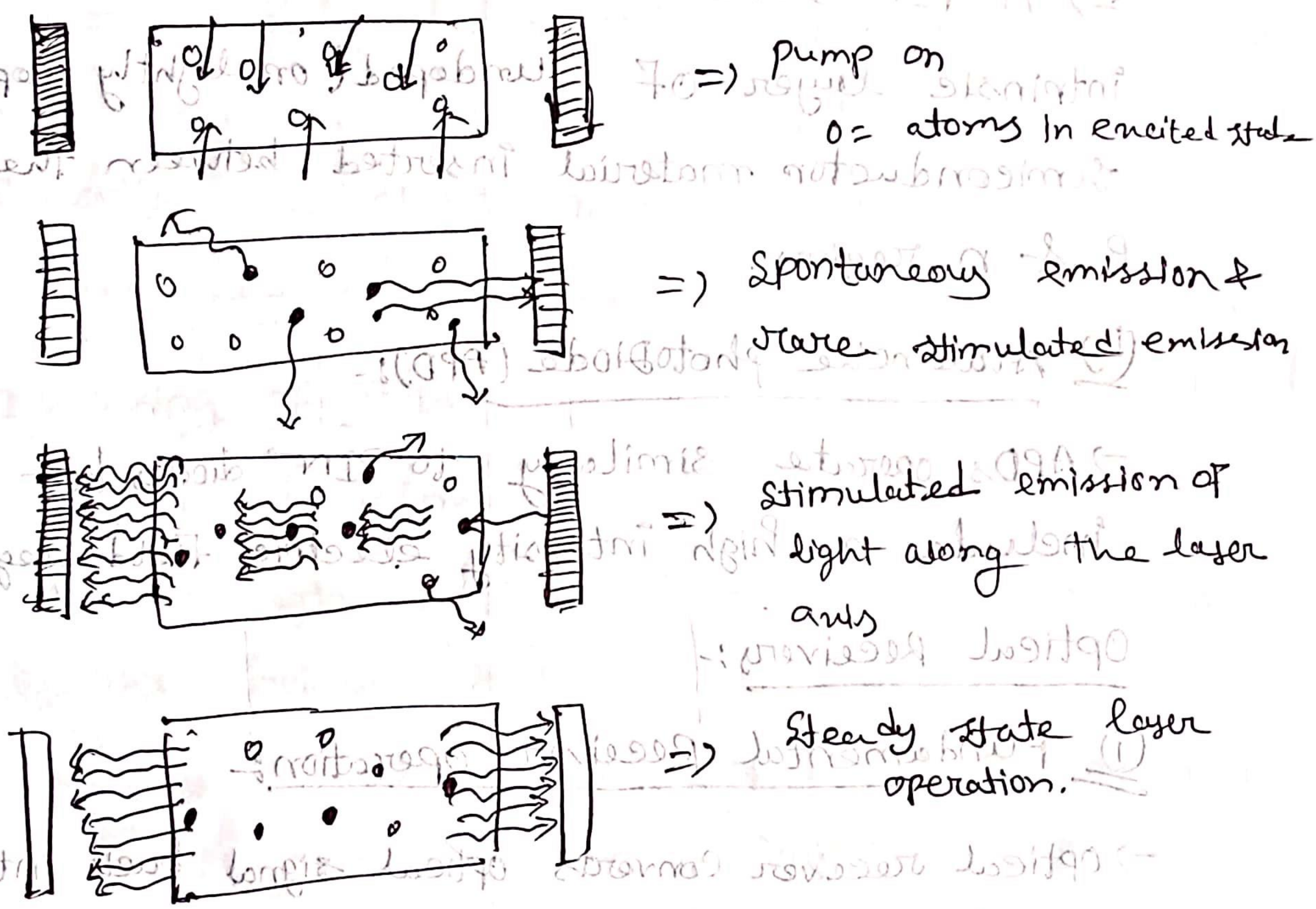


Fig:- How a laser works.

Optical Detector & Receiver:-

Optical Detector:-

(i) PIN Diode:-

=> A PIN Diode is a P-N junction with an intrinsic layer of undoped (or lightly doped) semiconductor material inserted between the P & n regions.

(ii) Avalanche photoDiode (APD):-

→ APDs operate similarly to PIN diodes but include a high intensity electric field region

Optical Receivers:-

(i) Fundamental Receiver operation:-

→ Optical receiver converts optical signal back into electrical signals.

→ A photodetector receives the optical signal & generates a corresponding electrical current

(ii) Digital Signal Transmission:-

→ The optical signal is modulated to represent 0, 1.

3)(iii) Error source:-

-) Many errors are showed up during transmission.

(iv) Receiver configuration:-

-> ~~The~~ Receiver design involves appropriate photodetectors, amplifieatrs, signal processing unit.

-> Configuration aims to maximize the sensitivity & accuracy of the receiver.

4) Working of APD:-

-) It has high intensity electric field region

-) In this region electron hole-pairs are generated by the incident photons.

-) The physical phenomenon ~~behind~~ behind the internal current gain is known as impact ionization.

-> The Impact Ionization leads to avalanche breakdown.

-> Generation of more than one electron-hole pair from incident photon is referred to as avalanche effect.

-) Avalanche multiplication results in amplification of photodiode current.

田 Comparison of PIN Diode & APD:-

PIN Diode	APD (Avalanche Photodiode
① Does not have high intensity electric field region	① Has high intensity electric field region.
② Responsively of PIN is limited.	② Responsively of APD can have much larger values.
(3) They exhibit lower noise levels	(3) Exhibits higher noise levels
(4) Response time half of APD.	(4) Response time is double than PIN

田 Optical Receiver Design:- (Diagram of Digital Signal Transmission).

⇒ Design includes a photodetector (like PIN / APD)

→ Converts optical signals ~~to~~ into electrical signals.

= - - (Same as Digital Signal Transmission)

☐ Consideration of system design:-

(1) ~~Transmission~~ Attenuation:- Loss of signal strength

(2) Dispersion :- signal pulse বাড়ানোর কারণে সৃষ্ট সমস্যা

(3) ~~The~~ Info transfer capability.

(4) optical sources:- (LED)

(5) Detectors : (PN, PIN, APD)

(6) Distance of transmission

(7) Transmission type

(8) System fidelity.

(9) Repeater spacing

(10) Cost Reliability.

(11) Environmental factor

(12) Mechanical requirement

(13) Multiplexing techniques.

☐ Repeatery in long haul communication.

→ Repeatery are used to boost the signal over long distances. Receive weak optical signals, convert them to electrical signals, amplify them & convert them back to optical signals.

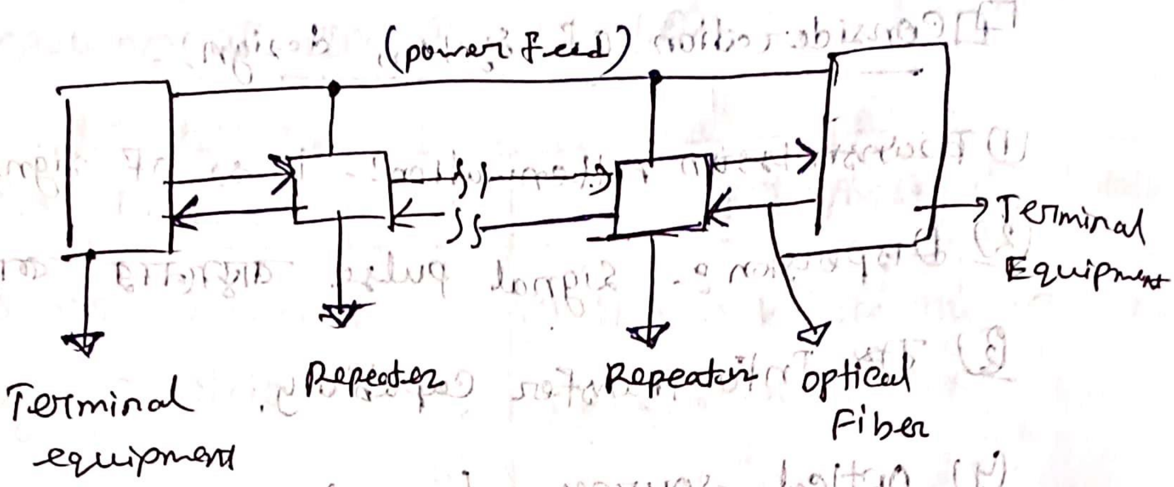


Fig: → Repeaters in long haul com-system

[11] Multiplexing :-

→ It is a technique used in optical communication to combine multiple signal for transmission over a single fiber optic cable

There are many types of multiplexing :-

(1) TDM (Time Division Multiplexing) :-

→ Divides the time into slots, each allocated to a different signal.

(2) WDM (wavelength Division Multiplexing) :-

→ Uses different wavelengths of light to carry different signals.

(3) FDM (Frequency ---)

→ Each signal a unique frequency

4 optical Communication System Architecture:-

(1) point to point Architecture:- Directly connects two locations..

Components:- (i) Transmitter
(ii) Optical Fiber
(iii) Receiver

Advantage:- → High bandwidth & low latency
→ Simple & straightforward design.

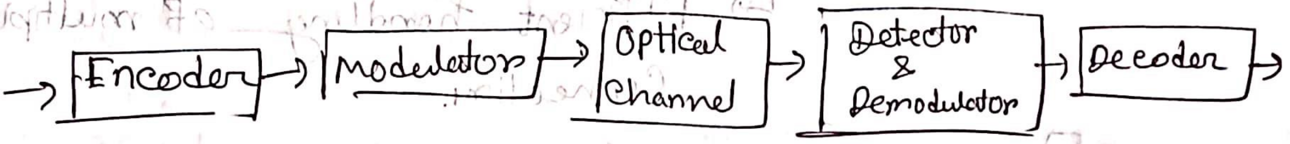


Fig: point to point

(2) Distributed Architecture:-

→ Multiple nodes are connected

Compontent:- ① Transmitter
② receiver
③ optical splitters
④ couplers
⑤ Amplifier

Advantages → Flexible in network design.
→ Scalability. to add more node

(3) Local Area Network (LAN):-

⇒ Multiple devices within a localized area are connected, ~~to~~ usually within a building or Campus.

Components:-
- (i) Transceiver
- (ii) Optical switches
- (iii) Hubs
- (iv) Fiber optical cables.

Advantages:-
- → High speed data transfer
- → Efficient handling of multiple Connection

☐ Need of WDM:- (wavelength Division multiplexing)

→ Increased Capacity:- Allows multiple channel data channels to be transmitted simultaneously

→ Scalability:- Can easily add more channel

→ Flexibility:- Supports a mix of different data rates.

1 CWDM vs DWDM:-

CWDM:-

→ Course wavelength Division Multiplexing
→ Typically spans from 1270 nm to 1610 nm
→ wider spacing of 20 nm
→ Supports upto 18 channels within the standard CWDM range.
→ uses in MAN

DWDM:-

→ Dense wavelength Division Multiplexing
→ Operates in the C band (1525 nm to 1565 nm)
→ Much narrower spacing (0.8 nm, 0.4 nm)
→ Can support up to 80 or more.
→ uses in Trunk Network.

2 Howling Dog Analogy:-

⇒ A simple & illustrative way to explain the concept of optical amplification.

1 Optical Amplification:-

(i) Signal Transmission:- কুকুর ডাকলে কাছাকাছি জোরে শোনা যায়, দূরত্ব বাড়লে sound এ কমে।

(ii) Signal Attenuation:- কুকুরের ডাক দূরত্ব এবং Obstacles কারণে power কমতে থাকে। similarly optical এ signal এ loss হয় as it travels through Fiber

(iii) Amplification Concept :-

=) কুকুরের ডাক দূর হতে শোনার জন্য কুকুরের দলকে নির্দিষ্ট স্থান হতে বারংবার দিতে হবে। এখানে যা amplifiers কে represent করছে। Power বাড়ানোর জন্য।

(iv) Repeater Dogs :-

⇒ প্রতিটি কুকুর অন্য কুকুরের sound তাদের কানে আসার পর ~~[illegible]~~ ডাকতে থাকে। যার ফলে তাদের ডাক same strength এ থাকে, original sound এর মতো।
In optical communication EDFAs are like these repeater dogs

Key point :-

① Maintaining signal strength (Repeater part)

② No conversion Needed (Dogs simply repeat howl without changing the original)

③ position of amplifiers

Topology:-

(1) Point to point:- Direct connection between two nodes.

A:-
- → Easy to install & manage
- → High ~~ba~~ BW & low latency.

D:-
- → Limited scalability
- → Connection fails? communication distrupted.

(2) Star Topology:- All nodes are connected to a central hub or switch.

A:-
- → Easy to add or remove
- → Centralized management

D:-
- → Central hub is a single point of failure
- → Higher cabling cost

(3) Ring Topology:-

⇒ Each node is connected to two other nodes.

- → Used in MANs, LANs
- → ~~Can ft~~ Data travel in both directions.
- → One link failure leads reroute.
- → Higher latency.
- → More complex.

4] **Mesh Topology:-** Every node connected with each other

-> Used in backbone networks.

A2 ~~D2~~

-> Extremely fault tolerant

-> High availability, redundancy.

D:

-> High cabling

-> High ~~cost~~

-> Complex Configure

5] **Bus Topology:-**

=> All nodes share a single communication line.

-> ~~For~~ uses in Small networks

A2

-> Easy to install

-> Requires less cabling

D2-

-> A failure in the main cable stops all.

-> Limited cable length.

6] **Tree Topology:-** -> Combines characteristics of star & bus topologies.

-> ~~A~~ Uses in large networks. (university, & similar)

A2-

-> Hierarchical structure

-> Easy to manage..

D2-

-> Backbone line fails entire network fails

-> More complex cabling.

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7] Hybrid Topology:- Combination OF two or more different topologies.

→ Large & complex networks

AD

→ Flexible

→ Combines the strength of different ~~top~~ topologies

D:-

→ Complex & expensive

→ Management & troubleshooting challenging

— — - —

8] Need OF modulation:-

→ Modulation a technique ~~to~~ ~~to~~ to encode information onto a carrier wave for transmission.

(1) Efficient used of BW.

(2) Signal Integrity → Noise Reduction
↳ Dispersion Management.

(3) Long Distance Transmission → power efficiency
↳ Error correction

(4) Compatibility with Digital System

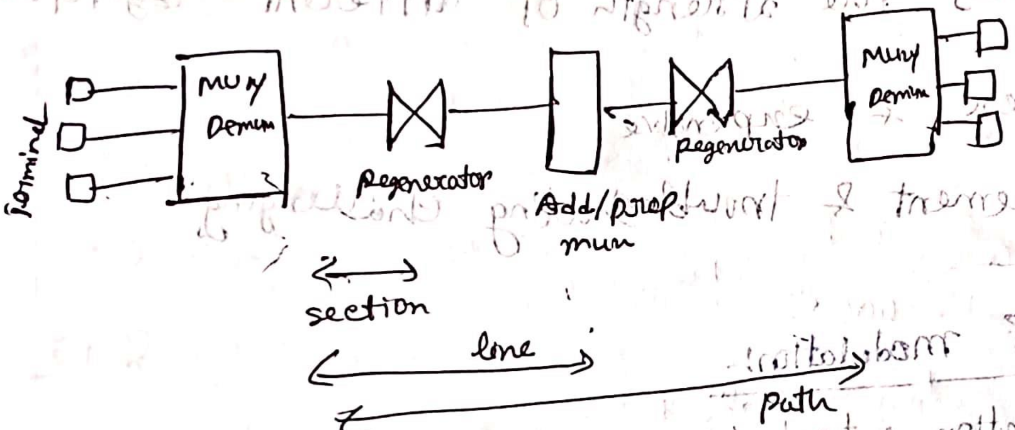
(5) multiplexing

(6) Security

(7) Freq translation

⧉ SONET:-

Synchronous optical Network (SONET) is a standardized protocols that transfers multiple digital bit streams over optical Fiber using Laser or LED's.



STS Multiplexer:-

→ converts electrical signals to optical signal

STS Demux:-

→ converts optical signal to electrical signal

Regenerator:- → Repeater

Add/drop:- Add signal coming from different sources.

⧉ SONET Layers:-

① path Layer:.

→ optical source to Destination (responsible for the movement of signal).

② Line Layer

→ Responsible for the movement of signal across a physical link.

③ Section layer:-

-) Responsible for the movement of signal across a physical section.

④ Photonic layer:-

→ Corresponds to the physical layer of the OSI model

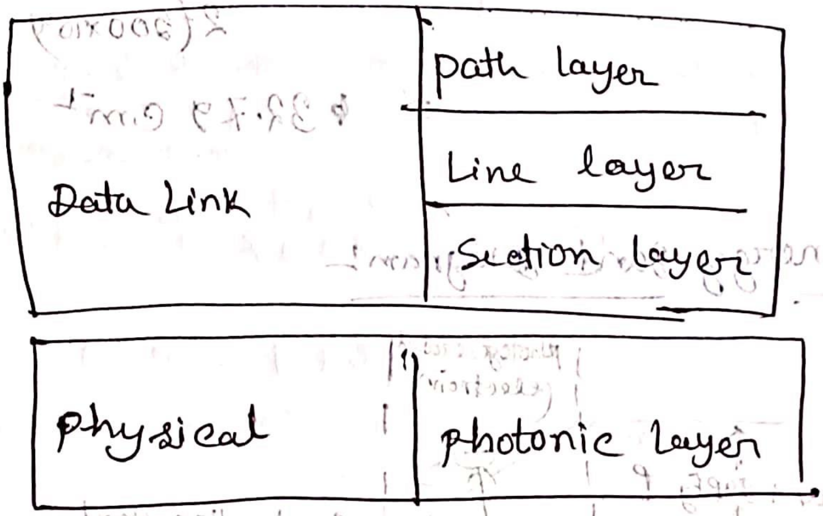


Fig :- layer.

Math

[P] Find the optical ~~value~~ gain at thresold of a Heteres Ro laser diode having following parametricvalues

$R_1 = R_2 = 0.32,$

$\alpha = 10 cm^{-1}$

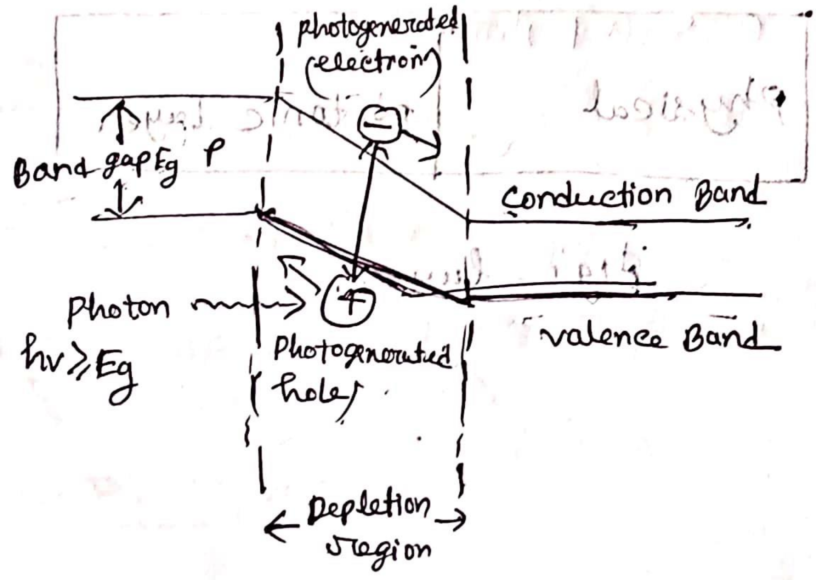
$L = 500 \mu m = 500 \times 10^{-4} cm$

$\Rightarrow$ we know, $r g_{th} = \cancel{q} a = \alpha + \frac{1}{2L} \ln\left(\frac{1}{R_1 \cdot R_2}\right)$

$= 10 + \frac{1}{2(500 \times 10^{-4})} \ln\left(\frac{1}{0.32 \times 0.32}\right)$

$= \cancel{6}\, 32.79 \, cm^{-1}$

[P] Energy Band Diagram :-



Photodetector Noise & S/N

=) Detection of weak optical signal requires that the photodetector & its following amplification circuitry be optimized for desired signal to noise ratio.

→The minimum detectable optical power defines. the sensitivity of photo detector.

$$S/N = \frac{\text{Signal power from } \cancel{\text{pho}} \text{ photocurrent}}{\cancel{\text{Photocurrent}} \text{ photodetector noise power + Amplifier Noise power}}$$

Compute the emitted wavelength from an optical source having $x = 0.07$. $\left[E_g = 1.424 + 1.266x + 0.266x^2\right]$

=) Here, $x = 0.07$

$$E_g = 1.424 + 1.266\,x + 0.266\,x^2$$

$$E_g = 1.424 + 1.266 \cancel{x} \times 0.07 + 0.266\,(0.07)^2$$

$$= 1.513 \text{ ev}$$

$hc = 6.625\times10^{-34}$

$c = 3\times10^{8}$

$\lambda_c = \frac{hc}{E_g}$

Now, $\lambda_c = \frac{hc}{E_g} = \frac{1.24 \xrightarrow{} \text{given}}{1.513} = 0.819\ \mu m$

For an alloy with the quaternary alloy composition ~~lix~~ x ~~Gax~~ ~~As P1-y it is found~~ ~~that~~, Find the wavelength
In0.74 Ga0.26 As 0.57 P0.43 to be used in led.

$\Rightarrow x = 0.26$ & $y = 0.57$

$E_g = 1.35 - 0.72y + 0.12y^2$

$\Rightarrow$ using, $E_g = 1.35 - 0.72y + 0.12y^2$

$= 1.35 - 0.72\times0.57 + 0.12(0.57)^2$

$= 1.35 - 0.4104 + 0.0389$

$= 0.978$ ev

$\therefore \lambda_c = \frac{hc}{E_g} = \frac{1.24}{0.978} = 1.267\ \mu m$ (Ans)

Q. The radiative & non radiative recombination life times of minority carriers in the active region of a double heterojunction LED are 60 nsec & 90 nsec respectively. Determine the total carrier recombinatio life time & optical power generated internally if the peak emission wavelength is 870 nm & the drive current is 40 mA

⇒ Here,

$\lambda = 870\ nm = 0.87 \times 10^{-6} m$

$\tau_r = 60\ nsec$

$\tau_{nr} = 90\ nsec$

$I = 40\ mA = 0.04\ Amp$

① Total carrier recombination life time :-

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}$$

$$= \frac{1}{60} + \frac{1}{90} = 0.028 \quad \therefore \tau = 36$$

(ii) We know, internal optical power,

$$P_{int} = \cancel{\frac{hc}{I}}\ \eta_{int} \frac{h.cI}{q\lambda}$$

$$= \frac{\tau_r}{\tau_{nr}} \left(\frac{36}{60}\right) \left[\frac{(6.625\times10^{-4}) \times (3\times10^{8}) \times 0.04}{(1.602\times10^{-19})\,(0.87\times10^{-6})}\right]$$

4) A double heterojunction InGaAsP LED operating at 1310 nm has radiative & non-radiative recombination times of 30 & 100 ns respectively. The current injected is 40 Ma.

Calculate - Bulk recombination life time. Internal quantum efficiency internal power level.

⇒ Here,

$\lambda = 1310\ nm = 1.31 \times 10^{-6}\ m$

$\tau_r = \boxed{30\ ns}$

& $\tau_{nr} = 100\ ns$

(i) $I = 40\ MA = 0.04\ Amp$

(ii) Bulk recombination :-

$$\eta_{int} = \tau / \tau_{nr}$$

$$1/\tau = 1/\tau_r + \frac{1}{\tau_{nr}} = \frac{1}{30} + \frac{1}{100} =$$

$\therefore \tau = 23.076\ ns$

$$\therefore \eta_{int} = \frac{23.076}{30} = 0.7692$$

(ii) Internal quantum efficiency

$$\eta_{int} = \frac{23.07}{30} = 0.7692$$