PHY 1701 (ASSIGNMENT-III) OPTOELECTRONICS

1. Write a short note on:-
   a). Attenuation.
   b). Dispersion.

2. Derive an expression for intermodal dispersion in multi-mode step-index optical fiber.

3. Explain the role of fiber optics in communications with a block diagram.

4. Write a short note on the working principle of (a) LED (b) LASER diode.

5. Explain about PIN Photodiode with suitable example.

6. Derive the expression for responsivity and quantum efficiency of PIN photodiode.

7. Describe the application of fiber optics in endoscopy and explain its working.

8. For a step index OF, numerical aperture is 0.26 and refractive index of core is 1.5 and core diameter is 100μm. Find (i) refractive index of the cladding. (ii) Acceptance angle (iii) Critical angle.

9. A silica glass optical fiber has a core refractive index of 1.5 and cladding refractive index 1.46. Calculate critical angle, acceptance angle and numerical aperture.

10. In an optical fiber, the core material has refractive index of 1.6 and cladding material has refractive index of 1.3. Calculate the critical angle and the angle of acceptance cone.

(1) Write short notes on :-

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(a) Attenuation :-

When light is transmitted into one end ~~of~~ a with a certa power, the output power received at the other end of the cable is less than the input power. This phenomenon of loss in power as light propagates through an optical fiber cable is called attenuation.

It is the rate at whigh light decreases it's intensity. Glass fibers usually have low attenuation and hence are used in long-distance cables while plastic fibers have higher attenuation

The relation that defines attenuation, absorption coefficients in term of length L of fibre is :-

$$\alpha = \frac{10}{L} \log_{10}\left(\frac{P_i}{P_o}\right)$$

The unit of attenuation is decibels/kilometers. i.e. dB/km.

The major causes of attenuation in optical fibre is :-

(a) Absorption

(b) Scattering

(c) Bending Losses.

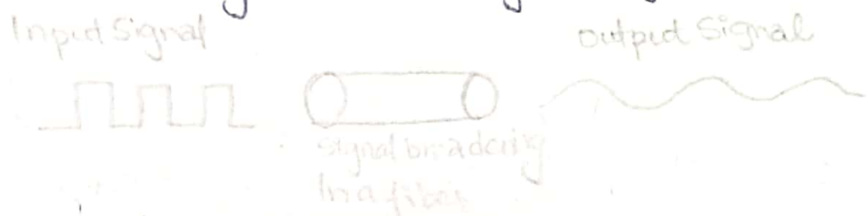
Each mechanism of loss is influenced by the properties of fibre Material and fibre structure.

b) ① Dispersion:- 20BDS0405

↳ It refers to the loss caused by the broadening of actual time-width of the pulse due to material properties and imperfections.

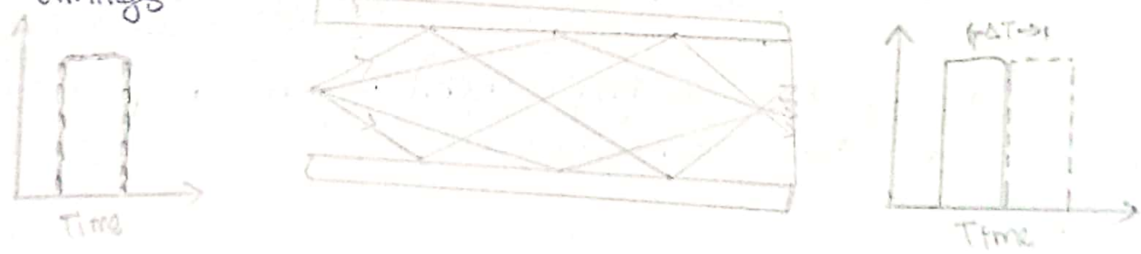
↳ As pulses travel through the fiber, dispersion causes pulse spreading. This limits the distance travelled by the pulse and the bit rate of data on optical fiber.

↳ Dispersion mechanisms cause broadening of the transmitted light pulses as they travel along the fiber.



There are two major types of dispersion in optical-fiber.

① Intermodal Dispersion:
It is caused by multipath propagation of light energy leading to pulse widening. Different modes travel with different angles hence different routes but same velocity, so, at the end of fiber, they come at different timings.



② Intramodal dispersion.
Pulse broadening within a single mode is known as intramodal or chromatic dispersion. Since it is wavelength dependent and group velocity is function of wavelength, it is called group velocity dispersion (GVD).
Its two types are:-

ⓐ Material dispersion.
↳ Pulse spreading due to the dispersive properties of materials arising due to the variation of refractive index of core material.

ⓑ Waveguide dispersion.
↳ It occurs mostly in single mode fiber because the light in cladding travels faster than that in core hence leading to dispersed output.

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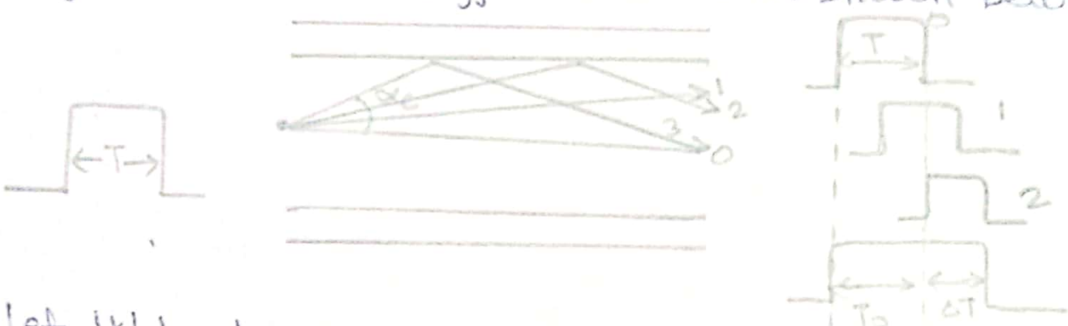
2) Derive the expression for Intermodal dispersion in multi-mode step index fiber.

Ans A step index fiber is the one which has uniform refractive index throughout the core and undergoes sudden change in refractive index when it hits the cladding.

Such design makes ~~intermode~~ multi-step-index fiber susceptible to intermodal dispersion. So, a pulse coming to a step index fiber travels in different modes as shown below.

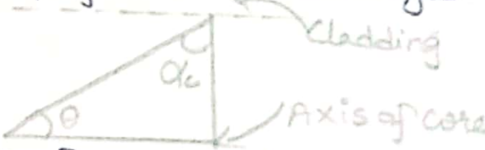


let 'L' be the length of cable, 'v' be the velocity of pulse.

For the zero mode travelling along axis, time taken $t_0 = \frac{L}{v}$

let 'θ' be the angle of highest mode such that it forms critical angle.

Here, α_c is the ~~refr~~ critical angle.



suppose, n_1 and n_2 be the refractive index of core and cladding respectively. For a fiber, $n_1 > n_2$.

Time for highest ~~mo~~ order mode of propagation is:-

$$t_c = \frac{L}{v\sin(\alpha_c)}$$

Pulse widening due to modal dispersion is:- $\Delta t = t_c - t_0$

$$= \frac{L}{v}\left(\frac{1}{\sin(\alpha_c)} - 1\right)$$

From snells law, we have, $\sin\alpha_c = n_2/n_1$

$$\therefore \Delta t = \frac{L}{v}\left(\frac{n_1}{n_2} - 1\right).$$

$\Rightarrow \Delta t = \frac{L}{v}\left(\frac{n_1 - n_2}{n_2}\right)$ ——— (1) is the expression for pulse widening in multimode single-~~index~~ fiber.

Also, further we know,

$$n_1 = \frac{c}{v} \Rightarrow v = \frac{c}{n_1}$$

Substituting above, $\Delta t = \frac{L n_1}{c}\left(\frac{n_1 - n_2}{n_2}\right)$

as $n_2 \simeq n_0$, $\Delta t = \frac{L n_1}{c}\Delta$ ——— (ii) where, $\Delta = \left(\frac{n_1 - n}{n}\right)$

Eqn (1) and (ii) are the eqn of pulse widening in multimode step index fiber.

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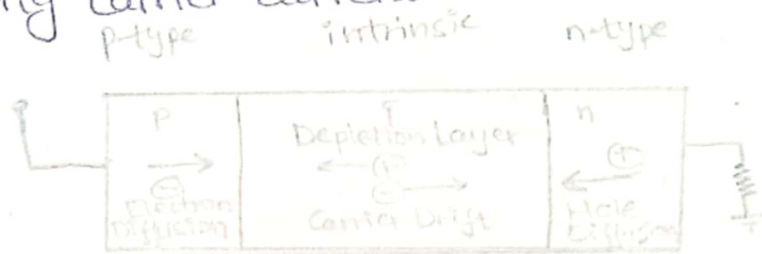
(5) · Explain about the PIN Photo diode with a suitable diagram.

↳ Ans :- Photodiodes are the semiconductor devices that produce electrons/holes by absorbing incident photons.

PIN Photodiode is a special kind of photodiode which is formed by sandwiching an additional layer of intrinsic semiconductor between the p-type and n-type semiconductor.

It has ~~higher~~ wider depletion region and thereby the minority carrier current.



When light energy is applied to the PIN diode, most part is absorbed by intrinsic or depletion region. As a result, large no. of electrons-hole pairs are generated.

Photons entering these layers produce charge carriers, this action results in high quantum efficiency of this device.

Dark Current :- When no light is applied to the reverse bias photodiode, it carries small reverse current due to external voltage which is called the dark current and denoted by I_λ.

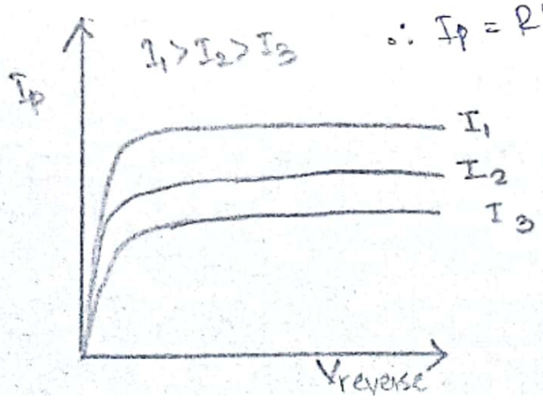
Photo Current :- The electric current generated when photodiode is exposed to light is called photo current.

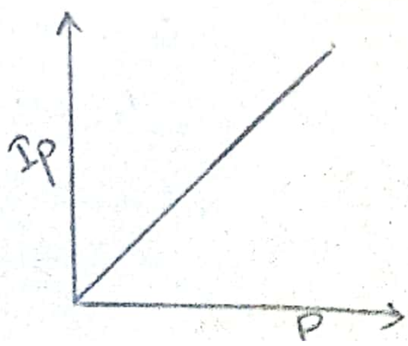
In a photodiode, the reverse current is independent of bias voltage and mostly depends on light power.

i.e. $I_p \propto$ Intensity of light.

$I_p \propto$ Power (if area is constant).

$\therefore I_p = RP$.





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10). In an optical fibre, the core material has refractive index of 1.6 and refractive index of cladding material is 1.3. Calculate the critical angle and angle of acceptance cone.

↳ Solution.

Refractive Index of core (μ_1) = 1.6

Refractive Index of cladding (μ_2) = 1.3

Now, Let, critical angle $= \theta_c$

From snell's law,

$$\mu_1 \sin\theta_c = \mu_2 \sin 90^\circ$$

$$\Rightarrow \sin\theta_c = \frac{\mu_2}{\mu_1}$$

$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{1.3}{1.6}\right)$$

$$= 54.34^\circ$$

Then, Let, acceptance angle be θ_a such that total angle of acceptance cone $= \theta_a \times 2 = 2\theta_a$.

Then, $\sin\theta_a = \sqrt{\mu_1^2 - \mu_2^2}$

$$\Rightarrow \sin\theta_a = \sqrt{1.6^2 - 1.3^2}$$

$$\Rightarrow \theta_a = \sin^{-1}(0.9327).$$

$$\Rightarrow \theta_a = 68.866^\circ$$

Hence, The angle of acceptance cone is $2 \times \theta_a$

$$= 2 \times 68.6657^\circ$$

$$\approx 137.73^\circ$$

∴ Critical angle = 54.34°

Angle of acceptance cone = 137.73°

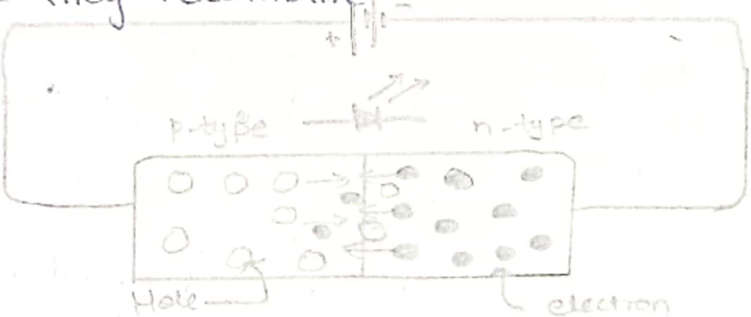
4). Write in short about working principle of
a). LED

↳ LED stands for Light Emitting Diode.
It is an opto-electronic device that converts electrical energy into light energy. It emits light (photon) when electrical signals (voltage) is applied to it.

↳ The process of working of an LED is called injection electroluminiscence.

↳ A typical LED consists of a p-n junction diode that is forward biased. In the LED, electrons and holes recombine in huge number to emit light energy along with heat.

↳ When the forward biasing is applied, e⁻ in N-region and holes in p-region are ~~repelled to~~ attracted towards depletion region where they recombine.



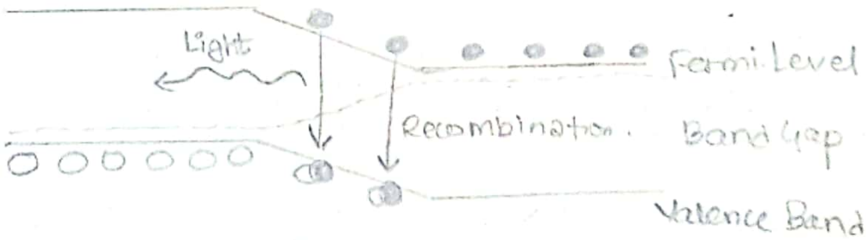


Fig: Working of an LED

↳ When the movement of e⁻ and holes take place, there is change in energy level as voltage drops from conduction band to valence band. There is a release of energy due to the motion of electrons.

↳ In standard diodes, this is released as heat while in LED, there is significant amount of light radiation.

↳ The ~~energy~~ light released can be in the region of UV, Visible or IR. The quanta of light energy is approximately equal to the bandgap of semiconductor used in LED.

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Q. For a step Index optical fiber, numerical aperture is 0·26 and refractive index of the core is 1·5 and core diameter is 100μm. Find the following :- (i) Refractive index of cladding.
(ii) Acceptance angle.
(iii) Critical angle.

Sol:-

Numerical Aperture $(N_A) = 0.26$ (unitless)
Refractive index of core $(\mu_1) = 1.5$ (unitless).
Diameter of core $(D_c) = 10^{-4}$ m.

Then, We know that,

$$N_A = \sin\theta_a$$ where θ_a is the acceptance angle.

$$\Rightarrow \theta_a = \sin^{-1}(N_A)$$
$$= \sin^{-1}(0.26)$$
$$= 15.07°$$

Also, let, refractive index of cladding $= \mu_2$.

Then, $N_A = \sqrt{\mu_1^2 - \mu_2^2}$

$$\Rightarrow 0.26 = \sqrt{1.5^2 - \mu_2^2}$$
$$\Rightarrow \mu_2 = 1.477 \text{ (unitless)}.$$

We know that, Snell's law states,

$$\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$$

Taking $\theta_2 = 90°$, we get $\theta_1 = \theta_c$

$$\Rightarrow \sin\theta_c = \frac{\mu_2}{\mu_1}$$
$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{1.477}{1.5}\right)$$
$$\Rightarrow \theta_c = 80.02°$$

∴ The refractive index of cladding is 1·477 (unitless).
The acceptance angle is 15·07°
The critical angle is 80·02°.

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(9). A silica glass optical fiber has a core refractive index of 1·5 and cladding refractive index of 1·46. Calculate the ~~refractive~~ critical angle. acceptance angle and numerical aperture.

↳ Sol^n

Refractive Index of Core $(\mu_1) = 1{\cdot}5$

Refractive Index of cladding $(\mu_2) = 1{\cdot}46$.

Then,

$$\text{Numerical Aperture (NA)} = \sqrt{\mu_1^2 - \mu_2^2}$$
$$= \sqrt{1{\cdot}5^2 - 1{\cdot}46^2}$$
$$= 0{\cdot}344.$$

Let, critical angle be θ_c and acceptance angle be θ_a.

Then, $\sin\theta_a = NA$

$$\Rightarrow \theta_a = \sin^{-1}(NA)$$
$$= \sin^{-1}(0{\cdot}344)$$
$$= 20{\cdot}13^\circ$$

Also,

Critical angle $= \theta_c$.

From snell's law,

$$\mu_1 \sin\theta_c = \mu_2 \sin 90^\circ$$
$$\Rightarrow \sin\theta_c = \frac{\mu_2}{\mu_1}$$
$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$
$$= \sin^{-1}\left(\frac{1{\cdot}46}{1{\cdot}5}\right)$$
$$= 76{\cdot}74^\circ$$

(6) Derive the expression for responsivity and quantum-efficiency of a PIN photodiode.

↳ A PIN photodiode is a semiconductor device formed by sandwitching a thick intrinsic layer between p-type and n-type layers.

For a PIN-diode, it has been found that the photocurrent (I_p) is directly propotional to the intensity of light after certain reverse voltage.

ie. $I_p \propto$ Intensity of light.

$I_p \propto P$ (when Area is kept constant).

$\therefore I_p = RP$ — (1) (where R is a propotionality constant) called ~~conversion efficien~~ responsivity whose unit is Amp/Watt.

Energy of photon is quantized as:-

$E = N_e \cdot e$.

Then, $I_p = \frac{N_e \cdot e}{t}$ —— (2).

Light power is the energy of each photon times rate of photon emission.

$P = \frac{E_p \cdot N_p}{t}$

$\therefore P = \frac{hcN_p}{\lambda \cdot t}$ where $h \to$ planck's constant (6.624×10^{-34} Js). $c \to$ speed of light (3×10^8 m/s).

Then, Eqn (1) becomes,

$$\frac{N_e e}{\cancel{t}} = R \cdot \frac{hcN_p}{\lambda \cancel{t}}$$

$$\Rightarrow R = \left(\frac{N_e}{N_p}\right) \cdot \frac{\lambda e}{hc} \quad \text{—— (3)}$$

Here, $\left(\frac{N_e}{N_p}\right)$ ratio is defined as quantum efficiency which is the ratio of e^- produced to the number of photons incident.

ie. $\eta = \frac{N_e}{N_p}$ —— (4).

$$\therefore \boxed{R = \eta \cdot \frac{\lambda e}{hc}} \text{ —— (5)}$$

The above equations 3, 4, 5 give the relation of responsivity and quantum efficiency.

3). Explain the role of optical fiber in communication with block-diagram.

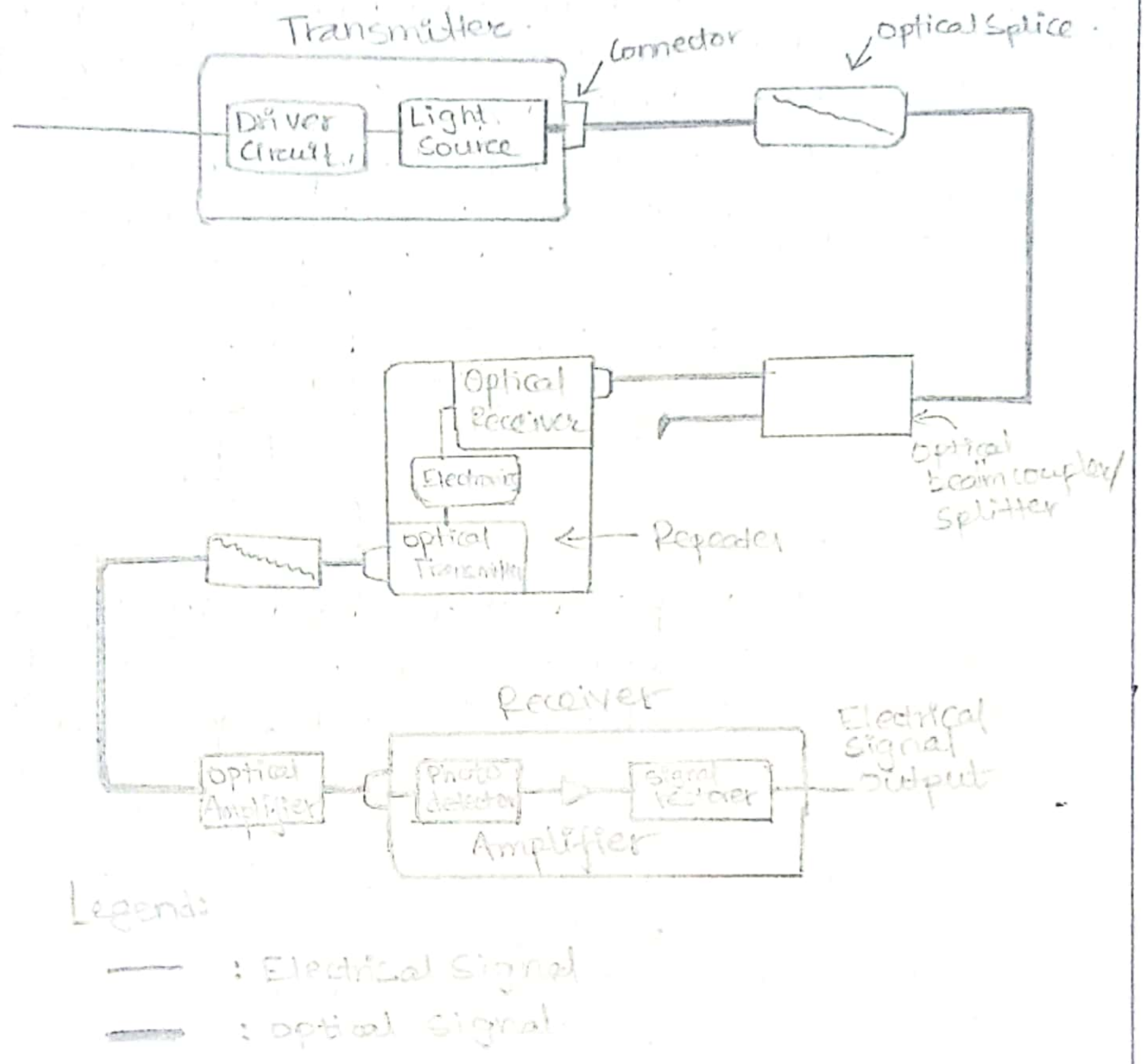

Fig:- Block diagram of communication systems.

The parts of a fiber optic communication system are:-

1). Transmitter.

↳ It receives the signal in analog/digital form in the form of electrical pulses.

↳ It converts the data into optical pulses.

↳ The connector connects optical fiber to transmitter module.

ii). Channel of Transmission.

↳ It consists of the cable, protecting part, signal amplifiers and repeaters, ~~etc~~ splices, connectors, etc.

↳ A cable consists of multiple fibers which individually acts as a separate channel.

↳ The cables are connected ~~to~~ permanently using splices.

↳ Connectors can be added at the end inorder to other cables or devices.

↳ optical coupler/splitter devices separate the single optical data into two different path so that they can be further used separately.

↳ Repeaters ~~and amplifier~~ work by reboosting the signals and help to prevent loss due to attenuation, dispersion, scattering etc in long distance communication.

iii). Receiver.

↳ This is the terminal part of the communication system. that converts incoming optical signal to electrical signal.

↳ It consists of photodetectors and optical signal restorers/amplifiers that work in turn to convert light signal into ~~meaningful~~ useful electrical pulses.

The components necessary for short/long distance communication are

i). Short distance communication.

Source – LED
Fibre – Multi-mode Step-Index fibre.
Detector – PIN Detector.

ii). Long distance communication.

Source – Laser Diode.
Fiber – single mode fiber
Detector – Avalanche Photo Detector (APD).