B.sc - IVth sem ①
Physics.

UNIT - II

opticle fibre: →

opticle fibre also called light pipe is a very thin cylinderical, flexible pipe like structure, ~~through~~ through which light can propagate by the phenomenon of total internal reflection.

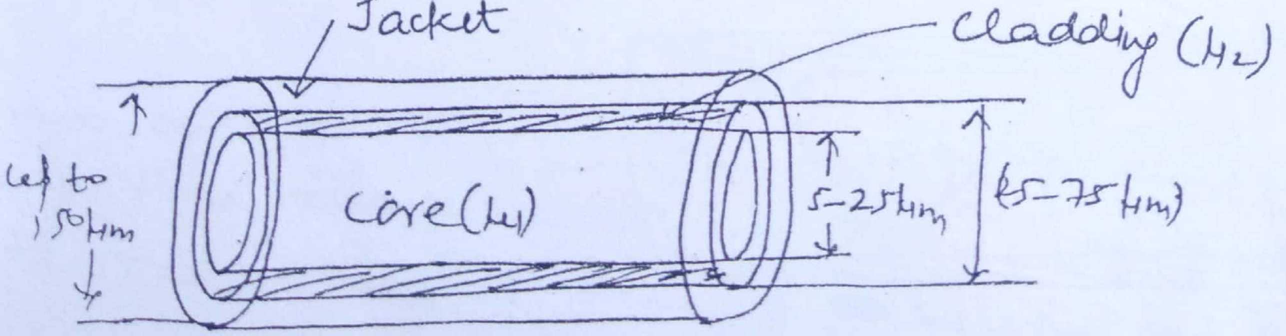
A typical opticle fibre consist of three layers:-
(i) core (ii) cladding (iii) Jacket

Core: → Core is the innermost section of fibre. It is the heart of fibre and has remarkable property that it conducts the light beam through it by phenomenon of total internal reflection. The core is made up of glass/plastic. The typical size of core may vary from 5 μm to 25 μm.

Cladding: → The layer surrounding the core is called cladding. It is also made up of glass or plastic. However material used in cladding has less refractive index than that used in core. i.e core always acts as denser medium and cladding acts as rarer medium.
If μ_1 is refractive index of material of core and μ_2 is refractive index of material of cladding, then

$$\boxed{\mu_1 > \mu_2}$$

Jacket: → The outermost layer of an opticle fibre is called Jacket. It is made up of any polymeric material. The jacket protects the fibre from mechanical abrashion, chemical contamination, environmental danger like lightening etc.



Propagation of light through optical fibre:—→

light wave enters at one end of a fibre in proper conditions, ost of it is propagated down the length of fibre and comes ut from other end of the fibre. The phenomenon by which ight propagates through optical fibre is total internal eflection.

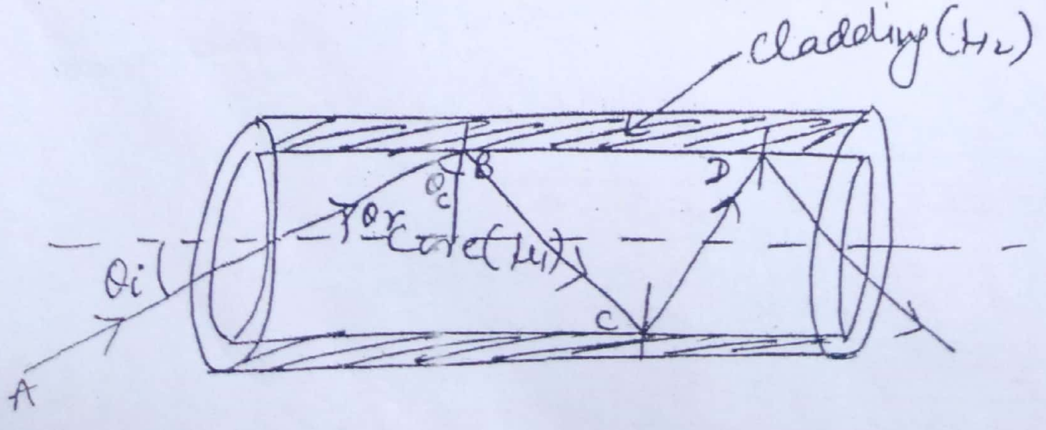
ollowing conditions are to be satified for total internal reflection to take place:-

i) light should go from denser medium to rarer medium.

ii) The angle of incidence should be greater than critical angle, where critical angle is given by

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

et us consider ray AB at one end of the fibre. If this ay is within the acceptance angle, then it is accomodated r accepted by the fibre and at point B within the core, it s incident at critical angle. Hence at point B, two conditions for total internal reflection are fulfilled i.e light is going from denser medium (core) to rarer medium (cladding) nd secondly it falls at critical angle at point B. Hence from B, it is internally reflected towards point C, where t again undergoes total internal reflection and so on and after several reflections ray of light comes out from emerging end of the fibre.



acceptance Angle, acceptance cone and Numerical aperture:—→

ceptance angle is that maximum value of incidence angle at unching end of the fibre, within which all light rays are ccepted and coupled into the fibre and will propagate. so ight rays incident within this acceptance angle fall at itical angle at core cladding boundary.

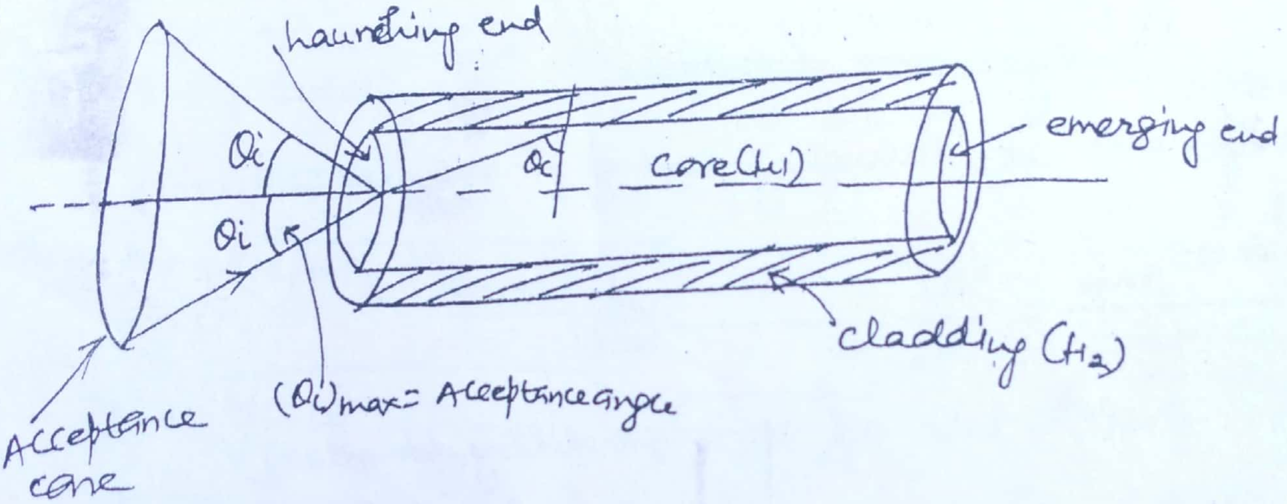
. cone formed by acceptance angle is called acceptance cone.

nce

$$(\theta_i)_{max} = \theta_a$$

where θ_i = incident angle

θ_a = acceptance angle.



erical aperture:— The light gathering ability of an optical fibre is given by numerical aperture. It is the figure of erit of an optical fibre.

hematically numerical aperture is given by

$$\boxed{NA = \sin\theta_a}$$

ie max. value of sin is always 1, ∴ so NA can have max. value . unity. Hence numerical aperture is simply a no. that ves the measurement of opening of ~~the~~ launching end of the re.

derive an. expression for numerical aperture in terms of index of core(n_1), Ref index of cladding (n_2); let us

μ_1 = ref. index of material of core

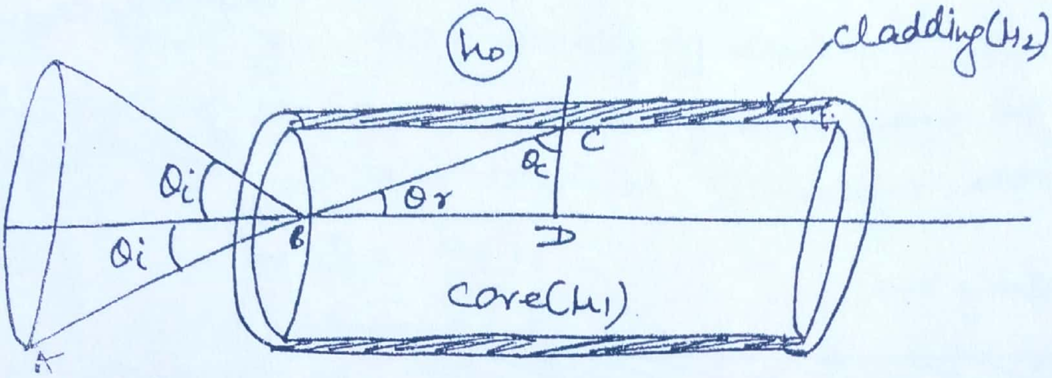
μ_2 = ref. index of material of cladding

μ_0 = Ref index of material outside the fibre

θ_i = angle of incidence at launching end of fibre

θ_r = angle of refraction

θ_c = critical angle.



Using snell's law at launching end of fibre, we can write,

$$\frac{\sin\theta_{imax}}{\sin\theta_r} = \frac{\mu_1}{\mu_0} \quad \text{———} \quad \text{(I)}$$

Also using snell's law at core cladding boundary

$$\frac{\sin\theta_c}{\sin 90^\circ} = \frac{\mu_2}{\mu_1} \quad \text{———} \quad \text{(II)}$$

$$\Rightarrow \sin\theta_c = \frac{\mu_2}{\mu_1} \quad \text{———} \quad \text{(III)}$$

From (I)

$$\frac{\sin(\theta_i)_{max}}{\sin(90-\theta_c)} = \frac{\mu_1}{\mu_0} \qquad \left[\begin{array}{l} \because \theta_r + \theta_c = 90^\circ \\ \Rightarrow \theta_r = 90 - \theta_c \end{array}\right]$$

$$\Rightarrow \frac{\sin\theta_{imax}}{\cos\theta_c} = \frac{\mu_1}{\mu_0} \Rightarrow \frac{\sin\theta_{imax}}{\sqrt{1-\sin^2\theta_c}} = \frac{\mu_1}{\mu_0}$$

$$\Rightarrow \sin\theta_{imax} = \frac{\mu_1}{\mu_0}\sqrt{1-\frac{\mu_2^2}{\mu_1^2}} \qquad \left[\text{from (III)}\right]$$

$$\Rightarrow \sin\theta_{imax} = \frac{\mu_1}{\mu_0}\sqrt{\frac{\mu_1^2-\mu_2^2}{\mu_1^2}}$$

$$\sin\theta_{i\,max} = \frac{\cancel{\mu_1}}{\mu_0}\sqrt{\mu_1^2-\mu_2^2}\cdot\frac{1}{\cancel{\mu_1}}$$

t the material surrounding the fibre is air. Then $\mu_0 = 1$

$$\sin\theta_{i\,max} = \frac{\sqrt{\mu_1^2-\mu_2^2}}{\mu_0=1}$$

$$\Rightarrow \sin\theta_{i\,max} = \sqrt{\mu_1^2-\mu_2^2}$$

$$\Rightarrow \boxed{NA = \sqrt{\mu_1^2-\mu_2^2}}$$

is expression for NA can be further modified as,

$$NA = \sqrt{(\mu_1+\mu_2)(\mu_1-\mu_2)}$$

we know that there is slight difference of ref index core and cladding. i.e

$$\mu_1 \approx \mu_2$$

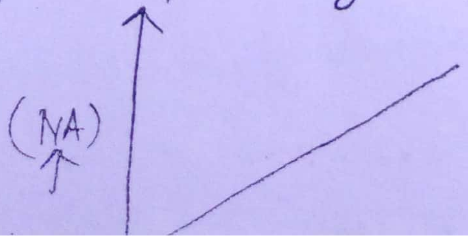
$$\therefore NA = \sqrt{(\mu_1+\mu_1)\frac{(\mu_1-\mu_2)}{\mu_1}\cdot\mu_1}$$

$$NA = \sqrt{2\mu_1^2\frac{(\mu_1-\mu_2)}{\mu_1}} = \sqrt{2\mu_1^2\,\Delta}$$

$$\boxed{NA = \mu_1\sqrt{2\Delta}}$$

here $\Delta = \frac{\mu_1-\mu_2}{\mu_1}$ = fractional difference between ref index of core and cladding.

most of the cases, larger value of numerical aperture is ferred because it becomes easy to launch the optical e into the fibre. However in many cases, smaller value numerical aperture is also required. Fig below shows ting of acceptance angle (θ_a) with NA.



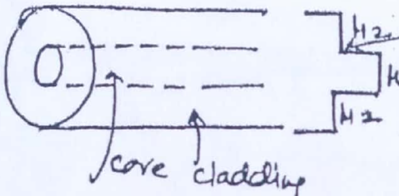
ypes of optical fibre:→

Fibres are classified broadely into follawing categories:-

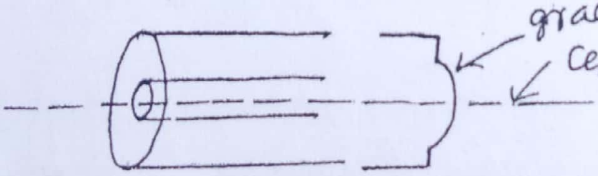
(i) Step index fibre (SI)
(ii) Graded index fibre (GRIN) } Depending upon index profile

(iii). Single mode fibre
(iv) Multi mode fibre } Depending upon no. of modes supported by fibre.

) **Step index fibre:→** If the refractive index of core is constant throughout the core region and changes abruptly i.e in a step at core cladding boundary, then it is called ~~core cladding~~ step index fibre. Fig below shows its refractive index profile.



) **Graded index (Grin) fibre:→** If the ref. index of the core is not constant throughout the core region i.e refractive index of core goes on decreasing as we go from core axis towards cladding, then the fibre is called graded index fibre. Fig below shows ref. index profile of a grin fibre.



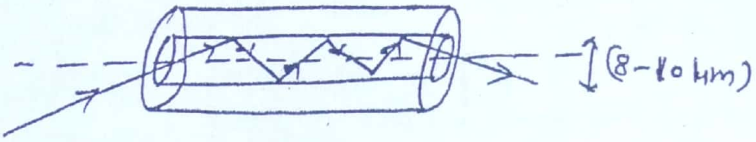
If 'a' is radius of core and μ_r is ref. index of core at a distance r from central axis of core,

$$\mu(r) = \mu_1 \left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]^{1/2}$$

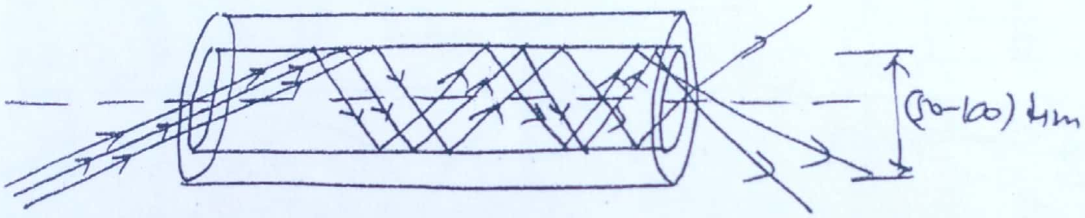
Where α = Constant,
μ_1 = ref index at centre
Δ = fractional diff between ref index of core & cladding

Single mode fibre:→

..gle mode fibre is one which allows only one mode of propagation. These fibres are also called mono mode fibres. ..ese fibres have very small core diameter. V number for such a fibre is less than 2.4.



Multimode fibres: → These fibres can support many hundreds of modes of propagation. These fibres have ..rge core diameters around (50-100) μm and V number is greater than 2.4.



..de of propagation and V-number: →

..hen light wave propagates through the core of an optical fibre, the path followed by the wave is a function of ..ngle of incidence or acceptance angle at core cladding ..oundary. The light rays falling within the acceptance ..ngle are accepted by the fibre and hence propagates ..rough the core. But there are certain allowed paths ..light which the light wave follows as it travel down the core of an optical fibre.

..e no. of modes 'N' supported by a step index fibre is given by,

$$\boxed{N = \frac{2\pi^2 a^2}{\;^2}\left(\mu_1^2 - \mu_2^2\right)}$$

where

a = radius of core
λ = operating wavelength
n_1 = Ref index of core
n_2 = Ref index of cladding

number also called normalized frequency of an optica
ibre is given by relation,

$$V = \frac{2\pi a}{\lambda}(NA)$$

or

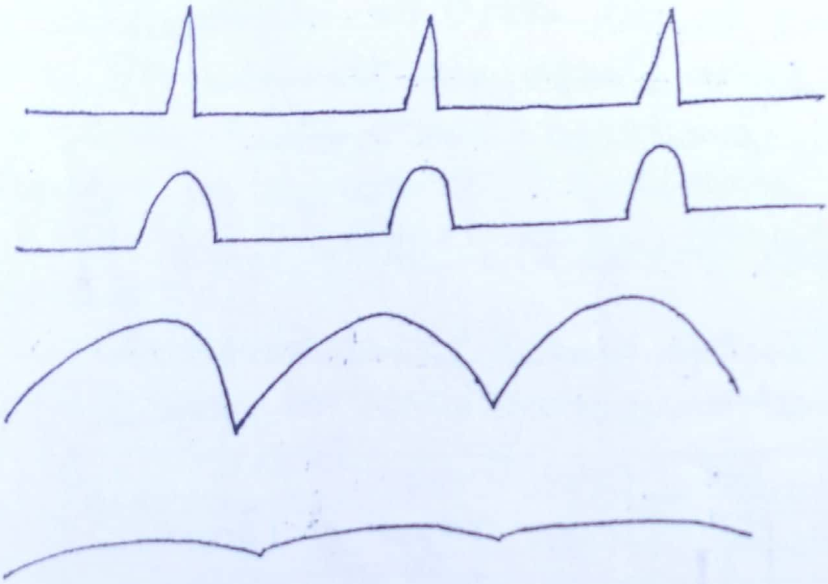
$$\boxed{V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}} \quad \text{---} \; \text{(II)}$$

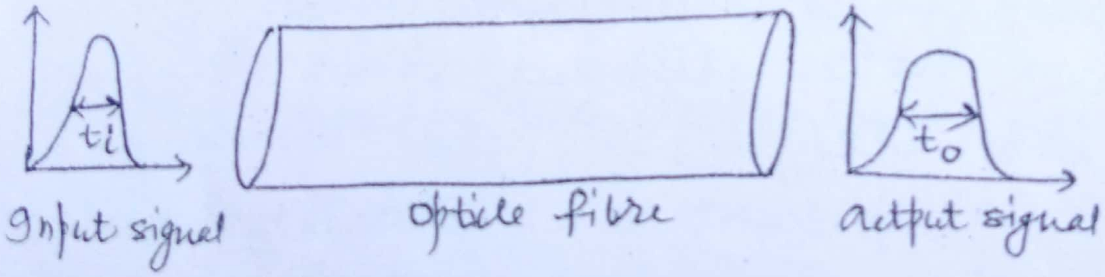
from (I) and (II), we can write

$$\boxed{N = \frac{V^2}{2}}$$

SE DISPERSION :→

In digital communication systems, a large no. of Pulses are sent through an opticle fibre. If a pulse of light is sent through one end of the opticle fibre, then after being propagated through it, pulse at the other end will have lower amplitude and a larger duration. i.e it broadens in time. This phenomenon is called pulse dispersion.





ulse dispersion Δt is defined as,

$$\boxed{\Delta t = \sqrt{t_o^2 - t_i^2}}$$

Where t_i = width of input pulse

t_o = width of output pulse

he total dispersion produced by a fibre depends pon its length. Longer is the fibre, broader will be e pulse i.e larger dispersion.

ulse dispersion occurs due to following three nechanisms:-

i) Intermodal dispersion
ii) Intramodal dispersion
iii) Waveguide dispersion

Intermodal dispersion:→

In multimode fibres, different modes travels with different velocity with respect to the axis i.e different mode take different times to propagate through given length of fibre. This is called intermodal dispersion.

TO avoid it, single mode fibres should be used.

Intra modal dispersion:→ Intra modal dispersion also called as material or chromatic dispersion depend upon wavelength of light. We know that light source in the fibre consists of large range of wavelen light of wavelengths of different λ travels at differen speed in the medium. The waves of shorter wavele travel slower than longer wavelength waves i.e different waves takes different times to opagate along same length, so pulses broaden as they travel. It is present in both single mode and multimode fibres.

TO avoid this, LED is used as light source with λ = 1300 nm. At 1300 nm, speed of larger and shorter wavelengths are same, hence materia dispersion is minimum.

Waveguide dispersion: →

It occurs only in single mode fibres. This dispersion arises due to guiding properties of the fibre. This type of dispersion can be minimised by changing ref. index profile of the fibre. For this, a graded index fibre (GRIN) can be used in place of step index (SI) fibre; Although GRIN fibres are most expensive.

Attenuation: →

In an opticle fibre, whenever a signal is transmitted, there is a loss in its power and hence its output intensity decreases with respect to distance travelled. This loss of intensity of light beam through a fibre is called attenuation.

Attenuation loss is generally measured in terms of dB, which is a logrithamic unit.

$$\boxed{\text{Attenuation(dB)} = -10 \log \frac{P_{out}}{P_{in}}}$$

where P_{in} = opticle signal power entering at one end of fibre

P_{out} = output signal power emerging from other end of fibre.

There are three mechanisms responsible for attenuation in opticle fibres:-

1) Scattering of light
2) Absorption of light by materials
3) Waveguide & Microbend losses

Scattering of light: → At molecular level, glass of core is rough and irregular, which causes scattering of light. During manufacturing of fibre, ref index & hence density varies and [illegible] scattering of light takes place. Scattering loss varies with wavelength as $S \propto \frac{1}{\lambda^4}$.

) Absorption of light by materials:→

When a light signal propagates through the core of an optical fibre, it interacts with molecular structure of core material as well as impurities present in it. So loss of light occurs due to absorption. Hydroxyl radical ions(OH^-) and Nickel, copper etc have absorption of light. Such absorption losses are minimum at 1300 nm wavelength light.

(ii) Bending loss:→ Bending loss may be of two types (i) Micro bending loss (ii) Macro bending loss. Micro bending loss may be created during manufacturing of the fibre. This can be minimised by proper monitoring during manufacturing of fibre. Whereas Macro bending loss occurs during installation of fibre because of carelessness.

Applications of optical fibres:→

I) Medical Applications:→ Endoscopy means viewi of internal organs of human body is done with the help of an optical fibre connected with a camera and a monitor to visualise internal organs. Moreover in cardiology, laproscopy, opthalo-logy etc; optical fibre is widely used.

Military Applications:→ ⑪

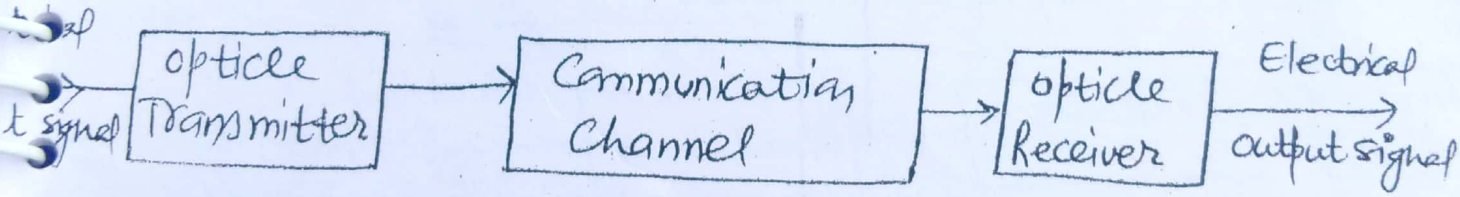
opticle fibres are used in military applications, particularly in submarines to avoid heavy and bulky coaxial cable copper wires mesh.

7) Fibre optical communication system:→

Communication system transmits information (signal) from one place to another, seperated by small or large distance. A fibre optical communication system consists of

(i) optical transmitter
(ii) Communication channel
(iii) An optical Receiver

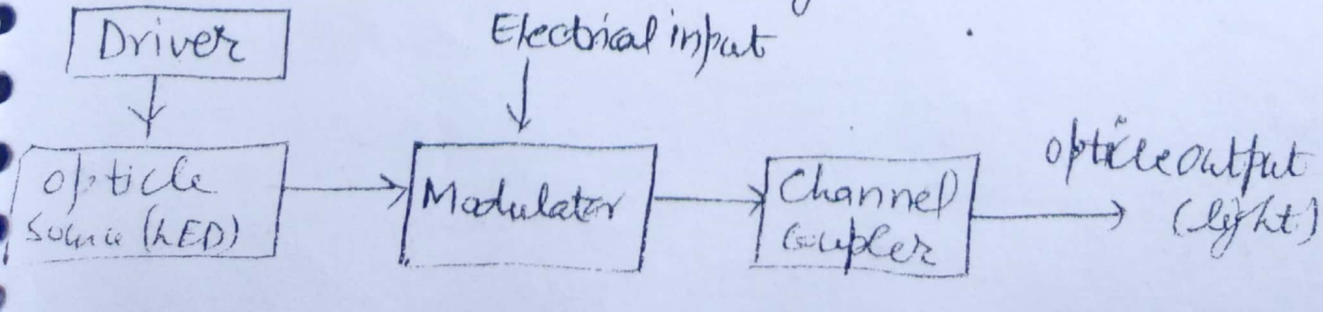
fig. below shows a typical fibre optical communication system.



i) opticle Transmitter:→

An opticle transmitter converts Electrical input signal into opticle signal and launches opticle signal into opticle fibre.

fig. below shows block diagram of opticle transmitter.

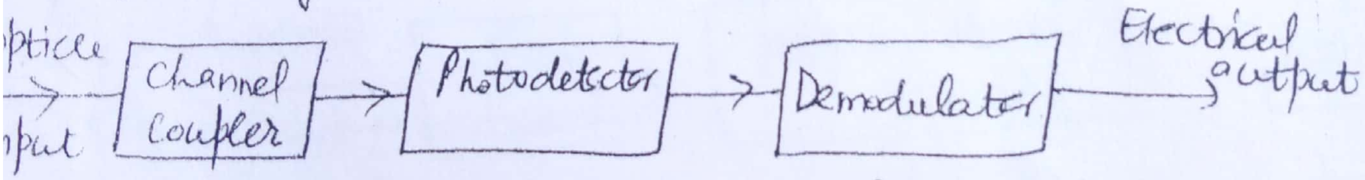


pticee Source is generally semiconductor laser diode or Light emitting diode (LED) which converts Electrical energy into optical energy i.e. light. Channel coupler is a lens that focusses light signal obtained from LED onto launching end of opticle fibre.

) Communication channel:→

he role of communication channel is to transport the light signal from transmitter to receiver without distortion. An opticle fibre serves as opticle channel for a opticle fibre communication system.

) Opticle Receiver:→ This accept opticle signals from the opticle fibre and converts them into electrical signals. Fig shows block diagram of an opticle receiver.



Channel coupler focusses the light signal obtained from fibre onto the photodetector, which converts light into electrical signal. Photodetect nay be a Photo diode.