$$= e^{\frac{-6.626\times10^{-34}\times3\times10^{8}}{1.39\times10^{-6}\times1.38\times10^{-23}\times3300}} - 1$$

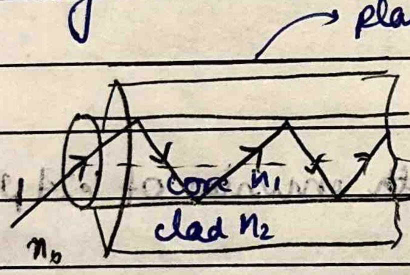
$$= 0.97\times10^{-15}$$

Application of laser in defence and printing.

OPTICAL FIBRES:

used in communication, principle of total internal reflection.

Advantages → min^n signal loss, high speed transmission, no EM interference, safe and secure means of communication — as it is harder to tap the signal



$n_1 > n_2$

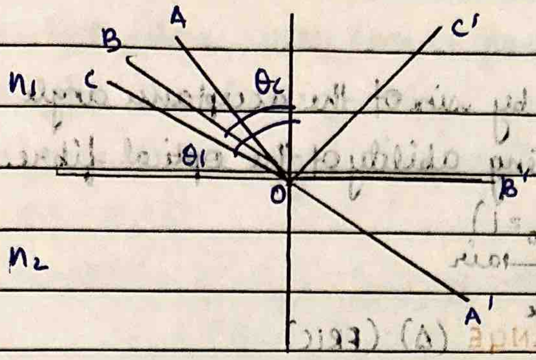
The principle employed in the design of OF → Total internal reflection.

Applying Snell's law:

$$n_1 \cdot \sin\theta_c = n_2 \cdot \sin 90^\circ$$

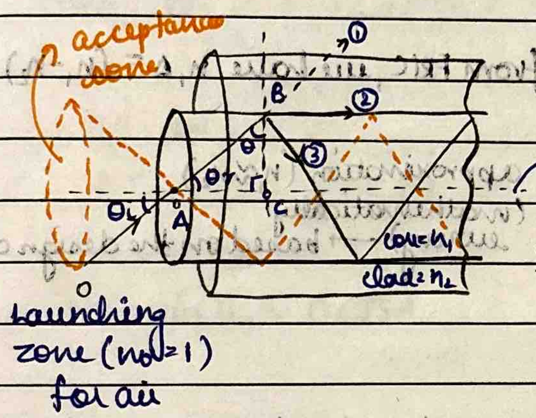
$$n_1 \cdot \sin\theta_c = n_2$$

$$\sin\theta_c = \frac{n_2}{n_1}$$



(A) The light ray undergoes multiple TIR as it undergoes through the optical fibres.

(I) EXPRESSION FOR ACCEPTANCE ANGLE OF AN OPTICAL FIBRE IN TERMS OF REFRACTIVE INDICES OF THE FIBRE:



core → transmitting medium

clad → reflecting medium

Applying Snell's law:

$n_0 \sin\theta_i = n_1 \sin\theta_r$

from ΔABC → $n_0 \sin\theta_i = n_1 \sin(90-\theta)$

$n_0 \sin\theta_i = n_1 \cos\theta$ —— eq ①

(from launching zone into the core of the optical fibre)

For maximum angle of incidence ($\theta_i = \theta_{i(max)}$) the light ray will graze the surface of seperation, i.e. $\theta = \theta_c$

substituting this condition in eq ①, we get

$n_0 \sin[\theta_{i\,max}] = n_1 \cos\theta_c$ $\boxed{\theta_{i\,max} = \theta_0}$

$n_0 \sin\theta_0 = n_1 \cos\theta_c$

From snell's law, we have $\sin\theta_c = n_2/n_1$; $\cos\theta_c = \sqrt{1-\left(\frac{n_2}{n_1}\right)^2} = \frac{\sqrt{n_1^2-n_2^2}}{n_1}$

$n_0 \sin\theta_0 = \cancel{n_1} \cdot \frac{\sqrt{n_1^2-n_2^2}}{\cancel{n_1}}$

$$\boxed{\sin\theta_0 = \frac{\sqrt{n_1^2-n_2^2}}{n_0}} \Rightarrow \boxed{\theta_0 = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right)}$$

θ_0 is called as the acceptance angle.

The max^m angle through which the light has to be incident such that the light ray propagates through the optical fibre.

Pure sillica glass is used in the design of optical fibres.

abundantly available in its purest form. , nowadays polymers are used as they are more flexible

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(II) NUMERICAL APERTURE: (NA)

Mathematically it is given by sin of the acceptance angle. It decides the light gathering ability of the optical fibre.

$\boxed{NA = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}}$ ($n_0 = 1$) air

(III) FRACTIONAL REFRACTIVE Index CHANGE (Δ) (FRIC)

$\boxed{\Delta = \frac{n_1 - n_2}{n_1}}$ This paramter is always positive and always lesser than 1

(IV) RELATION B/W NA AND FRIC

We know that $NA = \sqrt{n_1^2 - n_2^2}$, from FRIC, we have $n_1\Delta = (n_1 - n_2)$

$NA = \sqrt{(n_1 - n_2)(n_1 + n_2)}$

$= \sqrt{(n_1\Delta)(n_1 + n_2)}$ → approximation ($n_1 \approx n_2$) (mathematically wrong) → based on the design and experim

$= \sqrt{(n_1\Delta)(2n_1)}$

$\boxed{NA = n_1\sqrt{2\Delta}}$

(Q) Calculate the numerical aperture and angle of acceptance for an optical fibre having refractive indices 1.563 and 1.498 for the core and cladding respectively.

(A) $NA = \sin\theta_0 = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.563)^2 - (1.498)^2} = 0.4460$

$\theta_0 = \sin^{-1}(0.4460)$

$= 26.48^\circ$

(Q) An optical fibre has a NA = 0.39, the refractive index of its clad is 1.5, find the refractive index of the core, the acceptance angle of the fibre and the fractional index change.

(A) $\sin\theta_0 = 0.39 = \sqrt{n_1^2 - (1.5)^2}$

$= 0.39 \times 0.39 = n_1^2 - (1.5)^2$

$= n_1 = \sqrt{2.4021} = 1.549$

$\theta = \sin^{-1}(0.39)$

$\theta = 22.95^\circ$

$\Delta = \frac{1.549 - 1.5}{1.549} = 0.032$

(Q) A glass clad fibre, with core of glass, refractive index 1.5, has FRIC of 0.0005, find the cladding index, critical internal reflection angle, external acceptance angle, numerical aperture.

(A) $n_1 = 1.5$; $n_2 = ??$

$$\Delta = 0.005 = \frac{n_1 - n_2}{n_1} = \frac{1.5 - n_2}{1.5} \Rightarrow n_2 = 1.499$$

$$\cos\theta_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \Rightarrow \theta_c = \cos^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

$$\Rightarrow \cos^{-1}\left(\right.$$

$$\sin\theta_c = n_2/n_1 = \theta_c = \frac{1.499}{1.5} = \sin^{-1}(0.999)$$

$$= 87.43^\circ.$$

$$\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

$$= \sin^{-1}\sqrt{(1.5)^2 - (1.499)^2}$$

$$= 3.13^\circ$$

$$NA = \sin\theta_0 = 0.054$$

(Q) An optical fibre has NA = 0.2, and cladding refractive index of 1.59 in air, determine the acceptance angle of the fibre in water which has a refractive index of 1.33.

(A) $$NA = \sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} = \frac{\sqrt{(1.60)^2 - (1.59)^2}}{1.33} = 0.147.$$

$$0.2 = \sqrt{n_1^2 - n_2^2}$$

$$\theta = \sin^{-1}(0.147) = 8.45^\circ.$$

$$(0.2)^2 = n_1^2 - (1.59)^2$$

$$n_1 = 1.602.$$

$$\theta_{0(water)} = \sin^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right)$$

$$= \sin^{-1}\left(\frac{NA}{n_0}\right) = \sin^{-1}\left(\frac{0.2}{1.33}\right) = \sin^{-1}(0.147)$$

$$= 8.45^\circ$$

(Q) The angle of acceptance of an optical fibre is 30° when kept in air, find the angle of acceptance when it is in a medium of refractive index 1.33.

(A) $$\sin\theta_0 = \sqrt{n_1^2 - n_2^2} \Rightarrow \sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} = \frac{1}{2 \times 1.33}$$

$$1/2 = \sqrt{n_1^2 - n_2^2}$$

$$\theta = \sin^{-1}\left(\frac{1}{2 \times 1.33}\right) = 22.08^\circ.$$

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(Q) The velocity of light in the core of a fibre is 2×10^8 m/s and the critical angle at the core-cladding interface is 60°, determine the refractive index of the core and the cladding and the numerical apperture.

(A) $\mu = \frac{c}{v} = \frac{3\times10^8}{2\times10^8} = 1.5 = n_1$

$\sin\theta_c = \frac{n_2}{n_1} = \frac{\sqrt{3}}{2} = \frac{n_2}{1.5}$

$= n_2 = \frac{3\sqrt{3}}{2\times2} = \frac{3\sqrt{3}}{4} = 1.299$

NA = 0.75

(Q) The core refractive index of an optical fibre is 1.40, its relative refractive index is 2.5%. Determine the numerical aperture and the critical angle

(A) $\Delta = \frac{n_1 - n_2}{n_1} = \frac{2.5}{100\times10} = \frac{1.5 - n_2}{1.5} = \frac{2.5}{100\times10}$ $\to$ $2.5\times10^{-3}\times1.5$ $\to$ $1.5 - 3$

$n_2 = 1.49$

$\sin\theta_c = n_2/n_1 = \frac{1.491}{1.5}$; $\theta_c = \sin^{-1}\left(\frac{1.49}{1.5}\right) = 83.38°$

Unit 3: Optical Fibre

Modes of propagation:

V – number → normalised frequency number.

$$V = \frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2}$$ → based on the acceptance cone

we have diameter (d) of the core of the optical fibre.

$$V = \frac{\pi d}{\lambda}(NA)$$ ← normalised frequency number

The no. of modes supported in an optical fibre is determined by V-parameter

$$V = \frac{2\pi r}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$$N_m = \frac{V^2}{2}$$ for step index fibre

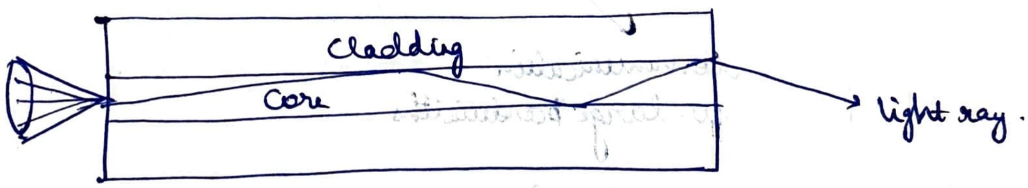
modes

$$N_m = \frac{V^2}{4}$$ for graded index fibre.

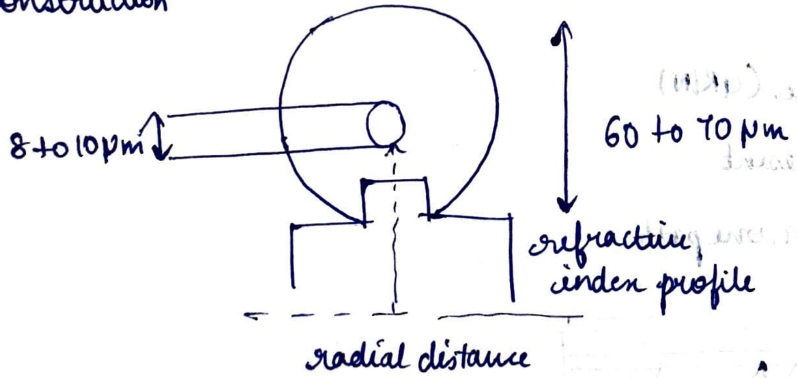
Types of Optical fibres based on modes of propagation:

(1) Single mode step index fibre

(i) The light ray takes only one path

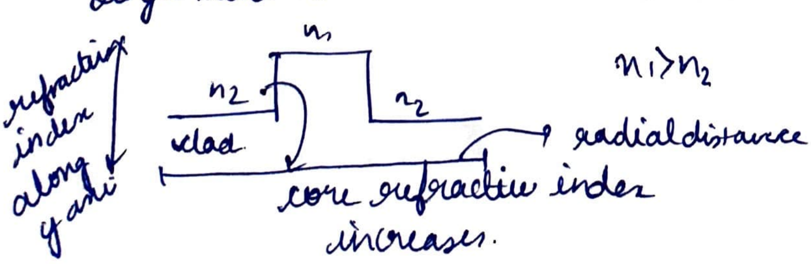


(2) Construction



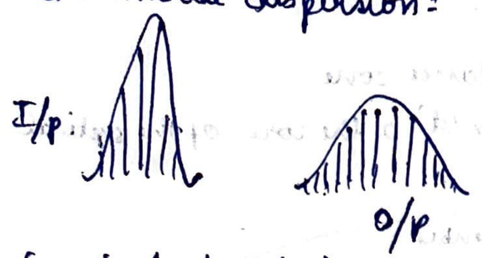
(3) Refractive index profile:

Single mode SIF



(4) Since the light ray takes a single path within the OF, intermodal dispersion does not exist.

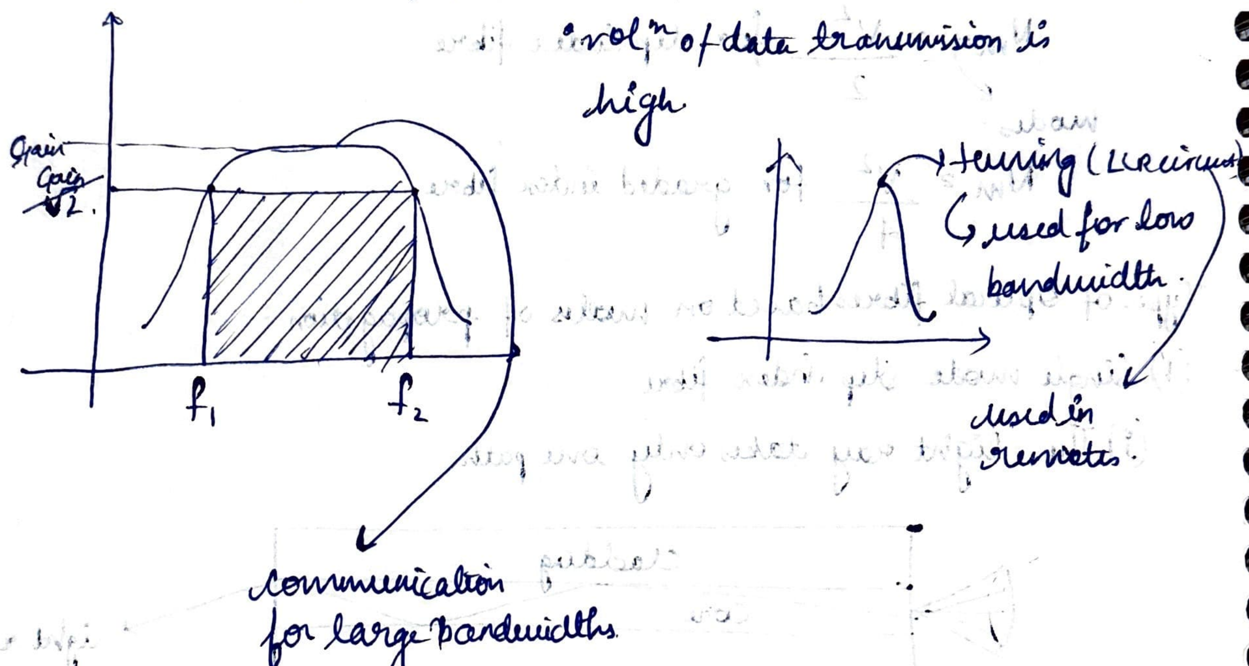
Intermodal dispersion:



(i) decrease in amplitude because loss of energy, unwanted signal introduced as signal is propagating.
(ii) increase in wavelength
(iii) noise introduced

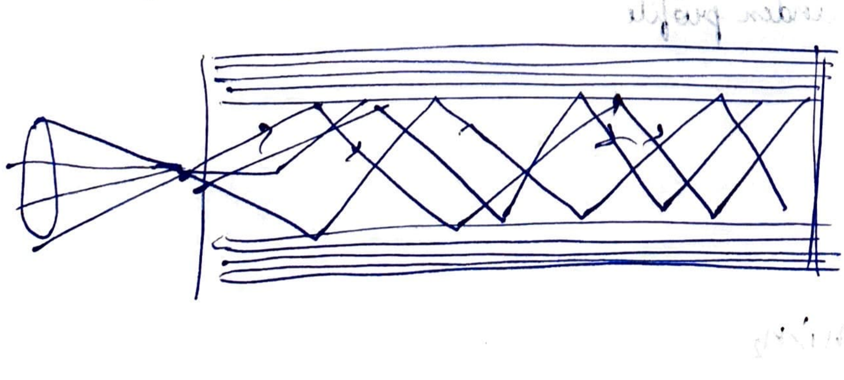
Fourier Analysis (FA)

(5) Used for long distance communication since the fibre offers large bandwidth. bandwidth → applicable range of frequencies.



(6) Source of light used is laser only. (highly monochromatic)

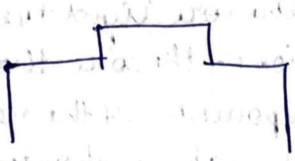
(2) Multimode step index fibre. (GRIN)
(i) intermodal dispersion is present.
light ray takes more than one path.



(2) Construction: diameter increases of the core.

50–100 and 100 to 250 μm

(3) RI profile :

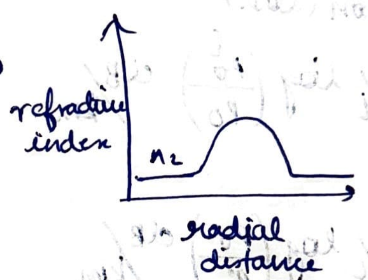


RI profile.

(4) Since intermodal dispersion exists, this fibre is used for short distance communication.

(5) This fibre offers low bandwidth, source of light used is LED, other than lasers.

(3) Graded index fibre (multimode fibre)

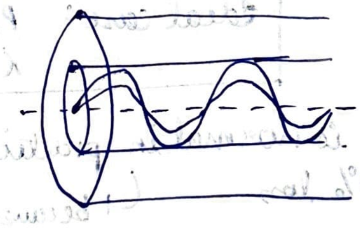


(1) It is a multimode fibre.

Grading → changing the refractive index.

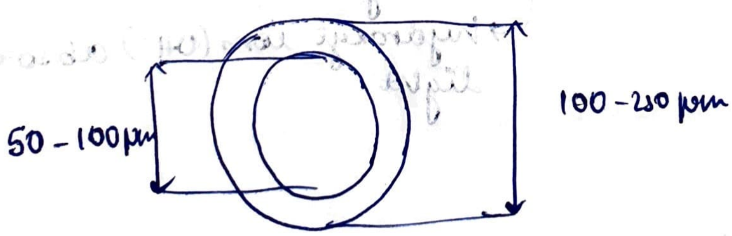
$n = c/v$ → $n_1 = c/v$

C refractive index

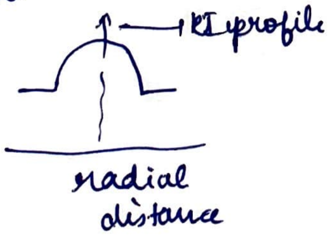


→ only one ray incident with the max^m angle is required for TIR, then the core refractive index keeps changing thus the remaining rays need not touch the core-cladding surface

(2) construction:

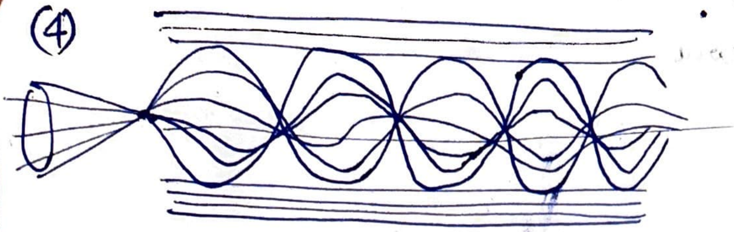


(3) RF profile



In grin (GRIN), the core consists of concentric layers of different refractive indexes, this refractive index (RI) of the core varies with distance from the fibre axis, it has a high value at the centre and falls off with increasing radial distance from the fibre axis. RI of the clad is fixed

(4)



Rays take a sinusoidal path through the core. Light travels with low speed in the high refractive index region of the core than that in the low index region, since the fastest / components of the rays take a longer path and the slower components take a shorter path in the core, the travel time of different modes will almost be the same, this reduces the effect of intermodal dispersion, hence losses are low with little pulse broadening effect.

This fibre is used for medium distance communication.
Sources of light used are lasers and LED.

Attenuation (loss)

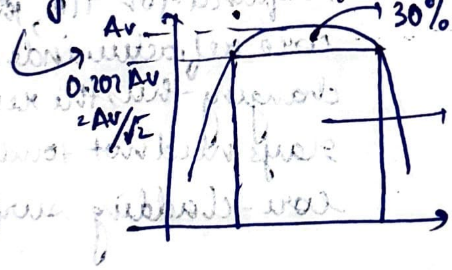
$$\alpha = \frac{10}{L} \log\left(\frac{P_i}{P_0}\right) \ dB/km$$

$L \rightarrow$ length of the optical fibre.
$P_i \rightarrow$ input power
$P_0 \rightarrow$ output power.

$$\alpha = -\frac{10}{L} \log\left(\frac{P_0}{P_i}\right) \ dB/km$$

$\boxed{\text{Ideal case: } P_0 = P_i \quad \alpha = 0 \ dB/km}$

Typically a loss of 3 dB/km is normal in practice.



↳ because of

(1) intermodal dispersion

(2) Absorption loss

↳ core made of glass absorbs the light.

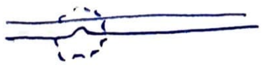
↳ hydroxyl ions (OH^-) absorb light.

(3) Scattering loss:

Rayleigh scattering ($RS \propto 1/\lambda^4$)

(4) Bending loss:

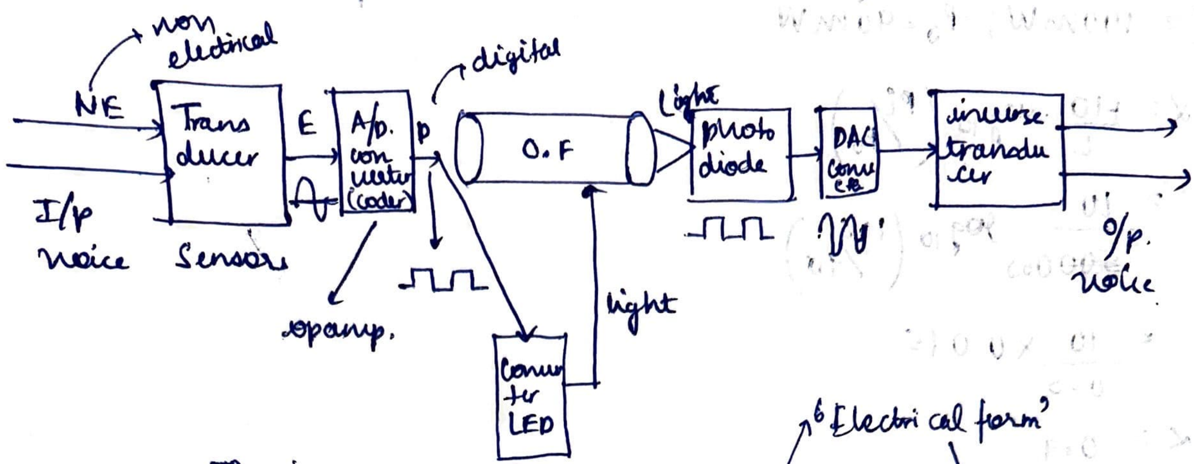
↳ during manufacturing
while laying the wire.



(5) Coupling loss:

Applications of Optical fibres:

(1) Point to Point Communication: (6 marks)



Repeater → Receiver → receives light signal → amplifies the signal ("Electrical form") ⊗ → does not give any high gain

Repeater → Transmitter

Transmitter → amplified signal → light form → transmitted.

some conditions: $n_1 > n_2$, θ_0, losses (cannot be made 0, minimized) → to reduce we use repeater

(In the optical fibre).

(Q) A step index fibre in air has a numerical aperture of 0.12, core of refractive index 1.42, core diameter of 20cm, determine the normalised frequency for the fibre when light of wavelength 0.8 μm is transmitted.

(A)

$$V = \frac{2\pi r}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$$V = \frac{\pi d}{\lambda} \cdot NA$$

$$= \frac{3.14 \times 20 \times 10^{-2} \times 0.12}{0.8 \times 10^{-6}} = 9.42 \times 10^4$$

(Q) Calculate the V number for a fibre of core diameter 40μm and refractive index 1.55 and 1.5 for core and clad, when wavelength of propagating wave 1400nm. Also calculate the no. of modes the fibre can support for propagation (N_m)

(A) $$V = \frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$N_m = 612.$

$$= \frac{3.14 \times 40 \times 10^{-6}}{1400 \times 10^{-9}}\sqrt{(1.55)^2 - (1.5)^2}$$

$$= 89.71 \times 0.390$$

$$= 34.98$$

(Q) Find the attenuation in an optical fibre of length 500m, when a light signal of power 100mW emerges out of the fibre with a power 90mW.

(A) $P_i = 100mW$; $P_o = 90mW$

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

$$= \frac{10}{\cancel{500} \, 0.5} \log_{10}\left(\frac{10\cancel{0}}{9\cancel{0}}\right)$$

$$= \frac{10}{0.5} \times 0.045$$

$$\alpha = 0.9.$$

(Q) A certain OF has an attenuation of 3.5dB/km, 0.5mW of optical power is launched into the fibre, what is the power level in μW after 4KM.

(A) $$\alpha = \frac{10}{4} \log_{10}\left(\frac{0.5 \times 10^{-3}}{x}\right)$$

$$\frac{3.5 \times 4}{10} = \log_{10}\left(\frac{0.5 \times 10^{-3}}{x}\right)$$

$$1.4 = \log_{10}$$

$$25.11 = \frac{0.5 \times 10^{-3}}{x}$$

$$x = \frac{0.5 \times 10^{-3}}{25.11} = 1.99 \times 10^{-5}$$

$$= 19.9 \times 10^{-6} \, W = 19.9 \, \mu W.$$