

Holography:

- Holo means "hole" (complete) → Graphy means (writing).
- Writing all information at one place is known as holography.

Application:

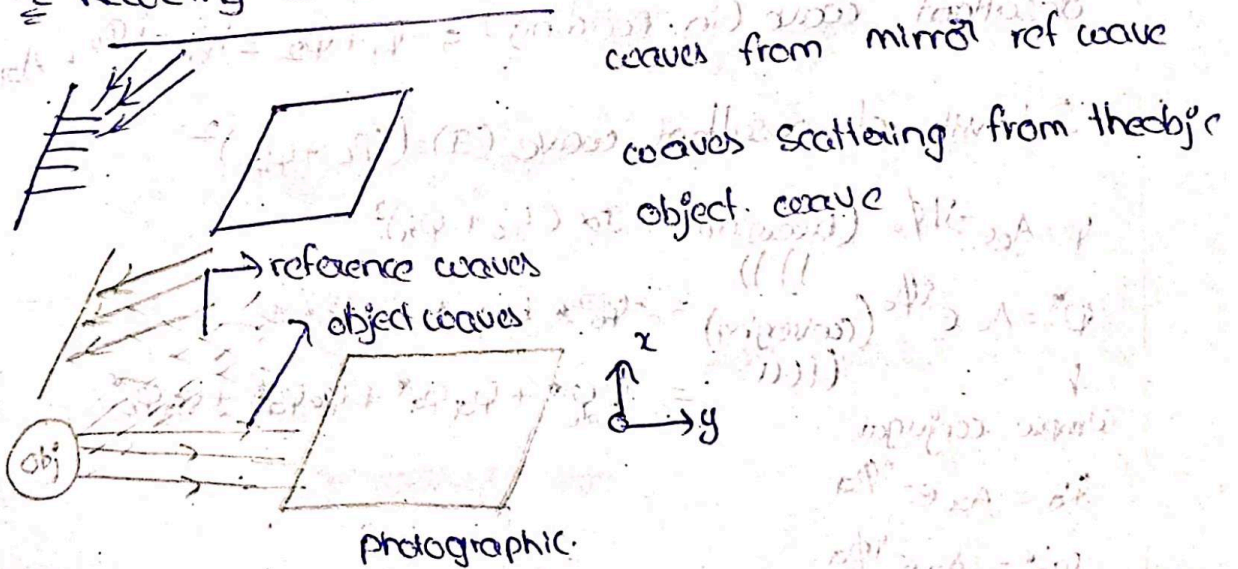
- A.I
- Data writing
- Gabor who invented the basic process involving in Holography
- Microscopy
- Holographic data storage
- Holographic interferometer
- Security systems
- at the time of laser invention

≡ Recording of a hologram.

≡ Reconstruction of hologram.

- Holography is basically an interference phenomena.

≡ Recording of a hologram



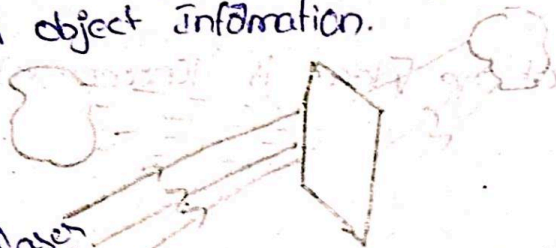
- splitting into waves reference wave and object wave
- for interference

Recording interference of O.W and R.W on photographic plate (encoding the object information on p.p)

developing the photographic plate.

Reconstruction wave process:

- * Illuminating the Hologram with Reconstruction wave and object information.



- * ~~develop~~ Integrate developed photograph the it gives the object information.

- * retrieving object

$$\psi_o = A_o e^{-i\phi_o}$$

ψ_o → wavefunction of object

A_o - Amplitude of the object wave

ϕ_o - phase distribution

$$\psi_R = A_R e^{-i\phi_R}$$

A_R = Amplitude of the Reference wave.

ϕ_R = Phase distribution of the ref wave

resultant wave (in reading) = $\psi_1 + \psi_2 = A_o e^{-i\phi_o} + A_R e^{-i\phi_R}$

Intensity of resultant wave $(I) = (\psi_o + \psi_R)^2$

$\psi = A_o e^{-i\phi_o}$ (Diverging) $\propto (\psi_o + \psi_R)^2$

$\psi^* = A_o e^{i\phi_o}$ (converging)

↓ complex conjugate
 $\psi_o^* = A_o e^{i\phi_o}$
 $\psi_R^* = A_R e^{i\phi_R}$

$\psi_o^* = A_o e^{i\phi_o}$

$$I = A_o e^{-i\phi_o} \cdot A_o e^{i\phi_o} + A_R e^{-i\phi_R} A_R e^{i\phi_R} + A_o e^{-i\phi_o} A_R e^{i\phi_R} + A_R e^{-i\phi_R} A_o e^{i\phi_o}$$

$$= A_o^2 + A_R^2 + 2 A_o A_R e^{i(\phi_R - \phi_o)}$$

- * we need ~~copy~~ converging wave to retrieve information.

$$I = A_o^2 + A_R^2 + A_o A_R e^{i(\phi_R - \phi_o)} + A_o A_R e^{i(\phi_o - \phi_R)}$$

$$I = A_0^2 + A_x^2 + A_0 A_x e^{-i(\phi_0 - \phi_x)} + A_0 A_x e^{i(\phi_0 - \phi_x)}$$

Transmission function of a Hologram:-

is defined as $\tau = \frac{\text{Amplitude of the transmitted wave}}{\text{Amplitude of the incident wave.}}$

$$\boxed{\tau = T}$$

is $\phi =$ reconstruction wave is similar to ref wave

$$y = A_x e^{-i\phi_x}$$

$$T = \frac{\phi_t}{\phi_x} \quad (\text{Transmission function})$$

$$\phi_t = T \phi_x$$

ϕ_t (Wave function of light coming from hologram)

$$= A_x e^{-i\phi_x} [A_0^2 + A_x^2 + A_0 A_x e^{-i(\phi_0 - \phi_x)} + A_0 A_x e^{i(\phi_0 - \phi_x)}]$$

$$= \underbrace{A_x (A_0^2 + A_x^2) e^{-i\phi_x}}_{\textcircled{I}} + \underbrace{A_0 A_x^2 e^{-i\phi_0}}_{\textcircled{II}} + \underbrace{A_0 A_x^2 e^{i(\phi_0 - 2\phi_x)}}_{\textcircled{III}}$$

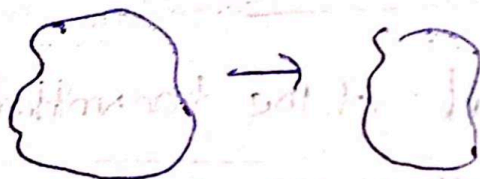
① Reconstruction wave itself but Amplitude is modulated

② Represents the virtual image

③ Represents the real image of object

Double Exposure Technique:

object - strain

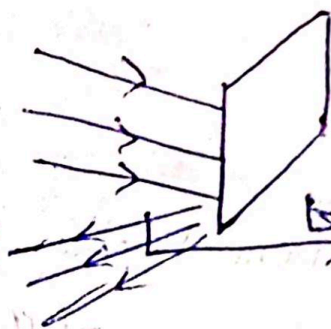


(1) unstrained object

→ recording process

(2) strained object

→ recording process



⇒ fringes information

→ two waves produced.

Optical fibres:

* 1960 → laser → channel → optical fibres

→ light weight.

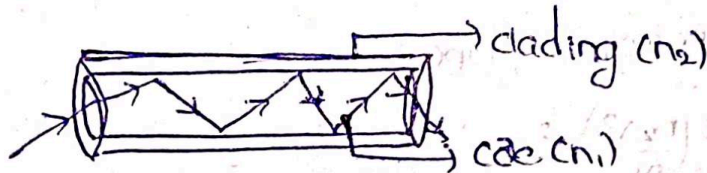
→ (10Gb/s)

medium channel

copper cables

Mb/sec

* Components in the optical fibre.



$$n_2 < n_1$$

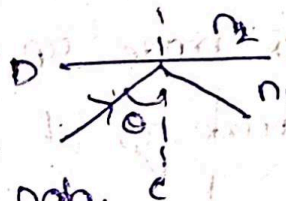
$$n_1 > n_2$$

* works based on the principle of T.O.R

T.O.R: When the light travel from the center to raise

Incident angle is greater than the critical angle

$$\theta > \theta_c$$

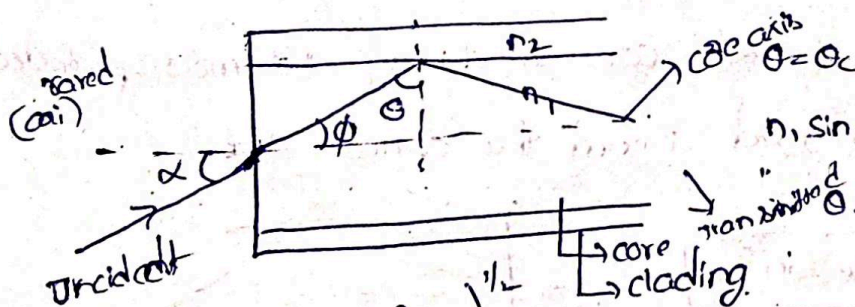


* C.O.F is Transmission for the data.

C.O.F: SiO_2 (doped with Germanium)

Diameter: 2-10 μm

Numerical aperture (Light gathering capacity)



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

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

$$\sin \theta_c = \frac{n_2}{n_1} \quad \text{from Snell's law}$$

$$\cos \theta_c = (1 - \sin^2 \theta_c)^{1/2}$$

$$\cos \theta_c = (1 - (\frac{n_2}{n_1})^2)^{1/2}$$

$$n_0 \sin \alpha = n_1 \sin \phi \quad \text{from Snell's law}$$

$$\phi + \theta = 90$$

$$\phi = 90 - \theta$$

$n_0 \approx 1$ (of air)

$$\sin \alpha = n_1 \sin(90 - \theta)$$

$$\sin \alpha = n_1 \cos \theta$$

$$\sin \alpha_m = n_1 \cos \theta_c$$

$n_0 \sin \alpha_m$ numerical aperture

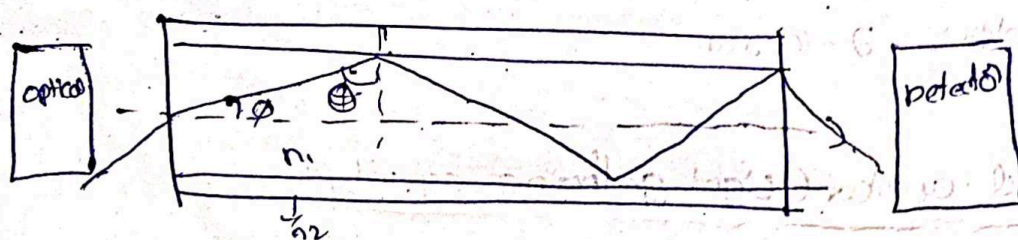
$$\cos \theta_c = \left(1 - \left(\frac{n_2}{n_1}\right)^2\right)^{1/2}$$

$$NA = n_1 \left[\left(n_1^2 - n_2^2\right)^{1/2}\right]$$

$$NA = \left[n_1^2 - n_2^2\right]^{1/2}$$

* cladding is made up of silica.

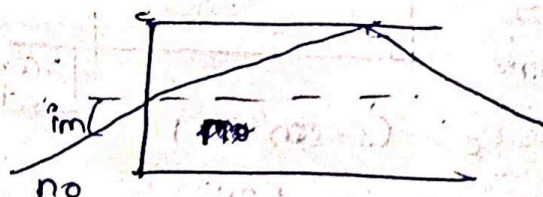
* core is made up of silica doped with $\text{GeO}_2, \text{B}_2\text{O}_3$ etc. To ~~increase~~ enhance the refractive index impurities ^{impurities} are added.



* In order to protect core and cladding ~~is~~ more protected layers are arranged around the optical fibre.

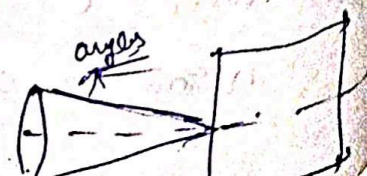
$$NA = n_0 \sin i_m$$

$$n_0 \approx 1$$



i_m - Maximum acceptance

angle



$$\boxed{NA = (n_1^2 - n_2^2)^{1/2}} \quad \text{--- (2)}$$

relative refractive index difference

represented as Δ

defined as $\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$

$$= \frac{(n_1 - n_2)(n_1 + n_2)}{2n_1^2}$$

$$\boxed{n_1 \approx n_2}$$

$\Rightarrow$ weakly guiding approximation.

$$\Delta \approx \frac{n_1 - n_2}{n_1} \left(\frac{2n_1}{2n_1} \right)$$

$$\boxed{\Delta \approx \frac{n_1 - n_2}{n_1}}$$

relative refractive index difference

$$\Rightarrow \Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \quad \text{--- (1)}$$

from (1) $(n_1^2 - n_2^2)^{1/2} = n_1 (2\Delta)^{1/2}$

$$\boxed{NA = n_1 (2\Delta)^{1/2}}$$

$$n_1 = 1.48 \quad n_2 \approx 1$$

$$\Rightarrow NA = (n_1^2 - n_2^2)^{1/2}$$

What is the max incident angle upto which light can be guided.

$$NA = [(1.48)^2 - 1]^{1/2} = \sqrt{1.1904} = 1.09105$$

$$NA = n_o \sin i_m$$

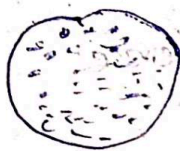
$$\sin^{-1}(1.09105) = i_m = 96^\circ$$

if we launch the ray more than i_m it may not undergo T.T.R

in that case core ^{core} is optical fibre in endoscope

100-1000 λ 1mm

each sum



* V-number of fiber (normalized frequency) :-

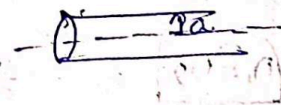
$$V = \frac{2\pi}{\lambda_0} \cdot a (n_1^2 - n_2^2)^{1/2} = \frac{2\pi}{\lambda_0} a \text{NA} = \frac{2\pi}{\lambda} a n_1 \sqrt{2}$$

$\lambda_0 \rightarrow$ wave length

$a \rightarrow$ diameter of the core

$n_1 \rightarrow$ n.s of the cladding core

$n_2 \rightarrow$ n.s of the cladding



Fiber classification

1. Single mode step index fiber $\rightarrow$ telecommunication purpose

2. Multi media step index fiber $\rightarrow$ LAB, sensing purpose

3. Graded index fibres (GRIN-fibers) $\rightarrow$ to overcome the consequences of multi media index fibres.

Ex: $\lambda = 1550 \text{ nm}$

$$a = 4 \mu\text{m}$$

$$n_1 = 1.48$$

$$n_2 = 1.47$$

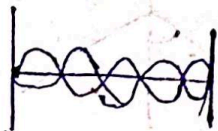
$$V = ?$$

$\frac{V^2}{2} =$ no of modes separated by the fiber.

$$\frac{V^2}{2} = 1 = \text{single mode fiber.}$$

$$\frac{V^2}{2} > 1 \text{ Multi mode}$$

Mode:



* Light distribution inside the fibre.

No of modes supported by the fibre

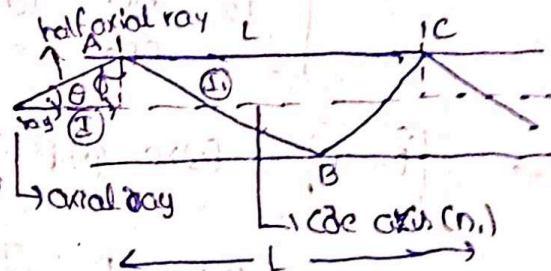
$$M \approx \frac{V^2}{2}$$

pulse dispersion in optical fibers:

* We pass a ~~ray~~ rays in the form of Pulse $\Delta_0/\Delta_0/\Delta_0$

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

$$\phi = \theta_c$$



* Time taken by the axial ray $\theta = 0$ is $t_1(\theta)$ tm

$$t = \frac{L}{v} \Rightarrow t_{min} = \frac{n_1 L}{c} \quad \text{--- (1)}$$

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

* Time taken by the half axial ray $\theta = \theta_m$ is t_2

$$t_2 = \frac{AB + BC}{c/n_1}$$

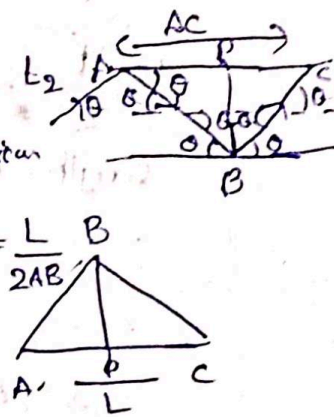
$t_2 \neq$

* ABP is right angle trian

$$\cos \theta = \frac{PB}{AB} = \frac{L/2}{AB} \Rightarrow AB = \frac{L}{2 \cos \theta}$$

BPC

$$\cos \theta = \frac{L/2}{BC} = \frac{L}{2BC} \Rightarrow BC = \frac{L}{2 \cos \theta}$$



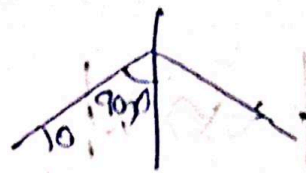
$$\Rightarrow AB = \frac{L}{2 \cos \theta}$$

$$BC = \frac{L}{2 \cos \theta} = \frac{L}{2}$$

$$t_2 = \frac{\frac{L}{2 \cos \theta} + \frac{L}{2 \cos \theta}}{c/n_1}$$

$$t_2 = \frac{L}{\cos \theta} / \frac{c}{n_1} = \frac{n_1 L}{c \cos \theta}$$

$$t_2 = \frac{n_1 L}{c \cos \theta} \quad \dots (2)$$



$$n_1 \sin(90 - \theta) = n_2 \sin 90^\circ$$

$$\cos \theta = \frac{n_2}{n_1}$$

In the limiting case

$$t_2 = \frac{n_1^2 L}{c n_2} \quad (\text{at } \text{total})$$

$$[t_2 - t_1] \rightarrow \text{Pulse dispersion} = \frac{n_1^2 L}{c n_2} - \frac{n_1 L}{c}$$

$$\Rightarrow \frac{n_1 L}{c} \left[\frac{n_1}{n_2} - 1 \right]$$

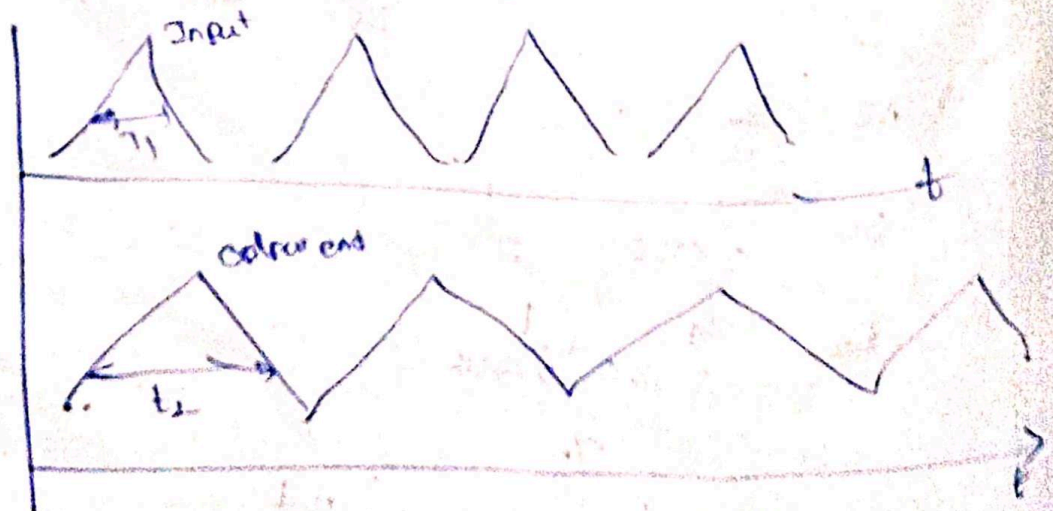
$$\Delta t = \tau = \frac{n_1 L}{c} \left(\frac{n_1 - n_2}{n_2} \right)$$

$$\star \frac{\Delta t}{L} = \text{pulse dispersion per unit length} \quad \Delta \lambda \quad \left| \quad \lambda \right|$$

$$(\text{at}) \quad \frac{\tau}{L} = \frac{n_1}{c} \left(\frac{n_1 - n_2}{n_2} \right)$$

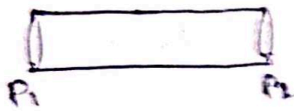
$$= \frac{n_1}{c} \Delta$$

$\tau \downarrow$ then data retrieving is easy and accurate.



(10.10)

Attenuation (loss) in optical fibre



P_1 - Input Power

P_2 - Output Power

- * α is small in single mode fibre (Glyme)
- * α is large in M-M-fibre (physics information)
- * Measured in (dB) decibels. (unit)
- * defined as $10 \log_{10} \left(\frac{P_1}{P_2} \right)$ (dB)
- * If $P_1 = P_2 \Rightarrow$ Loss is 0dB.

$$P_2 = P_1/2 \Rightarrow 10 \log_{10} 2 = 3.01 \text{ dB} \approx 3 \text{ dB} \Rightarrow 50\% \text{ power loss}$$

$$0.2 \text{ dB} = 10 \log_{10} \left(\frac{P_1}{P_2} \right)$$

$$0.2 = \log_{10} \frac{P_1}{P_2} = 10^{-2}$$

$$P_2 = P_1 10^{-0.2}$$

$$P_2 = 95\% P_1$$

$$20 \text{ dB} \Rightarrow P_2 = P_1 10^{-2} = 1\%$$

$$P = 0.01 P_1$$

* Loss present in optical fibre } P_1 - input power
 P_2 - output power:

$$\alpha \text{ (dB)} = 10 \log_{10} \frac{P_1}{P_2}$$

* $\alpha = 0.2 \text{ dB/cm}$ at 1550 nm (λ) $1.55 \mu\text{m}$ (I.R)

$$0.2 = 10 \log_{10} \frac{P_1}{P_2}$$

$$0.02 = \log_{10} \frac{P_1}{P_2}$$

$$10^{0.02} = \frac{P_1}{P_2} \Rightarrow$$

$$P_1 = P_2 \cdot 10^{0.02}$$

$$P_2 = \frac{P_1}{10^{0.02}} = 95.1\%$$

* Charles, Koch & Hickman 

* Let's 1. Residual cost 

* Let's 2. Residual cost 

* Dispersion 

$$\Delta T_{max} - \Delta T_{min} = \Delta T = \text{Dispersion} = \frac{n_1 L}{c} \left(\frac{n_1}{n_2} - 1 \right)$$

1st & 2nd order bandwidth

$$2 \log \frac{1}{\Delta T}$$

Loss Mechanisms: ($P_2 < P_1$)

* Reasons for losses are two types.

1. Absorptive loss - due to absorption process

2. Radiative loss - due to radiation

Absorption loss: Again classified into two types

1. Intrinsic :- SiO_2 - SiO_2 exists absorption in 0.5-0.9 μm and 1.2-1.5 μm fibre itself absorbs light.

2. Extrinsic :- In manufacturing process some of transition metal (Fe^{2+} , Cu^{2+} , Cr^{3+}) and OH- there will be present. Due to these some loss occurs.

Radiative loss: The loss occurring due to coupling of light into the cladding region.

* SiO_2 to increase refractive index chromatic (Ge, B, P, As) added acts like inhomogeneity due to this coupling of light into the cladding region occurs.

* 

* Rayleigh scattering losses

Size of the inhomogeneities is equal to the ^{wave} length of the light, due to this some of the light is scattered into cladding $\lambda \sim d$

$$\alpha(\lambda) = \alpha_0 \left(\frac{\lambda_0}{\lambda} \right)^4$$

$$\alpha_0 = 1.7 \text{ dB/km at } \lambda_0 = 0.88 \mu\text{m}$$

$$\alpha(\text{Rayleigh scattering losses}) = \frac{1}{\lambda^4} \propto \frac{1}{\lambda^4}$$

* Bending :-



* Some losses due to bending of optical fiber.

* Irregularities at core and cladding region (Interface)

* Diameter fluctuation:-

Single Mode	Multimode
* used in Telecommunication * Diameter-core $\rightarrow 2-10 \mu\text{m}$ * One mode (Intensity distribution) * Numerical aperture less * pulse dispersion is very low (negligible) * high cost * Bandwidth is high	* L.A.N (Local area network) * Sensor * 100-500 μm typically * mode mode S_1 * N.A is large. * pulse dispersion (disp) is high * low cost.

* To solve disadvantages in Multimode Fibres Graded index fibres are introduced.

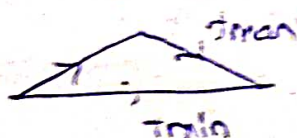
Graded index fibre:

* One of the ~~major~~ main disadvantage in multimode fibre is ^{high} dispersion.

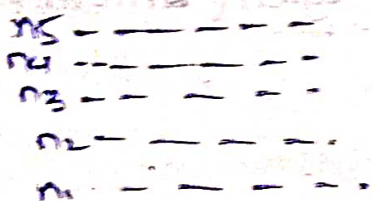
* To solve this Graded index fibres are introduced.

* A fibre in which the refractive index of the core varies with radius helps minimize (or) even eliminate the disadvantage.

We know that pulse dispersion



$$\Delta T = t_{\max} - t_{\min}$$



$$n_5 < n_4 < n_3 < n_2 < n_1$$

We know that $t = \frac{d}{v} = \frac{d}{\left(\frac{c}{n}\right)} = n \left(\frac{d}{c}\right)$

* So refractive index is more then the time taken to travel the ray increases so ΔT decreases