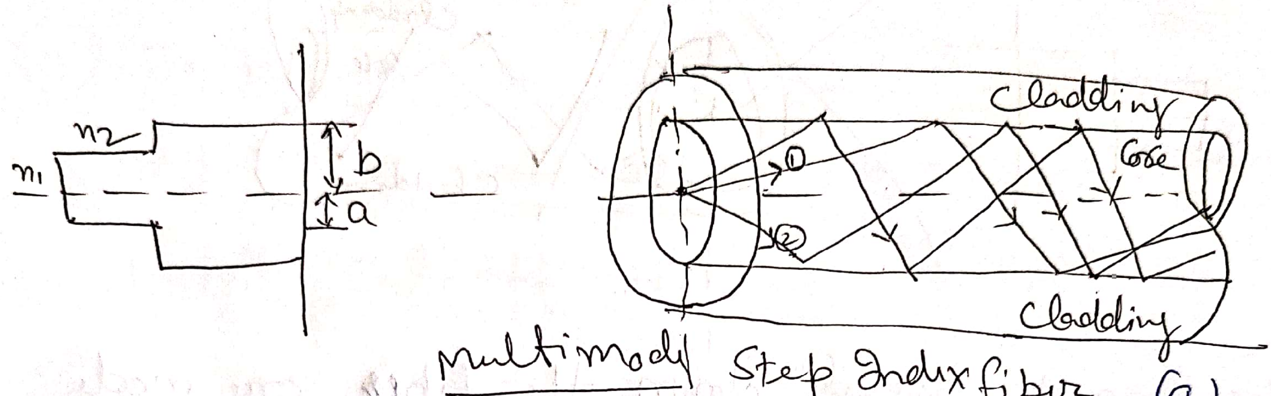
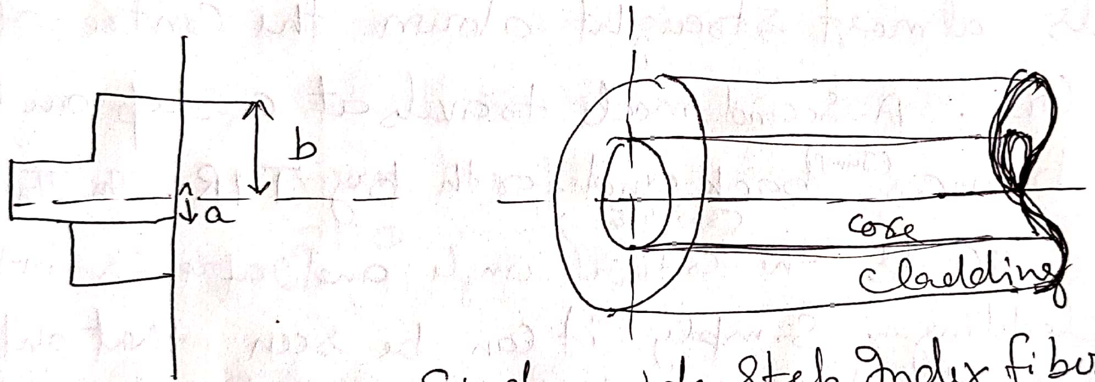
Single and Multi Mode fibres

(1) **Step Index fibre** → is one for which the refractive index of the core, n_1, is constant and is larger than



Multimode Step Index fiber (a)



Single mode Step Index fiber (b)

The refractive index of the cladding n_2.

$$n(r) = \begin{cases} n_1 & r < a \quad \text{Core} \\ n_2 & r \geq a \quad (\text{or } r < b) \quad \text{Cladding} \end{cases} \quad (1)$$

in both cases.

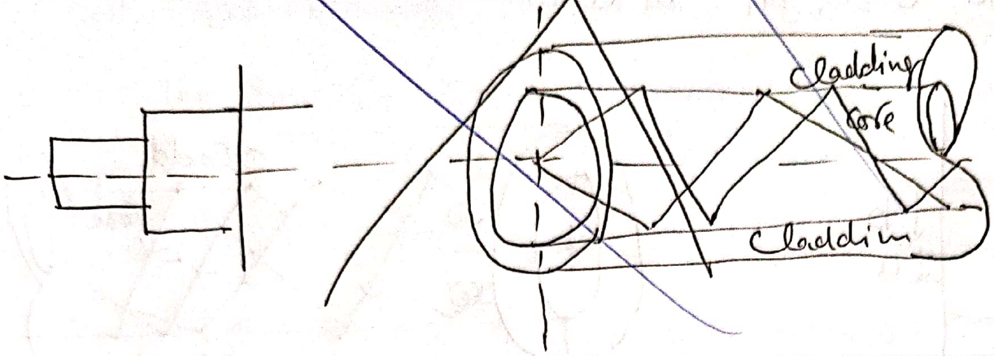
Fig (a) shows the ray transmission in multimode Step index fiber. due to RI (core) is higher than RI (cladding) $[n_1 > n_2]$. There is TIR for $\phi > \theta_c$.

(a) Multimode Step Index fiber [MMSIF] → has a core diameter of around 50 μm or greater, which is large enough to allow the propagation of many modes within the fibre core. in Fig (a) There are three different

(b)

Single and multimode fiber

(1) Step Index fiber



light waves travel down the fiber, one mode travels almost straight down the centre of the core. A second mode travels at a step angle and bounces (Jump) back and forth by TIR. The IIIrd mode exceeds the critical angle and refracts into the cladding. Simply it can be seen that different mode travels different distance. This disparity between arrival times of the different light rays knows as Modal dispersion.

(b) The Single mode step Index fiber (SMSIF)

has a very fine thin core, so that only one mode can be propagated. SMSIF allows for a higher capacity to transmit information because it can retain the fidelity of each light pulse over longer distances, and it exhibits no dispersion caused by multimodes. SMSIF also enjoys lower fiber altenation that MMSIF, So more information can be transmitted per unit of time.

Single mode step index fibers have disadvantages (of SMSIF) over multimode step index fibers:

(i) The smaller core diameter makes coupling light into the core more difficult.

(ii) The tolerance for single mode connectors and splices are also much more demanding.

Cut-off wavelength (λ_c) of fiber

An optical fiber is characterized by one more important parameter known as V-number, which is more generally called normalized frequency of the fiber. It is given by the relation.

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \quad \text{—(1)}$$

Here a - radius of core λ - free space wavelength.

in term of numerical aperture (NA)

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

or $$V = \frac{2\pi a}{\lambda} n_1 \sqrt{2\Delta} \quad \text{—(3)}$$

The maximum number of modes supported by a step index fiber is determined as

$$N_{max} \simeq \frac{V^2}{2} \quad \text{—(4)}$$

for single mode fiber $V < 2.405$ and multimode $V > 2.405$

so the wavelength corresponding to the value of $V = 2.405$ known as cut off wavelength (λ_c) of fiber

$$\boxed{\lambda_c = \frac{\lambda V}{2.405}} \quad \text{—(5)}$$

(2) Graded Index Fibre.

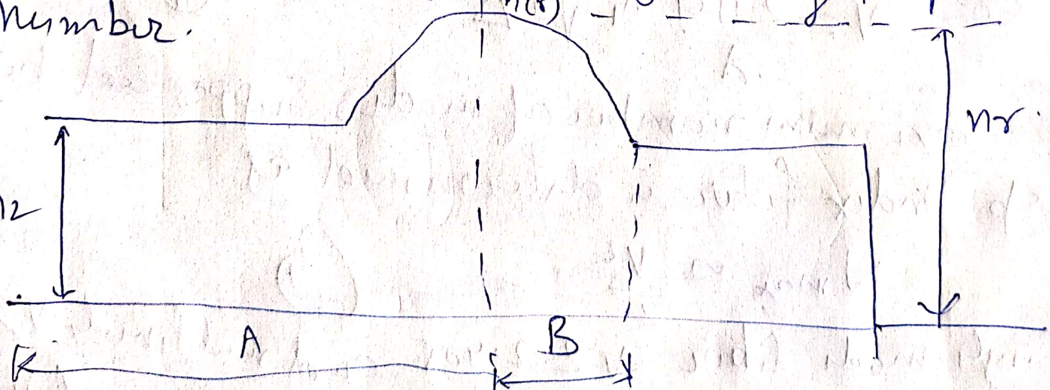
In this fibre, the refractive index of the core varies gradually as a function of radial distance from the fibre centre. Graded index fibres may be made with a variety of different index grading profiles. One of the more popular profile functions is the alpha profile function, in which the index of refraction with the core is made to vary radially by the function -

$$n(r) = n_1 \left[1 - 2\Delta \left(\frac{r}{a} \right)^{\alpha} \right]^{1/2}$$

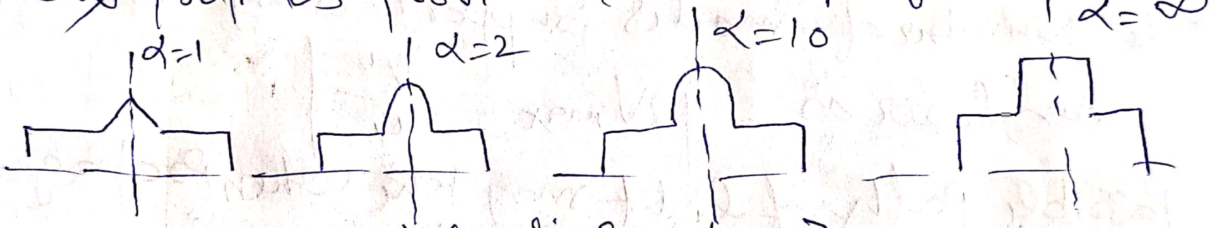
and

$$NA = [n_2^2(r) - n_2^2]^{1/2}$$

Here $n(r)$ is core index at radial distance r from the core axis, n_1 is the index at the core axis, Δ is the normalized differance between the core and cladding indices, a is the core radius and α is the grading profile index number.



This fig. shows a possible refractive index profile n(r) for a multimode graded-index fiber. Notice the parabolic refractive index profile of the core. The profile parameter α determines the shape of the core's profile. As the value of α increases the shape of core's profile changes from a triangular to step. Most multimode graded index fiber have a parabolic refractive index profile. Multimode fibers with near parabolic graded index profiles provide the best performance.



Light propagates in multimode graded index fibers according to refraction and TIR. The gradual decrease in the core's refractive index from the center of the fiber causes the light ray to be refracted many times. The light rays become refracted or curved, which increases the angle of incidence ~~at the~~ becomes the larger than the critical angle of incidence. Light rays may be reflected to the axis of the fiber before reaching the core cladding interface.

The NA of multimode graded index fiber is at its maximum value at the fiber axis. This NA is the axial numerical aperture [NA(0)]

- Number of supported modes for a large number of modes is reduced according to expression

$$N_\alpha = \frac{\alpha}{\alpha+2} \cdot \frac{V^2}{2} = \frac{\alpha}{\alpha+2} \left[\frac{2\pi a}{\lambda}\right]^2 \frac{(NA)^2}{2}$$

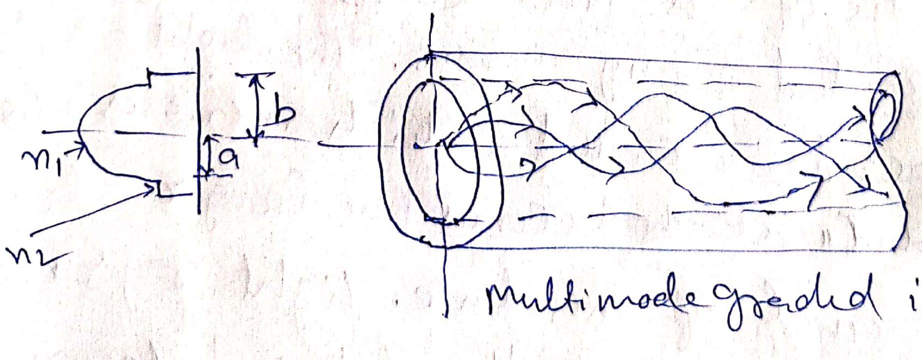
$$N_\alpha = \frac{\alpha}{\alpha+2} \left(\frac{2\pi a}{\lambda}\right)^2 n_1^2 \Delta$$

Here $\Delta = \frac{n_1 - n_2}{n_1}$

The Number of modes supported by a graded index fiber is $N_{max} = \frac{V^2}{4}$

Possible paths of light may take when propagating in multimode graded index fibers.

Light rays that travel farther from the fiber's axis travel a longer distance. Light rays that travel further from the center travel in one material with an average lower refractive index



Multimode graded index fibre.

Difference between Singlemode and multimode fiber

Single mode fibre	Multimode fiber
1- Single-mode fiber sustains only one mode of propagation	1- Multimode fiber can propagate hundreds of modes.
2- Small radii of single mode fibers make it difficult to launch optical power into the fiber	2- Large radii of multimode fibers make it easier to launch optical power into the fiber
3- SMF must generally be excited with laser diode (LD).	3- in MMF light can be launched by a Light emitting diode LED
4- SMF are free from free from free from intermodal dispersion	4- MMF suffer intermodal dispersion.
5- Attenuation – between 2–5 dB/km – Scattering limit around 1 dB/km at wavelength 850nm.	5- Attenuation – between 2.6 to 50 dB/km at wavelength 850 nm. – and Scattering limit between 2 to 10 dB/km at wavelength 850nm
6- SMF is used for very long haul communication	6- MMF used for short haul application.
7- SMF have higher bandwidth (>500MHz-km)	7- MMF have 6–50 MHz km Bandwidth and in multimode graded index 300MHz-km to 3 GHz-km
8- V-number for SMF V ≤ 2.405	8- V number for MMF V > 2.405
9- best for longer transmission distance	9- best for short transmission distances.

① The core diameter of multimode step index is 60 μm. The difference in refractive indices is 0.013. the Core refractive index is 1.46. Determine the number of guided modes when the operating wavelength is 0.75 μm.

→ V Number = $\frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$

$= \frac{2 \times 3.14 \times 30\mu m}{.75\mu m}\sqrt{(1.46)^2 - (1.447)^2} = 9.493$

Number of guided modes $N = \frac{V^2}{2} = \frac{(9.493)^2}{2} = \frac{90.118}{2} = 45.06$

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② A single mode fiber is made with a core diameter of 10μm and is coupled to a laser diode that produces 1.3μm light. Its core glass has a RI of 1.55.

ⓐ Find the maximum value required for the normalized index difference

ⓑ RI required for cladding glass

ⓒ Fiber acceptance angle.

ⓐ $V = \frac{2\pi a}{\lambda}(NA)$ given $2a = 10\mu m$, $\lambda = 1.3\mu m$

$(NA)_{max} = \frac{V_{max}\lambda}{2\pi a} = \frac{2.405 \times 1.3\mu m}{3.14 \times 10\mu m} = 0.0995$

Δ (Normalised index difference) $= \frac{1}{2}\left(\frac{NA}{n_1}\right)^2 = \frac{1}{2}\left(\frac{.0995}{1.55}\right)^2 = .00206$

ⓑ Cladding index $n_2 = n_1(1 - \Delta) = 1.55(1 - .00206)$

$= 1.547$

ⓒ Maximum acceptance angle for fiber:

$\theta_m = \sin^{-1}(NA)_{max} = \sin^{-1}(.0995)$

$= 5.710$