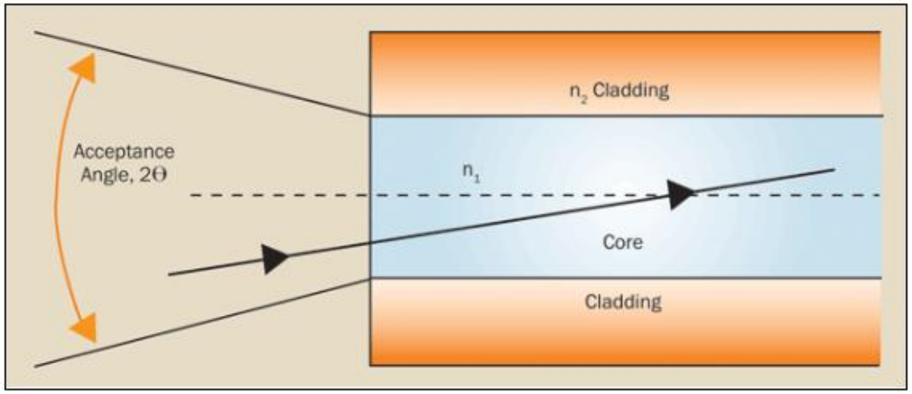
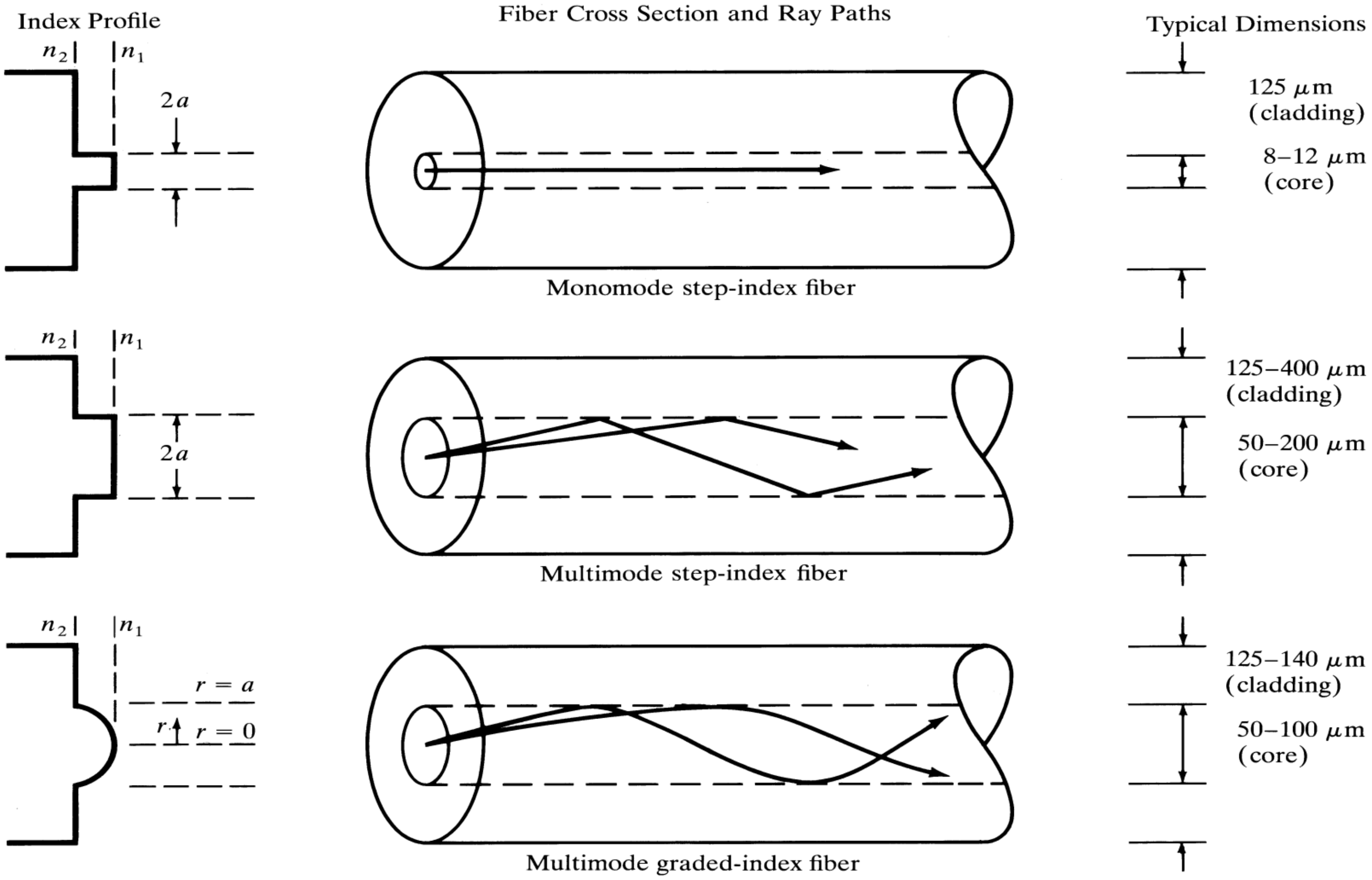
OPTICAL FIBER WAVEGUIDE-III



Step Index / Graded Index fiber



Step Index Fibers

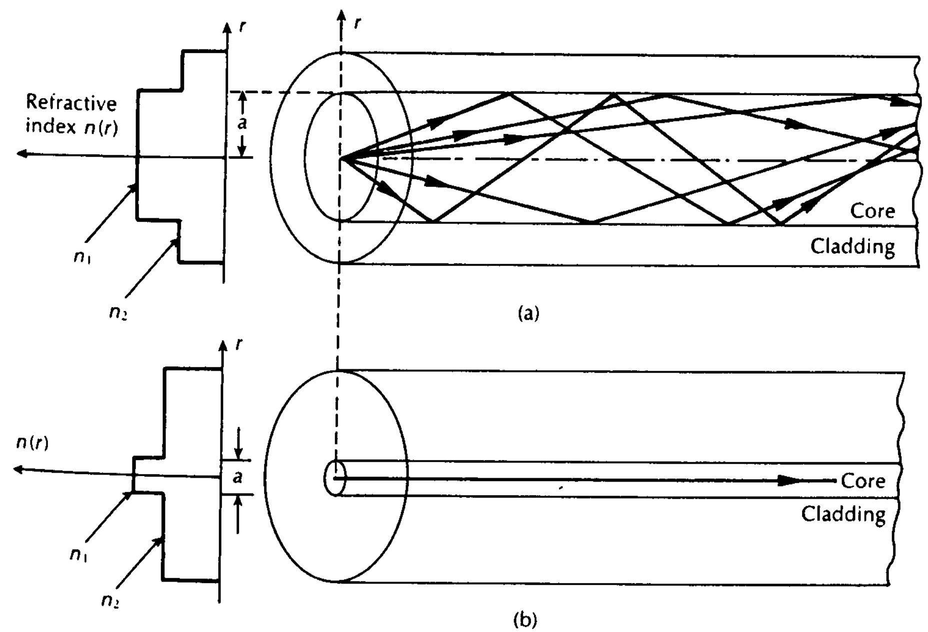
Fiber with a core of constant refractive index n_1 and a cladding of slightly lower refractive index n_2 .

- ➢ Refractive index profile makes a step change at the core-cladding interface

Refractive index profile

$$n(r) = \begin{cases} n_1 \quad ; \quad r<a \;\; \text{(core)} \\ n_2 \quad ; \quad r \geq a \;\; \text{(cladding)} \end{cases}$$

- Multimode Step Index
- Single mode Step Index



The refractive index profile and ray transmission in step index fibers: (a) multimode step index fiber. (b) single-mode step index fiber.

Modes in SI Fibers

- **MM SI fibers allow the propagation of a finite number of guided modes along the channel.**
  - Number of guided modes is dependent upon the physical parameters ; a, Δ of fibers and wavelength of the transmitted light – included in **V-number**

- The total number of guided modes or mode volume M_s for SI fiber is related to V-number for the fiber by approximate expression

$$M_s \approx V^2/2$$

  - Allows an estimate of number of guided modes propagating in a particular MM SI fiber.

- **For example**: A MM SI fiber of core diameter 80μm, core refractive index 1.48, relative index difference of 1.5% and operating at 850nm supports 2873 guided modes.

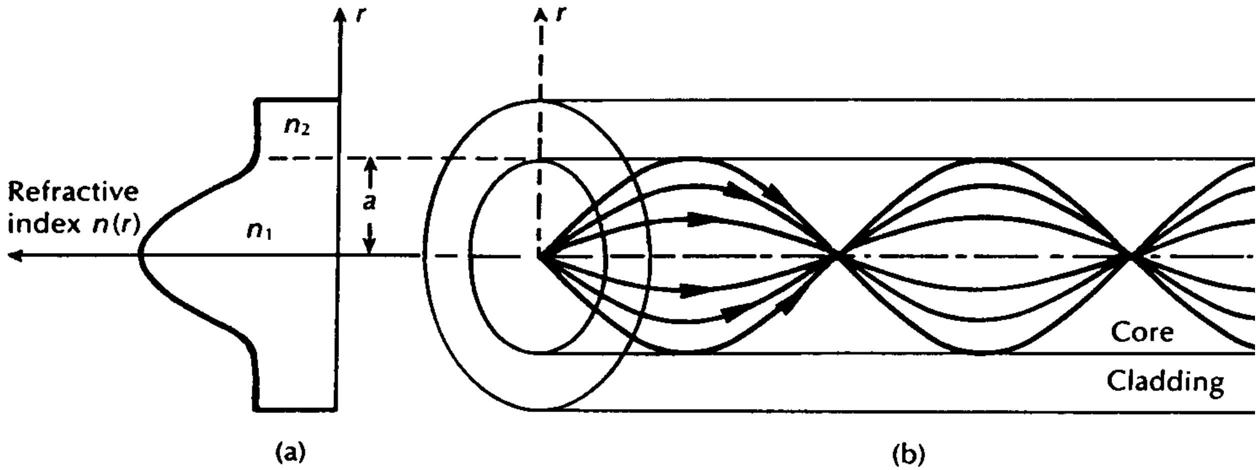
Graded Index Fiber Structure

- GI fibers do not have a constant refractive index in the core, but a ***decreasing core index n(r) with radial distance*** from a maximum value of n_1 at the axis to a constant value n_2 beyond the core radius ‘a’ in the cladding. – ***Inhomogeneous core fibers***

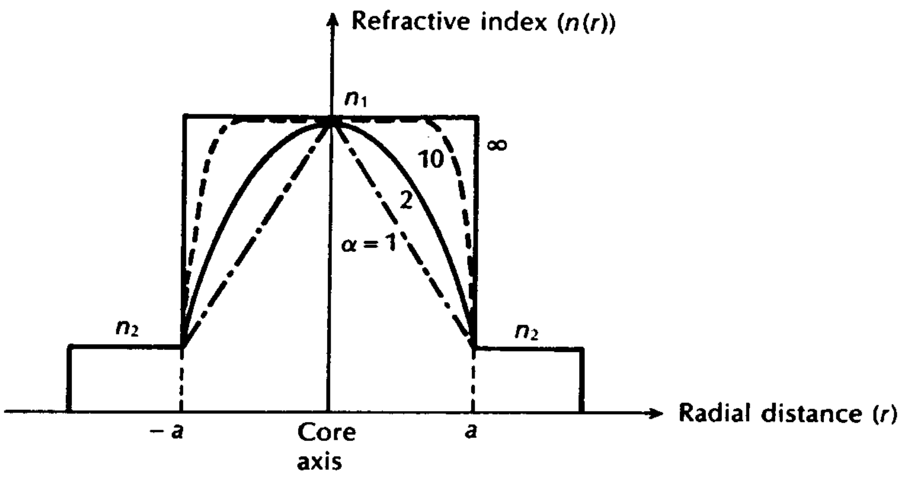
Index variation is represented as

$$n(r) = \begin{cases} n_1\left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]^{1/2} & \text{for} \quad 0 \le r \le a \\ n_1(1 - 2\Delta)^{1/2} \simeq n_1(1 - \Delta) = n_2 & \text{for} \quad r \ge a \end{cases}$$

where, Δ is relative refractive index difference and α is the profile parameter which gives the characteristic RI profile of the fiber core.



The refractive index profile and ray transmission in a multimode graded index fiber.

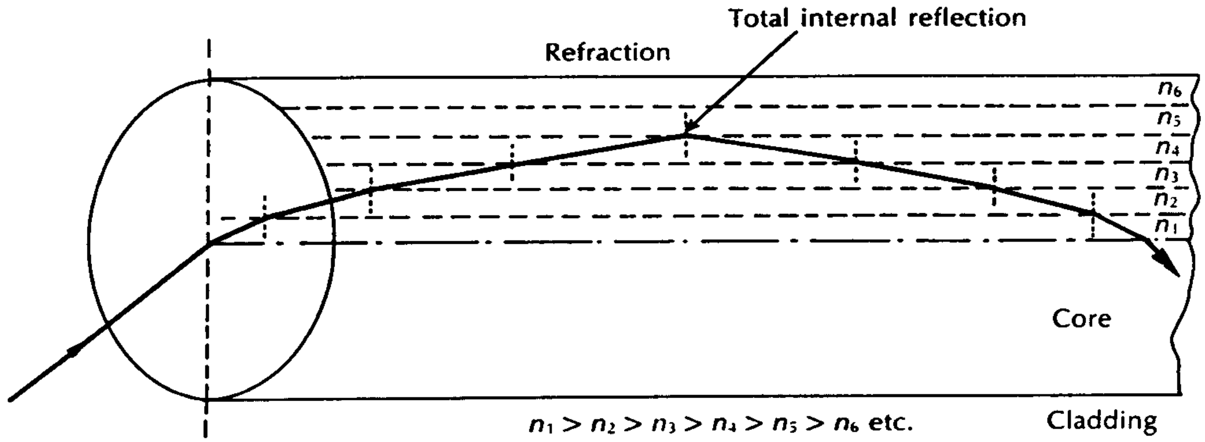


Possible fiber refractive index profiles for different values of α

α= ∝; Step index profile

α= 2; Parabolic profile

α =1 Triangular profile



An expanded ray diagram showing refraction at the various high to low index interfacial within a graded index fiber, giving an overall curved ray path.

- In GI fibers, the rays traveling close to the fiber axis have shorter paths when compared with the rays which travel into the outer regions of the core. However, the near axial rays are transmitted through a region of higher refractive index and therefore travel with a lower velocity than the more extreme rays.
  - **This compensate for the shorter path lengths and reduces dispersion in the fiber.**

Graded Index Fiber Parameters

- The parameters defined for SI fibers (NA, Δ, V) may be applied to GI fibers and give comparison between two. However, in GI fibers situation is more complicated because of radial variation of RI of core from the axis, NA is also function of radial distance.

Local numerical aperture

$$\mathrm{NA}(r) = \begin{cases} [n^2(r) - n_2^2]^{1/2} \simeq \mathrm{NA}(0)\sqrt{1 - (r/a)^\alpha} & \text{for} \quad r \leq a \\ 0 & \text{for} \quad r > a \end{cases}$$

Axial numerical aperture

$$\mathrm{NA}(0) = [n^2(0) - n_2^2]^{1/2} = (n_1^2 - n_2^2)^{1/2} \simeq n_1\sqrt{2\Delta}$$

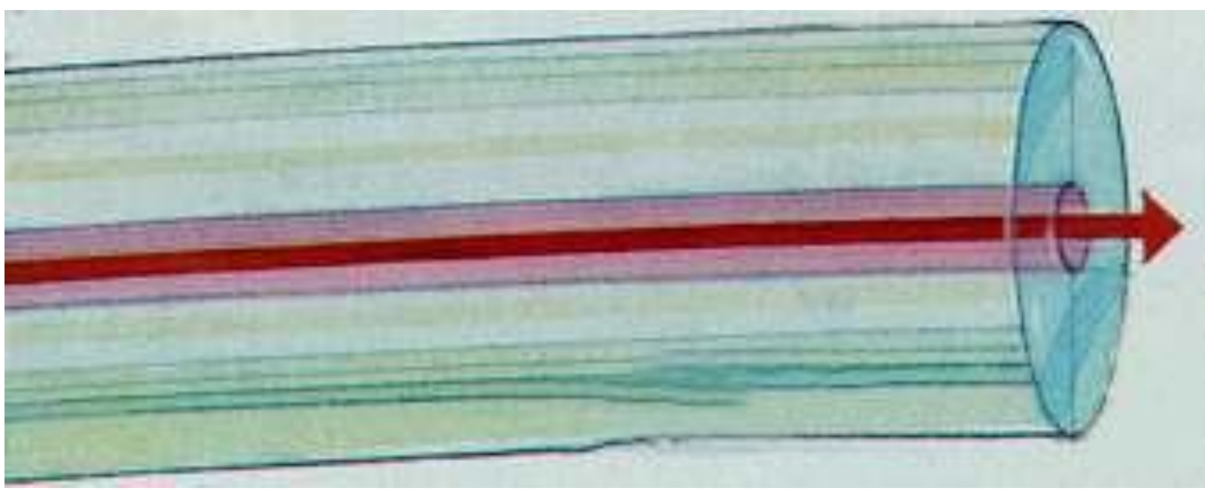
Number of bound modes in graded index fiber is

$$M_g = \left(\frac{\alpha}{\alpha+2}\right)(n_1 ka)^2 \Delta \cong \left(\frac{\alpha}{\alpha+2}\right)\left(\frac{V^2}{2}\right)$$

- For parabolic profile core (α=2), $M_g=V^2/4$, which is half the number supported by a SI fiber with sane V value

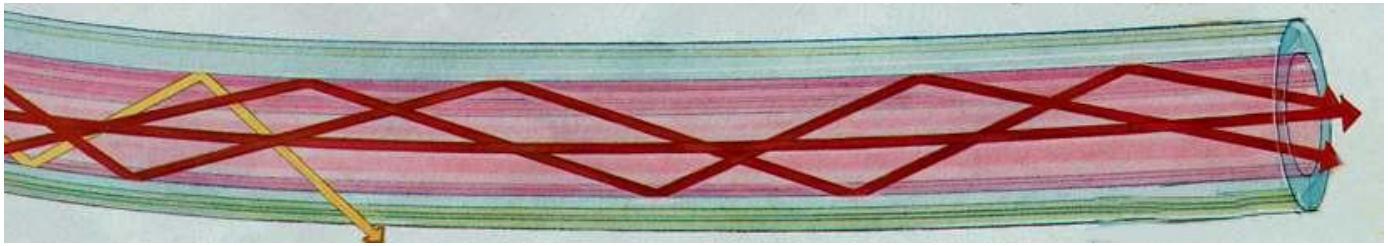
Single mode (mono-mode) Fibers

- SMFs: Most important for long-haul use (carrier and Internet core).
- Small core (8 to 10 microns) that forces the light to follow a linear single path down its length.
- Lasers are the usual light source.
- Most expensive and delicate to handle,
- Highest bandwidths (GHz) and distance ratings (more than 100 km).

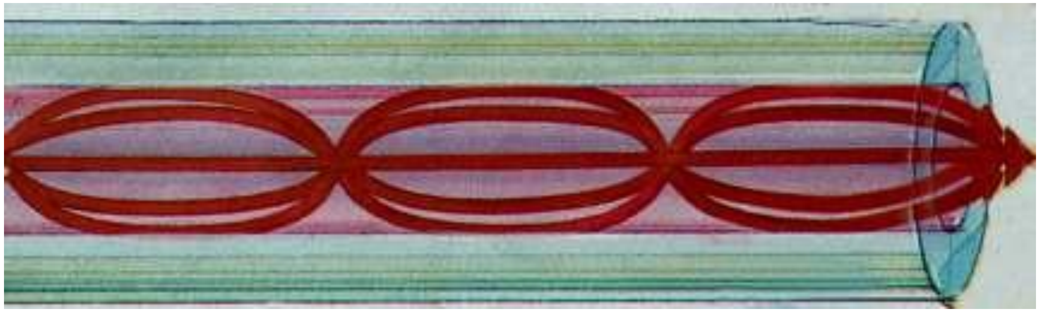


Multimode Fibers

- Relatively large diameter core (50 to 100 microns)
- Step-index multimode cable has an abrupt change between core and cladding. It is limited to about 50 Mbits/sec
- Graded-index multimode cables has a gradual change between core and cladding. It is limited to 1 Gbit/sec.



SI



GI

Cutoff Wavelength

For, SM operation only above a theoretical cutoff wavelength, λ_c:

$$\lambda_c = \frac{2\pi a n_1}{V_c} (2\Delta)^{\frac{1}{2}}$$

λ_c is the wavelength above which a particular fiber becomes single-moded

For SI fiber, V_c=2.405, the cutoff wavelength

Power distribution:

- At V=2.405: 80% of mode's power in core
- At V=1: only 30% power in core;
- Do not want V too small, design compromise: $2 < V_{SM\ SI} < 2.405$

Application Areas

- **Single mode fibers**: Mostly Step index type
  - Ideally suited for high bandwidth, very long-haul applications using single-mode ILD sources; **Telecommunication, MANs**

- **Multimode fibers** : Step index, Graded index
  - **Step Index Fibers**: Best suited for short-haul, limited bandwidth and relatively low cost applications.
  - **Graded Index Fibers**: Best suited for medium-haul, medium to high bandwidth applications using incoherent and coherent sources (LEDs and ILDs); LANs

THANK YOU