Graded Index Fibers

The Multi-Mode/Single-Mode Trade-Off

Multi-mode guides:

- Large core (e.g. 50 μm diameter) ⇒ easier to couple light into waveguide
- Large modal dispersion ⇒ decreased transmission capacity

Single-mode guides:

- Less optical dispersion
- Small core (e.g. 9 μm diameter for optical fiber) ⇒ more difficult coupling

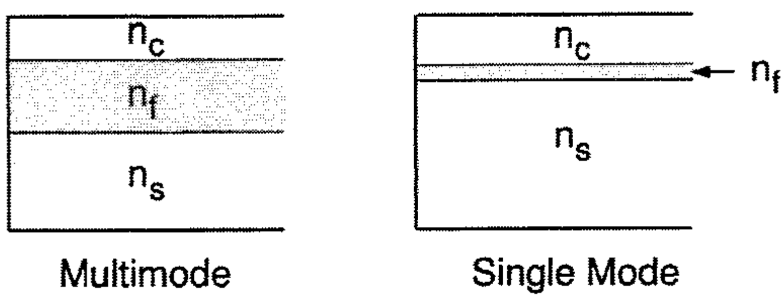


Figure 7.1. Two waveguides made with identical materials, but with different guiding film thickness. The larger film is a multimode structure.

Compromise? → Yes, graded-index, multi-mode optical fiber.

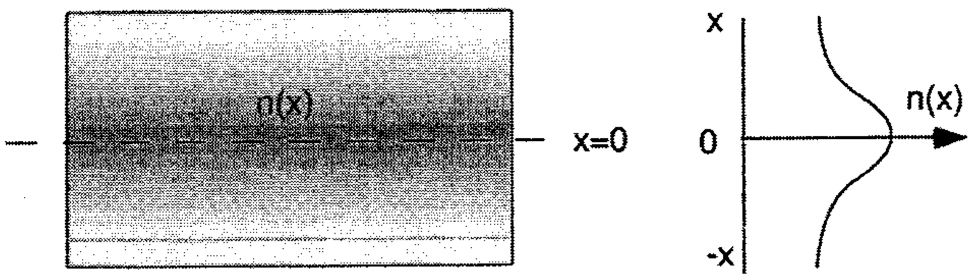


Figure 7.2. The index profile of a graded index planar waveguide.

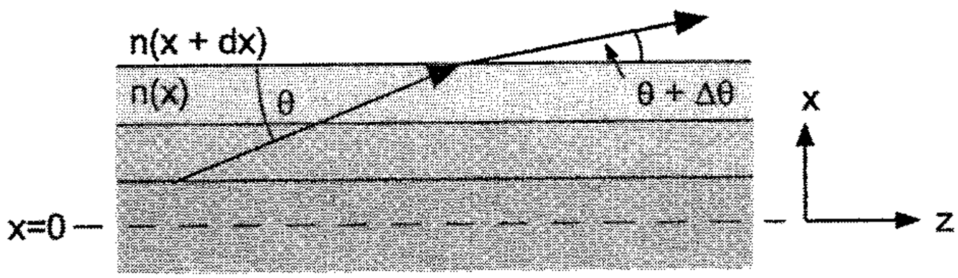


Figure 7.3. A graded index material can be modelled as a stack of thin layers, each with index n(x). Refraction occurs at the interface between two adjacent layers.

Eikonal Equation:

$$\boxed{\frac{d^2x}{dz^2} = \frac{1}{n(x)}\frac{dn(x)}{dx}}$$

Light rays bend towards regions of higher refractive index.

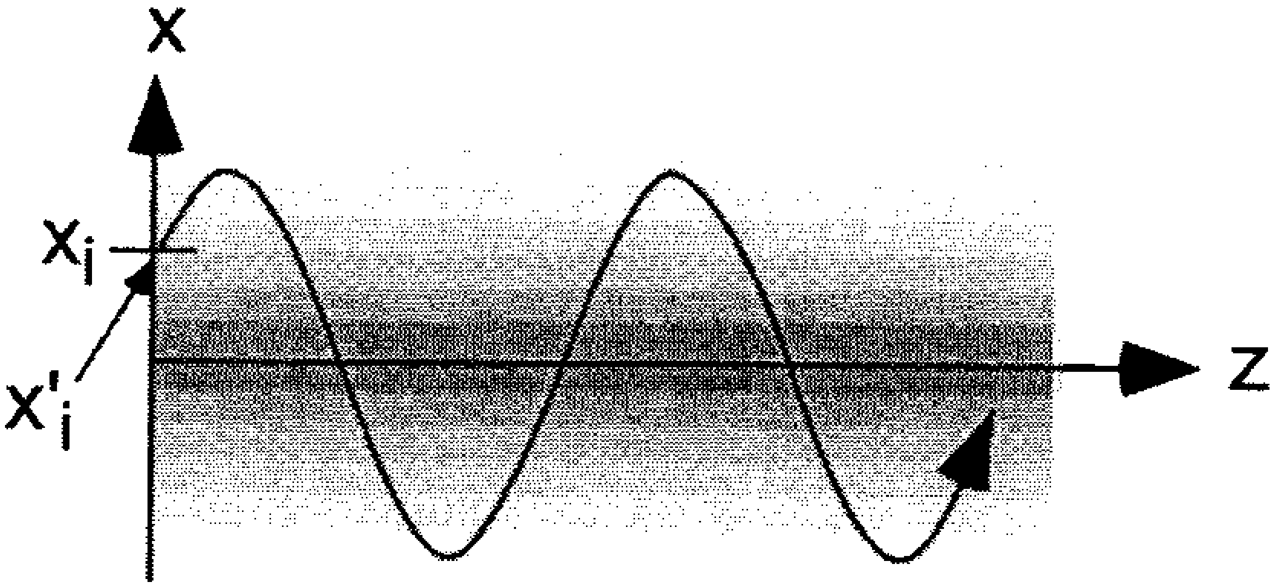
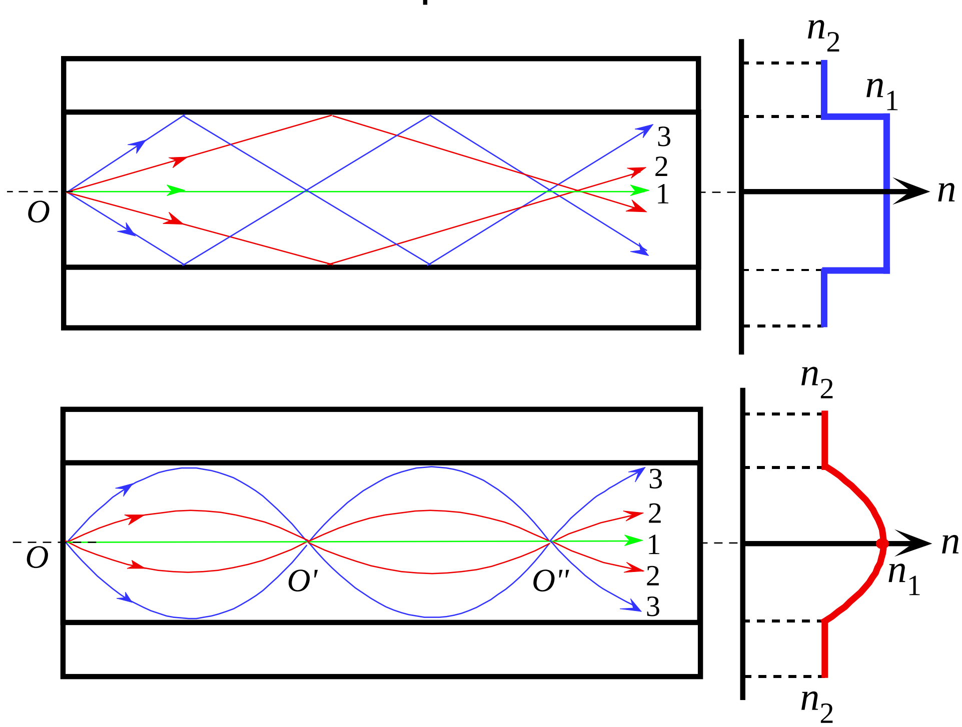


Figure 7.4. The ray path in a parabolic profile graded index.

Reduced Modal Dispersion in Graded-Index Fibers:



(a) Multimode step index fiber. Ray paths are different so that rays arrive at different times.

(b) Graded index fiber. Ray paths are different but so are the velocities along the paths so that all the rays arrive at the same time.

Example: Dispersion in a graded-index fiber with a parabolic index profile.

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

where

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

To be concrete, take diameter = 50 μm, n_1 = 1.480, n_2 = 1.460,

The Group Delay Dispersion is:

$$\Delta\tau_g = \frac{n_1}{8c}\Delta^2 = \frac{1.480}{8\times3\times10^{-7}}(0.0135)^2 = 112\frac{ps}{km}$$

For comparison we calculate the Group Delay Dispersion for a multi-mode step-index fiber with n_1 = 1.480, n_2 = 1.460

$$\Delta\tau_g = \frac{n_1 - n_2}{c} = \frac{1.480 - 1.460}{3\times10^{-7}\ {}^{km}/_{ps}} = 66{,}700\ {}^{ps}/_{km}$$

and for a single-mode step-index fiber (λ_0=1.55μm, $\Delta\nu$=19GHz)

$$\Delta\tau_g = |D_{tot}|(\Delta\lambda) = 16\ {}^{ps}/_{km\cdot nm}(0.15nm) = 2.4\ {}^{ps}/_{km}$$