Module:6 Propagation of EM waves in Optical fibers

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$$NA = \sqrt{n_1^2 - n_2^2} \longrightarrow (1)$$

$$\Delta = \frac{n_1 - n_2}{n_1} \longrightarrow (2)$$

From eq (2)

$$\Delta n_1 = n_1 - n_2$$

$$a^2 - b^2 = (a+b)(a-b)$$

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

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

here n_1 is nearer to n_2

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

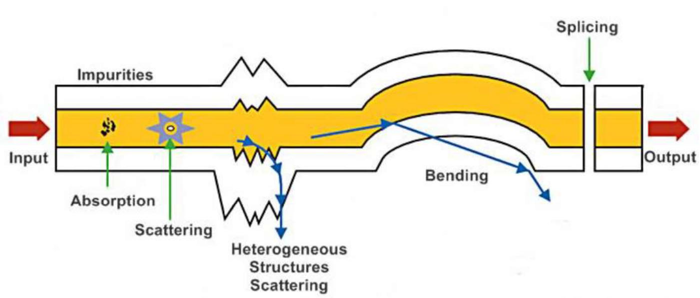
$$\boxed{NA = n_1\sqrt{2\Delta}}$$

Losses in Optical fiber

Optical fibers have negligible losses when light traveling inside a core

The transmission through an optical fiber is limited by

- **Attenuation**
- **Dispersion.**



- When light travels along the fibre, there is a loss of optical power, which is called attenuation.

Definition:

Attenuation: Ratio of optical input power (P_i) to the optical output power (P_o)

Optical Input power: The power transmitted into the fibre from an optical source

Optical output power: The power received at the fibre end

Attenuation is the rate at which the signal light decreases in intensity. For this reason, glass fiber (which has a low attenuation) is used for long-distance fiber optic cables; plastic fiber has a higher attenuation and, hence, shorter range.

Attenuation

Fiber Attenuation

This relation defines the signal attenuation or absorption coefficient in terms of length L of the fibre:

$$\boxed{\alpha = \frac{10}{L}\log_{10}\frac{P_i}{P_0}}$$

Length **L** of the fibre is expressed in **kilometers**

Here, the unit of Attenuation is decibels/kilometer i.e. **dB/km.**

The main causes of attenuation in optical fibre are:

(a)Absorption

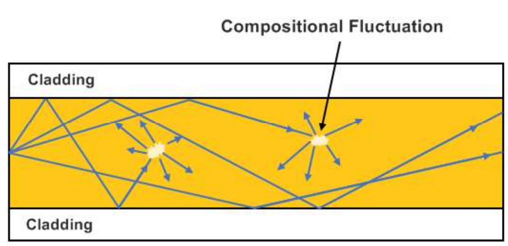
(b)Scattering

(c)Bending losses

Each mechanism of loss is influenced by the properties of fibre Material and fibre structure.

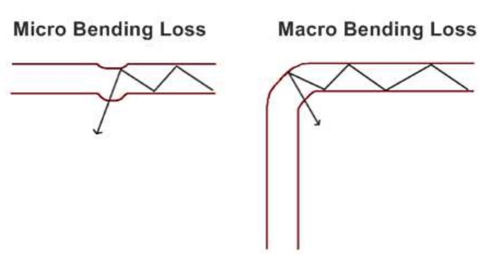
Intrinsic Optical Fiber Losses

Scattering losses in optical fiber are due to microscopic variations in the material density, compositional fluctuations, structural inhomogeneities and manufacturing defects.



Extrinsic Optical Fiber Losses

Bending is the common problem that can cause optical fiber losses generated by improper fiber optic handling. There are two basic types. One is micro bending, and the other one is macro bending (shown in the picture below). Macro bending refers to a large bend in the fiber (with more than a 2mm radius).



Dispersion

- Dispersion is the broadening of actual time-width of the pulse due to material properties and imperfections.
- As pulse travels down the fiber, dispersion causes pulse spreading. This limits the distance travelled by the pulse and the bit rate of data on optical fiber.
- Dispersion mechanisms cause broadening of the transmitted light pulses as they travel along the fiber.

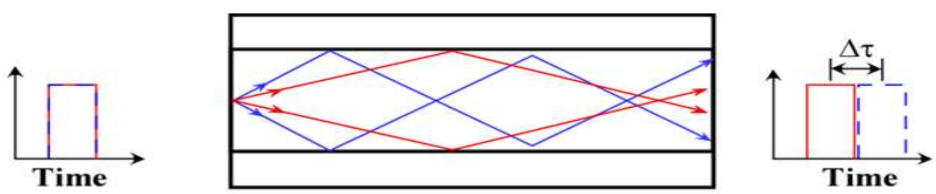
Signal broadening in a fiber

There are two major types of dispersion in fiber-optics

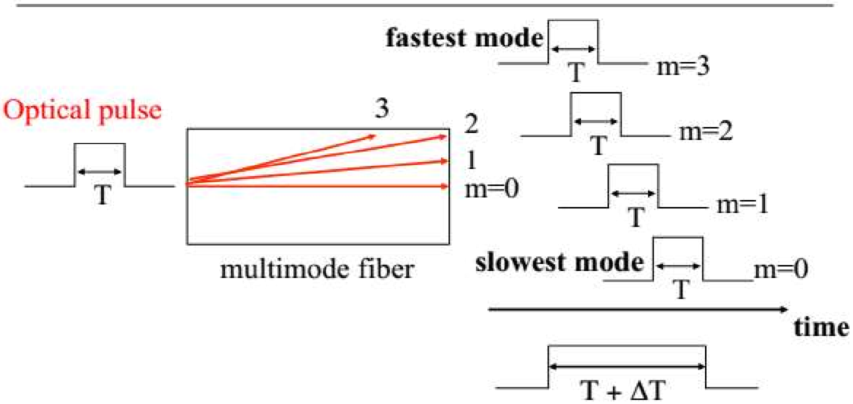
- **Intermodal**
- **Intramodal**

Intermodal

- Dispersion caused by multipath propagation of light energy is referred to as intermodal dispersion.
- Different modes will travel with different propagation angles, hence these modes takes different routes but travel with the same velocity, but at the end of fiber they come at different timings.
- This causes pulse widening
- Signal degradation occurs due to different values of group delay for each individual mode at a single frequency



Modal dispersion results in pulse broadening



modal dispersion: different modes arrive at the receiver with different delays => pulse broadening

Intramodal dispersion

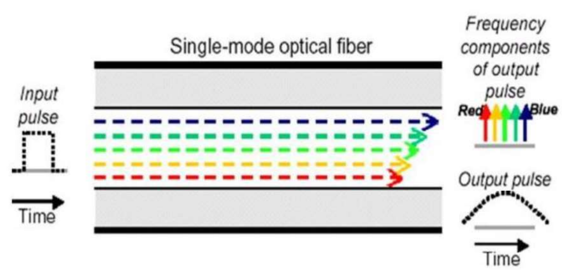
- ❑Pulse broadening within a single mode is called as intramodal dispersion or chromatic dispersion.

- ❑Since this phenomenon is wavelength dependent and group velocity is a function of wavelength, it is also called as group velocity dispersion (GVD).

- ❑Two types: 1) **Material dispersion** 2) **Waveguide dispersion**

Material dispersion

- ❑ It is the pulse spreading due to the dispersive properties of material.
- ❑ It arises from variation of refractive index of the core material as a function of wavelength.
- ❑ Material dispersion is a property of glass as a material and will always exist irrespective of the structure of the fiber.
- ❑ Called material dispersion since it results from the refractive index variation of the material of the fiber with the wavelength of light propagating through it.



CD causes the shorter λ to travel faster than the longer λ.

Waveguide dispersion

- ❑ It occurs because a single mode fiber confines only about 80% of the optical power to the core.

- ❑ Dispersion thus arises since the 20% light propagating in the cladding travels faster than light confined to the core.

- ❑ The amount of waveguide dispersion depends on the structure of the fiber and can be varied by altering the parameters such as NA, core radius etc.