LOSSES (ATTENUATION) IN OPTICAL FIBER

❖ Introduction:

- When light propagates through an optical fiber, a small percentage of power of light is lost through different mechanisms, which means the power of light at the output end is less than the power launched at the input end. This loss of optical power in fiber is generally referred to as Attenuation or Signal loss.
- It is measured in terms of dB/km.

❖ Definition:

- The ratio of the optical power output (Pout) from a fiber of length "L" to the optical power input (Pin) is called Attenuation.
- It is represented by α(alpha) and α**= (10/L)log(Pin/Pout)**

  Where: L is Length of the optical fiber.
- This Attenuation occurs because of the following Losses in optical fiber.

  1.Absorption Losses

  2.Scattering Losses

  3.Radiation or Bending Losses

  4.Dispersion losses

  5.Coupling losses

1. Absorption Losses:

- It is caused by the fiber itself or by impurities in the fiber such as water & metals used in the fabrication process.The amount of absorption by these impurities depends on their concentration and wavelength of light.
- It occurs in **two ways**. They are

  (i) Intrinsic absorption or Internal absorption

  (ii) Extrinsic absorption or Impurity absorption

(i) Intrinsic absorption or Internal absorption:

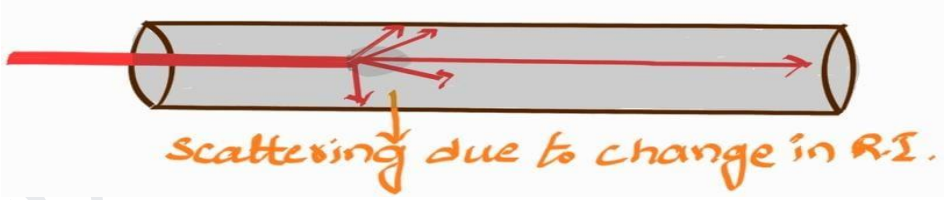
- The fiber itself as a material has a tendency to absorb light energy however small it
- The absorption that takes place in fiber material assuming that there are no impurities in it, is called intrinsic absorption.

(ii) Extrinsic absorption or Impurity absorption:

- The impurities present in the fiber are transition metal ions, such as iron, chromium, cobalt & copper.
- During signal propagation when photons interact with these impure atoms, then the photons are absorbed by atoms. Hence loss occurs in the power of light.

❖ 2. Scattering Losses:

- When the signal travels in the fiber, the photons may be scattered due to variations in the Refractive Index or density inside the fiber.This scattering is called Rayleigh scattering.
- It is also a wavelength dependent loss in optical fiber.



- There are **two main types of scattering** they are
  - i) Linear scattering Losses.
  - ii) Nonlinear scattering Losses.

i)Linear Scattering Losses:

- Linear scattering occurs when optical energy is transferred from the dominant mode of operation to adjacent modes. It is proportional to the input optical power injected into the dominant mode.
- Linear scattering is divided into **two** categories: Rayleigh scattering and Mie scattering.

- Rayleigh scattering is due to molecular-level irregularities in the glass structure, while Mie scattering occurs due to larger defects in the fiber core.

  Rayleigh scattering loss $\propto 1/\lambda^4$

ii)Non-Linear Scattering Losses: Nonlinear scattering is caused by high values of electric field within the fiber (modest to high amount of optical power).

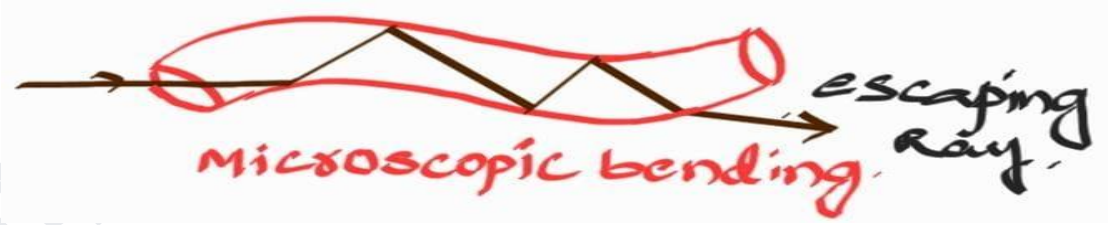
- Nonlinear scattering causes significant power to be scattered in the forward, backward, or sideways directions.
- Non-Linear scattering is divided into **two** categories: Stimulated Brillouin Scattering(SBS) and Stimulated Raman Scattering (SRS) .
- SBS may be regarded as the modulation of light through thermal molecular vibrations within the fiber while Stimulated Raman Scattering is similar to SBS except that high frequency optical phonon rather than acoustic phonon is generated in scattering processes.

❖ 3. Radiation or Bending Losses:

- Radiation loss occurs in fibers due to bending of finite radius of curvature in optical fibers.
- Radiation losses occur in two ways: (a) Microscopic bending (b) Macroscopic bending.

(i)Microscopic bending:

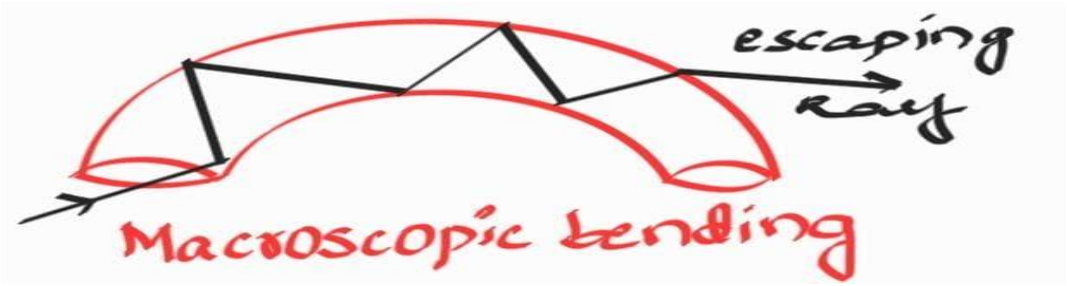
- These are caused due to non-uniform pressures created during the cabling of the fiber or during the manufacturing of the fiber which causes irregular reflections.This leads to the loss of light by leakage through the fiber.



- To prevent microscopic bending by reducing pressure and avoid unnecessary bendings.

(ii)Macroscopic bending:

- These are caused due to the large radius of the core compared to fiber diameter in fiber manufacturing, which causes large curvature of the bends.
- At these bends, the light will not satisfy the condition for TIR and light escapes out from the fiber.It is called macrobending.



- To prevent macrobends, optical fiber has a minimum bend radius specification that should not be exceeded.

❖ 4. Dispersion losses:

- Dispersion is a measure of the temporal spreading that occurs when a light pulse propagates through an optical fiber.
- Dispersion is sometimes referred to as delay distortion in the sense that the propagation time delay causes the pulse to broaden.

- The pulse broadening or dispersion will occur in following ways.
  - i)Inter-modal dispersion
  - ii)Intra Modal Dispersion
  - iii)Material dispersion or chromatic dispersion
  - iv)Waveguide dispersion

i)Intermodal dispersion: When more than one mode is propagating through the fiber, then the inter modal dispersion will occur.

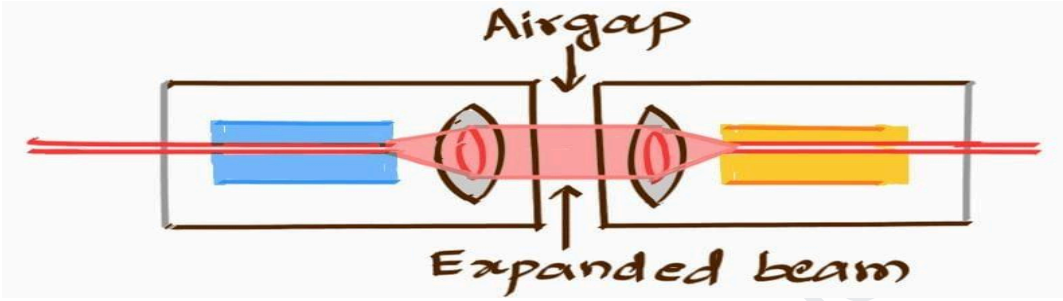
ii)Intra Modal Dispersion: When the pulse spreads that occurs within a single mode.

iii)Material dispersion: In material dispersion, the dispersion occurs due to different wavelength travelling at different speed inside the fibers

iv)Waveguide dispersion: The waveguide dispersion arises due to the guiding property of the fiber and due to their different angles at which they incident at the core-cladding interface of the fiber.

❖ 5.Coupling losses:

- Coupling loss in optical fiber refers to the power loss that occurs when light is transferred from one optical device or medium to another, particularly when connecting two fibers.
- This loss is often caused by misalignment, Mode Mismatch & Air Gaps.
- It can also arise from differences in the optical properties of the fibers (like core size or numerical aperture) or from the presence of air gaps between the fibers.



- Causes of Coupling Loss:

  i)Misalignment: The most common cause is misalignment of the fiber cores, including lateral (side-to-side) displacement, angular (rotational) misalignment, or end gap (distance between the fiber ends).

  ii)Mode Mismatch: When the optical modes (light patterns) in the input and output fibers are not compatible, coupling loss occurs. This can happen if the core sizes or numerical apertures of the fibers differ.

  iii)Air Gaps: A gap between the fiber ends, even if perfectly aligned, causes some light to escape, reducing the power coupled into the receiving fiber.