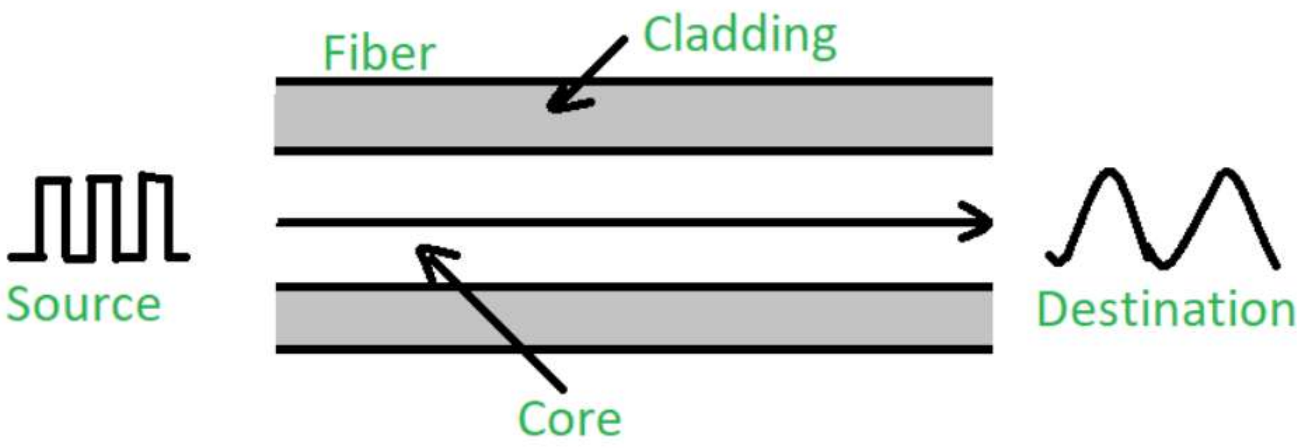
1. Based on the Number of Modes

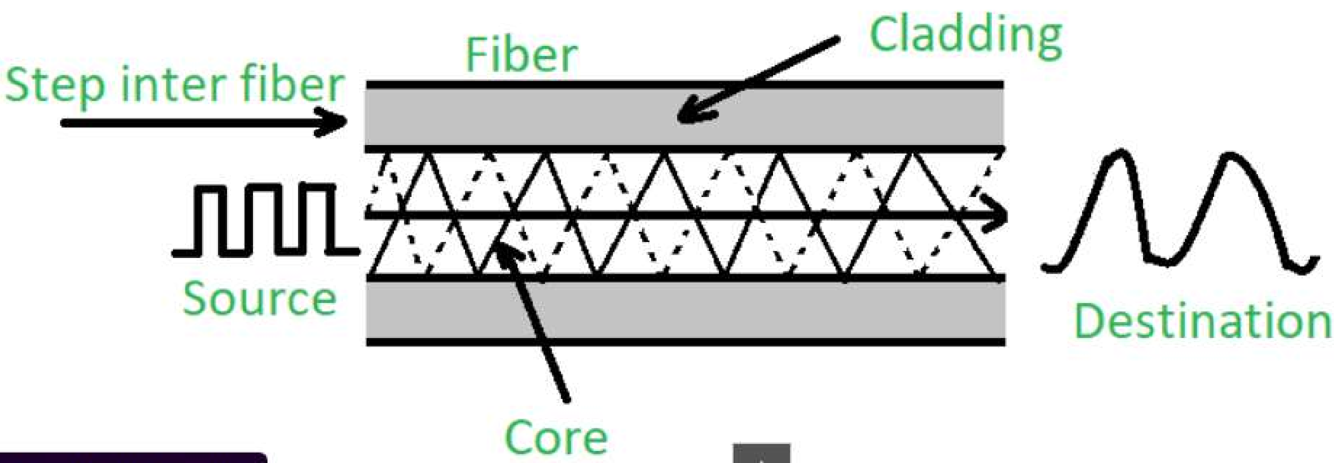
- **Single-mode fiber:** In single-mode fiber, only one type of ray of light can propagate through the fiber. This type of fiber has a small core diameter (5um) and high cladding diameter (70um) and the difference between the refractive index of core and cladding is very small. There is no dispersion i.e. no degradation of the signal during traveling through the fiber. The light is passed through it through a laser diode.



- **Multi-mode fiber:** Multimode fiber allows many modes for the light rays traveling through it. The core diameter is generally (40um) and that of cladding is (70um). The relative refractive index difference is also greater than single-mode fiber. There is signal degradation due to multimode dispersion. It is not suitable for long-distance communication due to the large dispersion and attenuation of the signal. There are two categories based on Multi-mode fiber i.e. **Step Index Fiber** and **Graded Index Fiber**. These are categories under the types of optical fiber based on the Refractive Index

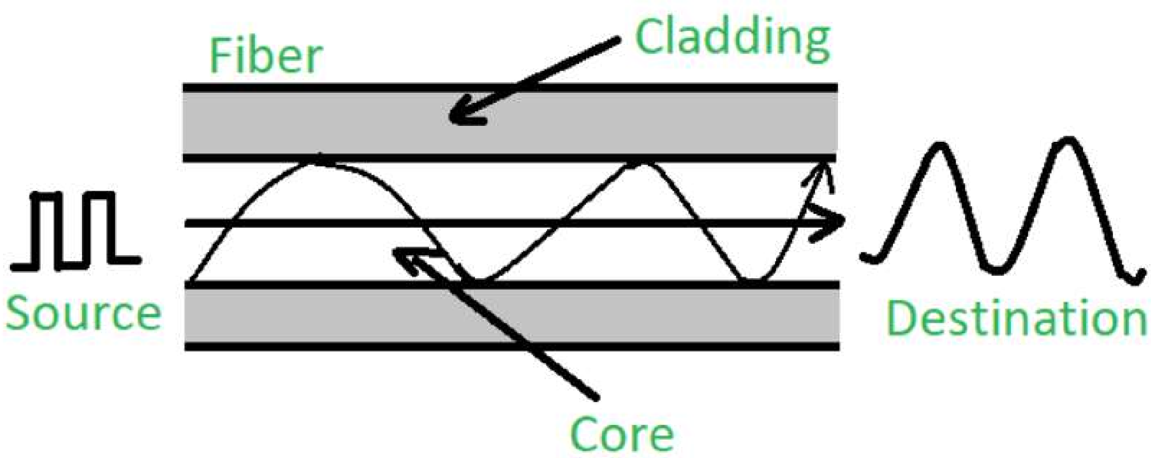
2. Based on Refractive Index

- **Step-index optical fiber:** The refractive index of the core is constant. The refractive index of the cladding is also continuous. The rays of light propagate through it in the form of meridional rays which cross the fiber axis during every reflection at the core-cladding boundary.



Core

- **Graded index optical fiber:** In this type of fiber, the core has a non-uniform refractive index that gradually decreases from the center towards the core-cladding interface. The cladding has a uniform refractive index. The light rays propagate through it in the form of skew rays or helical rays. it does not cross the fiber axis at any time.



The fiber is acting as a transmission medium in optical communication.

The signal passes through this transmission medium, is affected by Attenuation and Dispersion.

Both the parameters will determine the transmission characteristics of the fiber.

Attenuation – The light intensity decreases over a distance.

Dispersion – The width of the pulse is broadening.

2.1 ATTENUATION

Transmission loss (or) Attenuation is one of the important characteristics of a fiber.

It is a measure of decay of signal strength or loss of light power that occurs through the length of the fiber. This characteristic is taking major role in determining the maximum distance between the transmitter and receiver without repeaters. The basic attenuation mechanisms are

i) Absorbtion loss

ii) Scattering loss

iii) Radiative loss

`The unit of attenuation is expressed in terms of logarithmic unit of the decibel. The decibel is defined as the ratio of the input optical power P_i to the output optical power P_o.

$$\text{Number of decibels (db)} = 10 \log_{10} \frac{P_i}{P_o}$$

fiber.

Three basic attenuation mechanisms:

1. Absorption loss- It is related to the fiber material.

2. Scattering loss – It is due to fiber structure imperfections.

3. Radiative loss- It occurs due to bend of the cable.

2.2 ABSORPTION / MATERIAL ABSORPTION LOSS

It is caused by absorption of photons within the fiber. The photons move the valence electrons to higher energy levels. Hence photons are destroyed and the radiant energy is transferred into electric potential energy.

Absorption is caused by three mechanisms.

i) Absorption by atomic defects in the fiber materials.

ii) Intrinsic absorption by the basic constituent atoms of the fiber material.

iii) Extrinsic absorption by impurity atoms in the fiber material.

2.2.2 Intrinsic Absorption

Intrinsic absorption occurs when the material is in absolutely pure state with no impurities.

Electronic absorption – It occurs when a light particle (photon) interacts with an electron and excites it to a higher energy level.

The intrinsic absorption having two type

i) Intrinsic absorption due to ultra violet fail.

i) Intrinsic absorption due to infrared absorption fail

The optical communication wavelength range in terms of µm is 0.8 µm to 1.7 µm. In silica fibers, intrinsic absorption will occur above 1.5 µm. The photons of light energy are converted into random mechanical vibration infrared absorption. Maximum IR peak value at 0.8 µm and minimum peak value at 3.2, 3.8 and 4.4 µm.

2.2.3 Extrinsic Absorption by Impurity Atoms

Extrinsic absorption is due to transition metal ions such as iron, chromium, copper, maganese and nickel. This type of absorption is more pronounce in direct melt methods because in that type of fabrication method, the dopants are added directly to the silica. In the case of Vapour Axial Deposition (VAD) the impurity level ranges from 1 to 5 parts per billion. The transision metal ions produce loss at $\mu = 0.8\ \mu m$.

Impurity absorption also results from OH ions. These OH impurity results from the oxyhydrogen flame used for the hydrolysis reaction of the $SiCl_4$, $GeCl_4$ and $PoCl_3$. This type of absorption is reduced by reducing the water content in the fiber below one ppb (parts per billion).

2.3 SCATTERING LOSSES

Scattering losses arise due to following factors

1. Compositional Fluctuations
2. Structural Inhomogeneties
3. Microscopic variations in the material density
4. Structural defects occuring during fiber fabrication

A glass is composed by randomly connected network of molecules and several oxides. These added molecules and oxides are the major cause of compositional structure fluctuation.

Scattering losses having two types

i) Linear scattering loss

a) Rayleigh Scattering

b). Mie Scattering

2.3.1 Linear Scattering Losses

Linear scattering transfers linearly the optical power in one propagating mode to a different mode. This losses will occurs as a leaky mode or as radiation mode. This mode does not continue to propagate within the fiber core but it is radiated from the fiber. Since there is no change in frequency of the signal, it is said to be linear scattering. Scattering loss will be more in multimode fibers due to higher dopant concentration and greater compositional fluctuations.

2.3.1.1 Rayleigh Scattering

This loss occurs in the Ultra violet region. Its tail extends upto infrared region. It arises from the microscopic inhomogeneities present in the material of fiber. Inhomogeneities may arise from the density fluctuations, reflective fluctuations and compositional variations.

For SiO_2 fiber, Rayleigh loss is given by

2.3.2 Non-linear Scattering Losses

Non linear scattering losses occurs at high power levels. It causes the optical power to be transferred in either forward or backward direction to the same, or other modes at a different frequency.

When the refractive index of the medium depends on the optical intensity of the signal, then these non linear scattering occurs. It becomes significant above threshold power levels. It can also be used to give optical amplification of integrated optical techniques.

Non-linear scattering losses will occur at high power levels. When the transferring of one mode to other mode taking place the output will be forward on reverse direction. This is inelastic scattering due to shift in the frequency when the refractive index of the medium depends on the optical intensity of the signal, then these non linear scatterings are occured.

Attenuation

Attenuation is a measure of decay of signal strength or loss of light power that occurs as light pulses propagate through the length of the fiber.

In optical fibers the attenuation is mainly caused by two physical factors absorption and scattering losses. Absorption is because of fiber material and scattering due to structural imperfection within the fiber. Nearly 90 % of total attenuation is caused by Rayleigh scattering only. Micro bending of optical fiber also contributes to the attenuation of signal.

The rate at which light is absorbed is dependent on the wavelength of the light and the characteristics of particular glass. Glass is a silicon compound, by adding different additional chemicals to the basic silicon dioxide the optical properties of the glass can be changed.

The Rayleigh scattering is wavelength dependent and reduces rapidly as the wavelength of the incident radiation increases.

The attenuation of fiber is governed by the materials from which it is fabricated, the manufacturing process and the refractive index profile chosen. Attenuation loss is measured in dB/km.

Rayleigh Scattering Losses

Rayleigh scattering is a phenomenon that occurs when light is scattered by small particles in a medium, such as air, water, or glass. In an optical fiber, Rayleigh scattering causes some of the light to be scattered out of the core and into the cladding, resulting in loss of signal strength.

The amount of Rayleigh scattering loss in an optical fiber depends on several factors, including the wavelength of the light, the refractive index of the core and cladding, and the size and concentration of the scattering particles. The scattering loss is proportional to the fourth power of the wavelength, which means that shorter wavelengths, such as those in the blue and green parts of the spectrum, are more strongly affected than longer wavelengths, such as those in the red and infrared parts of the spectrum.

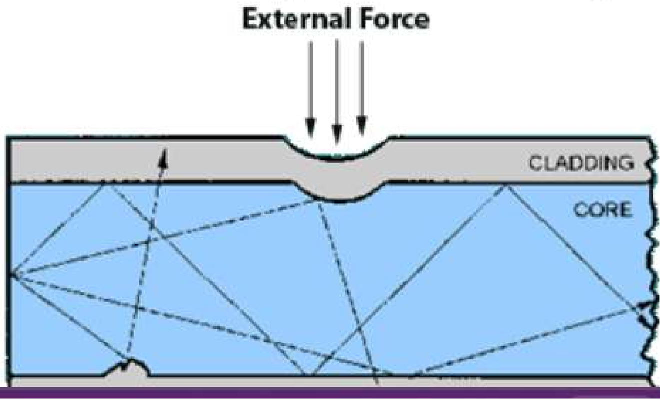
To minimize Rayleigh scattering losses in an optical fiber, designers typically use materials with low scattering coefficients, such as high-purity silica glass, and design fibers with small core diameters and low numerical apertures. Additionally, in long-haul communication systems, fiber amplifiers can be used to boost the signal strength and compensate for any losses due to Rayleigh scattering.

Bending Loss

Losses due to curvature and losses caused by an abrupt change in radius of curvature are referred to as 'bending losses.' The sharp bend of a fiber causes significant radiative losses and there is also a possibility of mechanical failure

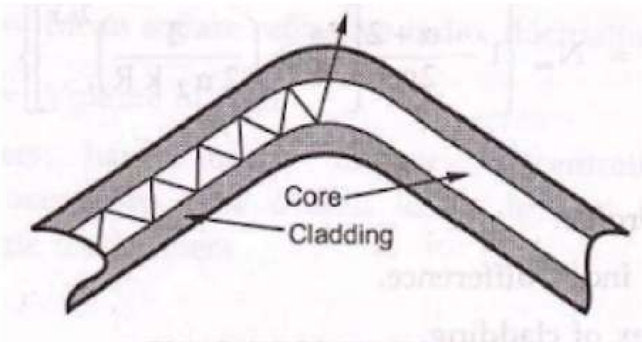
Micro bending

Micro bending is a loss due to small bending or distortions. This small micro bending is not visible. The losses due to this are temperature related, tensile related or crush related. The effects of micro bending on multimode fiber can result in increasing attenuation (depending on wavelength) to a series of periodic peaks and troughs on the spectral attenuation curve. These effects can be minimized during installation and testing



Macro bending

The change in spectral attenuation caused by macro bending is different to micro bending. Usually there are no peaks and troughs because in a macro bending no light is coupled back into the core from the cladding as can happen in the case of micro bends. The macro bending losses are cause by large scale bending of fiber. The losses are eliminated when the bends are straightened. The losses can be minimized by not exceeding the long term bend.



Waveguide Dispersion

Waveguide dispersion is caused by the difference in the index of refraction between the core and cladding, resulting in a ‘drag’ effect between the core and cladding portions of the power. Waveguide dispersion is significant only in fibers carrying fewer than 5-10 modes. Since multimode optical fibers carry hundreds of modes, they will not have observable waveguide dispersion.

Chromatic Dispersion

The combination of material dispersion and waveguide dispersion is called chromatic dispersion. These losses primarily concern the spectral width of transmitter and choice of correct wavelength.

Modal Dispersion

As only a certain number of modes can propagate down the fiber, each of these modes carries the modulation signal and each one is incident on the boundary at a different angle, they will each have their own individual propagation times. The net effect is spreading of pulse, this form o dispersion is called modal dispersion. Modal dispersion takes place in multimode fibers. It is moderately present in graded index fibers and almost eliminated in single mode step index fibers.

OTDR (Optical Time Domain Reflectometer)

Optical Time Domain Reflectometer is a common measurement technique used in optical fiber communication systems to measure the optical fiber link characteristics such as attenuation, dispersion, and reflectivity. OTDR works by sending a short, high-intensity pulse of light into the optical fiber and measuring the time and intensity of the light that is reflected back. This reflected light is caused by scattering and reflections from any changes in the fiber's refractive index, such as connectors, splices, or breaks.

OTDR measurements provide information on the length of the fiber, the attenuation or loss of the signal as it travels through the fiber, and the location and severity of any discontinuities or reflections along the length of the fiber. By analyzing the reflections and attenuation, OTDR measurements can help identify and locate any problems in the fiber, such as breaks or damage, and provide information on the quality of the fiber link.

In addition to OTDR, other measurement techniques commonly used in optical fiber communication systems include optical power meters, optical spectrum analyzers, and optical wavelength meters. These tools provide additional information on the characteristics of the optical signal, such as its power level, wavelength, and spectral content.

Fabrication of fibers

Fiber optic cables are made of thin strands of glass or plastic, called optical fibers, that transmit light signals over long distances. The fabrication process of fiber optics involves several steps, including preform fabrication, fiber drawing, coating, and testing.

Preform Fabrication: The first step in making fiber optic cables is to create a preform, which is a cylindrical rod of glass or plastic that is used to draw the optical fiber. The preform is made by using a high-temperature process called chemical vapor deposition (CVD), which involves depositing layers of glass or plastic onto a cylindrical rod. This process creates a uniform composition and a controlled refractive index profile along the length of the preform.

Fiber Drawing: After the preform is made, it is heated in a furnace to a temperature that softens the glass or plastic material. A fiber drawing tower is used to pull a thin strand of glass or plastic from the softened preform. As the strand is pulled, it is cooled to solidify the material and form a uniform diameter optical fiber. This process is repeated to produce multiple fibers from a single preform.

Coating: Once the fibers are drawn, they are coated with a protective layer of polymer or acrylate. The coating protects the fragile glass or plastic fiber from damage during handling and installation. The coating also helps to reduce signal loss due to microbending or macrobending, which can occur if the fiber is bent too sharply.