UNIT- I
INTRODUCTION TO OPTICAL COMMUNICATION SYSTEM

OPTICAL FIBER COMMUNICATION SYSTEM:

The below figure (1) shows a block schematic of the different elements in an optical fiber communication system. The carrier is modulated using analog information signal. The variation of light emitting from the optical source is a continuous signal. The information source provides an electrical signal to the transmitter. The transmitter comprises electrical stage. The electrical stage (circuits) drives an optical source. The optical source output is a light which is intensity modulated by the information. The optical source converts the electrical signal into an optical signal. The source may be either semiconductor laser or Light Emitting Diode (LED). The intensity modulated light signal is coupled to fiber. The fiber which is made up of a glass acts as a channel between the transmitter and receiver.

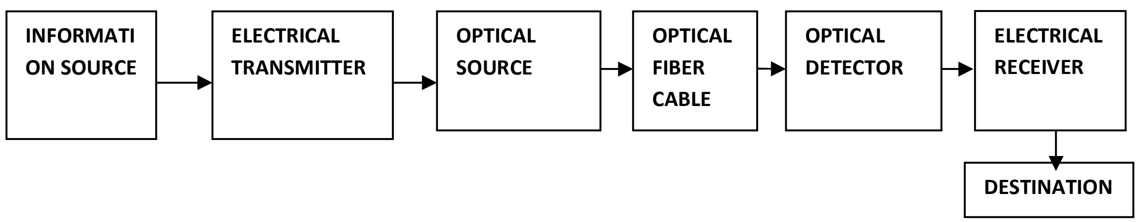


FIG:1 GENERAL BLOCK DIAGRAM OF OFC SYSTEM

At the receiver the optical signal is detected by the optical detectors such as PIN diode and Avalanche photodiode.

Sometimes photo transistors and photo conductors are used for converting an optical signal into electrical signal. The electrical signal is again processed and given to the transducer to get the original information.

Block diagram of a digital optical communication system

Figure (2) shows a schematic of a typical digital optic fiber link. The input is given as digital signal from the information source and it is encoded for optical transmission in the encoder. The encoder, encodes or modulates the digital signal as in the case of simple communication system where we are using a message signal in which the signal is in analog form, but here the signal is in digital form which is encoded i.e., modulated in the encoder. The laser drive circuit directly modulates the intensity of semiconductor laser with the encoded digital signal. Hence a digital optical signal is launched into the optical fiber cable. At the receiver we have to decode the digital optical signal for which we are using another Avalanche Photo Diode (APD) as detector. The avalanche photo diode detector is followed by a front-end amplifier and equalizer or filter to provide gain as well as linear signal processing and noise bandwidth reductions. Then the signal is passed through the decoder to get original digital information which is transmitted

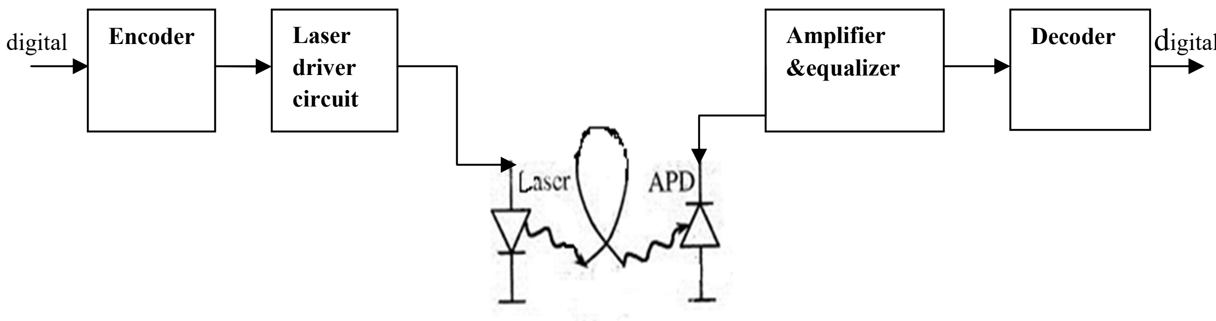


Fig :2 Block diagram of digital optical communication system

FIBER CHARACTERISTICS AND CLASSIFICATIONS:

A dielectric waveguide that operates at optical frequencies is known as optical fiber. It is generally available in cylindrical form.

Fiber Types

There are two fiber types

(i) Step index fiber

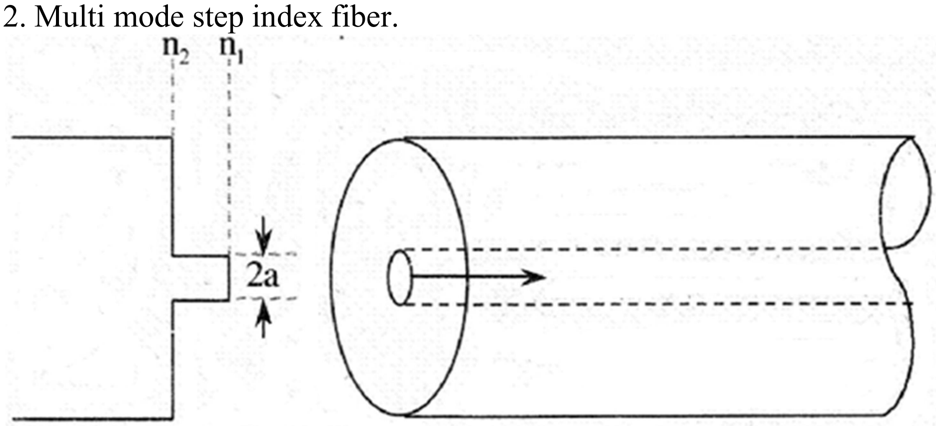
(ii) Graded index fiber.

(i) Step Index Fiber

Step index fiber is further divided in two types,

1. Single mode step index fiber

2. Multi mode step index fiber.

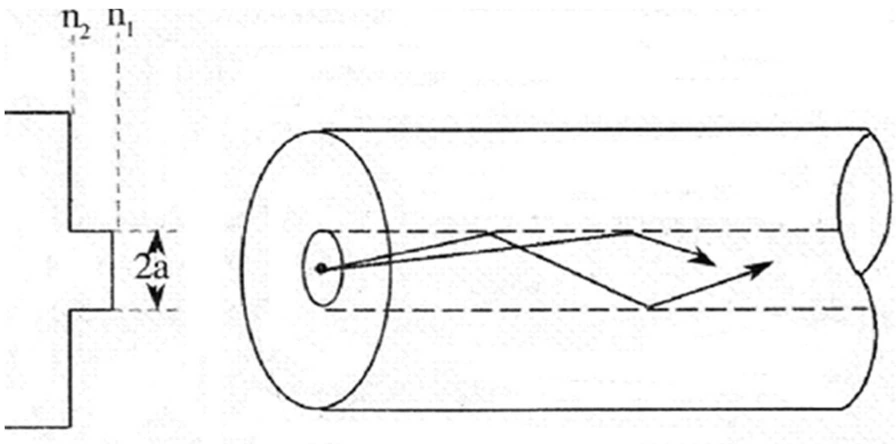


Single Mode Step index Fiber

The typical dimension of core is 8 to 12 μm and cladding is 125 μm.

In step index fiber, the refractive index of the core is uniform and at the cladding boundary, it undergoes a step change.

In single mode step index fiber, there is only one mode of propagation. The multimode step index fiber is shown below,

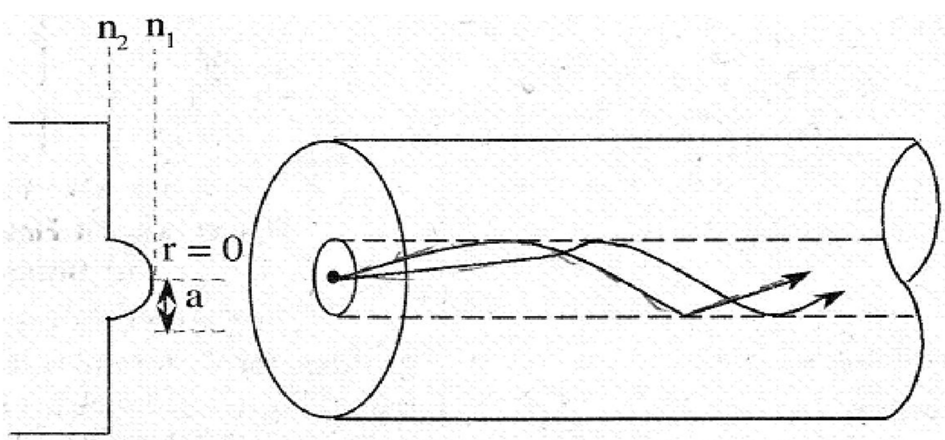


Multi Mode step index fiber

In multimode step index fiber, hundreds of modes are present .The typical dimension of core is 50 to 200 μm and cladding is 125 to 400 μm. Multimode fiber has several advantages, which includes, the transmitting the light directly in to fiber using LED.

Graded Index Fiber

Graded index fiber also contains single mode and multimode. The multimode graded index fiber is shown below,



7.3 Multi Mode Graded Index Fiber

In graded index fiber, the refractive index of the core is made to vary as a function of radial distance taken from the center of the fiber.

The dimension of its core is 50 to 100 μm and cladding is 125 to 140 μm.

In both cases (step index and graded index) multimode has several advantages. When compared with single mode, however, multimode has a drawback, that is, it suffers from inter model dispersion.

DISPERSION,DIFFRACTION,ABSORPTION &SCATTERING-FIBER LOSSES:

When a decrease in light power occurs during light propagation along an optical fiber then such a phenomenon is called attenuation. The major causes for attenuation in fiber optic communications are,

1. Bending loss
2. Scattering loss
3. Absorption loss

1. Bending Loss :

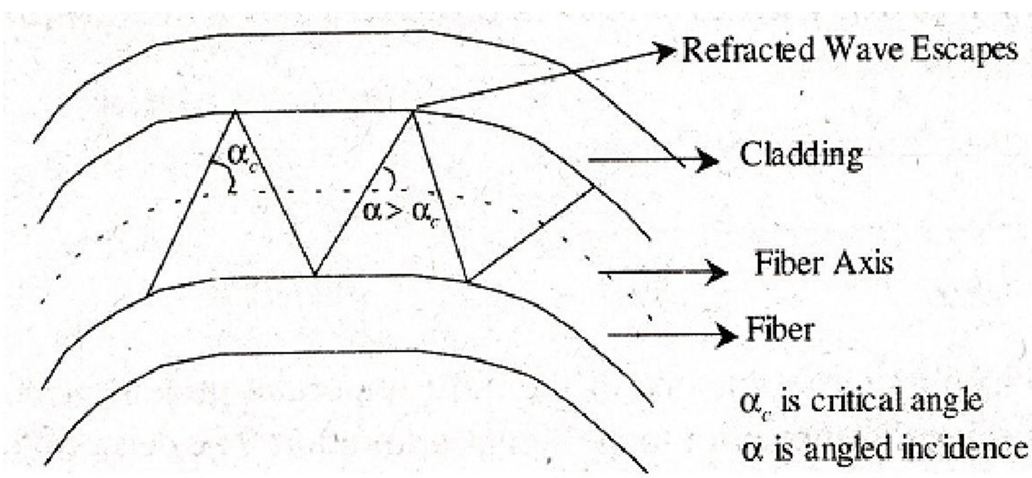
Bending loss is further classified into,

Macro bending loss-and

Micro bending loss.

Macro bending Loss:

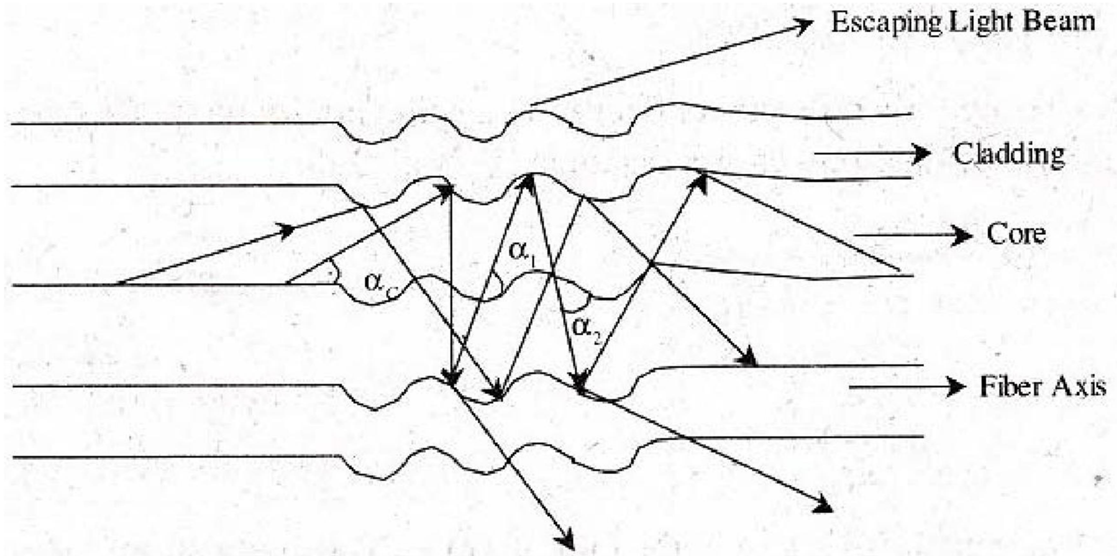
The light travels in fiber due to occurrence of total internal reflection inside the fiber at the interface of core and cladding. However the light beam forms a critical angle with the fiber's central axis at the fiber face. When the fiber is bend and the light beam travelling through fiber strikes at the boundary of core at an angle greater than critical angle then the beam fails to achieve total internal reflection. Hence this beam is lost through the cladding.



3.1 Macro Bending of optical Fiber

Micro bending Loss**:**

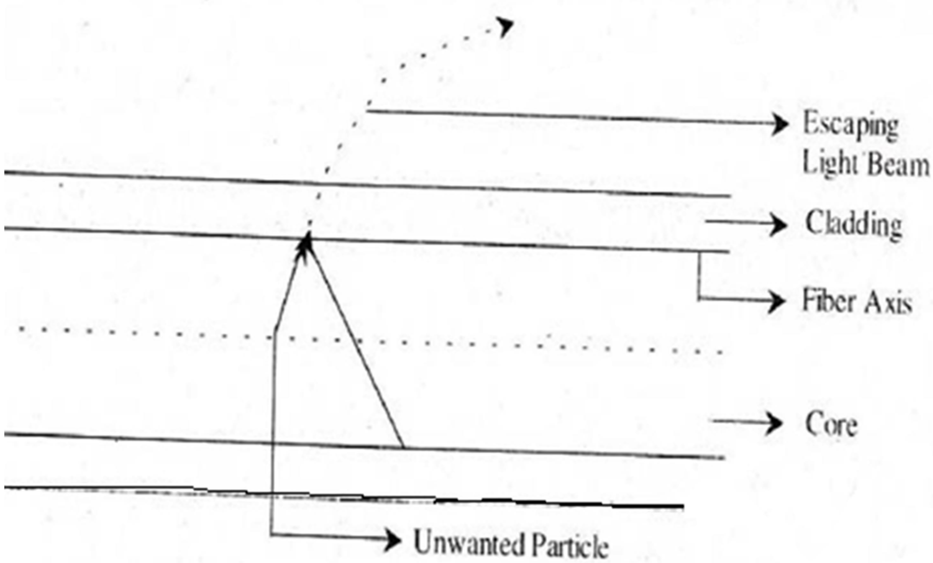
Micro bending loss is caused by micro-deformations of the fiber axis. The beam which travels at the critical propagation angle before incident on micro-deformations will change the angle of propagation after being reflected by the imperfection of fiber and hence the condition for total internal reflection is lost and the beam escapes from the fiber through cladding.



3.2 α_C **is Critical Angle where** $\alpha_1 > \alpha_C$, $\alpha_2 > \alpha_C$

2. Scattering Loss :

A light beam propagating through the fiber core at critical angle or less will change its direction after hitting on an obstacle in the core region. The obstacle can be any particle in core that may have diffused inside the core at the time of manufacturing when the light beam hits the particle it



Scattering Loss

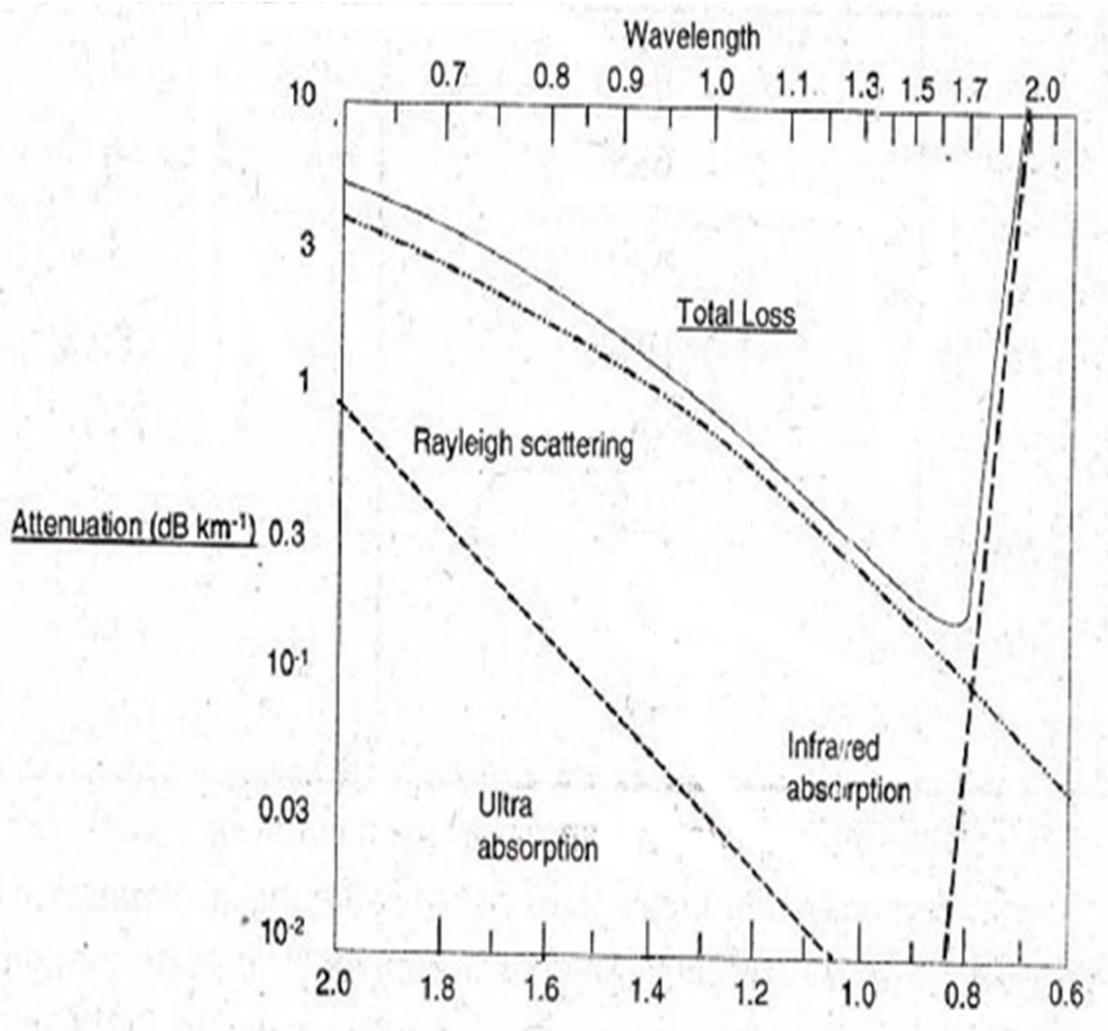
get scattered and due to this total internal reflection is not achieved hence, the beam is lost through the cladding.

3. Absorptions Loss :

Whenever a beam of light photon having energy equal to energy band gap then the light photon is absorbed by the material resulting in absorption loss. Absorption loss occur due to presence of anions OH~ in silica fibers and due to metallic ions like Iron (Fe), Chromium (Cr) and Nickel (Ni). The absorption loss peak is observed in the region of 2700 nm and 4200 nm wavelength with low-loss at 7200 nm, 9500 nm and 13800 nm wavelength windows.

Absorption, infrared absorption and ion resonance absorption losses in the pure and doped SiO_2 at various levels:

An absolutely pure silicate glass has little intrinsic absorption due to its, basic material structure in the near infrared region. However it does have two major intrinsic absorption mechanisms at optical wavelengths as illustrated in the following figure which shows a possible optical attenuation against wavelength characteristic for absolutely pure glass (i.e., SiO_2). There is a fundamental absorption edge, the peaks of which are centered in the ultraviolet wavelength region. This is due to the stimulation of electrons transitions within the glass by higher energy excitation. The tail of this peak may extend into the window region at the shorter wavelengths. Also in the infrared and far-infrared, normally at wavelengths above 7μm. Absorption bands from the interaction of photons with molecular variations within the glass occur. These give



The Attenuation Spectrum for intrinsic Loss mechanism in pure GeO2 ,SiO2 Glass absorption peaks which again extend into the window region. Hence,

abov1.5these largely far-infrared absorption peaks tend to increase

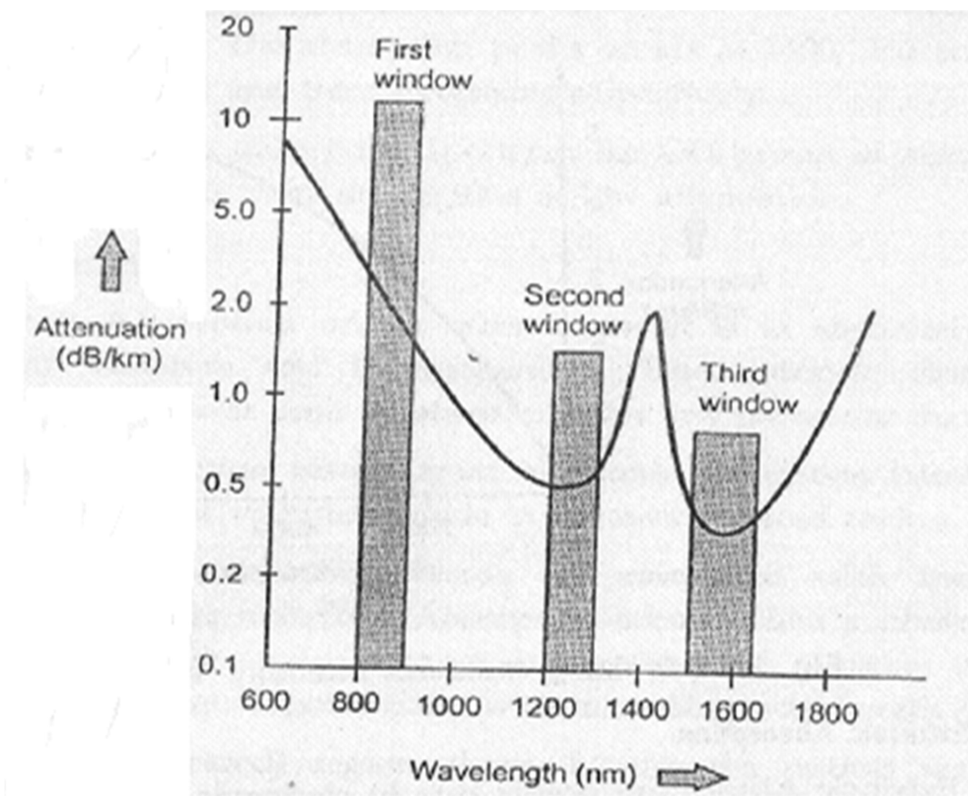
In practical optical fibers prepared by conventional melting techniques, a major source of signal attenuation is extrinsic (doped) absorption from transition metal element impurities. Certain impurities, namely Chromium and Copper, in their worst valence state can cause attenuation is excess of 1 dB/km in the near infrared region. Transition element contamination may be reduced to acceptable levels i.e., one part is 1010 by glass refining techniques such as vapor -phase oxidation. It may also be observed that the only significant absorption band in the region below a wavelength of 1urn is the second overtone at 0.95 am which causes attenuation of about 1 dB/km for one part per million (ppm) of hydroxyl. At longer wavelengths the first overtone at 1.38 urn and its side band at 1.24 am are strong absorbers giving attenuation of about 2 dB/km ppm and 4

Since most resonances sharply peaked, narrow window exist in the longer wavelength region around 1.3 and 1.55μm which are essentially unaffected by OH absorption, once the impurity, level has been reduced below one part in 10^7. This situation is illustrated in. figure (b) which shows the attenuation spectrum of an ultra-low-loss single mode fiber. It may be observed that the lowest attenuation for this fiber occurs at a wavelength of 1.55μm and is 0.2dB/km. This approaching is the minimum possible attenuation of around 0.18 dB/km at this wavelength.

Signal distortion and attenuation in optical fiber:

One of the important property of optical fiber is signal attenuation. It is also known as fiber loss or signal loss. The signal attenuation of fiber determines the maximum distance between transmitter and receiver. The attenuation also determines the number of repeaters required, maintaining repeater is a costly affair.

Another important property of optical fiber is distortion mechanism. As the signal pulse travels along the fiber length it becomes broader. After sufficient length the broad pulses starts



Fiber Attenuation As a function of Wave length overlapping with adjacent pulses. This creates error in the receiver. Hence the distortion limits the information carrying capacity of fiber

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 imperfections 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.

Attenuation Units As attenuation leads to a loss of power along the fiber, the output power is significantly less than the coupled power. Let the coupled optical power is P (0) i.e. at origin (z = 0) Then the power at distance z is given by

$$P(Z) = P(0)e^{-\alpha_p Z}$$

Therefore $\alpha_p = \left(\frac{1}{z}\right)\ln\left[\frac{P(0)}{P(Z)}\right]$

$$\alpha_{dB/Km} = 10.\left(\frac{1}{z}\right)\ln\left[\frac{P(0)}{P(Z)}\right]$$

This parameter is known as fiber loss or fiber attenuation. Attenuation is also a function of wavelength. Optical fiber wavelength as a function of wavelength is shown in fig 5.1

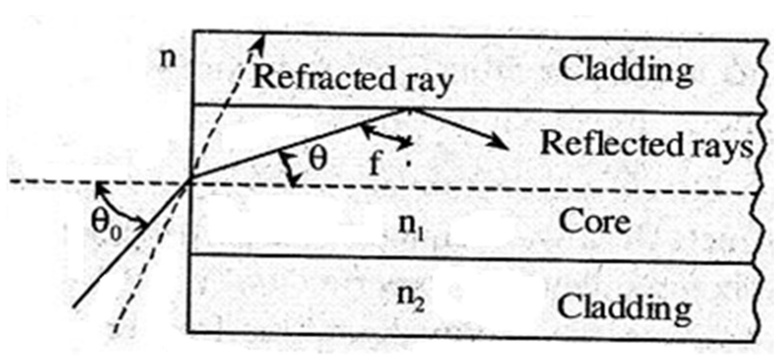
RAY OPTICS:

Ray optics is used for representing the mechanism of a ray which propagates through an ideal multimode step index optical waveguide. There are two types of rays, the skew rays and meridional rays which propagate through a fiber.

The path of meridional can be tracked very easily as they are confined to a single plane. Meridional are described in two classes. They are,

(i) Bound rays

(ii) Unboundrays.



Ray Representation of Meridional Rays in an ideal step index optical wave guide.

Bound rays are those rays which are trapped in a core and they move along the fiber whereas unbound rays are those rays which get refracted out of the fiber.

Skew rays are those rays which follow helical path but they are not confined to a single plane. We know that skew rays are not confined to a particular plane so they cannot be trackedeasily. Analyzing the meridional rays is sufficient for the purpose of result, rather than skew rays, because skew rays lead to greater power loss.

Now coming to ray theory, we need to consider meridional rays. Representation of meridional rays is given below.From the medium of refractive index 'n' which is at an angle 'θ_0'with respect to fiber axis, the light enters the fiber core. If the light strikes at such an angle then it gets reflected internally and the meridional ray moves in a zig zag path along the fiber core, passing through the axis of the guide. Now by using Snell's law the minimum angle 'ϕmin' supports total internal reflection for meridional ray is given by

If the ray strikes the core-cladding interface at an angle less than ϕmin then they get refracted out of the core and they will be lost from the cladding.

By applying Snell's law to the air-fiber face boundaries, we get θ_{max}

$n\sin\theta_{max} = n_1 \sin\theta_c$

Where $\theta_c = \Pi/2 - \theta_0$ (From^n the^n figure)

So, the rays whose entrance angle 'θ_0' is less than the 'θ_{max}' will be reflected back in to core cladding interface.

Numerical aperture for a step index is given by the formula

$N.A = n \sin\theta_{max}$

FIBER MATERIALS:

Requirements that be satisfied by materials used to manufacture optical fiber:

Most of the fibers are made up of glass consisting of either Silica (SiO_2) or .Silicate. High-loss glass fibers are used for short-transmission distances and low-loss glass fibers are used for long distance applications. Plastic fibers are less used because of their higher attenuation than glass fibers. Glass Fibers

The glass fibers are made from oxides. The most common oxide is silica whose refractive index is 1.458_at 850 nm. To get different index fibers, the dopants such as GeO_2, P_2O_5 are added to silica. GeO_2 and P_2O_3 increase the refractive index whereas fluorine or $B_2 0_3$ decreases the refractive index. Few fiber compositions are given below as follows,

(i) GeO_2 SiO_2 Core: SiO_2 Cladding

(ii) P_2Q_5 SiO_2, Core; SiO_2 Cladding

The principle raw material for silica is sand. The glass composed of pure silica is referred to as silica glass, nitrous silica or fused silica. Some desirable properties of silica are,

(i) Resistance to deformation at temperature as high as 1000°C.
(ii) High resistance to breakage from thermal shock.
(iii) Good chemical durability.
(iv) High transparency in both the visible and infrared regions.

Basic Requirements and Considerations in Fiber Fabrication

(i) Optical fibers should have maximum reproducibility.
(ii) Fibers should be fabricated with good stable transmission characteristics i.e., the fiber should have invariable transmission characteristics in long lengths.
(iii) Different size, refractive index and refractive index profile, operating wavelengths material. Fiber must be available to meet different system applications.
(iv) The fibers must be flexible to convert into practical cables without any degradation of their characteristics.
(v) Fibers must be fabricated in such a way that a joining (splicing) of the fiber should not affect its transmission characteristics and the fibers may be terminated or connected together with less practical difficulties.

Fiber Fabrication in a Two Stage Process

(i) Initially glass is produced and then converted into perform or rod.

Details about glass fiber and plastic optical fiber:

Glass fiber is a mixture of selenides, sulfides and metal oxides. It can be classified into,

1. Halide Glass Fibers
2. Active Glass Fibers
3. Chalgenide Glass Fibers.

Glass is made of pure SiO_2 which refractive index 1.458 at 850 nm. The refractive index of SiO_2 can be increased (or) decreased by adding various oxides are known as dopant.

The oxides GeO2 or P2O3 increases the refractive index and B_2O_3 decreases the refractive index of SiO_2 The various combinations are,

(i) GeO_2 SiO_2 Core; SiO_2 cladding

(ii) P_2 O_3 SiO_2 Core; SiO_2 cladding

(iii) SiO_2 Core; B_2O_3, - SiO_2 cladding

(iv) GeO_2- B_2O_3- SiO_2, Core; B_2O_3 - SiO_2 cladding.

From above, the refractive index of core is maximum compared to the cladding.

(1) Halide Glass Fibers

A halide glass fiber contains fluorine, chlorine, bromine and iodine. The most common Halide glass fiber is heavy "metal fluoride glass". It uses ZrF_4 as a major component. This fluoride glass is known by the name ZBLAN. since it is constituents are ZrF_4, BaF_2, LaF_3 $A1F_3$, and NaF

The percentages of these elements to form ZBLAN fluoride glass is shown as follows,

Materials	Molecular percentage
ZrF_4	54%
BaF_2	20%
LaF_3	4.5%
$A1F_3$	3.5%
NaF	18%

These materials add up to make the core of a glass fiber. By replacing ZrF_4 by HaF_4, the lower refractive index glass is obtained.

The intrinsic losses of these glasses is 0.01 to 0.001 dB/km

(2) Active Glass Fibers

Active glass fibers are formed by adding erbium and neodymium to the glass fibers. The above material performs amplification and attenuatio

(3) Chalgenide Glass Fibers

Chalgenide glass fibers are discovered in order to make use of the nonlinear properties of glass fibers.

It contains either "S", "Se" or "Te", because they are highly nonlinear and it also contains one element from Cl , "Br , Cd , Ba or Si .

The mostly used chalgenide glass is AS_2-S_3, $AS_{40}S_{58}Se_2$ is used to make the core and AS_2S_3 is used to make the cladding material of the glass fiber. The insertion loss is around 1 dB/m.

Plastic Optical Fibers

Plastic optical fibers are the fibers which are made up of plastic material. The core of this fiber is made up of Polymethylmethacrylate (PMMA) or Perflourmated Polymer (PFP).

Plastic optical fibers offer more attenuation than glass fiber and is used for short distance applications. These fibers are tough and durable due to the presence of plastic material. The modulus of this plastic material is two orders of magnitude lower than that of silica and even a 1 mm diameter graded index plastic optical fiber can be installed in conventional fiber cable routes. The diameter of the core of these fibers is 10-20 times larger than that of glass fiber which reduces the connector losses without sacrificing coupling efficiencies. So we can use inexpensive connectors, splices and transceivers made up of plastic injection-molding technology.

Graded index plastic optical fiber is in great demand in customer premises to deliver high-speed services due to its high bandwidth