Introduction

An optical fiber is a dielectric waveguide that operates at optical frequencies. This fiber waveguide is normally cylindrical in form.

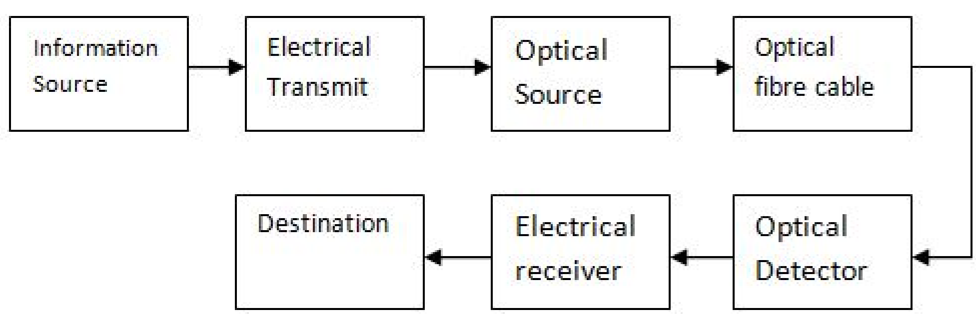
Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. Fiber is preferred over electrical cabling when high bandwidth, long distance, or immunity to electromagnetic interference are required. This type of communication can transmit voice, video, and telemetry through local area networks, computer networks or across long distances.

Optical fiber is used by many telecommunication companies to transmit telephone signals, Internet communication and cable television signals. Researchers at Bell have reached internet speed of over 100 petabits per * kilometer per second using fiber-optic communication.

History of optical fiber

In April 1977, General Telephone and Electronics tested and deployed the world's first live telephone traffic through a fiber optic system running at 6 Mbps in Long Beach, California. Charles Kuen kao, known as the father of optical fiber communication.

Block diagram of optical fiber communication



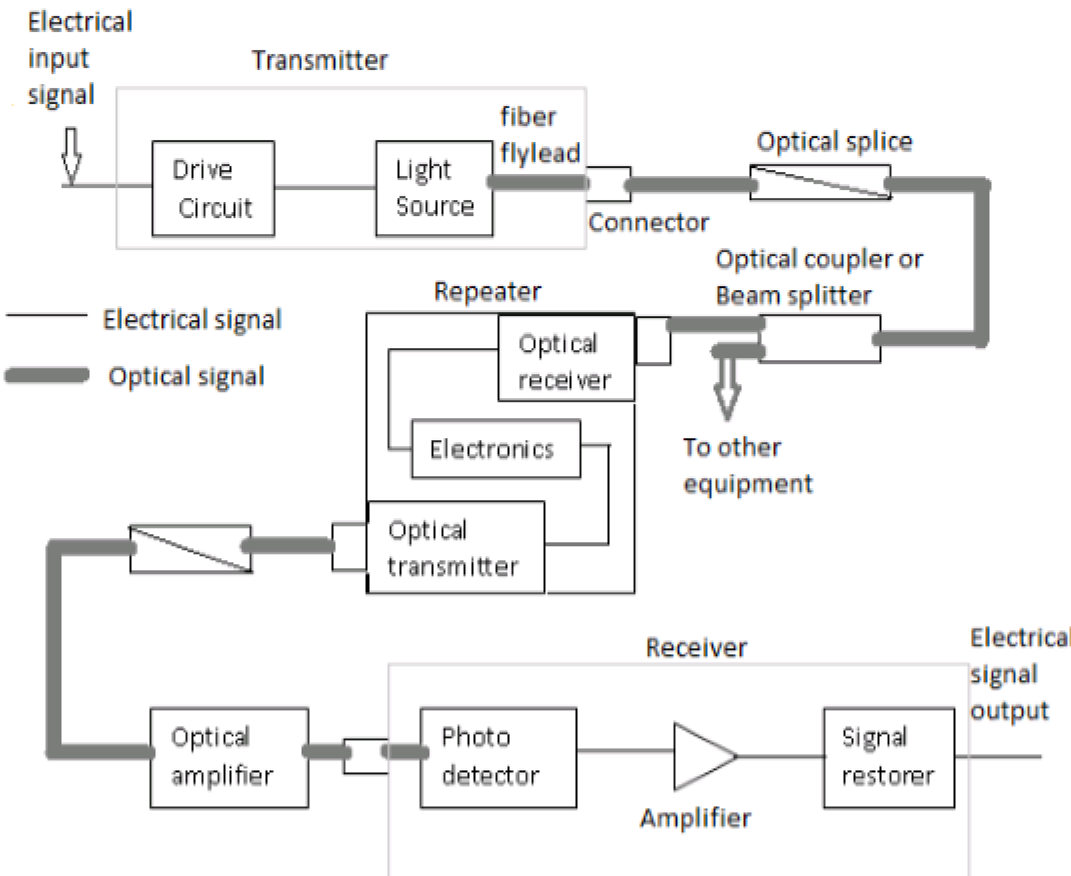


Figure 1

1. Transmitter

   An electric signal is applied to the optical transmitter. The optical transmitter consists of a driver circuit, light source and fiber flylead.

   - Drive circuit drives the Light source.
   - Light source converts electrical signal to optical signal.
   - Fiber flylead is used to connect optical signal to optical fiber.

2. Transmission channel

   It consists of cable that provides mechanical and environmental protection to the optical fibers contained inside. Each optical fiber acts as an individual channel.

   - Optical splice is used to permanently join two individual optical fibers.
   - Optical connector is for temporary non-fixed joints between two individual optical fibers.
   - Optical coupler or splitter provides a signal to other devices.
   - Repeater converts the optical signal into electrical signal using optical receiver and passes it to sector electronic Circuit where it is reshaped and amplified as it

gets attenuated and distorted with increasing distance because of Scattering, absorption and dispersion in waveguides, and this signal is then again converted into optical signal by optical transmitter.

3. Receiver

Optical signal is applied to the optical receiver. It consists of a photo detector, amplifier and signal restorer.

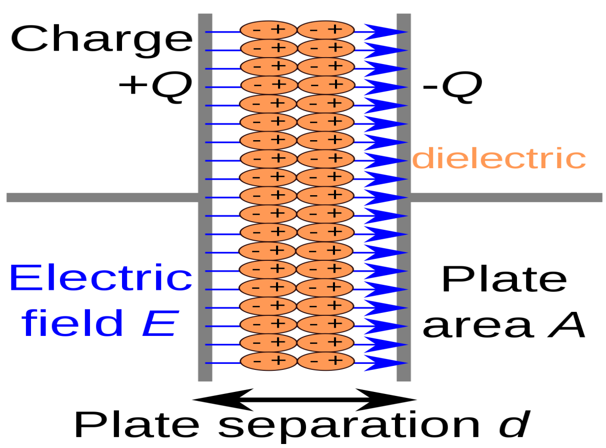
- Photo detector converts the optical signal to electrical signal.
- Signal restorers and amplifiers are used to improve signal to noise ratio of the signal as there are chances of noise to be introduced in the signal due to the use of photo detectors.

- For short distance
  Source: LED
  Fiber: Multimode step index fiber
  Detector: PIN detector

- For long distance Communication along with the main elements there is need for couplers, beam splitters, repeaters, optical amplifiers, attenuator
  Source: LASER diode
  Fiber: Single mode fiber
  Detector Avalanche photodiode (APD)

Dielectric

In electromagnetic, a dielectric (or dielectric medium) is an electrical insulator that can be polarized by an applied electric field.



A dielectric material is a poor conductor of electricity but an efficient supporter of electromagnetic fields. It can store electrical charges, have a high specific resistance and a negative temperature coefficient of resistance.

Advantage of optical fiber communication

Optical fiber has largely replaced copper wire communication in core networks in the developed world, because of its advantages over electrical transmission. Here are the main advantages of fiber optic transmission

1. Extremely High bandwidth

   No other cable - based data transmission medium offers the bandwidth that fiber does. The volume of data that fiber optic cables transmit per unit time is far greater than copper cables.

2. Longer distance

   In fiber optic transmission, optical cables are capable of providing low power loss, which enables signals to be transmitted to a longer distance than copper cables.

3. Resistance to Electromagnetic Interference

   In practical cable deployment, it's inevitable to meet environments like power substations, healting, ventilating and other industrial sources of interference. However, fiber has a very low rate of bit error (10 Exp -13), as a result of fiber to electromagnetic interface. Fiber optic transmission is virtually noise free.

4. Small Size

   Fiber optic cable has a very small diameter. For instance, the cable diameter of a single OM3 multimode fiber is about 2mm, which is smaller than that of coaxial cable. Small size saves more space in fiber optic transmission.

5. Light weight

   Optical fiber cables are made of glass or plastic, and they are thinner than copper cables. These make them lighter and easy to install.

6. Low Security Risk

   The growth of the fiber optic communication market is mainly driven by increasing awareness about data security concerns & use of the alternative raw material. Data or signals are transmitted via light in fiber optic transmission. Therefore there is no way to detect the data being transmitted by “listening in" to the electromagnetic energy "Leaning" through the cable, which ensures the absolute security of information

7. Easy to Accommodate increasing Bandwidth

With the use of fiber optic cable, new equipment can be added to existing cable information. Because optical cable can provide vastly expanded capacity over the originally laid cable. And WDM (wavelength division multiplexing) technology including CWDM, and DWDM, enables fiber cables more bandwidth.

Disadvantages of Optical fiber transmission

Though fiber optic transmission brings lots of convenience, its disadvantages also cannot be ignored.

1. Fragility

Usually, optical fiber cables are made of glass, which means they are more fragile than electrical wires. In addition, glass can be affected by various chemicals including hydrogen gas (a problem in underwater cables), making them need more care when deployed underground.

2. Difficult to install

It's not easy to splice fiber optic cable. And if you bend them too much, they will break. And fiber cable is highly susceptible to becoming cut or damaged during installation or construction activities. It is difficult to install.

3. Attenuation and Dispersion

As transmission distance is getting longer, light will be attenuated and dispersed, which requires extra optical components like EDFA to be added.

4. Cost is Higher than copper cable

Despite the fact that fiber optic installation costs are dropping by as much as 60% a year, installing fiber optic cabling is still relatively higher than copper cables. Because copper cable installation doesn't need extra cores like fiber cables. However, optical fiber is still moving into the local loop, and through technologies such as FTTx, (fiber to the home, premises, etc) and PONs (passive optical network), enabling subscriber and end user broadband access.

6. Special Equipment is often Required.

To ensure the quality of fiber optic transmission, some special equipment is needed. For example, equipment such as OTDR (optical time-domain reflectometry) is required and expensive, specialized optical test equipment such as optical probes and power meter are needed at most fiber end points to properly provide testing of optical fiber.

Applications of optical fiber communications:

Fiber optic cables find many uses in a wide variety of industries and applications. Some uses of fiber optic cables include:

1. Medical
   Uses as light guides, imaging tools and also a laser for surgeries.

2. Defense and government
   used as a hydrophone for seismic waves and SONAR, as wiring in aircraft, submarines and other vehicles and also for field networking.
3. Dota Storage
   used for data transmission
4. Telecommunications
   Fiber is laid and used for transmitting and receiving purposes
5. Networking:
   Used to connect users and servers in a variety of network settings and help increase the speed and accuracy of data transmission.
6. Industrial/Commercial:
   Used for imaging in hard to reach areas, as wiring where EMI is an issue, as sensory devices to make temperature, pressure and other measurements, and as wiring in automobiles and in industrial settings.
7. Broadcast/CATV
   Broadcast / cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video-on-demand and other applications.

Fiber optic cables are used for lighting and imaging and as sensors to measure and monitor a vast array of variables. Fiber optic cables are also used in research and development and testing across all the above mentioned industries.

Applications

1. Used in the telephone system
2. Used in Submarine cable networks
3. Used in data link for computer networks, CATV (community antenna) systems.
4. Used in CCTV Surveillance Cameras
5. Used for connecting fire police, and other emergency services.
6. Used in hospitals, schools, and traffic management systems.
7. They have many industrial uses and are also used in heavy duty constructions.

Electromagnetic spectrum

The radio waves and light are electromagnetic waves. The rate at which they alternate in polarity is called their frequency (f) measured in hertz (Hz). The speed of electromagnetic waves (c) in free space is approximately 3 x 10^{8} m/sec. The distance traveled during each cycle is called wavelength (λ). In fiber optics, it is more convenient to use the wavelength of light instead of the frequency with light frequencies, wavelength is often stated in microns or nanometers.

1 micrometer (μm) = 10^{-6} meter

1 nanometer (nm) = 10^{-9} meter

Fiber optics uses visible and infrared light. Infrared light covers a fairly wide range of wavelengths and is generally used for all fiber optic communications. Visible light is normally used for very short range transmission using a plastic fiber.

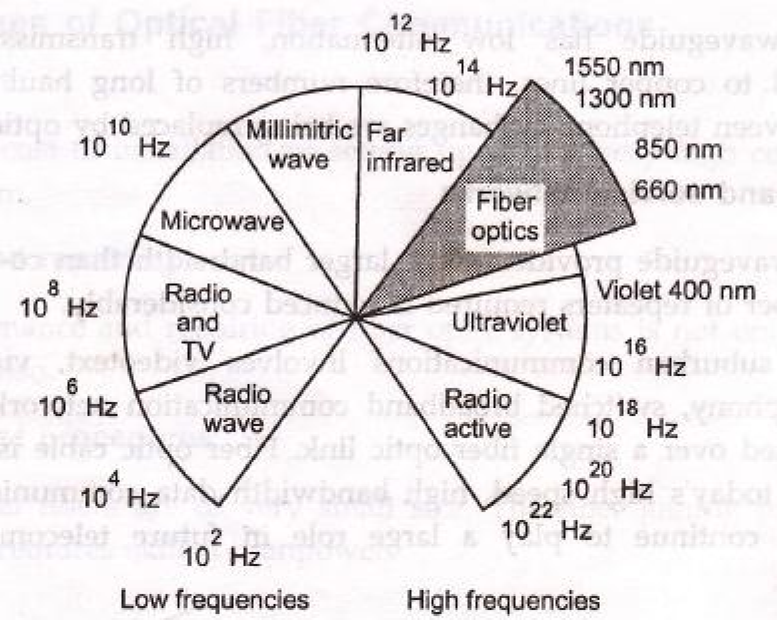


Fig. 1.6.1 Electromagnetic spectrum

Ray theory

The phenomenon of splitting of white light into its constituents is known as dispersion. The concepts of reflection and refraction of light are based on a theory known as Ray theory or geometric optics, where light waves are considered as waves and represented with simple geometric lines or rays.

The basic laws of ray theory geometric optics

- In a homogeneous medium, light rays are straight lines.
- Light may be absorbed or reflected
- Reflected ray lies in the place of incidence and angle of incidence will be equal to the angle of reflection.
- At the boundary between two media of different refractive indices, the refracted ray will lie in the plane of incidence. Snell's Law will give the relationship between the angles of incidence and refraction.

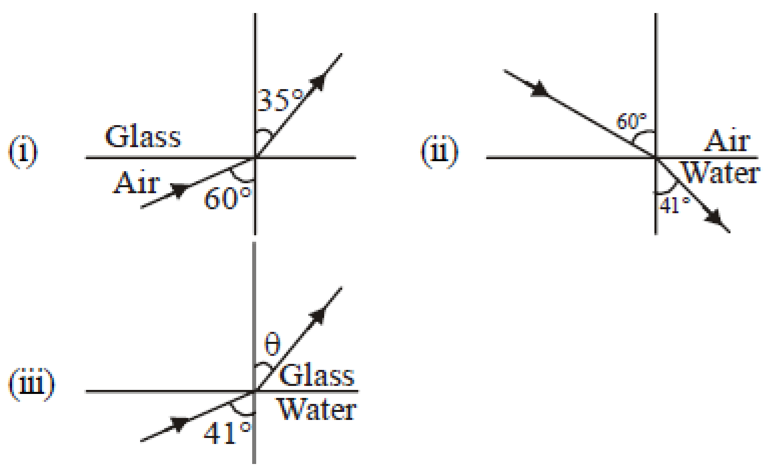
1. Refraction

Refraction is the bending of light in a particular medium due to the speed of light in that medium. The speed of light in any medium can be given as,

$v=c/n$

Refractive Index (η) = $\frac{\textit{Speed of light in air}}{\textit{speed of light in vacuum}} = \frac{c}{v}$

Examples:



Light passes lower to higher refractive index, incidence angle is larger than refracted angle.

Light passes higher to lower refractive index, incidence angle is smaller than refracted angle.

The refractive index for vacuum and air as 1.0 for water is 1.3 and for glass refractive index is 1.5. The refractive index of that medium. When a ray of light is incident at the interface of two media with different refractive indices, it will bend either towards or away from the normal depending on the refractive indices of the media.

Snell's law of Refraction

It states that the ratio of sines of angles of incidence and refraction is equivalent to the ratio of phase velocities in the two media or equivalent to the reciprocal of the ratio of the indices of refraction.

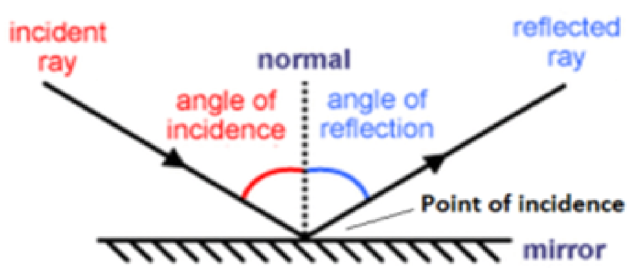
$$\frac{sin(i)}{sin(r)} = \frac{sin\theta1}{sin\theta2} = \frac{v1}{v2} = \frac{\lambda1}{\lambda2} = \frac{\mu2}{\mu1}$$

$$\text{or, } \mu1 sin\theta_I = \mu2 sin\theta_R$$

with each θ as the angle measured from the normal of the boundary. v as the velocity of light in the respective medium.

(2) Reflection

The reflection depends on the type of surface on which light is incident. An essential condition for reflection to occur with glossy surfaces is that the angle made by the incident Ray of light should be equal to the normal at the point of contact angle Normal of reflection with that normal.



Total internal reflection

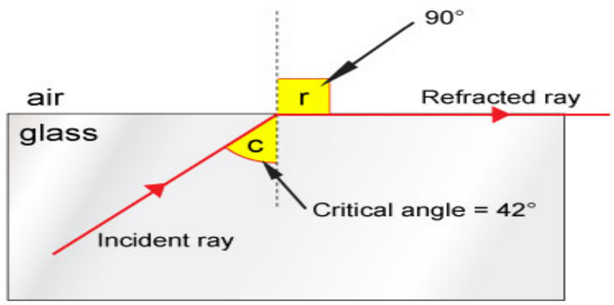
The complete reflection of a light ray reaching an interface with a less dense medium when the angle of incidence exceeds the critical angle.

case I: $\theta_i > \theta_c$ total internal reflection

Case II: $\theta_i < \theta_c$ refraction or partial reflection

Critical Angle

The incidence angle is called the critical angle if the refracted angle is 90°



Numerical Aperture and acceptance angle of Optical Fiber

Definition: Numerical Aperture is the measure of the ability of an optical fiber to collect or confine the incident light ray inside it. It is among the most basic properties of optical fiber.

Numerical aperture is abbreviated as **NA** and shows the efficiency with which light is collected inside the fiber in order to get propagated.

We know light through an optical fiber is propagated through **total internal reflection**. Or we can say multiple TIR takes place inside the optical fiber for the light ray to get transmitted from one end to another through an optical fiber.

Basically when the light is emitted from an optical source, then the fiber must be highly efficient so as to collect the maximal emitted radiation inside it.

Thus we can say that the light gathering efficiency of an optical fiber is the key characteristic while transmitting a signal through an optical fiber.

NA is related to **acceptance angle**. The acceptance angle is the max angle through which light enters the fiber. Hence the acceptance angle and numerical aperture are related to each other.

Propagation through Optical fiber

The light through an optical fiber is propagated by several continuous total internal reflections.

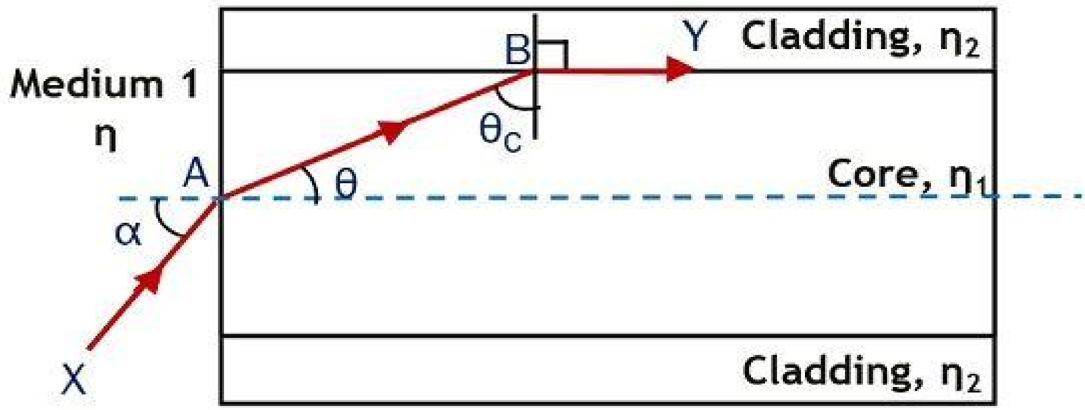
As we know that an optical fiber is composed of a core which is made up of a very pure form of glass silica and is surrounded by a glass cladding. So, the light is propagated inside the fiber by performing continuous reflections from the cladding.

But the condition of total internal reflection for the propagation of light rays comes into action only when most of the light is collected inside the fiber. So, let us now understand the numerical aperture for optical fiber in detail.

Derivation for Numerical Aperture of Optical Fiber

Consider a light ray XA, that incident inside the optical fiber. The refractive index of the core is η1 and that of cladding is η2.

The figure below shows an optical fiber inside which a light ray is focused.



Ray propagation through Optical Fiber

Circuit Globe

So, the ray XA is launched from denser medium to rarer medium by making an angle α with the fiber axis. This angle α is known as the acceptance angle of the fiber.

This incident ray propagates inside the fiber and gets reflected completely by the core-cladding interface.

But for this, the angle of the incident should be more as compared to the critical angle. Otherwise, if the incident angle is less than the critical angle then rather than being reflected, the ray gets refracted.

According to Snell's law, the incident and refracted ray propagate in the same plane. Hence, on applying Snell's law at medium 1 (usually air) and core interface. Then

$$\eta \sin\alpha = \eta_1 \sin\theta \qquad \text{--------------} \ \text{eq}^n\ 1$$

From the above figure, we can write

$$\theta = \frac{\pi}{2} - \theta_C \qquad \text{--------------- eq}^n \ 2$$

On putting the value of θ from the above equation in equation 1, we get,

$$\eta \sin\alpha = \eta_1 \sin\left(\frac{\pi}{2} - \theta_C\right)$$

$$\eta \sin\alpha = \eta_1 \cos\theta_C \qquad \text{(by trigonometric identity)}$$

$$\sin\alpha = \frac{\eta_1}{\eta} \cos\theta_C \qquad \text{--------------- eq}^n \ 3$$

Since we know

$$\cos\theta_C = \sqrt{1 - \sin^2\theta_c} \qquad \text{-------------- eq}^n \ 4$$

Applying Snell's law at core-cladding interface, we get

$$\eta_1 \sin\theta_C = \eta_2 \sin 90° \qquad \text{-------------- eq}^n \ 5$$

$$\eta_1 \sin\theta_C = \eta_2$$

$$\sin\theta_C = \frac{\eta_2}{\eta_1} \qquad \text{-------------- eq}^n \ 6$$

Substituting the above value in equation 4

$$\cos\theta_C = \sqrt{1 - \left[\frac{\eta_2}{\eta_1}\right]^2}$$

Substituting the above value in equation 3, we get

$$\sin\alpha = \frac{\eta_1}{\eta} \sqrt{1 - \left[\frac{\eta_2}{\eta_1}\right]^2}$$

$$\sin\alpha = \sqrt{\frac{\eta_1^2 - \eta_2^2}{\eta}} \qquad \text{-------------- eq}^n \ 7$$

As we have already discussed that medium 1 is air, thus refractive index i.e., η will be 1.

$$\sin\alpha = \sqrt{\eta_1^2 - \eta_2^2}$$

So more specifically we can say

$$NA = \sqrt{\eta_1^2 - \eta_2^2}$$

This is the expression for the numerical aperture of an optical fiber, having η_1 as the refractive index of core and η_2 as the refractive index of the cladding.

So we can conclude that as the numerical aperture shows the light collecting ability of the fiber thus its value must be high. The higher the value of NA, the better will be the optical fiber.

However, the greater value of NA will be achieved only when the difference between the two refractive indices is high and for this either, η_1 is to be high or η_2 to be low.

But no such material exists that has a lower refractive index than 1. So, an option stands that if we remove the cladding present over the core then greater NA can be achieved.

While, for optical signal propagation, the only motive is not to have a high accepting range but also to propagate the accepted signal with minimal attenuation.

This is so because an optical fiber that has the greatest light gathering efficiency but does not allow light propagation through it properly, is not of any use.

Thus several parameters must be taken into consideration, for selecting the appropriate optical fiber for signal propagation.

Types of optical fiber

On the basis of Material used

1. Glass fiber 2. Plastic fiber

On the basis Modes of transmission.

1. Single mode
2. Multi mode

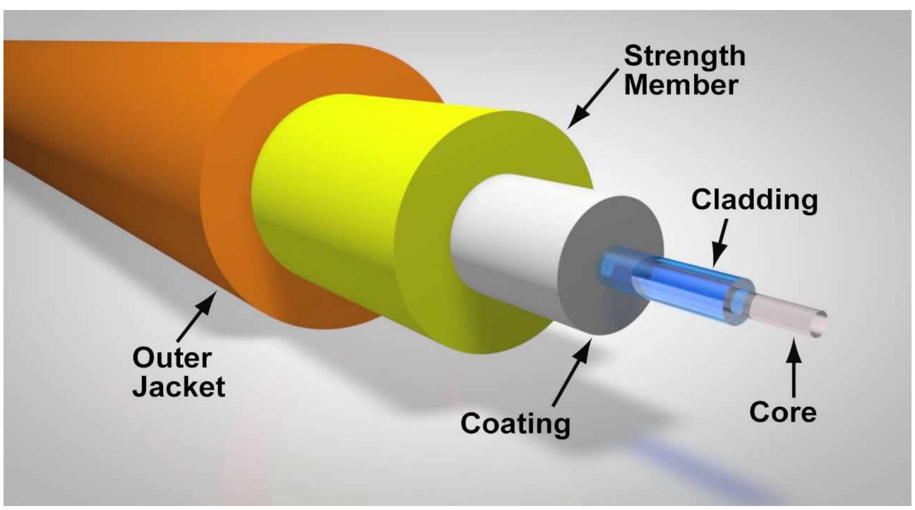
On the basis Refractive index profile

1. Step index
2. Graded index

1. Step Index Single mode
2. Step Index Multimode
3.Graded Index Multimode

Main Elements of optical fiber

An optical fiber is a cylindrical fiber of glass which is hair thin size or any transparent dielectric medium. The fiber which is used for optical communication is waveguides, made of transparent dielectrics.



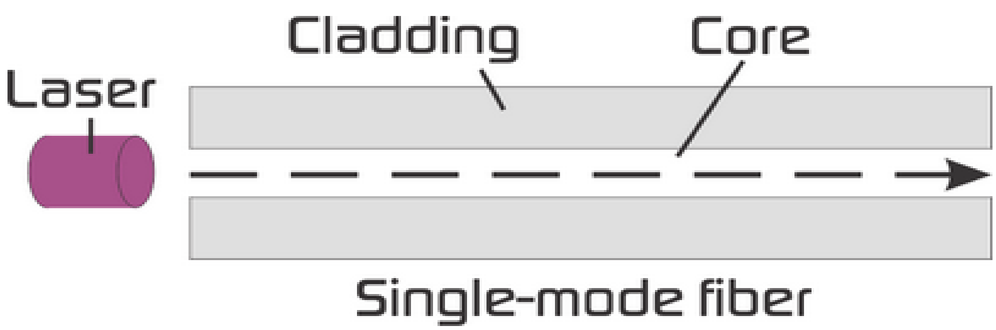
1. Core:
   It is the central tube of very thin size made of optically transparent dielectric medium and carries the light transmitter to receiver and the core diameter may vary from about 5μm to 100 μm.

2. Cladding:
   It is outer optical material surrounding the core having a reflecting index lower than core and cladding helps to keep the light within the core throughout the phenomena of total internal reflection.
3. Buffer coating
   It is a plastic coating that protects the fiber made of silicon rubber. The typical diameter of the fiber after the coating is 250 - 300 µm.

Types of optical fiber

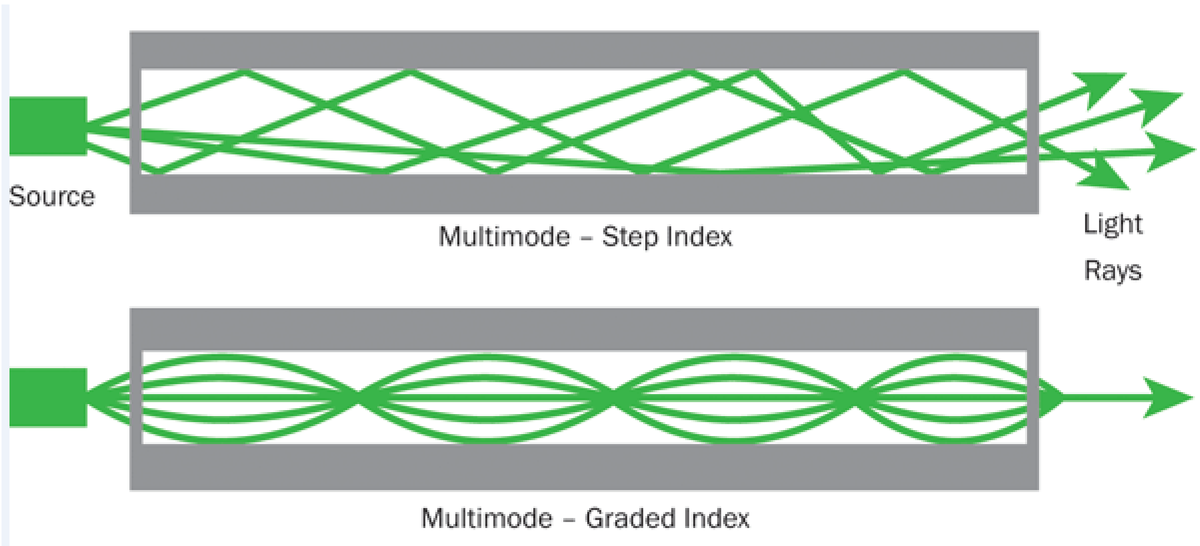
1. Single-mode fiber

- 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 9µm and high cladding diameter i.e. 125 µm
- 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 aLASER diode.
- Higher bandwidth
- long distance communication Fiber Cladding



2. Multimode fiber

- Multimode fiber allows a large number of modes for the light ray traveling through it
- the care diameter is generally 50/62.5 µm and cladding is 125 µm
- 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 large dispersion and attenuation of the signal.
- Multimode types are step index and Graded index (on the basis of refractive index)
- High dispersion
- Lower bandwidth
- Core diameter is higher
- Fabrication is less difficult and not costly.



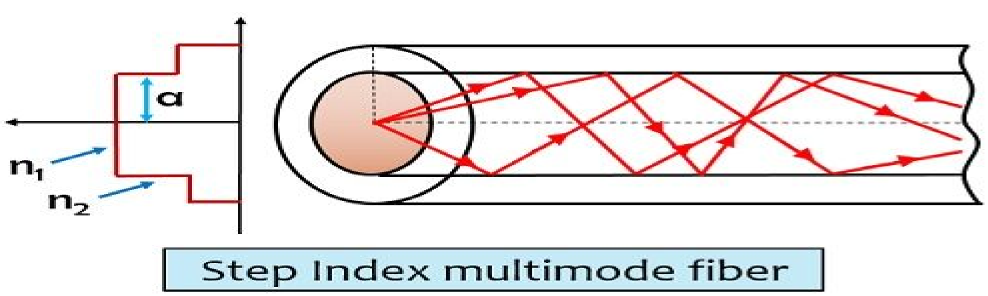
On the basis of refractive index

(a) Step Index optical fiber

The refractive index of the core is constant.

The refractive index of cladding is also constant

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.



$$\mu cladding < \mu core$$

I.e. Mathematically, refractive index of step index fiber is

$\mu(r)$ = {$\mu1$ for r < a core

{$\mu2$ for r ≥ a cladding

Where, a = core radius

r = radial distance (relation between fiber length and cross sectional area of core)

i. step index single mode

ii. Step - index multimode

It is to be noted in case of the step index fiber that the variation in index is given as,

$$\Delta = \frac{\mu1^2 - \mu2^2}{2\mu1^2} \sim \frac{\mu1 - \mu2}{\mu}$$

Advantages of step Index

1. The manufacturing of these fibers is quite easy.
2. It is inexpensive.
3. The propagation takes place through total internal reflection.

Disadvantages of step index

1. In their fibers, as only one light ray propagates through the fiber at a time then it somewhat leads to drawback in terms of its Capacity to carry information signal.
2. Also due to the small diameter of the core, coupling the light inside it is somewhat difficult.

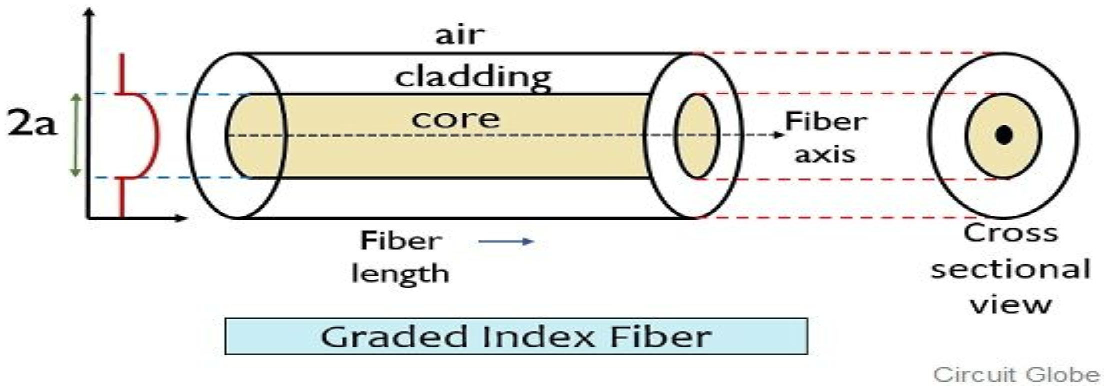
(b) Graded Index optical fiber

Graded Index fiber is another type of optical fiber in which the refractive index of the core is non-uniform.

This non-uniformity is present because the refractive index is higher at the axis of the core and continuously reduces with radial movement away from the axis.

However, the refractive index of the cladding is constant in the case of graded index fiber. Hence, the nature of the refractive index of the core is somewhat parabolic.

Unlike graded index fiber has a constant refractive Index at the core as well as cladding



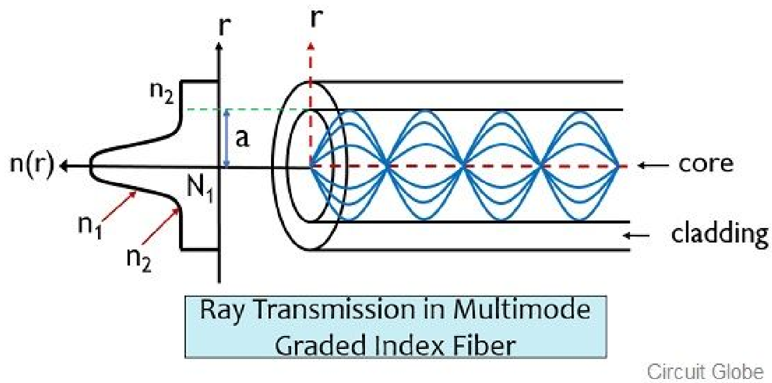
In this type of fiber, the light ray experiences refraction and thus gets bent towards the core. Thereby allowing propagation of rays in a Curved path.

The refractive index of graded index fiber in mathematical form it expressed as: the

$n(r) = \{ n_1[1 - 2\Delta(\frac{r}{a})^{\alpha}]^{1/2}$ for $0 \leq r \leq a$

$\{n_1[1-2\Delta]^{1/2} \sim n_1 (1-\Delta) = n2$ for $r \geq a$

a = radius of the core
r = radial distance from the core axis
α = shows the characteristics of the refractive index profile
μ1 and μ2 = refractive index of core and cladding.



Difference between Single mode and multimode fiber

Single mode	Multimode
1. Core radius is small 2. Supports one mode of propagation 3. Optical source : LASER	1. Core radius is large 2. Supports hundreds of modes 3. Optical source : LED

4. Launching optical power into fiber is difficult as the core radius is small.	4. The launching of optical fiber power into fiber is easier as the core radius is large
5. application : submarine cable system	5. Telephone links mobile baseband processing unit to RF radio unit connection
6. Cheaper	6. Costly
7. High bandwidth	7. Limited bandwidth
8. Do Not exhibit dispersion	8. Limited by modal dispersion
9. High cost connector	9. low cost connector

Difference between step index and graded index optical fiber

Step index optical fiber	graded index optical fiber
1. The refractive index of the core is uniform throughout and undergoes an abrupt change at the core cladding boundary.	1. The refractive index of the Core is made to vary gradually such that It is maximum at the center of the core.
2. Diameter of the core is about 50-200 μm in the case of multimode fiber and 10 μm in case of single mode fiber.	2. Diameter of the core is about 50 micrometers in the case of multimode fiber.
3. Path of light propagation is Zig-zag in manner.	3. Path of light is helical in manner
4. Attenuation is more for multimode step index fiber but for single mode it is very less.	4. Attenuation is less.
5. no. of modes = $\frac{v^2}{2}$	5. No. of modes = $\frac{v^2}{4}$
6. used for imaging and illumination.	6. Used for data communication and networks over moderate distance.
7. Modal dispersion is found.	7. Solves the problem of modal dispersion.

Mode propagation in SI and GI multimode

Mode is the one which describes the nature of propagation of EM waves, in a waveguide. Such mode fibers can propagate only the fundamental mode and multimode fibers can propagate hundreds of modes.

Propagation equation, $\Delta E = \mu_0 \epsilon_0 \mu^2 \frac{d^2E}{dt^2}$

where , $\frac{d^2E}{dt^2}$ = second derivative of electric field with respect to time

An index value value V, defined as the normalized frequency is used to determine how many different guided modes a fiber can support. In order to find a mode propagation constant and cut off frequencies of various modes of the optical, fiber, V-number is most important is given us

(modes supports using V - number)

$$V = \frac{2\pi a}{\lambda}\sqrt{\mu_1^2 - \mu_2^2} = \frac{2\pi a}{\lambda} NA$$

Where, a = radius of core

λ = optical free space wavelength

$\mu1$ *and* $\mu2$ = refractive indices of the core and cladding

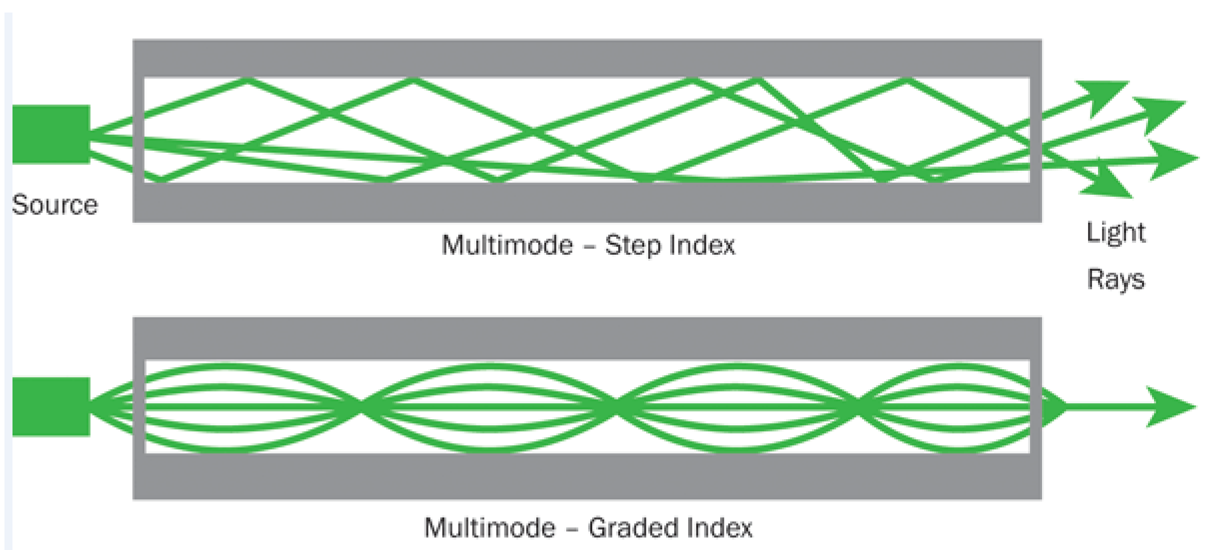


Figure : Different mode (in above figure multimode - step index 4 modes and multimode - graded index 5 modes)

Index profile of Optical Fiber

The radial distribution of the fiber refractive index is called the index profile.
In the case of slab waveguide the transverse refractive index is called the index profile. The index profile determines guiding properties of the fiber or Slab waveguide. In general the core region has a higher index than the cladding region. However, the index profile I can have regions where the index is lower than the cladding value.

Modern fiber or slab waveguide designs are based on index profile meer profile that assure proper operation within a range of wavelengths.

Constant index profile, n(X) = constant
Linear index profile, n(x) = [n(0) + (xn(w) - n(0)]/w
Parabolic index profile,
n(x) = [n(w) - n(0)](x/w)^2 + n(0)
where, n(0) and n(w) is the refractive index at x=0 and x=w

Attenuation, Dispersion, Bead loss in optical fiber

Attenuation is defined as the ratio of optical input power to the optical output power in the fiber of length L.

I.e. $\alpha = \frac{10}{L}\log(\frac{Pi}{Po})$ dB/km

Po = output power
Pi = input power
α = attenuation constant
Also we can use Pout/Pin where the losses indicate negative signs only.

Attenuation means loss of light energy as the light pulse travels from one end of the cable to the other. Also known as signal or power to loss. It decides the number of repeaters required between transmitter and receiver. Attenuation is directly proportional to the length of the cable. Attenuation in optical fiber takes place due to elements like couplers, splices, connector and fiber itself. Modern fiber material is very pure, but there is still some attenuation.

Bending losses : Radiative loss

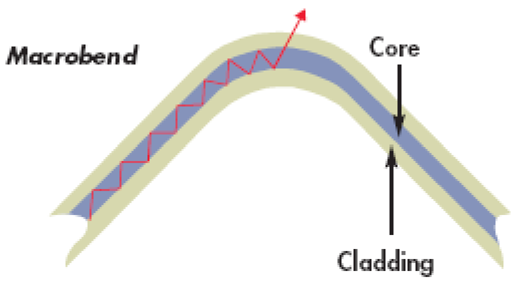
The loss which exists when an optical fiber undergoes bending is called bending losses. There are two types of bending:

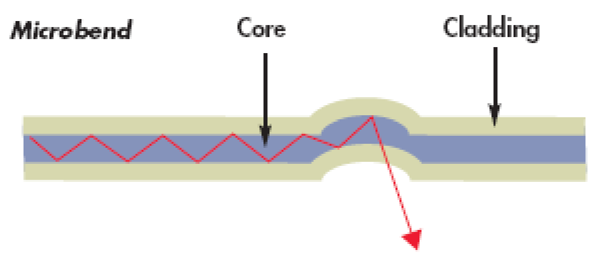
1. Macroscopic bending

Bending in which complete fiber undergoes bends. which causes certain modes not to be reflected and hence, causes loss to the cladding.

2. Microscopic Bending

Either the core or cladding undergoes slight bends of its surfaces.It causes light to be reflected at angles when there is no further reflection.





Dispersion

As a pulse travels down a fiber, dispersion causes pulse spreading. This limits the distance and the bit rate of data on an optical fiber. As an optical signal travels along the fiber, it becomes distorted. This distortion is a sequence of intermodal and intramodal dispersion.

1. Intermodal dispersion

Pulse broadening due to intermodal dispersion results from the propagation delay difference between modes within a multimode fiber.

2. Intramodal dispersion / chromatic dispersion

It is the pulse spreading that occurs within a single mode.

Material dispersion
Waveguide

a. Material dispersion

wavelength based effect caused by glass of which fiber is made

b. Waveguide dispersion

Occur due to change in speed of wave propagation through waveguide.

Optical Fiber Ground Wire

OPGW is overhead grounding wire to effect grounding of overhead transmission lines in which optical fibers are generated to provide Communication systems functions. OPGW enables long distance, high quality data transmission video transmission, without being affected by electromagnetic fields in any way, so that it is utilized as a transmission line, for remote or unattended power plants and substations in addition to communication between power plants.

OPGW is intended for the transmission of Communication. An OPGW is composed of a different number of fibers, one is intended for a multiplexer, two pairs for relay and possibly one for its own LAN.

Properties

1. It can be designed to achieve the desired tensile strength and sag characteristics.
2. It can also be used for conducting fault currents and lightning current without damage.

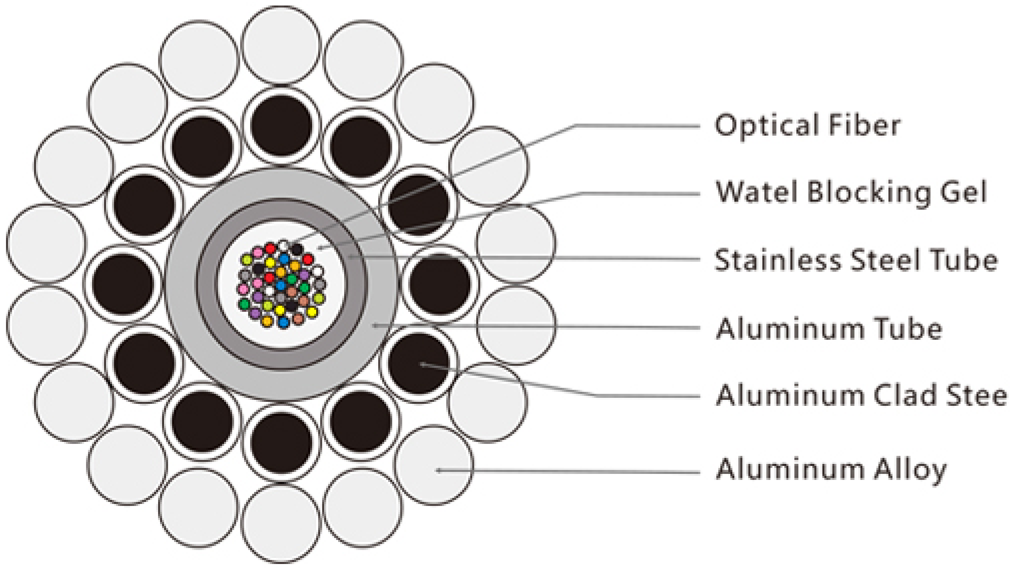
The cable is designed to be installed on transmission distribution lines to carry data, voice and communication especially in the lighting waveform monitoring system, maintenance data information system, power line protection system, power line operation system.

1. High load, long span capability.
2. Unique design has maximum allowable tension to control fiber strain.
3. Compact design results in excellent sag tension performance of the cable.

Construction

1. Central loose tube type

   The fiber is placed loosely in a sealed and water resistant Stainless steel tube filled with water blocking gel. This tube provides protection to the fiber during installation and operation under severe environmental conditions. Aluminum layer over the tube is optional. The stainless optical tube is located at the center of the cable protected by single or multiple layers of aluminum Clad steel and aluminum alloy wires. Thin types of constructions can accommodate up to 48 fibers in a cable. Despite such a high fiber count in a single tube, each optical fiber is clearly distinguishable utilizing a fiber identification system consisting of coloring and the number of ring marks on it. This compact design features high mechanical strength and fault current rating within a smaller diameter. The smaller diameter also results in excellent sag tension performance.



2. Multi loose tube type

   The fiber is placed loosely in a sealed and water resistant stainless steel tube filled with water blocking gel. Two or three stainless optical tubes are helically stranded in the inner layer of a multiple layer cable.

   The multi loose tube is designed mostly for very high fiber count requirements over 48 with the maximum fiber count 144. The multi loose tube type can meet the requirement of Huge cross and large current Capacity.

   OPGW cable combines the function of grounding and Communications.

   (1) The conductive cable links the tower to the earth ground, shielding the conductors from lightning

   (2) The optical fibers within the cable provide a telecommunication path for internal as well as third party communication.

   Typically OPGW contains single mode optical fibers with low transmission ·losses allowing long distance transmission at high speeds. The outer appearance of OPGW is similar to aluminum conductor steel reinforced cable (ACSR) usually used for shield wires.

OPGW as a communication medium has some advantages over buried optical fiber cable. Installation cost per km is lower than a buried cable (underground cable). Effectively, the optical Circuits are protected from accidental contact by the high voltage cables below. (and by the elevation of He off from ground)

Applications

1. OPGW is a dual functioning cable performing the duties of a ground wire and also providing a patch for the transmission of voice, video or data signals The fibers are protected from environmental conditions like lightning, short circuit loading to ensure reliability and longevity, which is used in overhead power lines.

Numericals

1. The refractive index for core and cladding for a step index fiber are 1.52 and 1.41 respectively. Calculate (1) critical angle (2) Numerical aperture (3) Maximum incidence angle

Solution

$\mu 1 = \mu$core = 1.52

$\mu 2 = \mu$cladding = 1.41

(1) critical angle (θc) = $\sin^{-1}(\frac{\mu 2}{\mu 1})$

$\theta c = \sin^{-1}(\frac{1.41}{1.52})$

θc = 68.068 degree

(2) Numerical Aperture (NA) = $\sqrt{(\mu_1^2 - \mu_2^2)}$

$= \sqrt{(1.52)^2 - (1.51)^2}$

= 0.568

(3) Maximum incidence angle (θo) = $\sin^{-1}\sqrt{\mu_1^2 - \mu_2^2}$

$= \sin^{-1}(NA)$

= 34.6 degree

2. An optical fiber has a refractive index of core and cladding 1.514 and 1.48 respectively. Calculate the acceptance angle and fractional index change.

Solution

$\mu 1 = \mu$core = 1.514

$\mu 2 = \mu$cladding = 1.48

$\phi_{in}(max)$ = ?

$\Delta = ?$

We have,

Acceptance angle = $\sin^{-1}\sqrt{\mu_1^2 - \mu_2^2}$

$= \sin^{-1}\sqrt{1.514^2 - 1.482^2}$

$= \sin^{-1}(0.316)$

= 18 degree

$\Delta = \frac{\mu 1^2 - \mu 2^2}{2\,\mu 1^2}$

$= \frac{1.514 * 1.514 - 1.48 * 1.48}{2 * 1.514 * 1.514}$

= 0.02220

3. For an optical fiber of length 150m has input power of 10 microwatt and output power of 9 microwatt. Compute loss in db/km.

   Solution

   Pin = 10 microwatt
   Pout = 9 microwatt
   Length (l) = 150m = 0.15 km
   Loss (db/km) = ?

   We have,

   Loss (dB/km) = $\frac{10}{L} \log_{10}(\frac{Pout}{Pin})$

   $= \frac{10}{0.15} * \log(9/10)$

   = -3.0484 db/km

Therefore, the loss in decibels per kilometer for the given optical fiber is approximately 3.0484 dB/km.