FIBRE OPTICS

Communication :

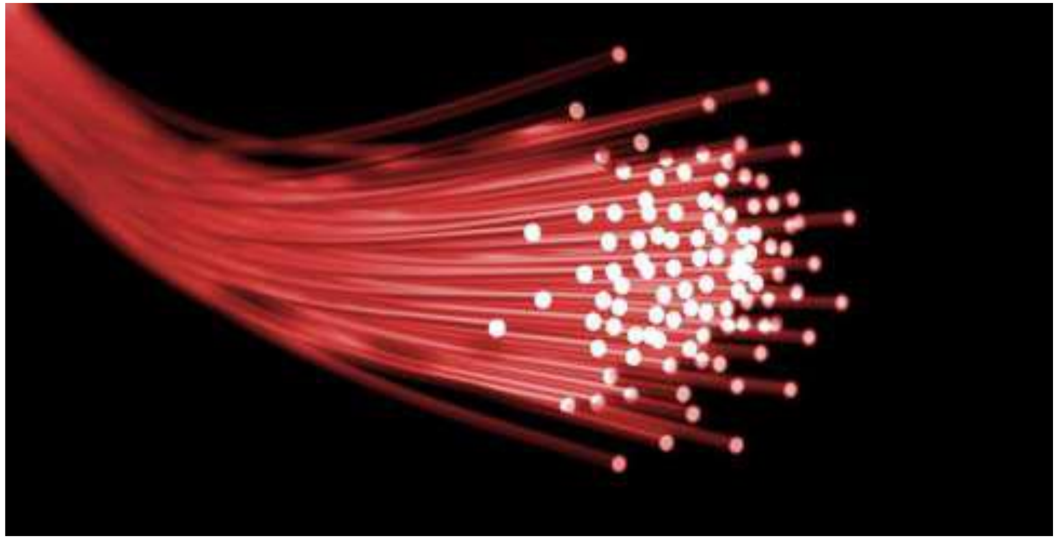
- The English word “communication” is derived from the Greek word *Comminicare* which means exchange of information.
- For as long as humans have been on this planet, we’ve invented forms of communication—from Cave Paintings, Symbols, Smoke Signals, Carrier Pigeon, Postal System, Newspapers, Radio, Telegraph, Telephone, Television, Internet, E-mail, TextMessage, Social Media like Facebook, Messenger, WhatsUp, Twitter, Instagram and Telegram etc., that have constantly evolved how we interact with each other.
- Technology has indeed redefined communication. People no longer have to wait for years, months, weeks, and days to receive information or message. Today, texts, e-mails, tweets, and personal messages can reach the recipient in just a matter of seconds. *i.e.* ,***we communicate in a fingersnap.***

Now, we can send information in forms : 1)Audio, 2) Video, 3) Data

- Now, optical fibers became one of the greatest communication media in the world.
- Everywhere on this planet optical fibers carry vast quantities of information from place to place.

What is Fiber Optics ?

Fiber optics is a branch of optics which deals with the study of propagation of information in the form of light (rays or modes) through transparent dielectric optical fibers.



Optical fiber

Optical fiber is a thin and transparent guiding dielectric medium or material that guides or transmits the information as light waves, using the principle of total internal refection.

Optical fiber

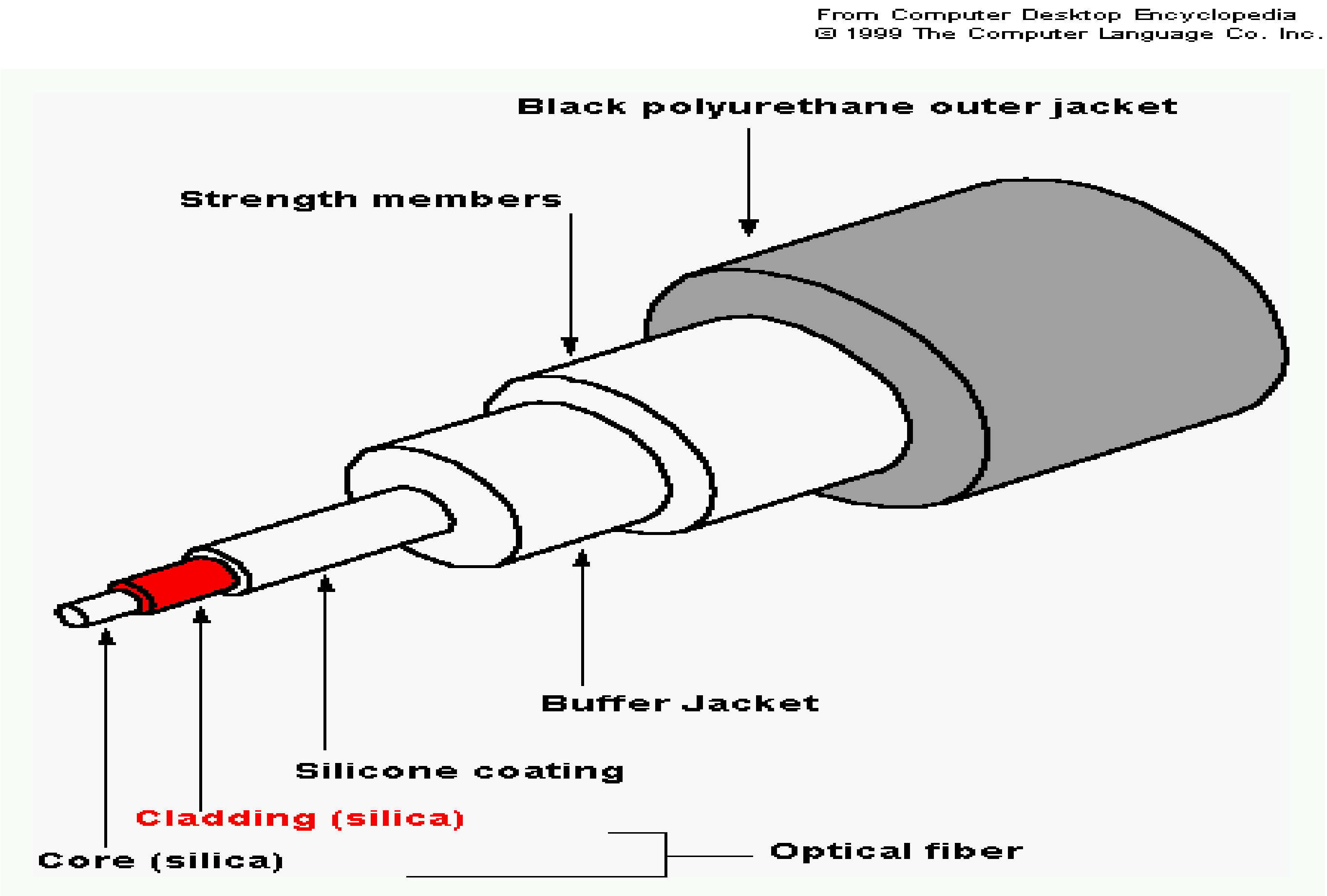
Optical fiber is a thin and transparent guiding dielectric medium or material that guides or transmits information as light waves, using the principle of total internal reflection.

Optical fiber cable

A bundle of optical fibers consists of thousands of individual fiber wires as thin as human hair, measuring 0.004mm in diameter is known as optical fiber cable.

Optical fiber structure and construction:

A typical structure of optical fiber as shown in figure.



Optical Fiber dimensions:

Core diameter : 5µm to 600µm.

Cladding diameter : 125µm to 750µm

Protective layer : 250µm to 1500µm.

Numerical aperture : 0.1 to 0.5.

Acceptance angle : 200t0 500.

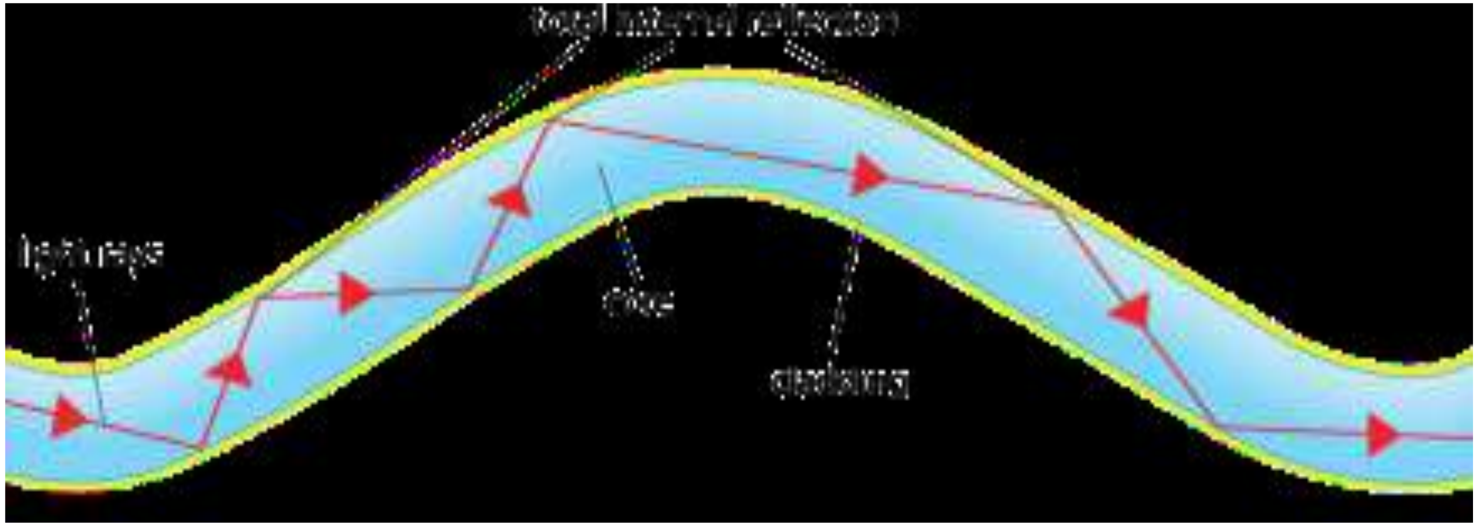
Band width : 50MHZ.

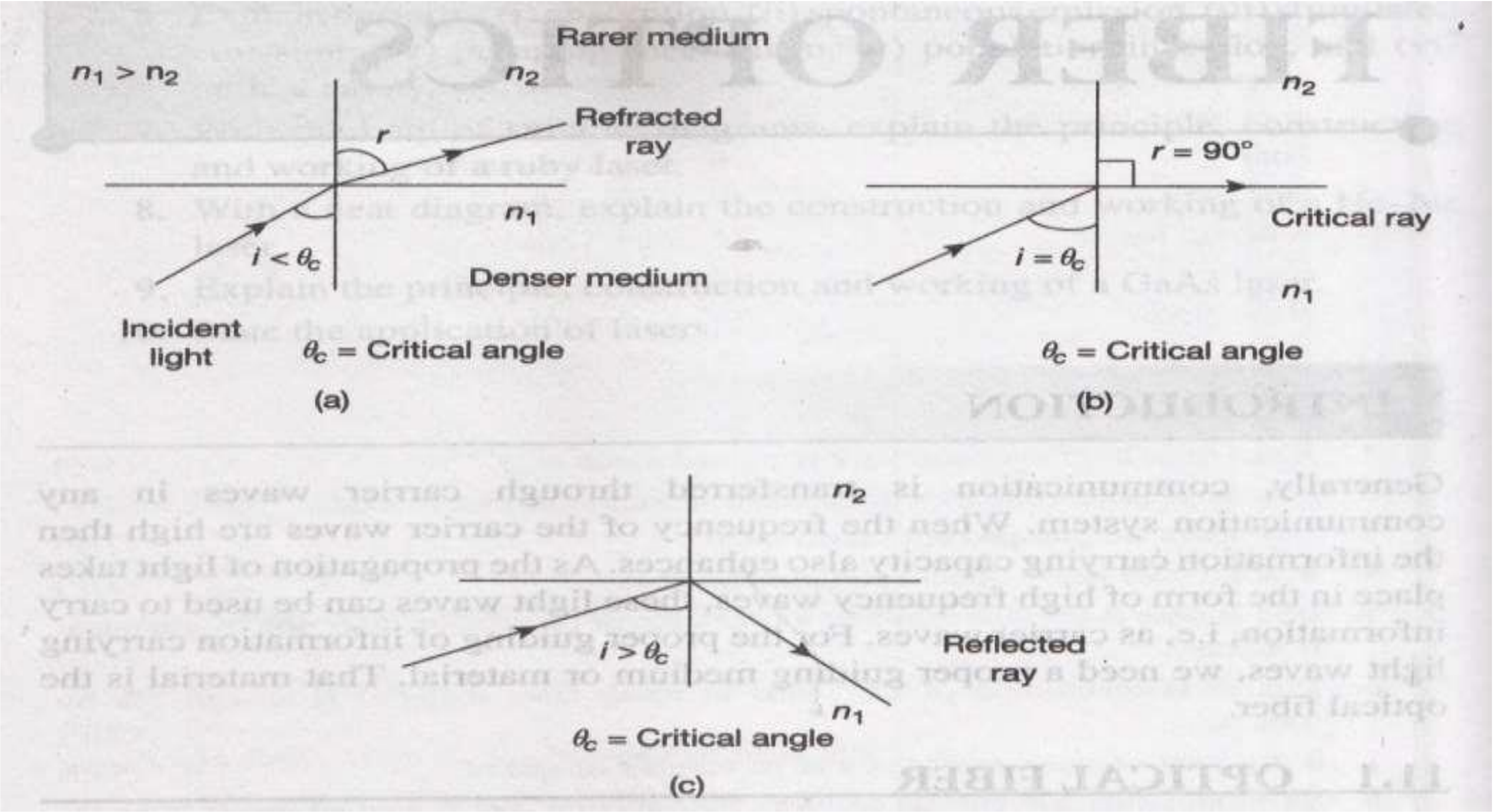
Principle of optical fiber:

- ❖ An optical fiber works on the principle of total internal reflection.
- ❖ John Tyndall observed that the propagation of light through the optical fiber will be in the form of multiple total internal reflections.

Definition:

When a light ray travels from denser medium to rarer medium and angle of incidence is greater than the critical angle, then the light ray reflects totally, this phenomenon is known as total internal reflection.

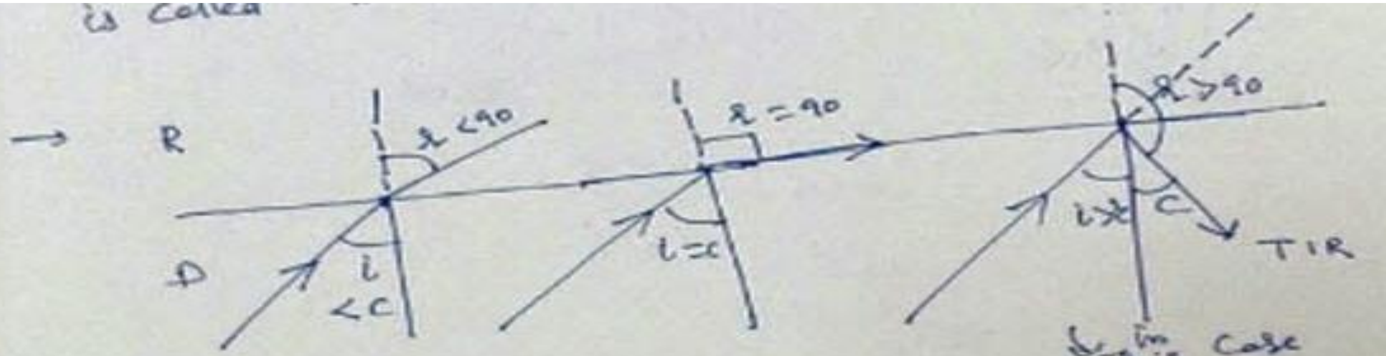




Principle of Optical Fibre

Derivation of Critical Angle

is called



In this case angle of deviation is $\pi - 2c$

→ In the case of critical angle

$${}_d\mu_r = \frac{\sin i}{\sin r}$$

$${}_d\mu_r = \frac{\sin c}{\sin 90}$$

$${}_d\mu_r = \sin c$$

$$\Rightarrow {}_r\mu_d = \frac{1}{\sin c}$$

in general it is referred as $\mu = \frac{1}{\sin c}$

→ where μ is refractive index of denser medium w.r.t rarer medium.

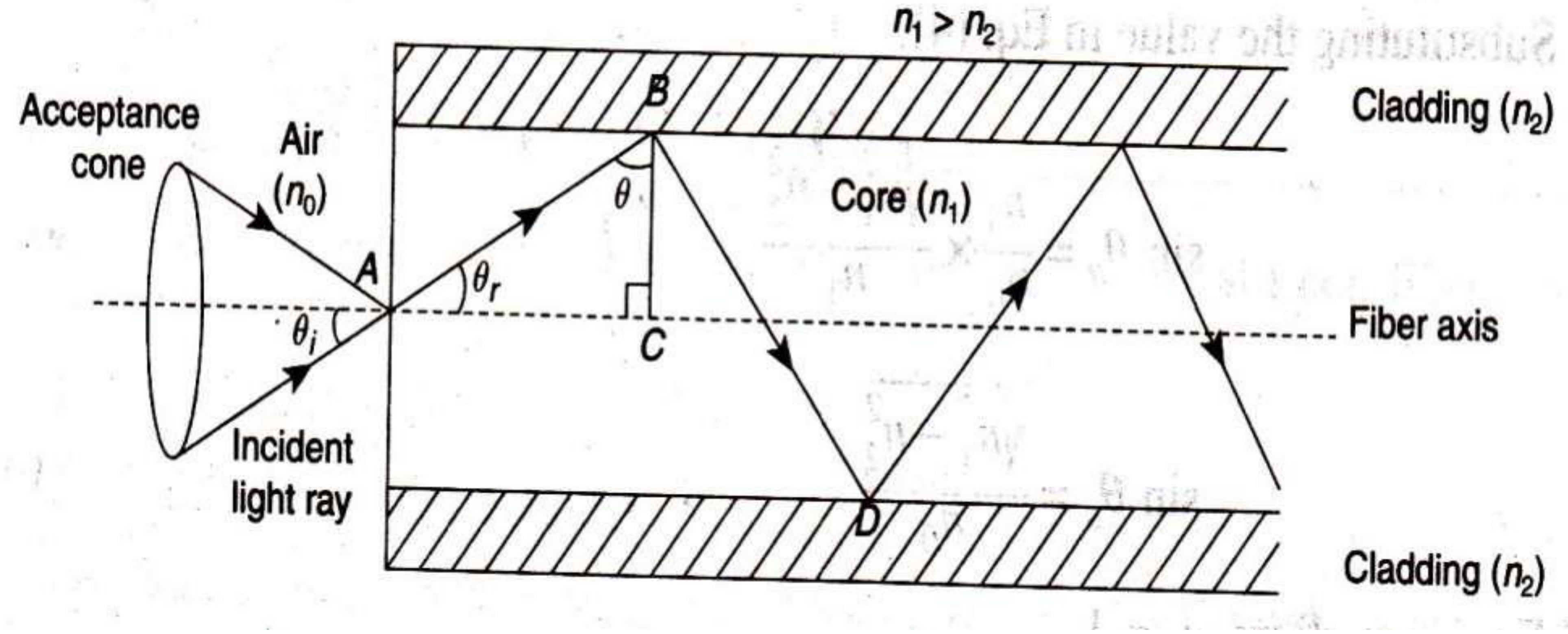
→ $\sin c = \frac{1}{{}_r\mu_d} = {}_d\mu_r = \frac{\mu_r}{\mu_d}$ $\Rightarrow c = \sin^{-1}\left(\frac{\mu_r}{\mu_d}\right)$

Conditions for total internal reflection:

1. The light ray should move from denser to a rarer medium.
2. When $i < \Theta c$, then the light ray refracts into a rarer medium.
3. When $I = \Theta c$, then the refracted light ray passes along the interface of the two media.
4. When $i > \Theta c$, then the light ray is reflected back into the denser medium and we get total internal reflection.

Acceptance angle and acceptance cone:

The maximum angle at which the light can suffers total internal refection is called as acceptance angle.
The acceptance cone is derived by rotating the Acceptance Angle about the fiber axis.



Numerical aperture (N.A):

- Numerical aperture represents the light-gathering power of an optical fiber. It is a measure of the amount of light that can be accepted by a fiber.
- The value of NA ranges from 0.13 to 0.50.
- Numerical aperture is proportional to the acceptance angle. So, numerical aperture is equal to the sine of the acceptance angle.

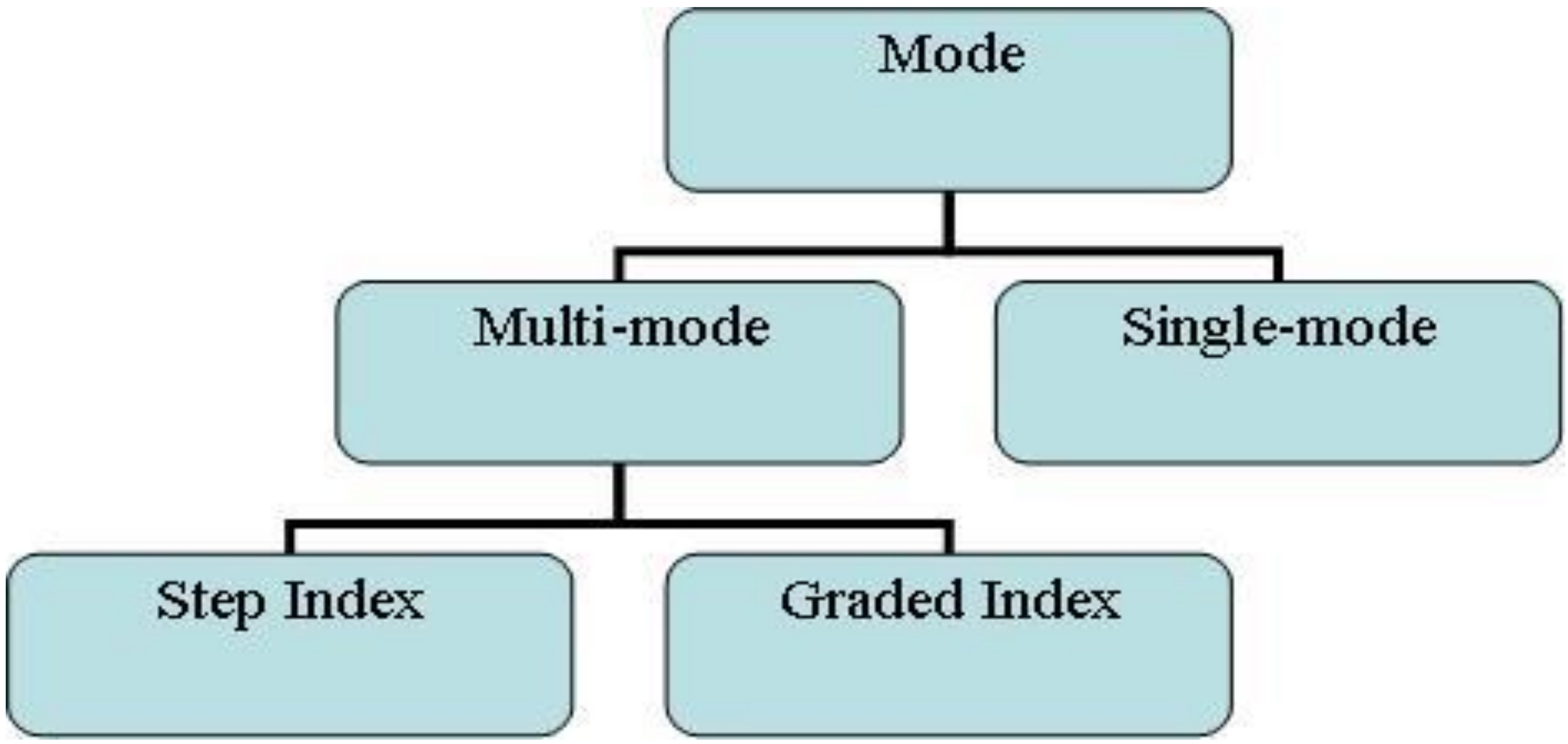
Types of optical fibers:

Optical fibers are classified into 2 major categories based on

1.Number of modes transmitted into the optical fibers and

2.Refractive index profile of the fibers.

According to the mode of propagation, optical fiber is classified into two: single-mode and multi-mode optical fibers

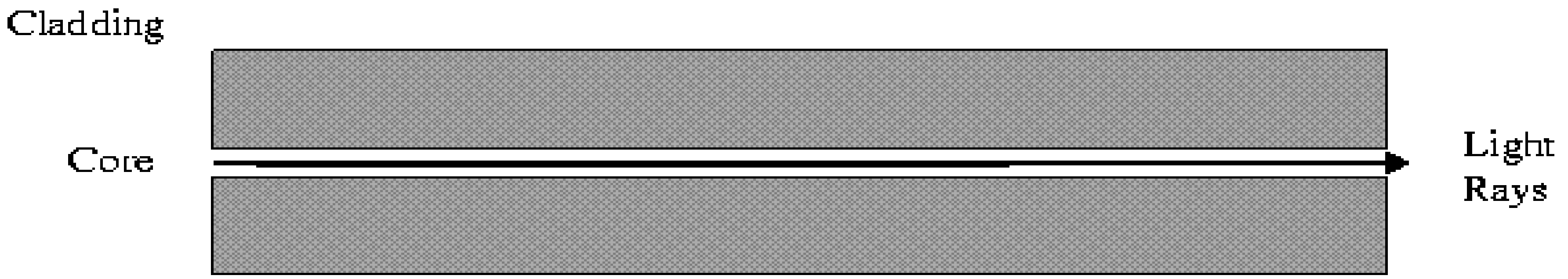


Single mode optical fibers:

- If the optical fiber which allows one mode of light propagation, then it is known as single-mode optical fiber. Because it has very small core diameter so that it can allow only one mode of light propagation as shown figure.
- In general single mode optical fibers are step index optical fibers.
- They are made from doped silica with mixtures of metal oxides.
- The ray travels along the **axis of** the fiber

Single mode Optical Fiber dimensions:

Core diameter : 5µm to 10µm.
Cladding diameter : around 125µm.
Protective layer : 250µm to 1000µm.
Numerical aperture : 0.08 to 0.10.
Acceptance angle : 200t0 300.
Band width : more than 50MHz.



Multi mode optical fibers:

- The core diameter is very large compared to single mode fibers, so that it can allow many modes of light propagation and hence, it is called multi-mode optical fiber as shown in fig.
- The multi mode optical fibers are useful manufacturing both for step index and graded index optical fibers.
- They are made by multi-component glass compounds such as Glass-clad silica, Silica-clad silica, doped silica etc.,

Multi mode Optical Fiber dimensions:

Core diameter : 50µm to 350µm.
Cladding diameter : 125µm to 500µm.
Protective layer : 250µm to 1100µm.
Numerical aperture : 0.12 to 0.5.
Acceptance angle : 200t0 300.
Band width : Less than 50MHz.

Step index optical fibers and graded index optical fibers:

Based on the variation in the refractive index of the core and the cladding, the fibers are classified into two types. They are.

1) **Step index optical fibers** (multimode, single mode)**and**
2) **Graded index optical fibers**(multimode)**.**

Step index optical fibers:

•In the step index fiber, the refractive index of the core is uniform throughout and undergoes an abrupt or step change at the core-cladding boundary.

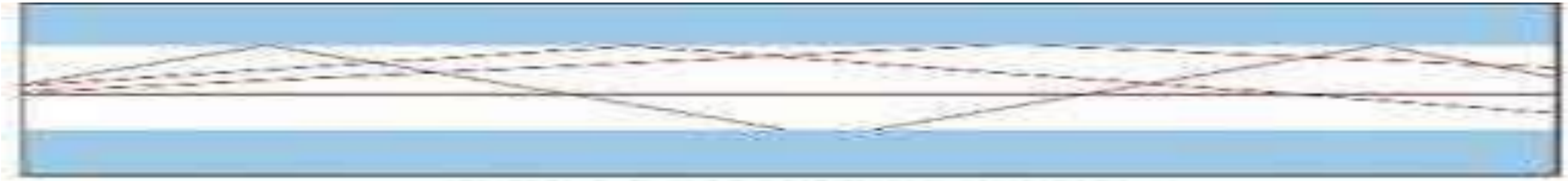
•The refractive indices of air, core and cladding varies step by step with increase radial distance from the axis of the fiber and hence, it is known as step index optical fiber as shown in fig.

•The path of light propagation is in zigzag manner.

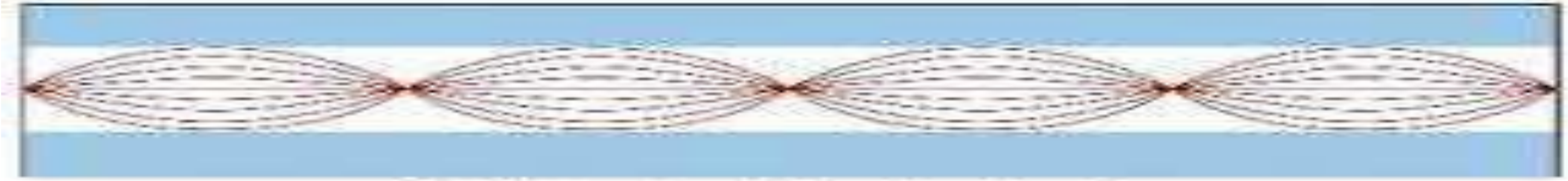
•Step index fiber can be single mode step index fiber or multimode step index fiber.

•The single mode step index fiber has low intermodal dispersion compared to multimode step index fiber.

•It is used widely as data link cables.



Multimode, Step-Index



Multimode, Graded Index

Applications:

Because of its less band width, they are used in short haul communication systems (data and audio/video applications in LANs)

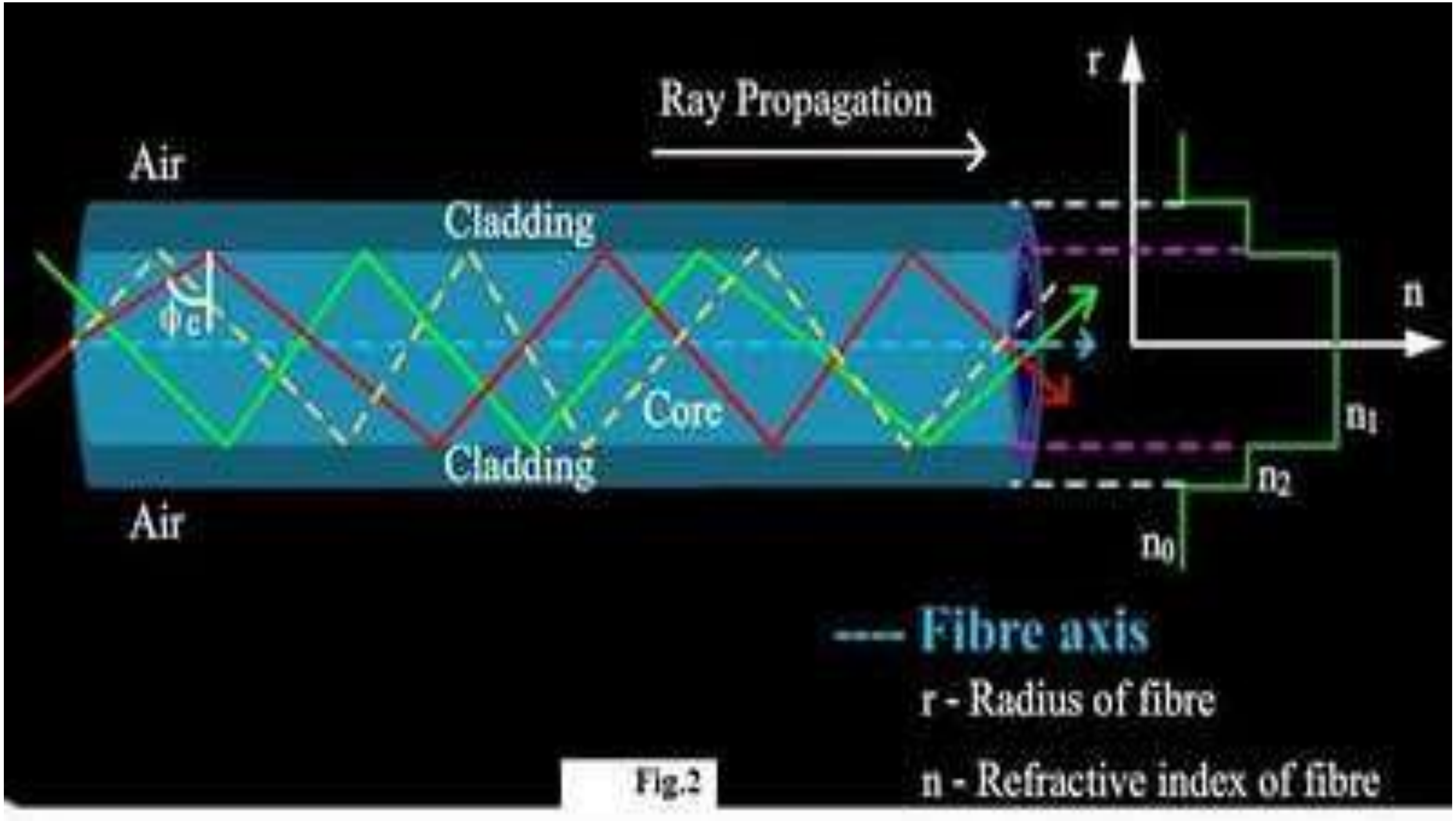
A **local area network (LAN)**is a computer networkthat interconnects computers in a limited area such as a home, school, computer laboratory, or office building using network media**Advantages:**

•**Launching of light is easy.**

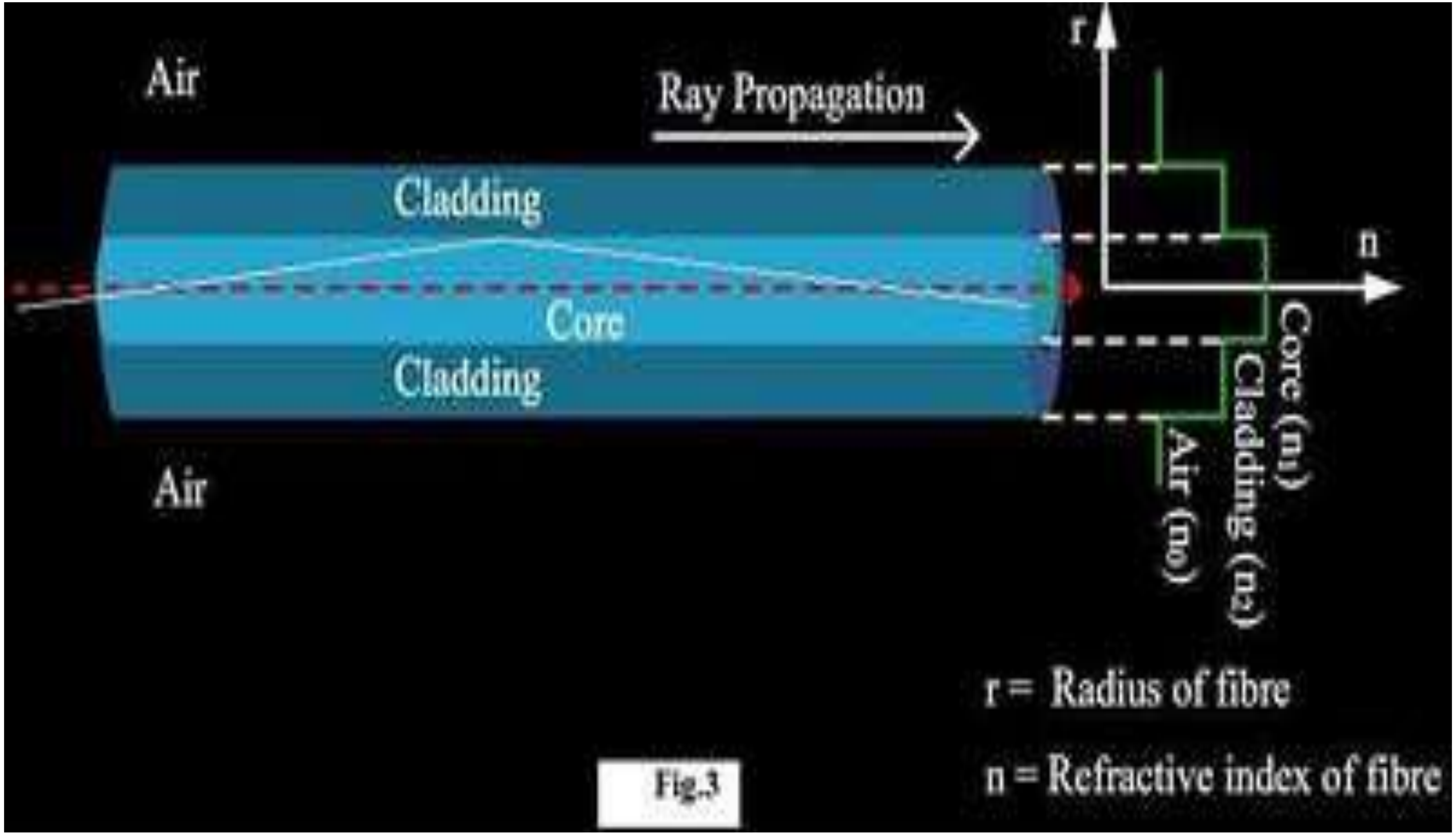
•**Connecting two fibers is easy.**

•**Fabrication is easy.**

•**Cost is low.**



Multimode step index optical fiber



Single mode step index optical fiber.

Graded index optical fiber:

Graded index fibers do not have a constant refractive index in the core but the refractive index decreases gradually with increase in radial distance from the axis of fiber, hence the name "graded-index as sown in fig.

The path of light propagation is in a helical or spiral manner.

Graded index fibers are multimode fibers.

The multimode graded index fiber has very less intermodal dispersion compared to multimode step index fiber.

It is used in medium range communications, medical field and in industries.

Multi mode graded index Optical Fiber dimensions:

Core diameter : 50μm to 350μm.

Cladding diameter : 125μm to 500μm.

Protective layer : 250μm to 1100μm.

Numerical aperture : 0.12 to 0.5.

Acceptance angle : 180t0 300.

Band width : Less than 50MHz.

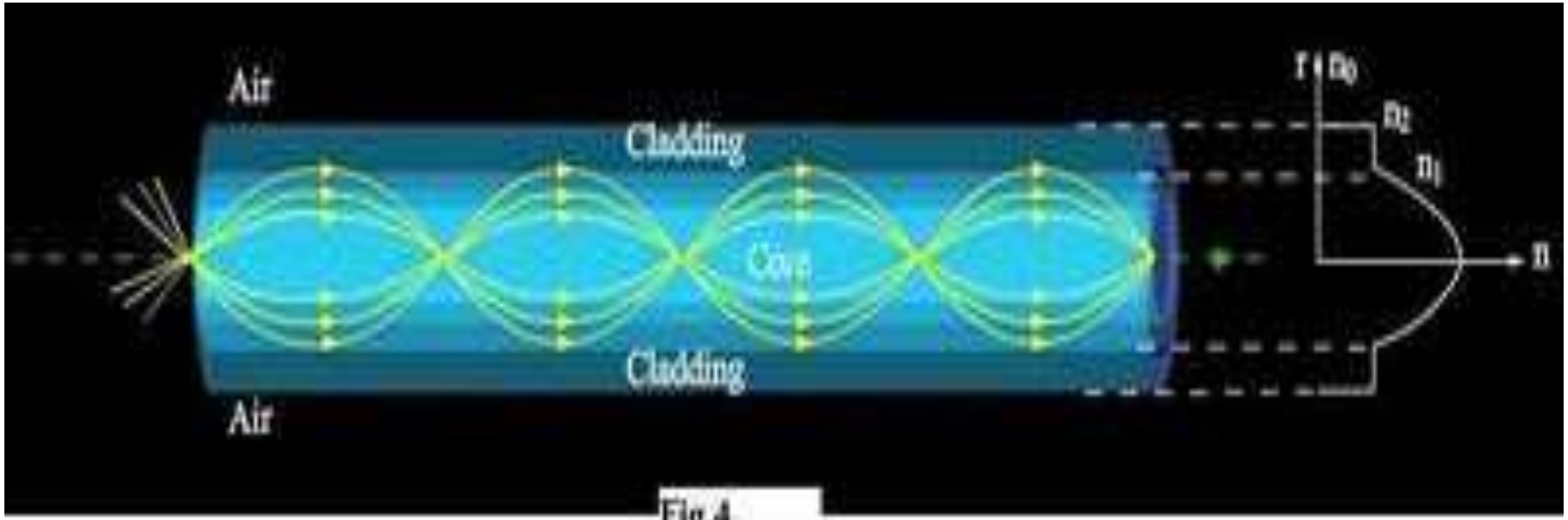


Fig.4

Graded-index optical fiber

Note: Inter-modal dispersion: When more than one mode is propagating through a fiber, then the inter-modal dispersion will occur. Since, many modes are propagating; they will have different wavelengths and will take different time to propagate through the fiber, this results in elongation or stretching of data in the pulse. This is known as inter-modal dispersion.

Optical fiber communication system:

An optical fiber communication system mainly consists of three parts viz., (1) transmitter section (2) optical fiber (3) receiver section as shown in figure.

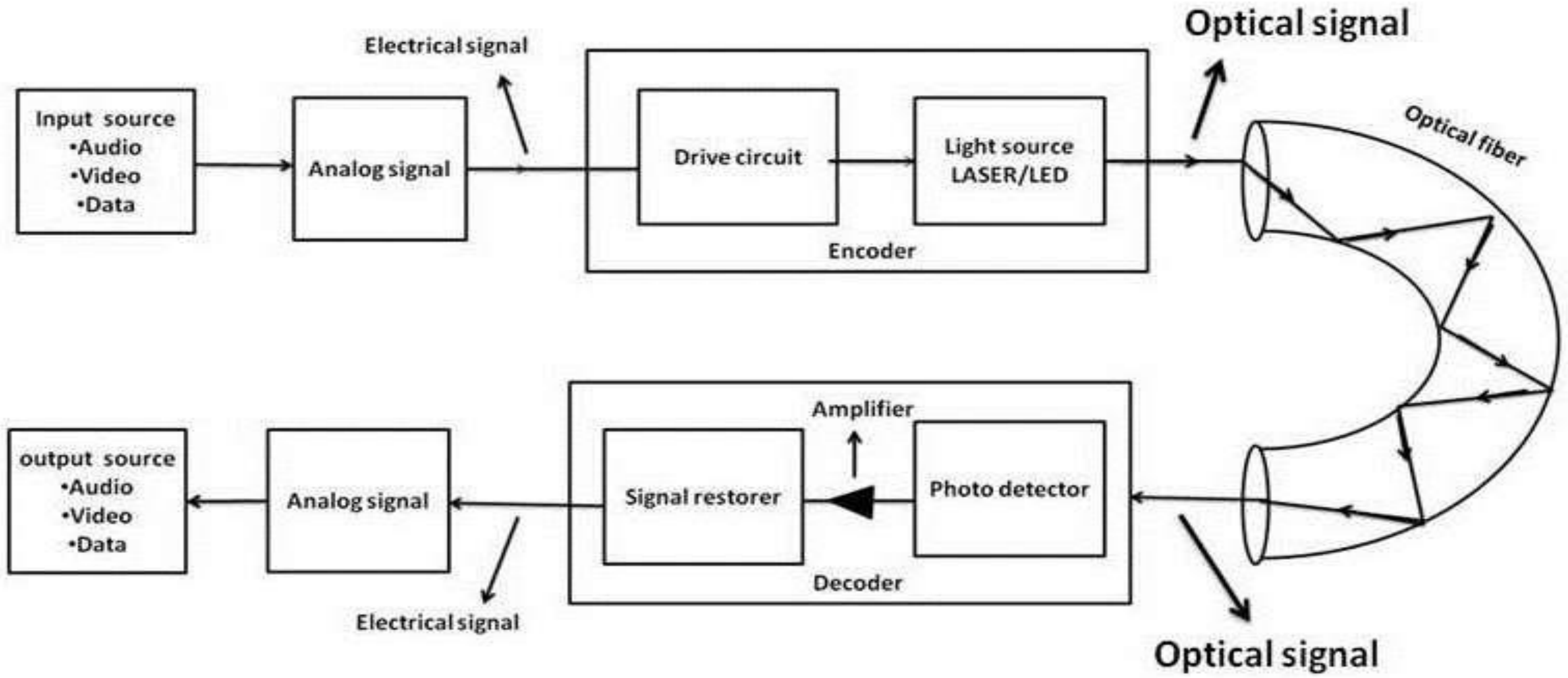


Fig: Fiber optical communication system

Advantages of optical fiber communication:

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

- **Safety**

▪ The fiber is non-conducting, and is therefore safe in all environments.
▪ It uses light waves for communication hence it is shockproof.
▪ Since it is shockproof, it is very useful in sensitive areas like petroleum industries, oil and natural gas industries, cotton industries etc.

Weight

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

Low Power Loss

An optical fiber offer slow power loss, which allows for longer transmission distances than comparison to copper cable.

Bandwidth

Fiber optic cables have a much greater bandwidth than metal cables. The amount of information that can be transmitted per unit time of fiber over other transmission media is far greater than copper cables.

Security :

1. It CANNOT be tapped unlike copper cables.
2. There is NO leakage of signals so communication is secured.
3. It is very strong, flexible and can work on high temperature.
4. It does NOT have corrosion due to water, chemicals and high humidity etc
5. It is cost effective and maintenance free.
6. It is very easy to install. It does NOT requires labor.

Losses in Fiber Optics

Attenuation
Dispersion-intermodel, Intramodel,
Bending loss-micro ,macro
scattering losses-Linear, Non linear,
Absorption-Intrinsic, Extrinsic
Coupling

Attenuation

Attenuation means loss of light energy as the light pulse travels from one end of the cable to the other.

It is also called signal loss or fiber loss.

It also decides the number of repeaters required between transmitter and receiver.

Attenuation is directly proportional to the length of the cable.

Attenuation

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

α= 10log10Pi/Po [in db/km]

where,

P_i= Input Power

P_o= Output Power, α is attenuation constant

The various losses in th e cable are due to

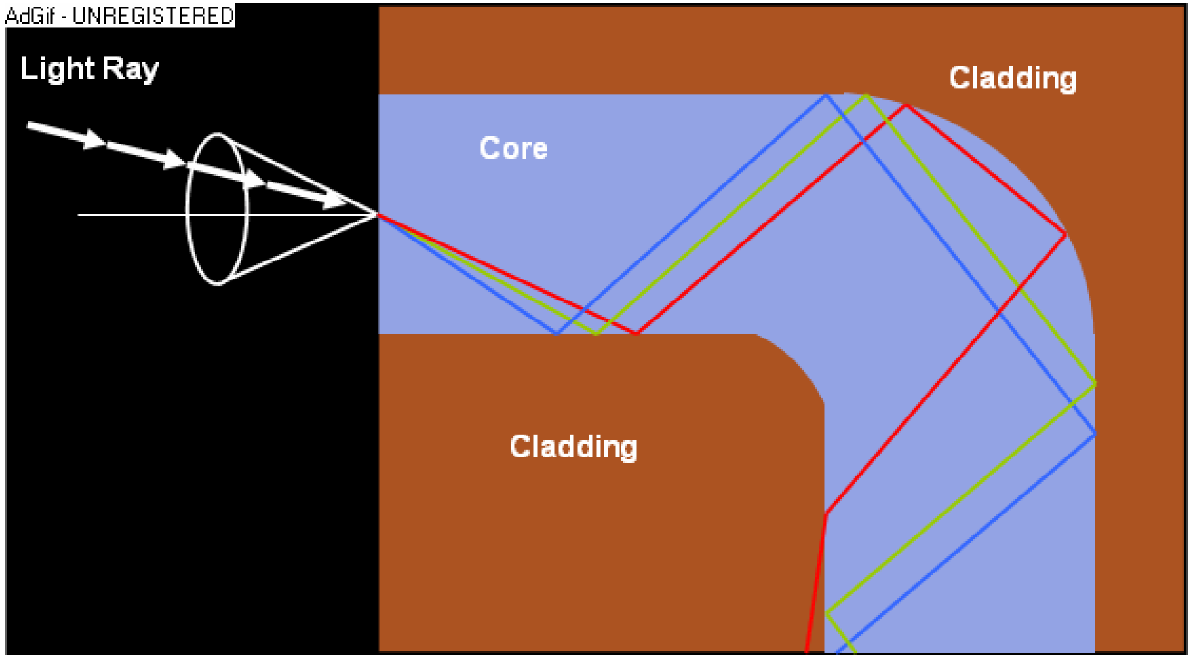
- Absorption
- Scattering
- Dispersion
- Bending

Bending losses

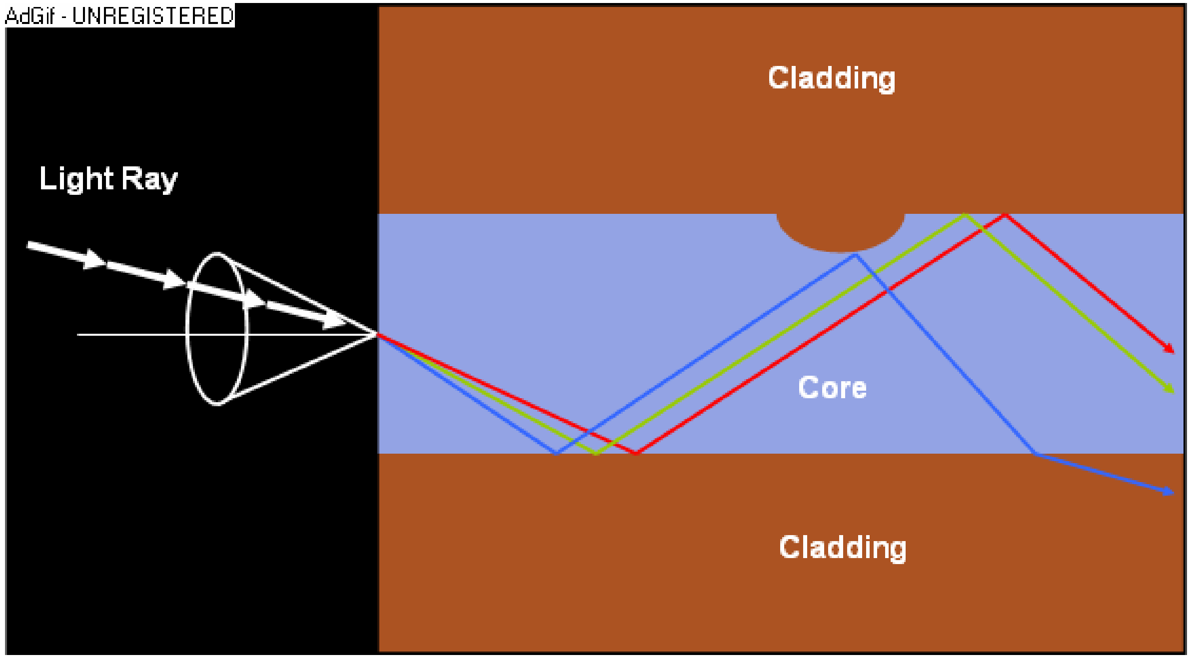
The loss which exists when an optical fiber undergoes bending is called bending losses. There are two types of bending.

i) **Macroscopic bending**
Bending in which complete fiber undergoes bends which causes certain modes not to be reflected and therefore causes loss to the cladding.

ii) **Microscopic Bending**
Either the core or cladding undergoes slight bends at its surface. It causes light to be reflected at angles when there is no further reflection.



Macroscopic Bending



Microscopic Bending

Absorption Loss

Absorption of light energy due to heating of ion impurities results in dimming of light at the end of the fiber.

Two types:

1. Intrinsic Absorption
2. Extrinsic Absorption

Intrinsic Absorption:

Caused by the interaction with one or more components of the glass

Occurs when photon interacts with an electron in the valence band & excites it to a higher energy level near the UV region.

Extrinsic Absorption:

Also called impurity absorption.

Results from the presence of transition metal ions like iron, chromium, cobalt, copper & from OH ions i.e. from water

Dispersion Loss

As an optical signal travels along the fiber, it becomes increasingly distorted.
This distortion is a sequence of intermodal and intramodal dispersion.
Two types:
1.Intermodal Dispersion
2.IntramodalDispersion

Intermodal Dispersion:
Pulse broadening due to intermodal dispersion results from the propagation delay differences between modes within a multimode fiber.
Intramodal Dispersion:
It is the pulse spreading that occurs within a single mode.
Material Dispersion
Waveguide Dispersion

Scattering Losses

It occurs due to microscopic variations in the material density, compositional fluctuations, structural in homogeneities and manufacturing defects.

Coupling Losses

The mechanical losses due to the coupling of optical fiber cables is called coupling losses