FIBER OPTICS

Introduction

Optical fiber is a long thin transparent dielectric material which carries EM waves of visible and IR frequencies from one end to the other end of the fiber by means of **Total Internal Reflection**.

Glass or Plastic is used as Dielectric material.

Optical fibers works as Wave guides in optical television signals, digital data to transmit voice television signals, digital data to any desired distance from one end to the other end of the fiber.

What are Fiber Optics?

- **Fiber optics** (optical fibers) are long, thin strands of very pure glass about the diameter of a human hair.
- They are arranged in bundles called **optical cables** and used to transmit light signals over long distances.
- Fiber Optics are cables that are made of optical fibers that can transmit large amounts of information at the speed of light.

Optical fiber consists of three sections

1. Core 2. Cladding 3. Protective Jacket

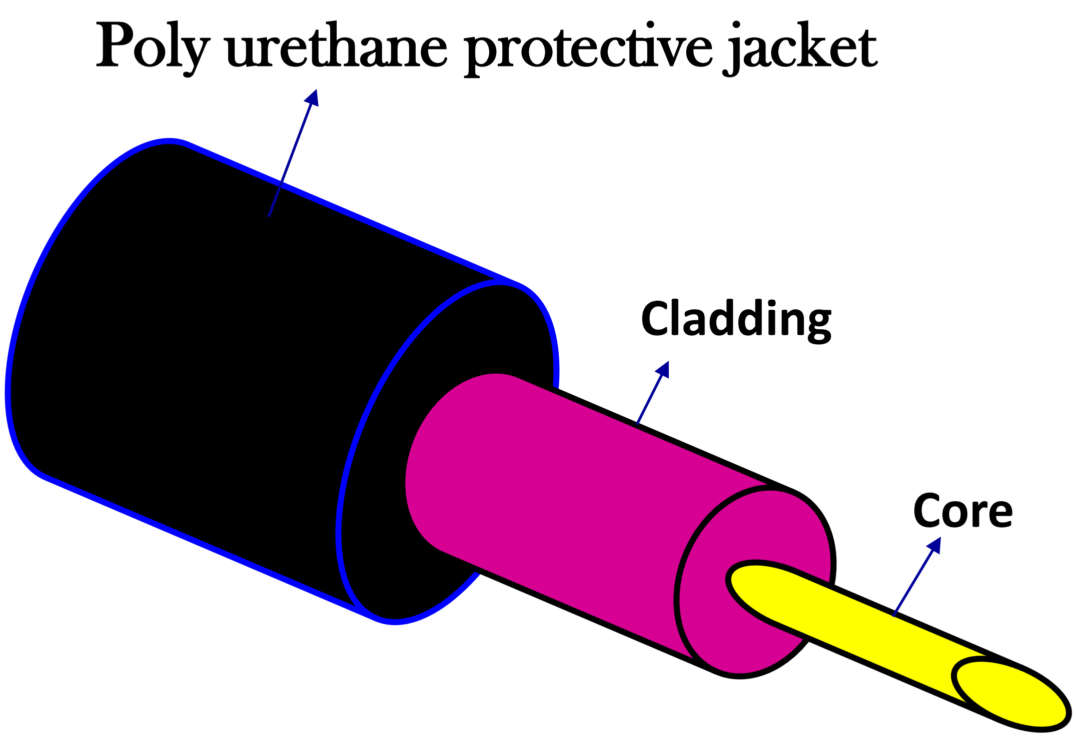
Core: It is an inner cylindrical material made up of **glass** or **plastic**.

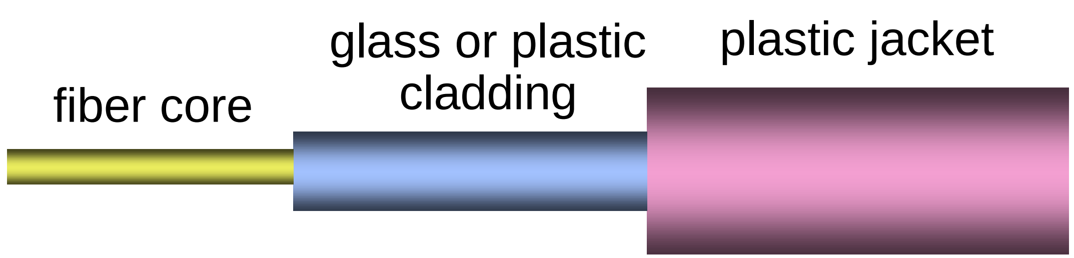
Cladding: It is a cylindrical shell of glass or plastic material in which Core is inserted.

Protective Jacket: The Cladding is enclosed in **polyurethane** jacket and it protects the fiber from surroundings.

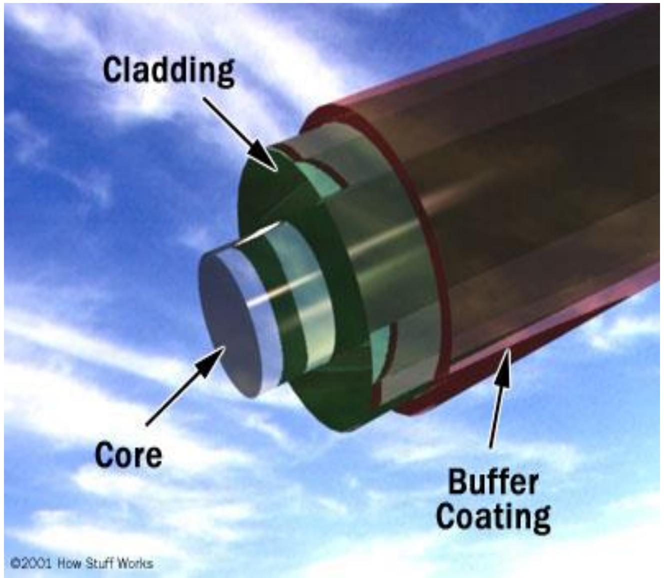
The RI of core is slightly greater than the RI of Cladding. The normal standard values are 1.48 and 1.46 respectively.

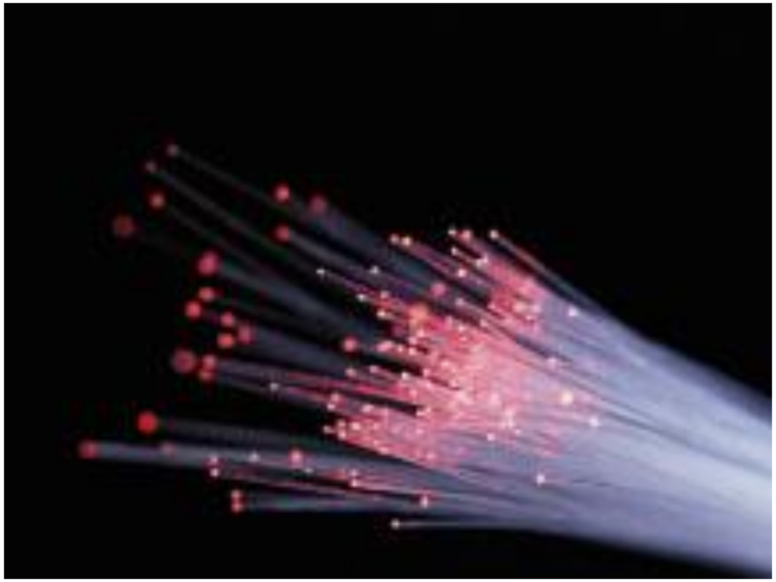
Structure of an Optical fiber





Fiber Optic Cables





SOURCE: SURFNET.NL

How Does Optical Fiber Transmit Light??

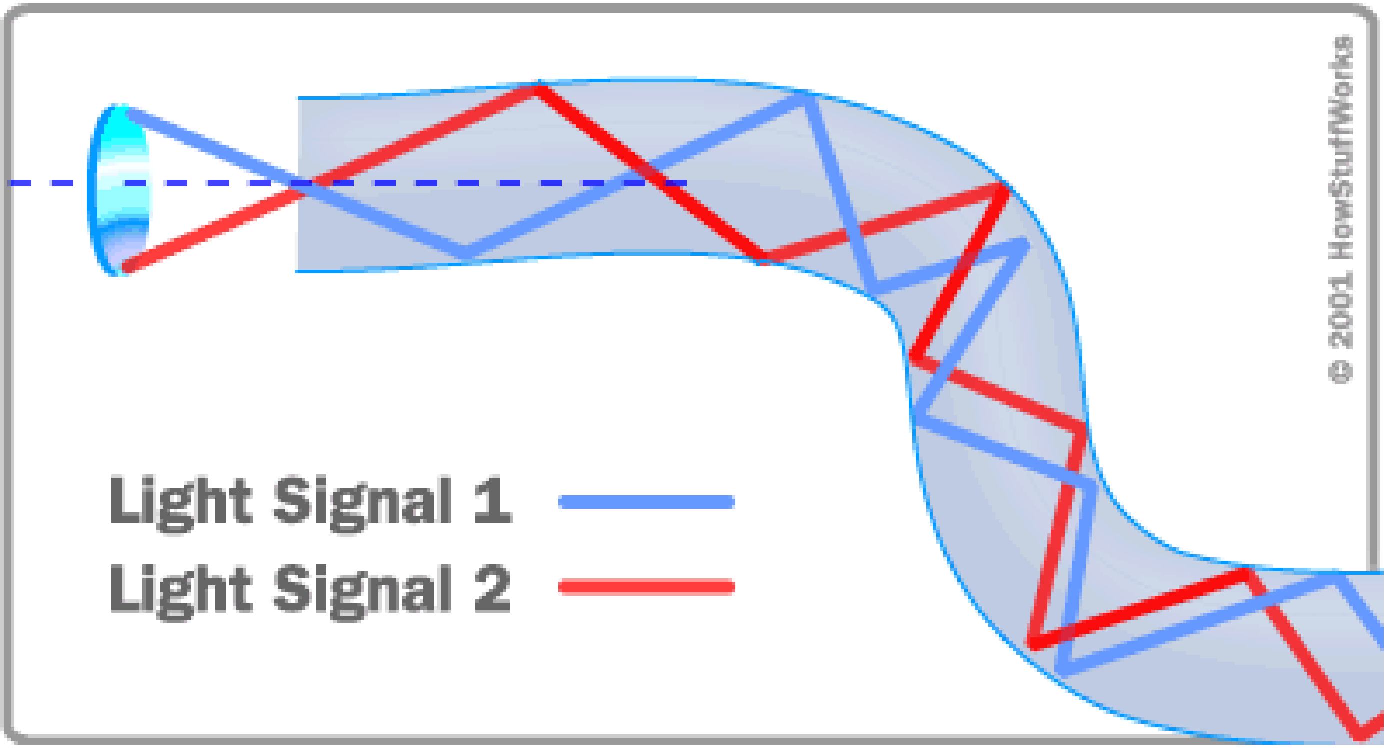
Principle: Optical fiber works on the principle of TIR. Once light ray enters into core ,it propagates by means of multiple TIR’ s at core-cladding interface.

The light in a fiber-optic cable travels through the core (hallway) by constantly bouncing from the cladding (mirror-lined walls), a principle called **total internal reflection**.

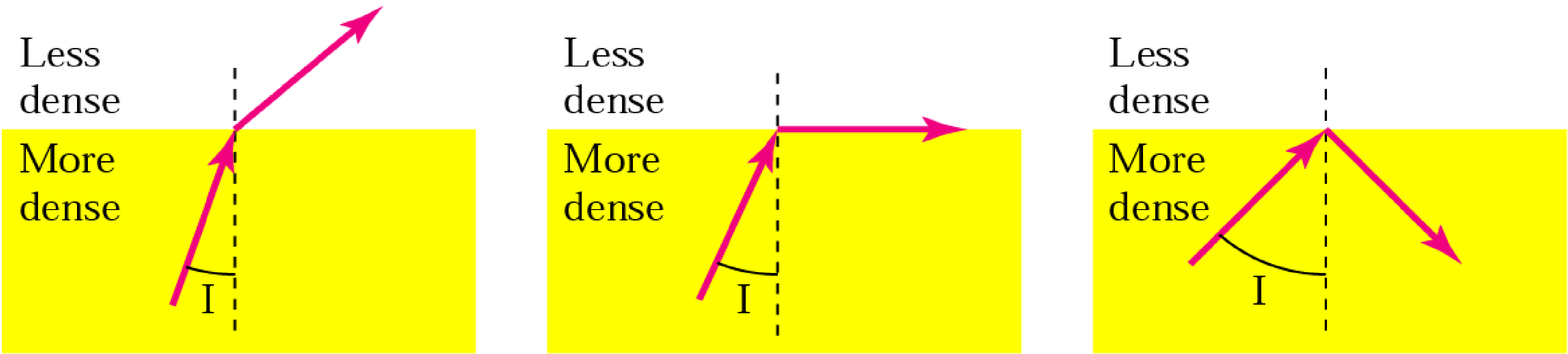
- Because the cladding does not absorb any light from the core, the light wave can travel great distances.
- However, some of the light signal **degrades** within the fiber, mostly due to impurities in the glass. The extent that the signal degrades depends on the purity of the glass and the wavelength of the transmitted light

How Does an Optical Fiber Transmit Light?

TOTAL INTERNAL REFLECTION



TOTAL INTERNAL REFLECTION



I < critical angle, refraction

I = critical angle, refraction

I > critical angle, reflection

$$according\ to\ law\ of\ refraction$$

$$n_1 \sin\theta = n_2 \sin r$$

$$\theta = \theta_c \rightarrow r = 90^0$$

$$\sin\theta_c = \frac{n_2}{n_1}\sin 90^0$$

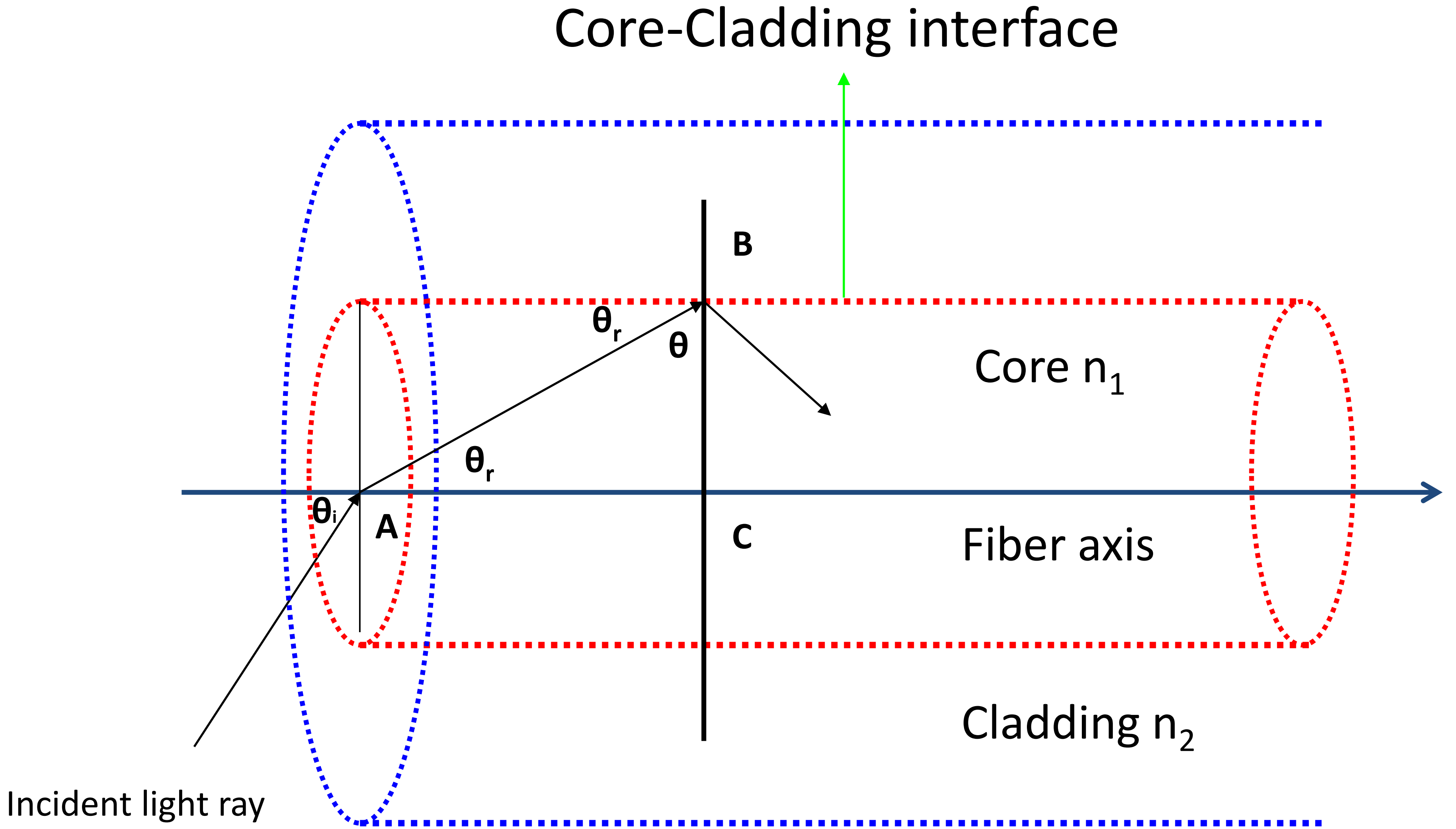
$$\sin\theta_c = \frac{n_2}{n_1}$$

- **Acceptance angle**

- **Numerical Aperture**

Acceptance Angle

- The maximum angle of incidence at the end face of an Optical fiber for which the light ray can be propagated along Core-Cladding interface is known as Acceptance angle.



Core-Cladding interface
B
θr
θ
Core n1
θr
θi
A
C
Fiber axis
Cladding n2
Incident light ray

Applying Snell' s law for Air-Core media

$$n_0 \sin\theta_i = n_1 \sin\theta_r \ldots\ldots\ldots\ldots\ldots(1)$$

from the right angle triangle ABC

$$\theta_r + \theta = 90^0$$

$$\theta_r = 90^0 - \theta$$

$$n_0 \sin\theta_i = n_1 \sin(90^0 - \theta)$$

$$n_0 \sin\theta_i = n_1 \cos\theta$$

$$\sin\theta_i = \frac{n_1}{n_0}\cos\theta \ldots\ldots\ldots(2)$$

$$when\ \theta = critical\ angle(\theta_c) \rightarrow \theta_i = \theta_m$$

$$\sin\theta_m = \frac{n_1}{n_0}\cos\theta_c \ldots\ldots\ldots\ldots\ldots(3)$$

according to law of refraction

$$n_1 \sin i = n_2 \sin r$$

$$i = \theta_c \rightarrow r = 90^0$$

$$\sin\theta_c = \frac{n_2}{n_1}\sin 90^0$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\cos\theta_c = \sqrt{1-\sin^2\theta_c} = \sqrt{1-(\frac{n_2}{n_1})^2}$$

$$\cos\theta_c = \frac{\sqrt{n_1{}^2 - n_2{}^2}}{n_1}\ldots\ldots\ldots\ldots(4)$$

$$substitute\ equation\ (4)\ in\ (3)$$

$$\sin\theta_m = \frac{n_1}{n_0}\frac{\sqrt{n_1^{\ 2} - n_2^{\ 2}}}{n_1}$$

$$if\ the\ medium\ surrounding\ the\ fiber\ is\ air, then\ n_0 = 1$$

$$\sin\theta_m = \sqrt{n_1^{\ 2} - n_2^{\ 2}}$$

$$\theta_{\max} = \sin^{-1}\sqrt{n_1^{\ 2} - n_2^{\ 2}}$$

Which is required expression for Acceptance Angle in optical fibers.

Numerical Aperture

- The light gathering capacity of an optical fiber is known as Numerical Aperture and it is proportional to Acceptance Angle.

- It is numerically equal to sine of Acceptance Angle.

Numerical Aperture

- It is the measure of the amount of light that can be accepted by a fiber.
- It depends only on Refractive indices of core and cladding and not on fiber dimensions.
- It is always <1 and ranges from 0.13 to 0.50.
- A larger numerical aperture implies that a fiber will accept a large amount of light from the source.

- **TYPES OF FIBERS**

TYPES OF OPTICAL FIBERS

On the basis of variation of RI of core, the optical fibers are mainly classified into following types. i.e.,

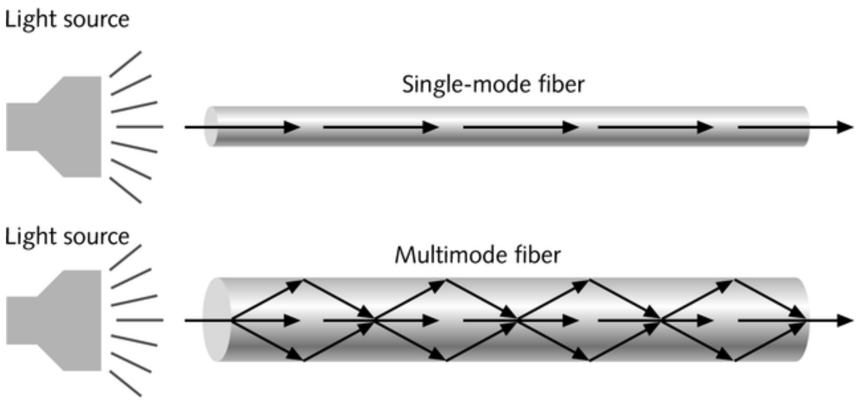
1.STEP INDEX FIBER 2.GRADED INDEX FIBER

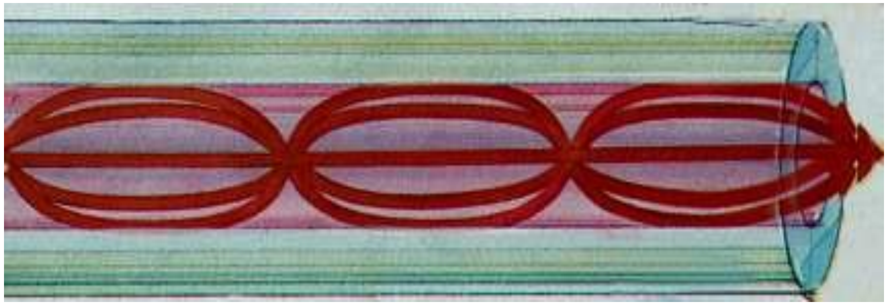
Based on Mode of propagation, the fibers are further divided into

1. SINGLE MODE 2.MULTI -MODE.

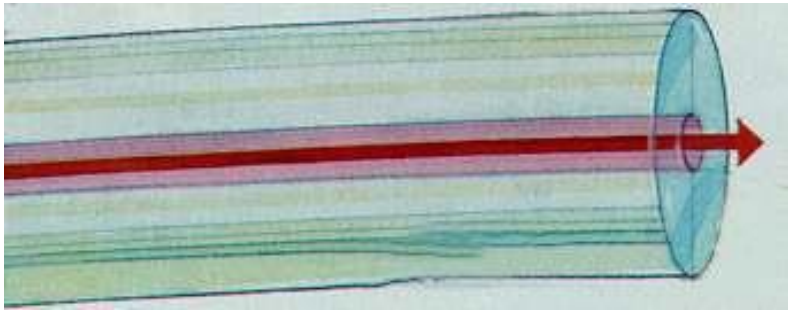
Single and Multi-Mode Fiber

- **Single-mode fiber**
  - Carries light pulses along single path
  - Uses Laser Light Source
- **Multimode fiber**
  - Many pulses of light generated by LED travel at different angles

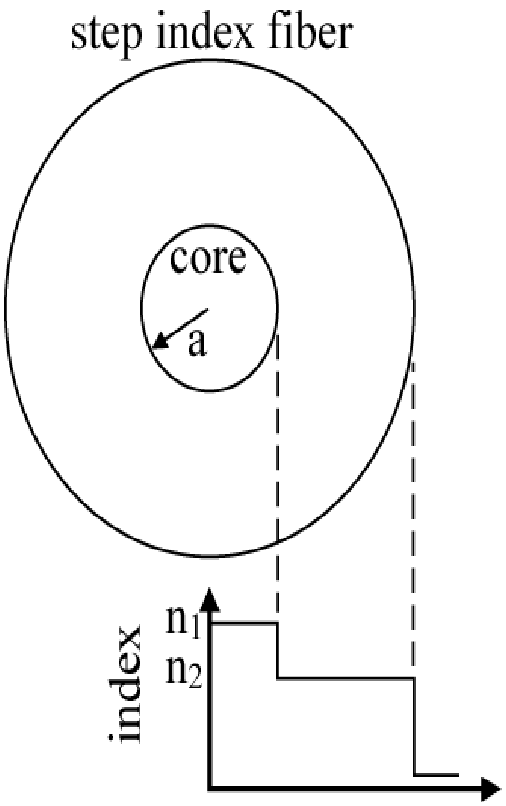


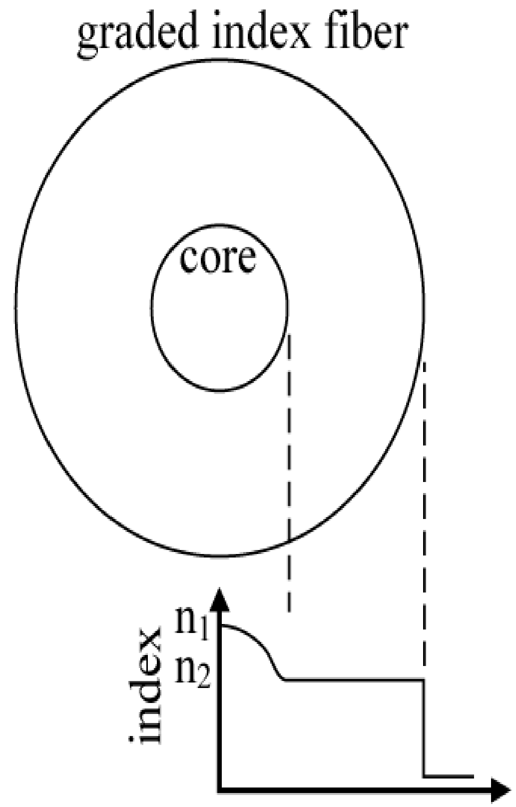


Multimode fiber



Single Mode fiber





Refractive index discontinuity at core-clad boundary

Refractive index gradually deceases as we move away from the center of the core material.

SINGLE MODE STEP INDEX FIBER

- The RI is constant for the core in this fiber. As we go radially from center of the core, the RI undergoes a step change at core-cladding interface .

- The core diameter of this fiber is about 8 to 10μm and the outer diameter of cladding is 60 to 70μm.

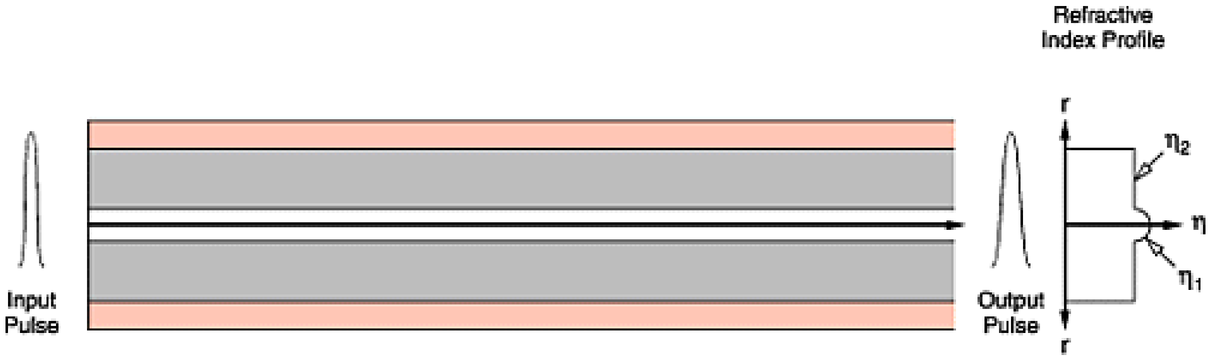
- There is only one path for light ray propagation. Hence it is called single mode step index fiber.

- It is a reflective fiber since light is transmitted from one end to the other end of a fiber by TIR.

- These are extensively used because distortion and transmission losses are very less.

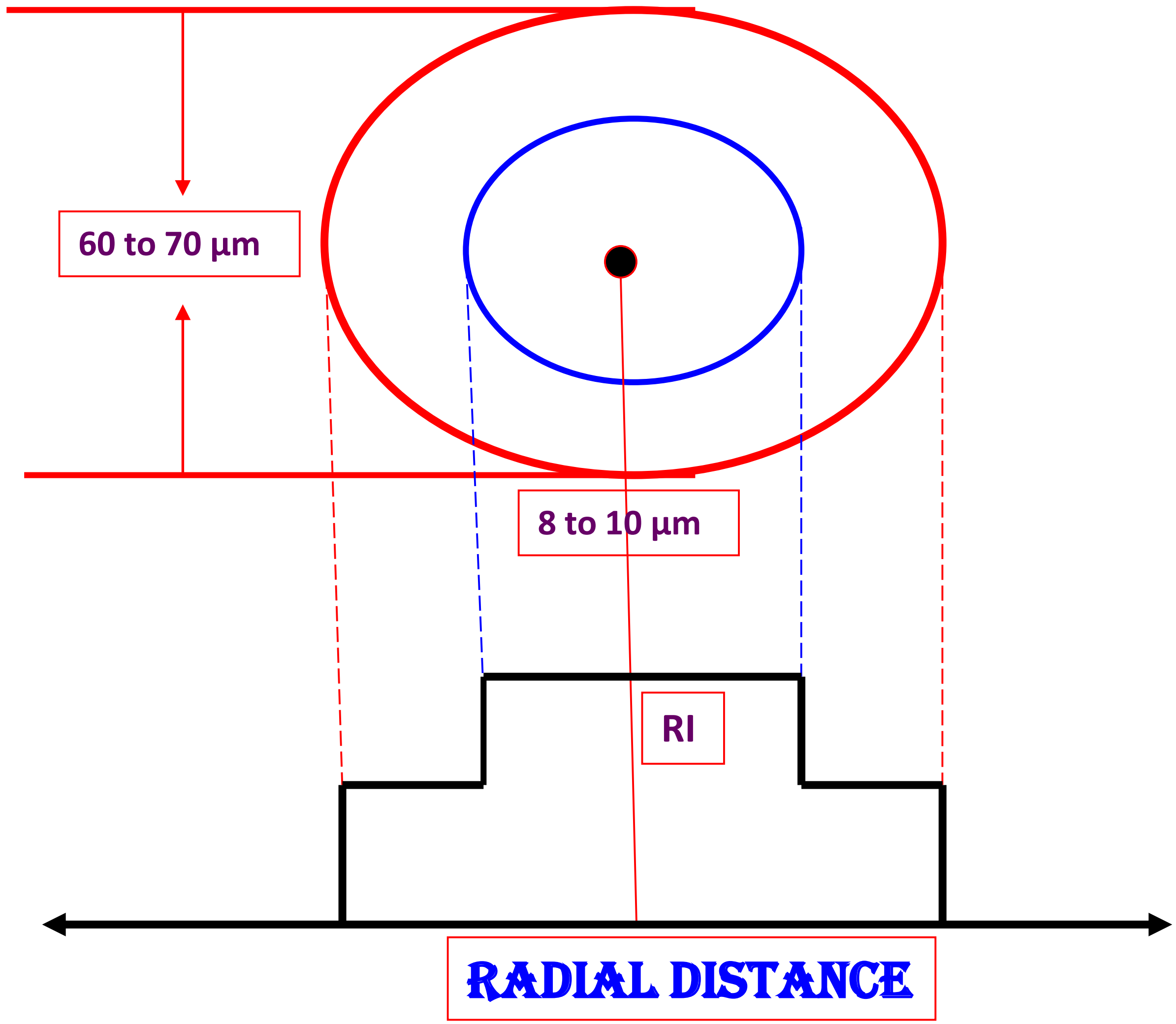
SINGLE-MODE STEP INDEX FIBER

- The Core diameter is 8 to 9μm
- All the multiple-mode or multimode effects are eliminated
- However, pulse spreading remains
- Bandwidth range is large.

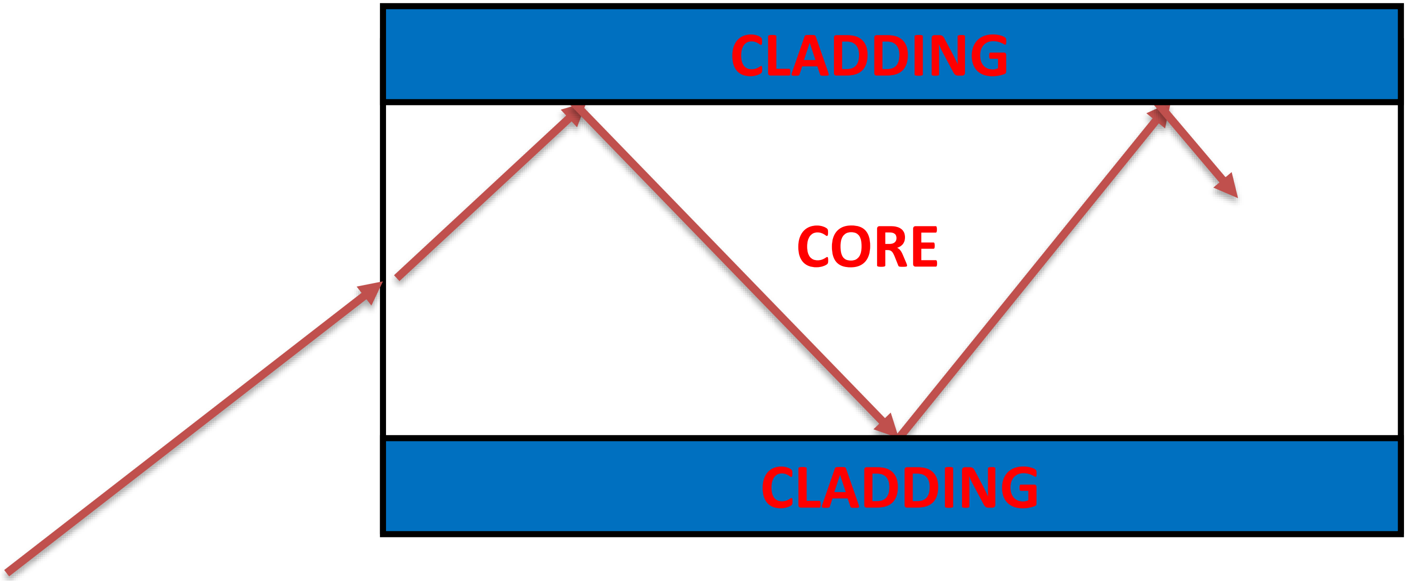


Single-Mode Step Index

REFRACTIVE INDEX PROFILE OF SINGLE MODE STEP INDEX FIBER



Propagation in SINGLE MODE STEP INDEX FIBER



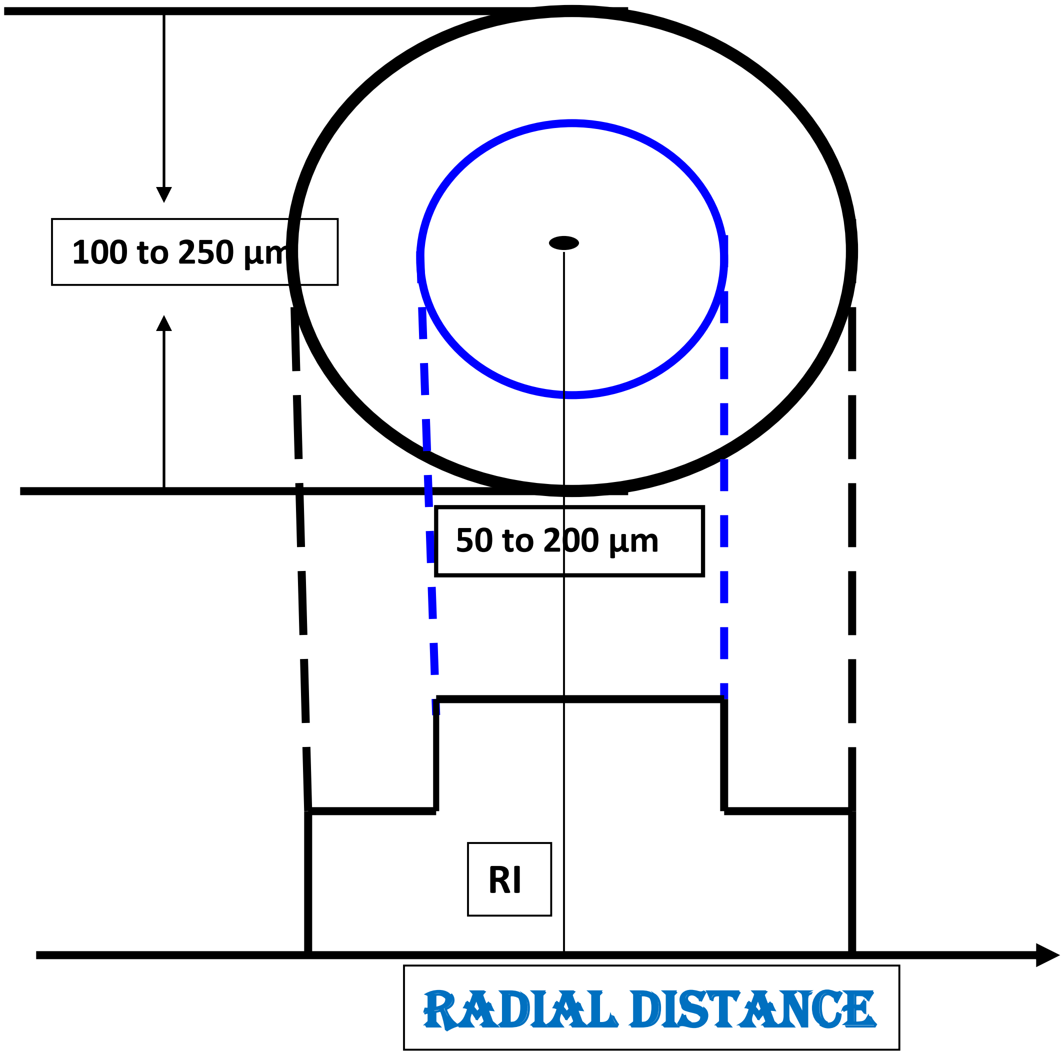
MULTIMODE STEP INDEX FIBER

The construction of this fiber is similar to Single mode step index fiber but dimensions of Core and Cladding are much larger to have more number of paths for light propagation.

The Core diameter varies from 50 to 200μm and the Cladding diameter varies from 100 to 250μm.

It is also a reflective fiber since light is propagated in the form of multiple TIRs.

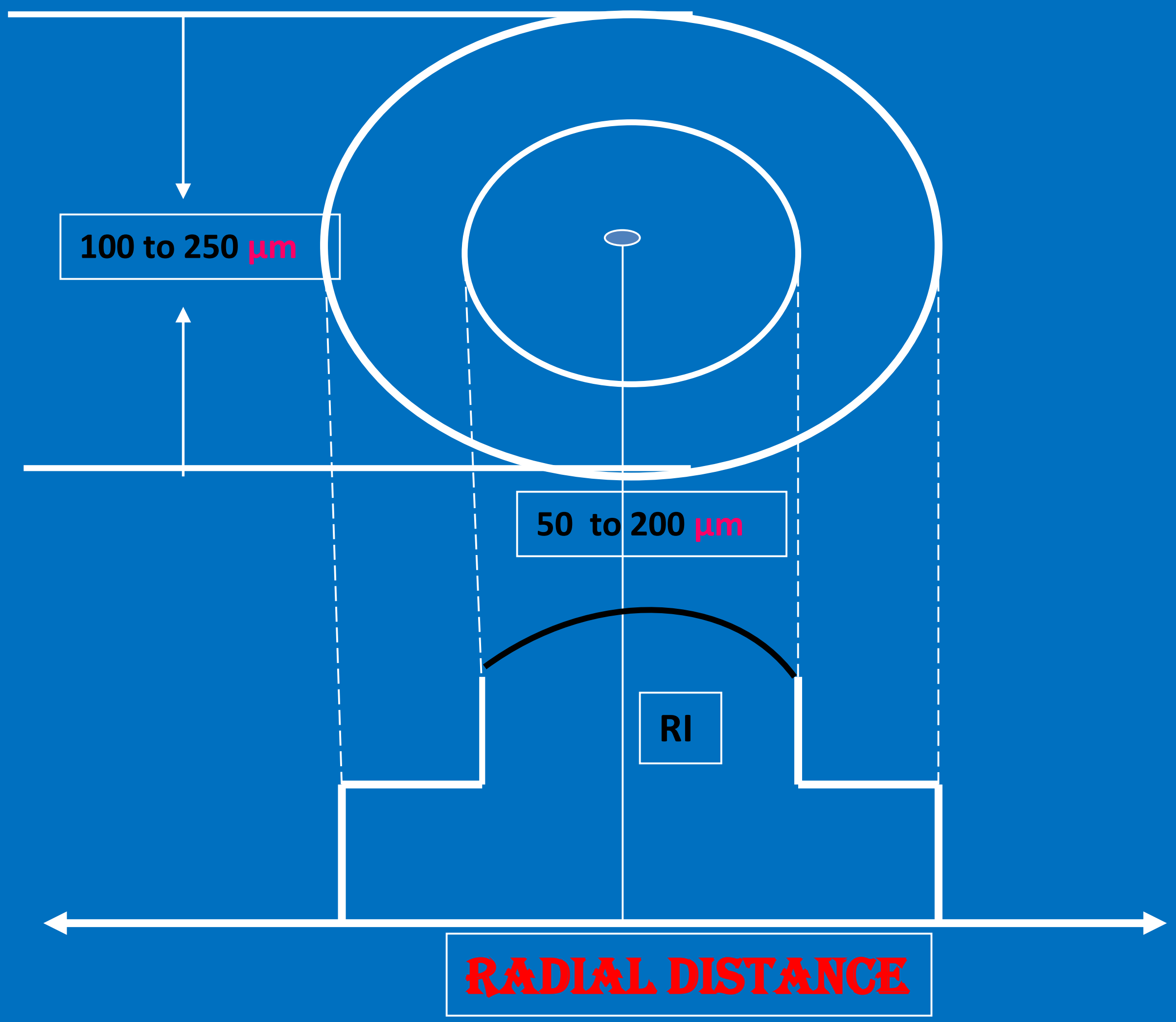
REFRACTIVE INDEX PROFILE OF MULTI MODE STEP INDEX FIBRE



GRADED INDEX FIBRE

- In this fiber , the RI of Core continuously decreases from center to the surface (radially).
- The RI is maximum at the center of Core and Minimum at the Surface.
- This fiber can be a single mode or Multimode ,the diameters of core and cladding varies from 50-200μm and 100-250μm respectively.

REFRACTIVE INDEX PROFILE OF GRADED INDEX FIBER



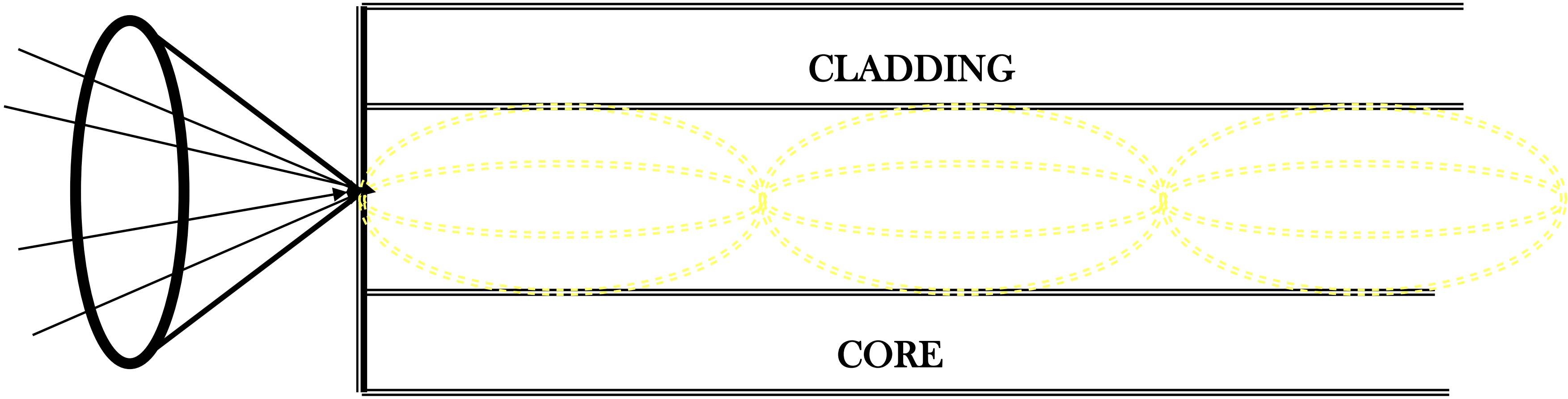
- As RI changes continuously radially in Core, the light rays suffers continuous refraction within the Core from its center to surface.

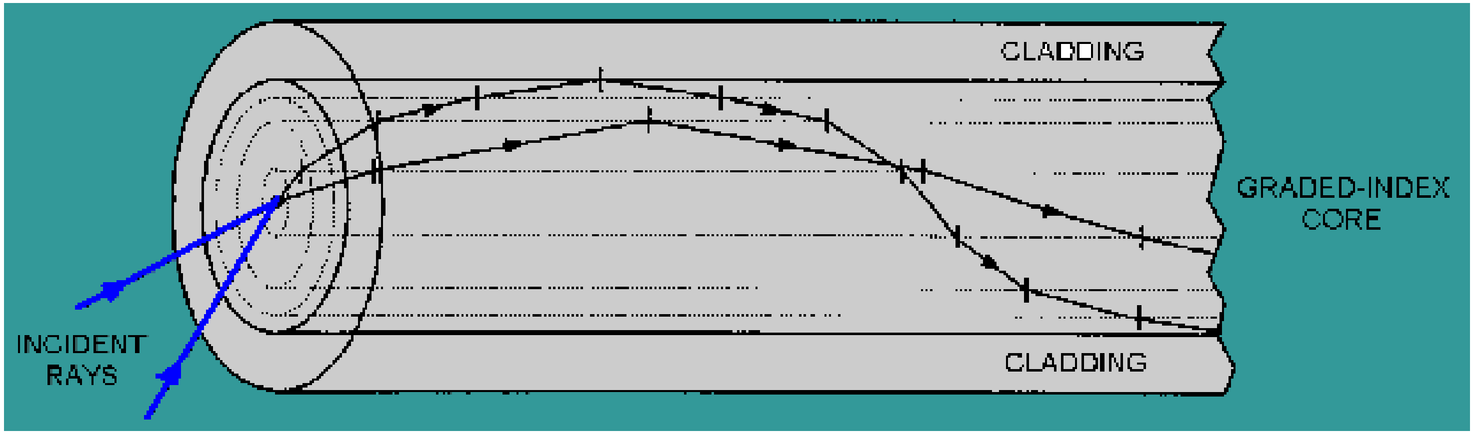
- Thus the propagation of light rays are not due to TIR but by refraction. Therefore it is called Refractive fiber.

- In this fiber, the light rays travel at different speeds in different parts.

- Near the surface RI is least so, the light rays travel faster compared to the light rays near the axis. Because of this all the rays almost arrive at the same time at the other end of the fiber----They follow different paths.

LIGHT PROPAGATION IN MUTI-MODE GRADED INDEX FIBER





NORMALIZED OR CUT-OFF FREQUENCY

$$V = \frac{2\pi r}{\lambda}\sqrt{{n_1}^2 - {n^2}_2} = \frac{2\pi r}{\lambda} NA$$

$n_1 = Refractive\ index\ of\ the\ core, n_2 = Refractive\ Index\ of\ the\ Cladding\ material$

$\lambda = Wavelength\ of\ the\ Light$

SINGLE-MODE FIBER $V<2.405$

MULTIMODE-MODE FIBER $V>2.405$

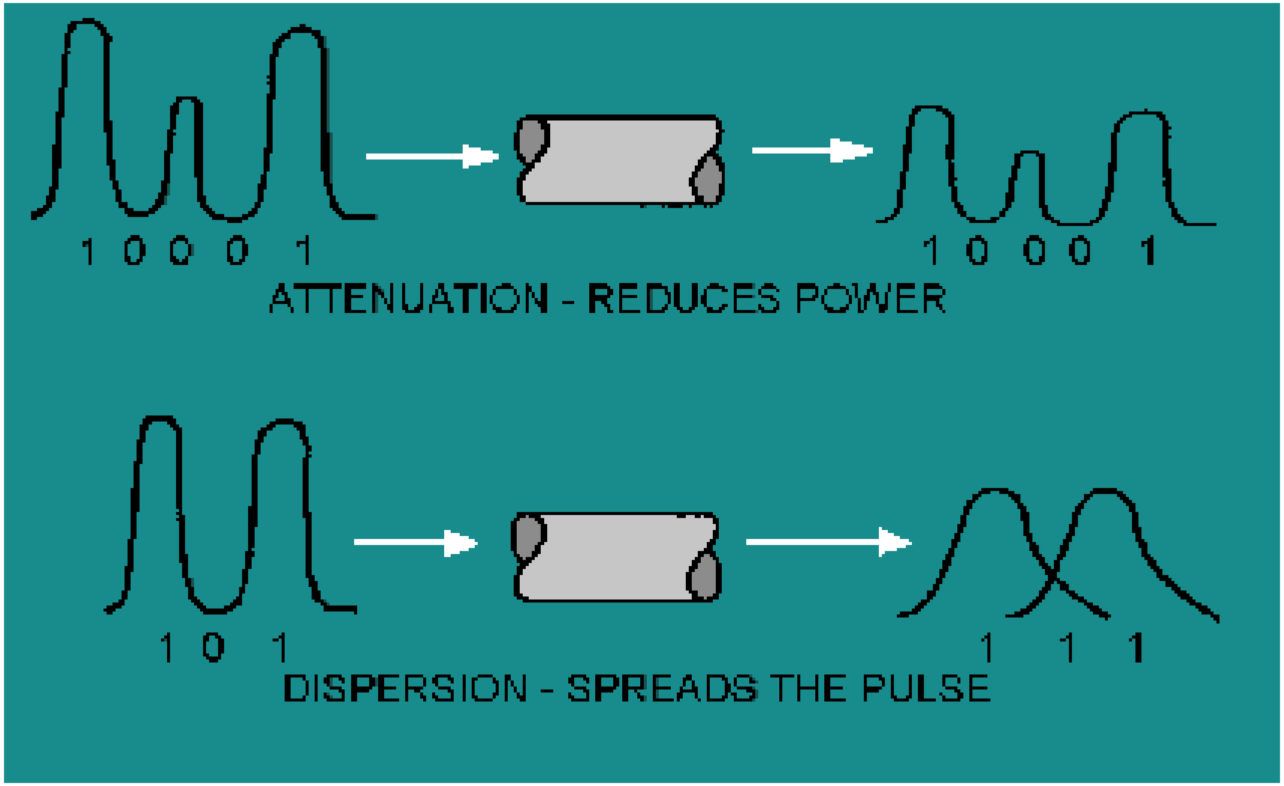
N → NUMBER OF MODES GENERATED INSIDE A FIBER

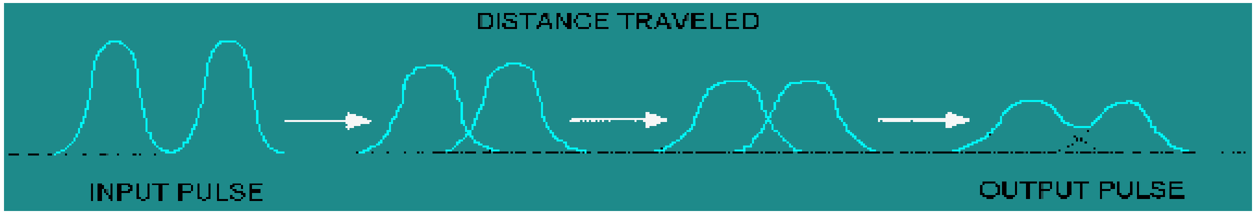
N= $\frac{V^2}{2}$ **STEP-INDEX FIBER**

N= $\frac{V^2}{4}$ **GRADED-INDEX FIBER**

- ATTENUATION
- DISPERSION

PROPERTIES OF OPTICAL FIBER TRANSMISSION





ATTENUATION OR POWER LOSS IN OPTICAL FIBERS

- The power of the light at the output end is found to be always less than the power launched at the input end.

- Attenuation is found to be a function of fiber material, wavelength of light and length of the fiber and it is measured in terms of the decibel.

FIBER ATTENUATION

- If P_{in} power is launched into the fiber, the power remaining after propagating a length L within the fiber P_{out} is

$$P_{out} = P_{in} \exp(-\alpha L)$$

$\alpha \rightarrow$ **Linear Attenuation Coefficient**

ATTENUATION

Attenuation types....

Intrinsic

1.Scattering losses

2.Absorption losses

Extrinsic

1.Absorption losses

2.Bending losses

(a) Macro-bending

(b) Micro-bending

MATERIAL ABSORPTION

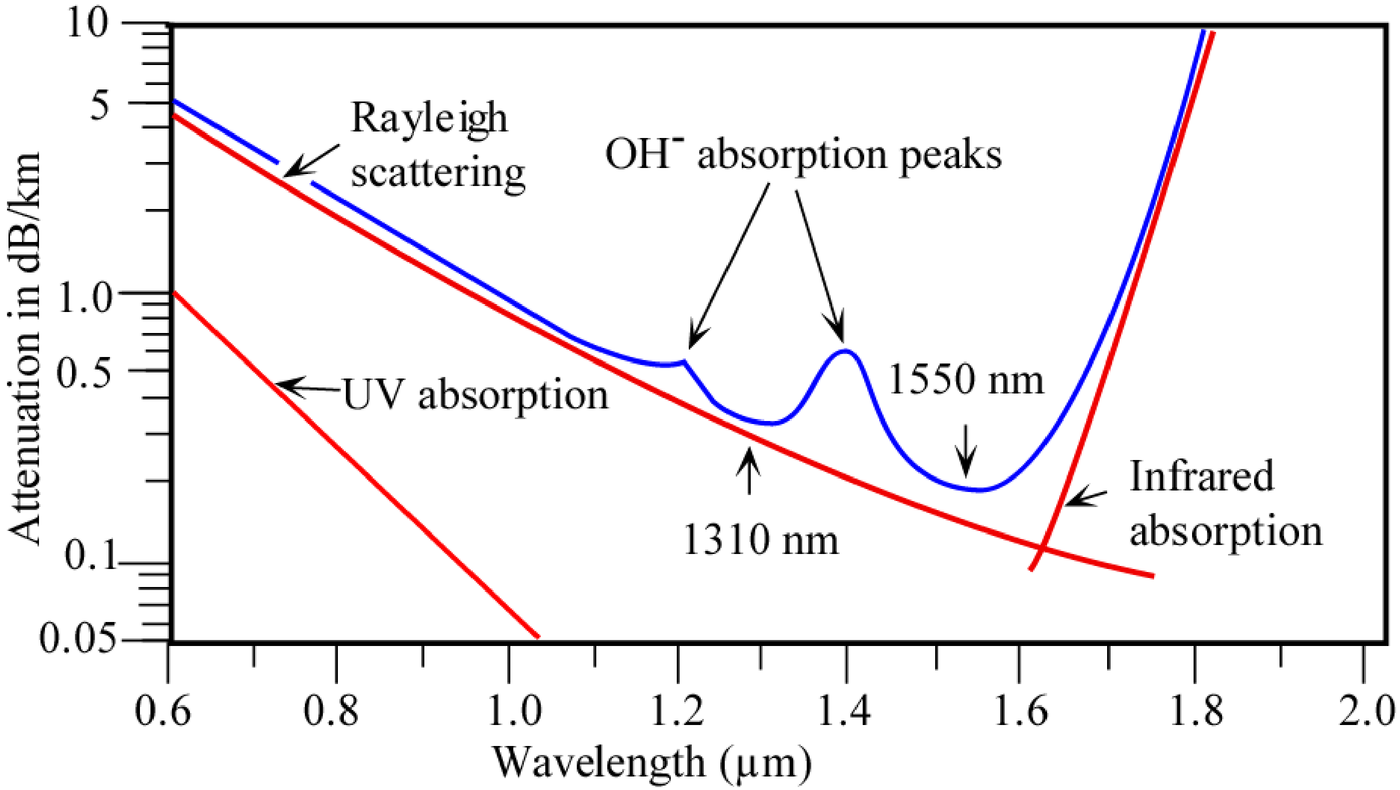
Intrinsic: Caused by atomic resonance of the fiber material.

Extrinsic: Caused by atomic absorptions of external particles in the fiber.

SCATTERING LOSS

- There are many kinds of scattering loss
  - Rayleigh scattering
  - Mie scattering
- Many other scattering losses are there which depend on the power inside the optical fiber
  - Insignificant unless the power is greater than 100mW

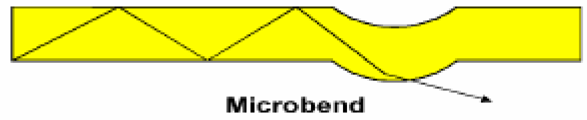
ABSORPTION AND SCATTERING LOSS

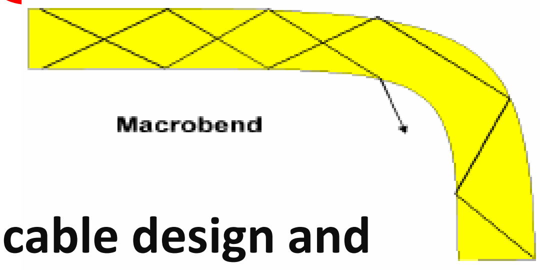


EXTERNAL LOSSES

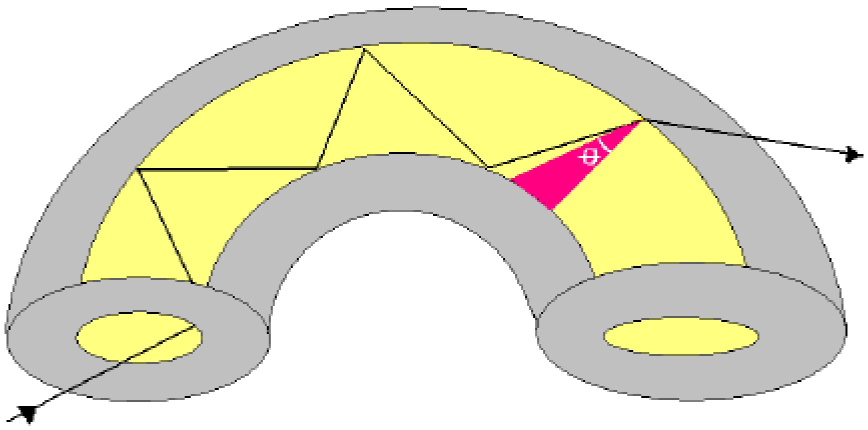
- Radiation loss at bends in the optical fiber
- Macro-bending
- Micro-bending
- Misalignment of core centers
- Air gaps
- End face reflections

Bending Loss





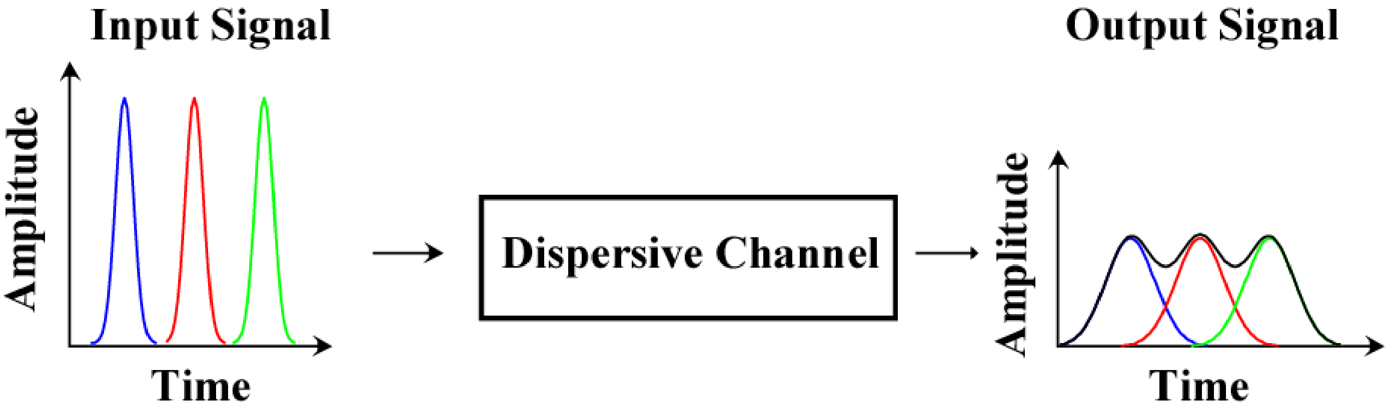
Micro-bending is commonly caused by poor cable design and poor installation and handling.



Macrobend loss.

Light Leak out of the fiber when the fiber is bend.

DISPERSION

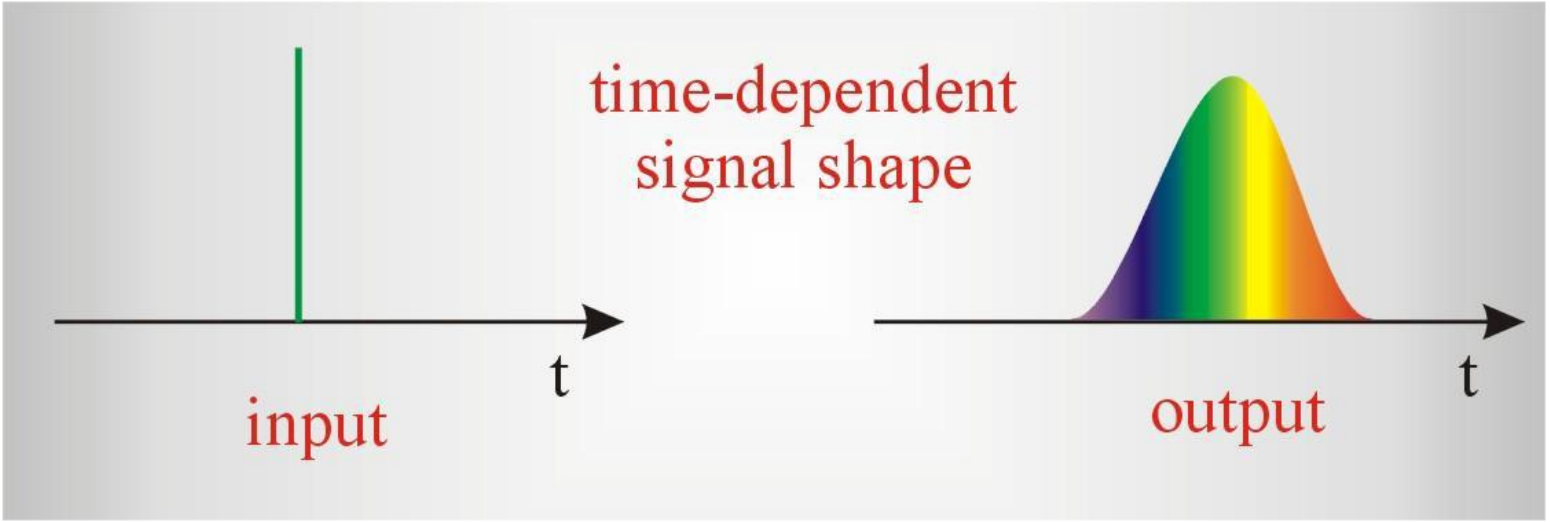


- Dispersive medium: velocity of propagation depends on frequency

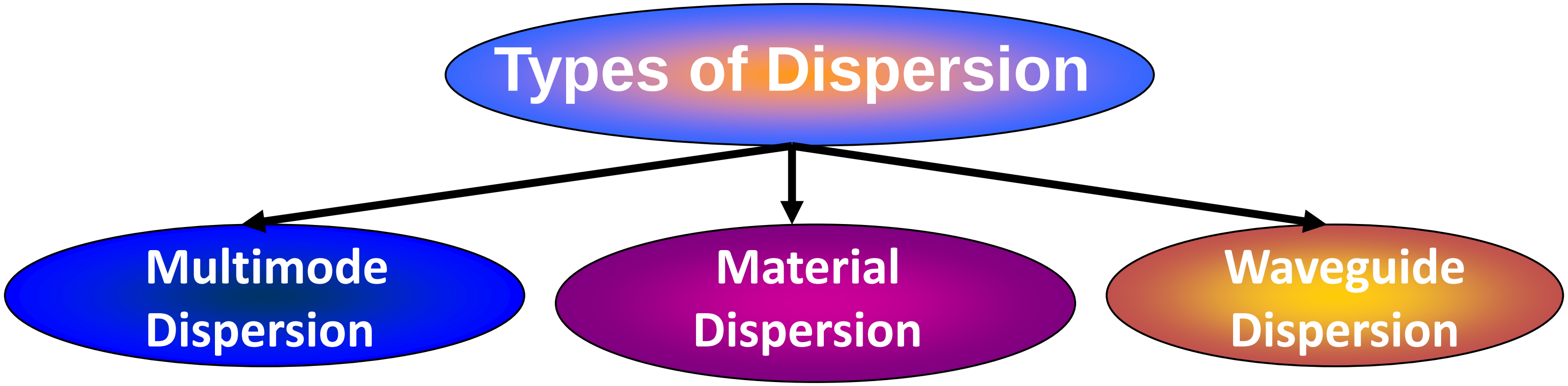
- Dispersion causes temporal pulse spreading

- Dispersion is related to the velocity of the pulse

Pulse Spreading Due to Dispersion



CAUSE OF FIBER DISPERSION



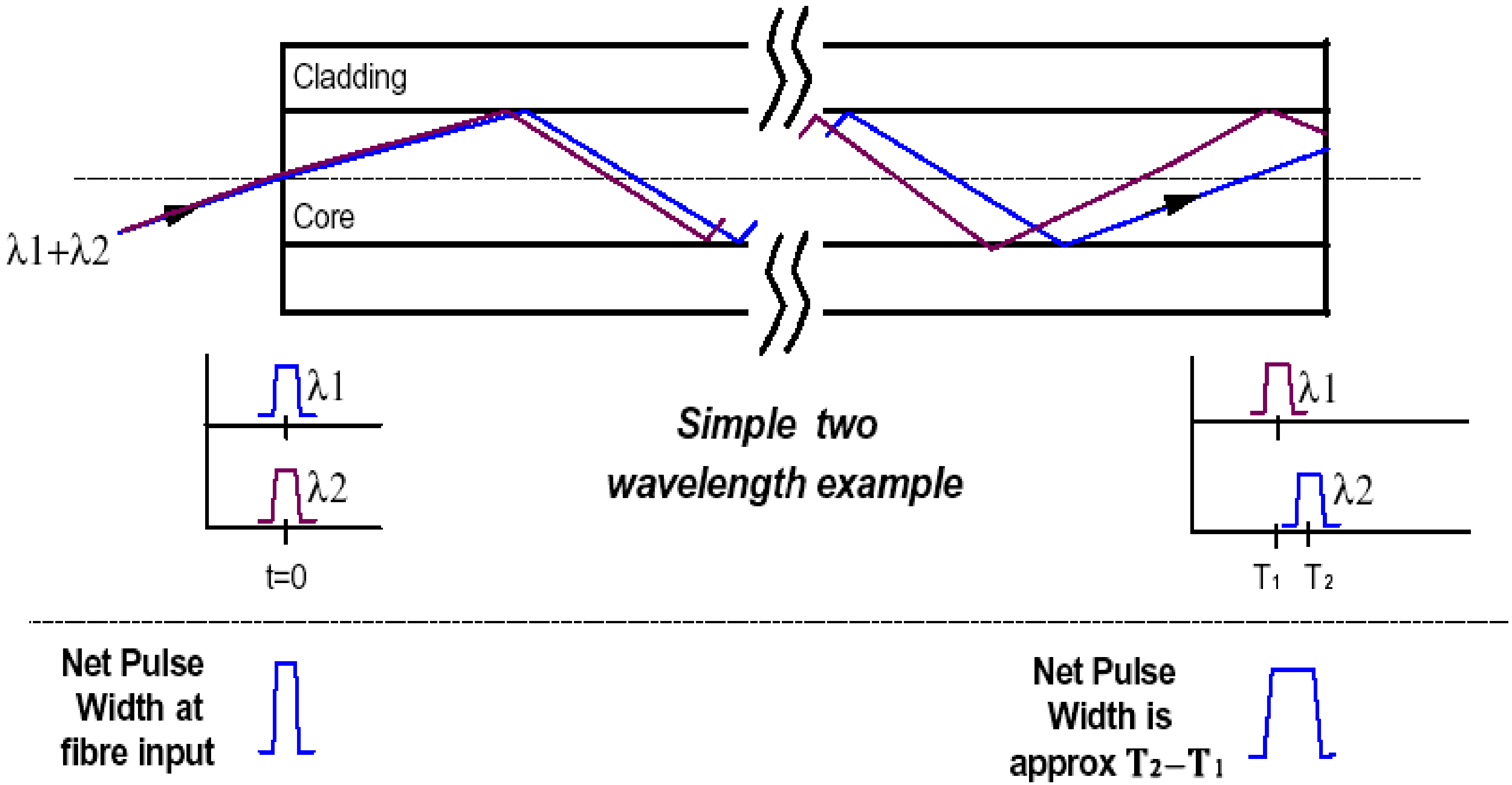
- Multimode group delay dispersion is the variation in group velocity among the propagation modes at a single frequency

- Material Dispersion is due to variation in the refractive index of the core material as a function of wavelength.

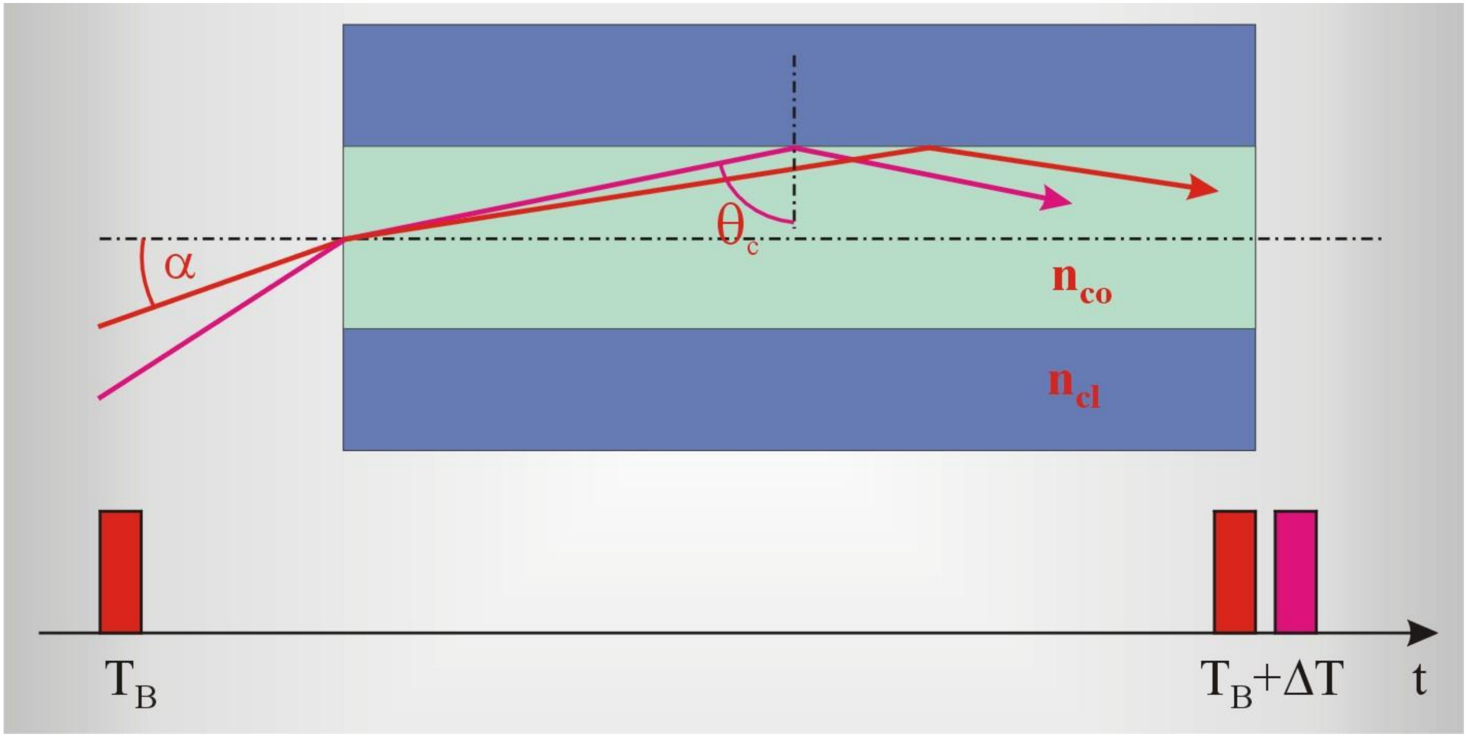
- Waveguide dispersion depends upon the fiber design. The propagation constant which is the function of the ratio of fiber dimension (i.e. core radius) to the wavelength.

MATERIAL DISPERSION

In an optical fibre the propagation velocity varies with wavelength. Thus a pulse made up of many wavelengths will be spread out in time as it propagates



MULTI-MODE DISPERSION



Temporal Pulse Broadening in a step index fiber

Rays have same speed but they cover different paths and reach the detector at different time-----Pulse Broadening

Basic communications system