Fiber optics-introduction

Dr .Bindu Krishnan

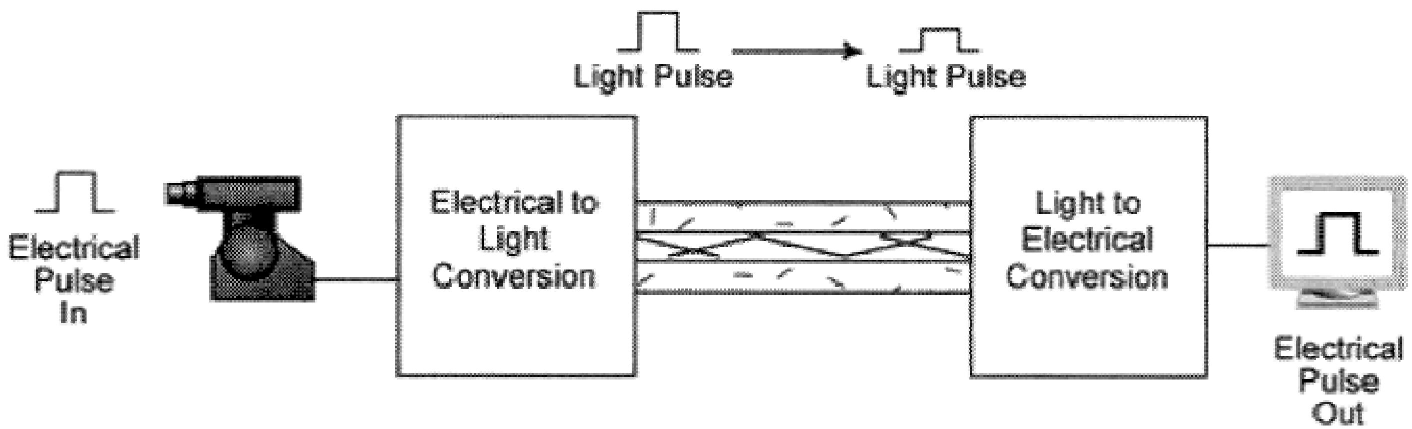
History

- 1961-“Industry researchers Elias Snitzer and Will Hicks demonstrate a laser beam directed through a thin glass fiber. The fiber’s core is small enough that the light follows a single path, but most scientists still consider fibers unsuitable for communications because of the high loss of light across long distances.” (www.greatachievements.com.)
- 1970- Researchers find a way to super purify glass fibers.
- 1980- At&t installs first set of fiber optic cables in major cities.

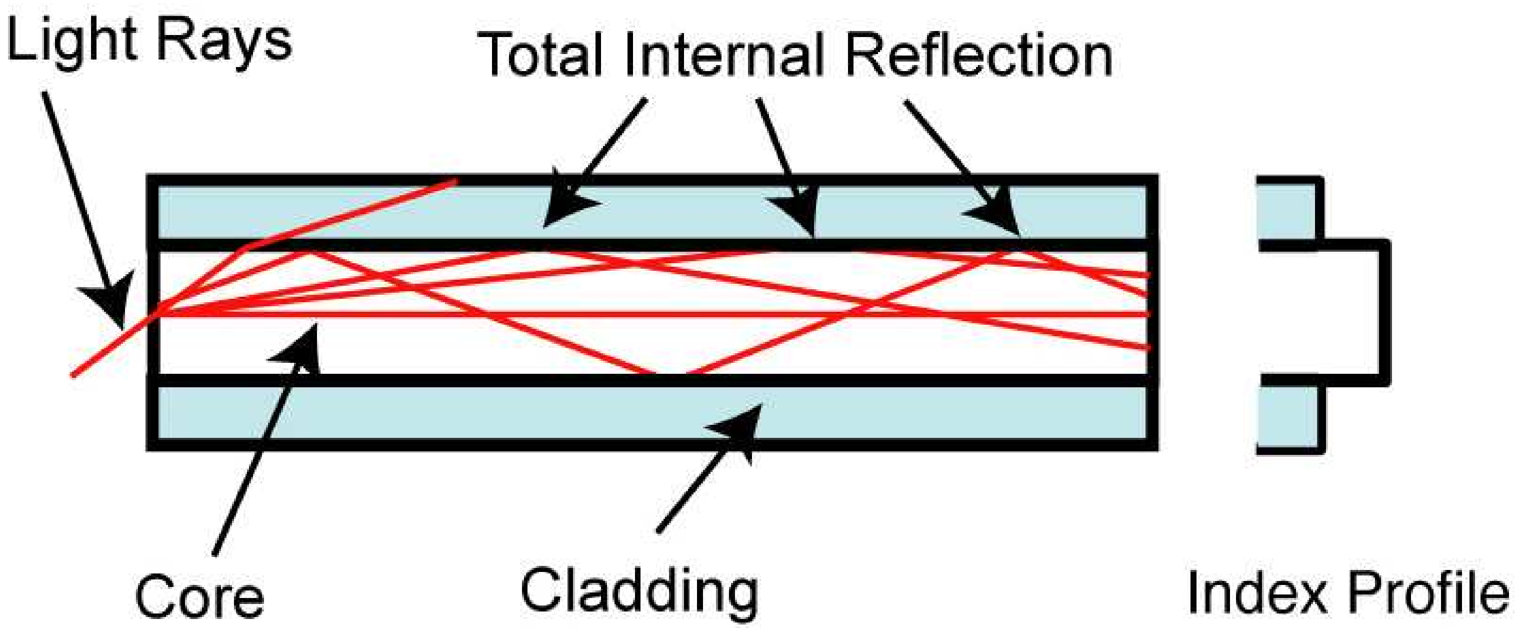
History

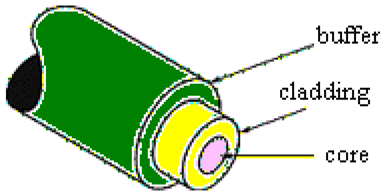
- 1988- First transatlantic cable
- 1996- First transpacific cable
- 1997- First Fiber Optic Link Around the Globe (FLAG)

OPTICAL FIBER COMMUNICATION



Fiber Technology





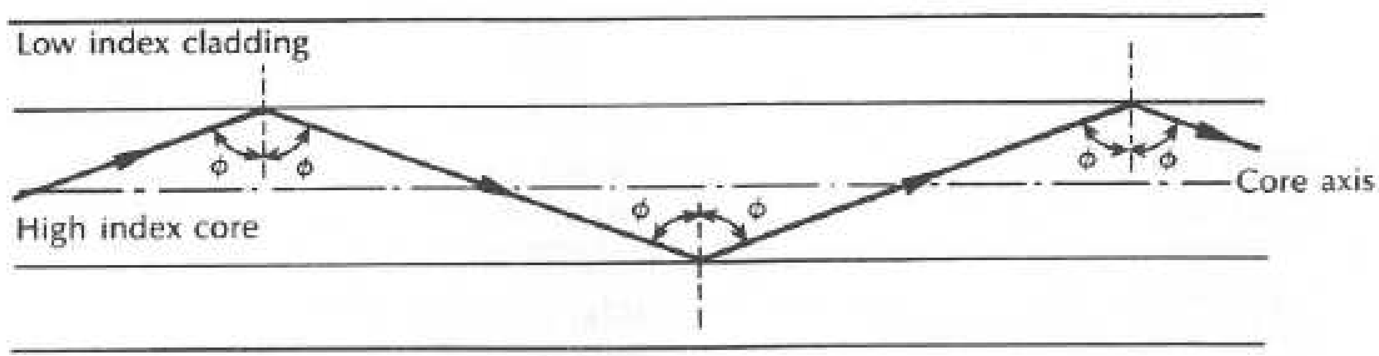
- Core: the inner light-carrying member with a high index of refraction.

- Cladding: the middle layer, which serves to confine the light to the core. It has a lower index of refraction.

- Buffer: the outer layer, which serves as a "shock absorber" to protect the core and cladding from damage. The coating usually comprises one or more coats of a plastic material to protect the fiber from the physical environment. Sometimes metallic sheaths are added to the coating for further physical protection.

3.3.1 Light propagation in an optical fiber

An optical fiber can be described by an cylindrical core surrounded by a cladding. Usually (at least for optical communication) the fiber core and the cladding are made of silica (SiO_2). The refractive index of the core is slightly higher than the refractive index of the cladding so that the light is guided in the fiber.

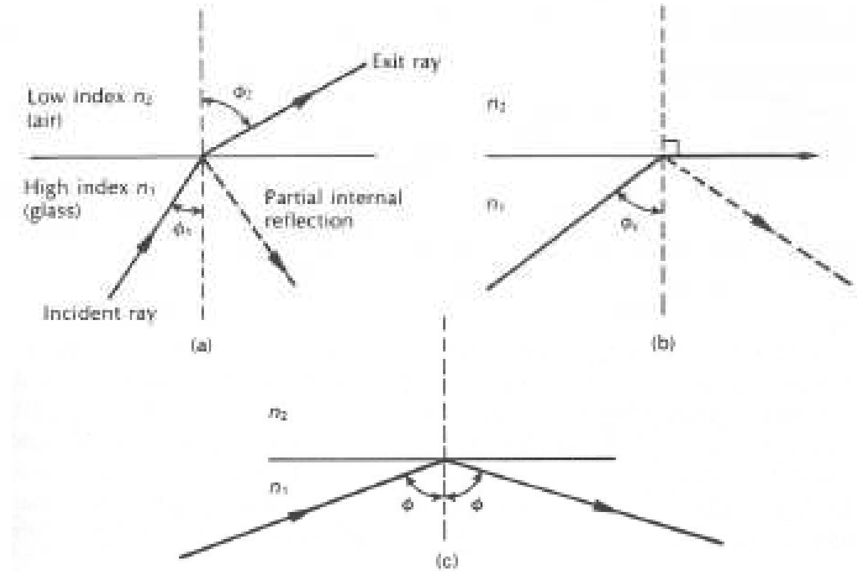


Transmission of a light ray in a perfect optical fiber.

Ref: J.M. Senior, Optical Fiber Communication

3.2 Reflection and Refraction at the Boundary between two Media

The reflection and refraction of light at an interface can be described by Snell's law. The angle of incidence is given by θ_1 which is related to the angle of refraction θ_2.



$$n_1 \cdot \sin\theta_1 = n_2 \cdot \sin\theta_2$$

Snell's law.

Reflection of rays at an interface. (a) From a high to a low refractive medium, (b) The critical angle, (c) Total internal reflection.

Ref: J.M. Senior, Optical Fiber Communication

3.3 Total internal reflection

With increasing angle of incidence θ_1 the angle of refraction θ_2 also increases. If $n_1 > n_2$, there comes a point when $\theta_2 = \pi/2$ radians. This happens when $\theta_1 = \sin^{-1}(n_2 / n_1)$. For larger values of θ_1, there is no refracted ray, and all the energy from the incident ray is reflected. This phenomena is called **total internal reflection**. The smallest angle for which we get total internal reflection is called the critical angle and θ_2 equals $\pi/2$ radians.

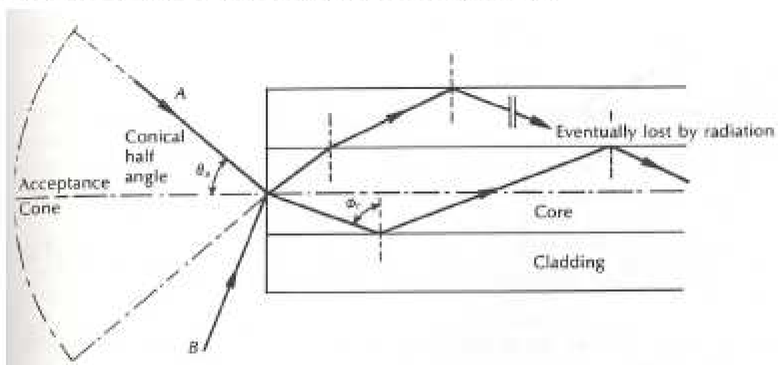
The total internal reflection is an requirement for the guidance of light in an optical fiber.

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

Critical angle

3.3.2 Acceptance angle

Total internal reflection is required to guide light in an optical fiber. We know that only light under sufficient shallow angles (angle greater than the critical angle) can propagate in the fiber. The question is now under what angle a ray can enter a fiber? It is clear that not all rays entering the fiber core will continue to be propagated along the fiber. Only rays that enter the fiber within a acceptance cone (acceptance angle) will propagate along the fiber, whereas rays outside of the cone will not be guided.



Coupling of a ray into a fiber. The ray can only be coupled into the fiber when the angle of incident is within the acceptance cone.

Ref: J.M. Senior, Optical Fiber Communication

3.3.2 Acceptance angle

In the following we will derive an expression for the the acceptance angle from the refractive indices of the three media involved, namely the core of the fiber (n_1), the cladding of the fiber (n_2) and the air (n_0).

In order to enter the fiber Snell's law has to be fulfilled.

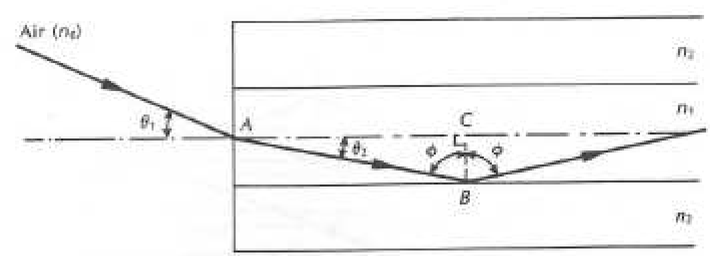
$$n_0 \cdot \sin\theta_1 = n_1 \cdot \sin\theta_2$$

The angle θ_2 can now be described by

$$\theta_2 = \frac{\pi}{2} - \phi$$

So that the Snell's law can be modified to

$$n_0 \cdot \sin\theta_1 = n_1 \cdot \cos\phi$$



Coupling of a ray into a fiber. The ray can only be coupled in the fiber when the angle of incident is within the acceptance cone.

Ref: J.M. Senior, Optical Fiber Communication

3.3.2 Acceptance angle

If we consider now the trigonometrically relationship

$$\sin^2(\phi) + \cos^2(\phi) = 1$$

The expression can be modified to

$$n_0 \cdot \sin\theta_1 = n_1\sqrt{1 - \sin^2\phi}$$

Now the equation can be combined with the equation for the critical angle

$$\phi = \sin^{-1}(n_2/n_1)$$

Leading to the relationship for the *numerical aperture*

$$NA = n_0 \cdot \sin\theta_1 = \sqrt{n_1^2 - n_2^2}$$

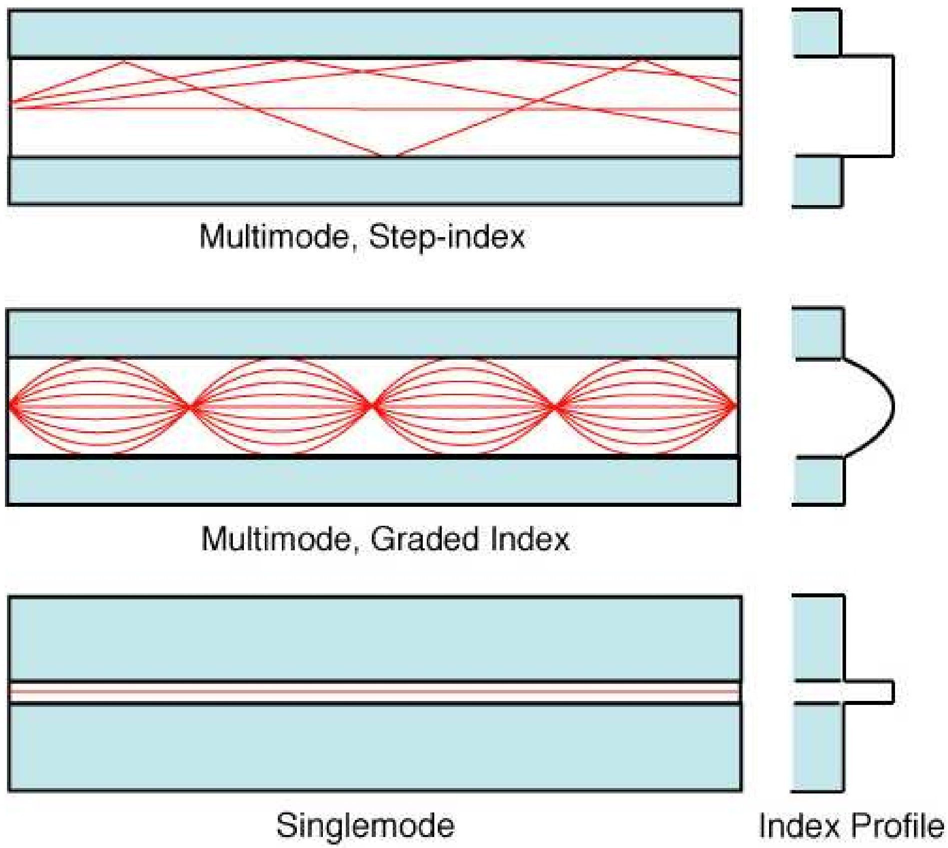
Numerical aperture

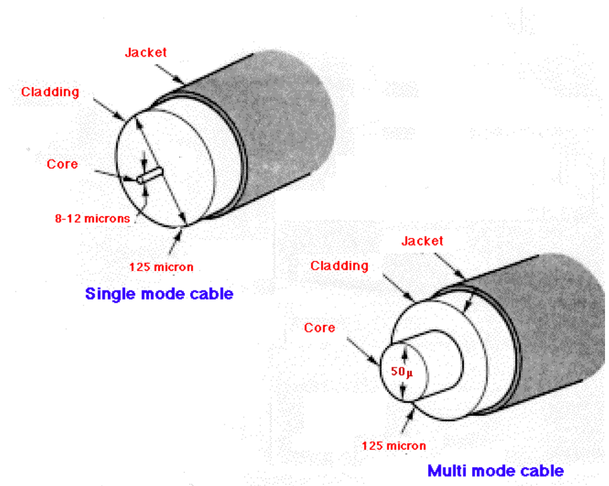
The acceptance angle can now be calculated by

$$\theta_a < \theta_1 = \sin^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right)$$

Acceptance angle

Fiber Types


Multimode, Step-index
Multimode, Graded Index
Singlemode
Index Profile


Jacket
Cladding
Core
8-12 microns
125 micron
Single mode cable
Jacket
Cladding
Core
50μ
125 micron
Multi mode cable

Fiber materials

- Must be possible to draw long, thin flexible fibers
- Must have low loss transmission at the desired wavelength
- Physically compatible materials having slightly different ref indices for core and cladding must be available

Glasses and Plastics

1. Plastic clad glass fibers
2. All plastic fibers

Attenuation

- Signals lose strength as they propagate through the fiber. This is known as beam attenuation.

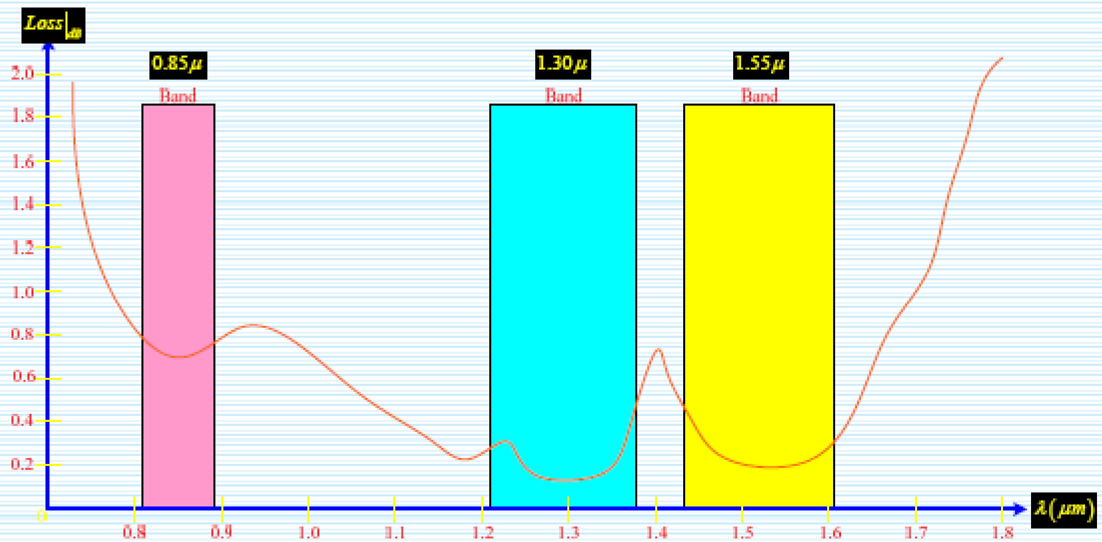
Attenuation is measured in decibels (dB).

$A(dB) = 10 \log_{10}(P_{in}/P_{out})$

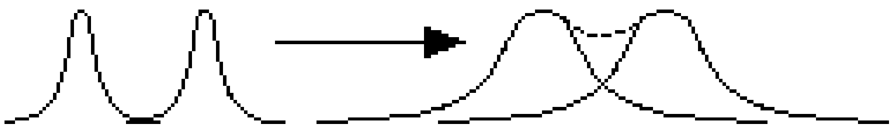
Losses- by scattering, absorption , and coupling losses, bending losses

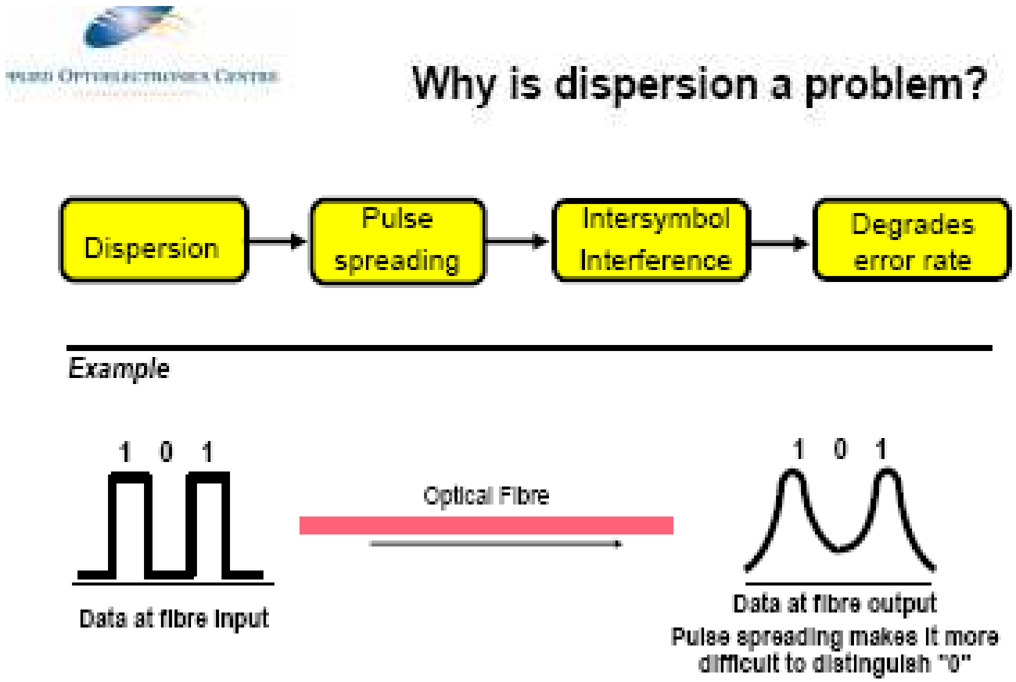
- Three low loss transmission windows exist circa 850, 1320, 1550 nm
- Earliest systems worked at 850 nm, latest systems at 1550.

Losses:



Dispersion




Why is dispersion a problem?
Dispersion
Pulse spreading
Intersymbol Interference
Degrades error rate
Example
1 0 1
Optical Fibre
1 0 1
Data at fibre input
Data at fibre output
Pulse spreading makes it more difficult to distinguish "0"

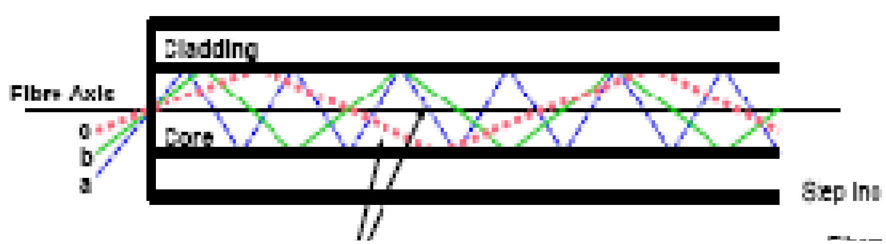
Intermodal dispersion

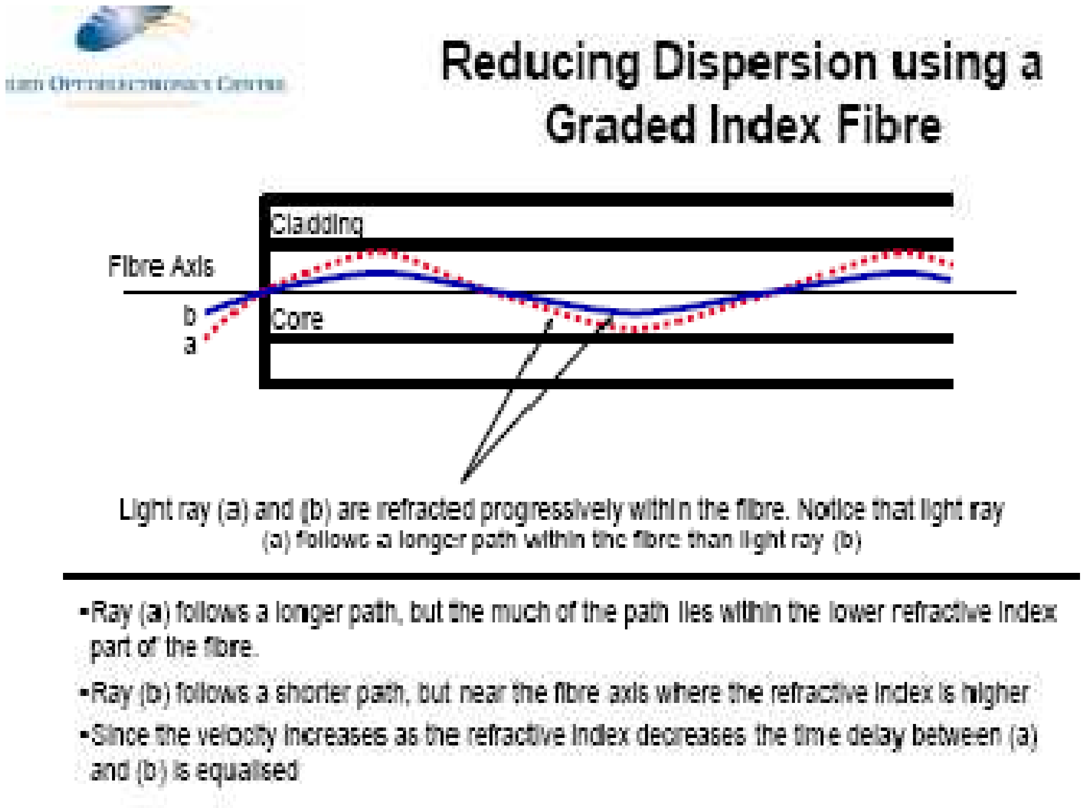
- Each mode in a step-index multimode fiber is associated with a different entrance angle. Each mode therefore travels along a different path through the fiber. Different propagating modes have different group velocities. As an optical pulse travels down a multimode fiber, the pulse begins to spread. Pulses that enter separated from each other will eventually overlap each other. This limits both the bandwidth of a multimode fiber and the distance over which it can transport data.

•Modal dispersion is greatest in multimode step index fibres

•The more modes the greater the modal dispersion

•Typical bandwidth of a step index fibre may be as low as 10 MHz over 1 km





Now, even though rays making larger angles with the axis traverse a larger path length, they do so in a region of lower refractive index (and hence greater speed). The longer path length is almost compensated for by a greater average speed such that all rays take approximately the same amount of time in traversing the fiber

Intramodal dispersion

Any given light source emits over a range of wavelengths, and because of the intrinsic property of the material of the fiber, different wavelengths take different amounts of time to propagate along the same path. This is known as ***material dispersion or chromatic dispersion*** *and obviously,* it is present in both single-mode and multimode fibers.

In single-mode fibers since there is only mode, there is no intermodal dispersion; however, we have what is known as *waveguide dispersion which is due to the* geometry of the fiber. Obviously,waveguide dispersion is present in multimode fibers also, but the effect is very small and can be neglected.

Optical Fiber Sensor

<u>Optical fiber sensor</u>: A sensor that measures a physical quantity based on its modulation on the *intensity*, *spectrum*, *phase*, or *polarization* of light traveling through an optical fiber.

<u>Advantages of optical fiber sensors</u>

- Compact size
- Multi-functional
- Remote accessible
- Multiplexing
- Resistant to harsh environment
- Immunity to electro-magnetic interference

Optical Fiber Sensor Types

Intrinsic: the effect of the measurand on the light being transmitted take place in the fiber

Extrinsic: the fiber carries the light from the source and to the detector, but the modulation occurs outside the fiber

Optical Fiber Sensor Types

- Intensity-based: measure physic measurand based on the intensity of the light detected through the fiber, e.g. fiber break, OTDR

- Interferometric (phase modulation):
  - Fabry-Perot Interferometry

- Grating based (wavelength modulation)
  - Fiber Bragg Grating (FBG)
  - Long Period Fiber Grating (LPFG)