# Fibre optics

**FIBRE OPTICS** **9**

Principle and propagation of light in optical fibres –Numerical aperture and Acceptance angle, Classification of optical fibres (material, mode & refractive index) – Losses in fibres – attenuation, dispersion – Fibre optical communication system (Block diagram) – Active and passive sensors – pressure, strain, displacement.

# Fiber Optics What Is It?

- Fiber Optics are cables that are made of optical fibers that can transmit large amounts of information at the speed of light. (www.dictionary.com)

# 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

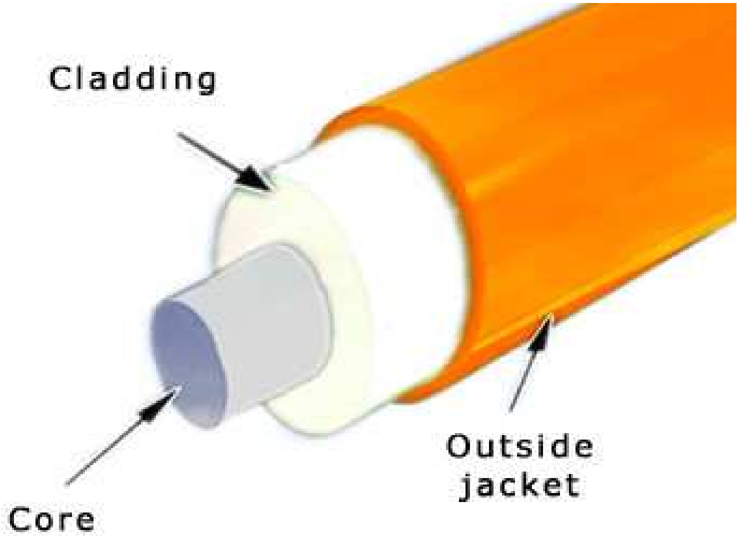
- 1988- First transatlantic cable
- 1996- First transpacific cable
- 1997- First Fiber Optic Link Around the Globe (FLAG)

# Present

- Telecommunications
- Internet Access
- Cable and Satellite Television
- Decorative Light Source

# The Cable

- Fiber Optic have three major characteristics
  - Composed of fibers either glass or plastic and sometimes both
  - Are very flexible
  - Have different types




- Outside Jacket
- Cladding
- Core

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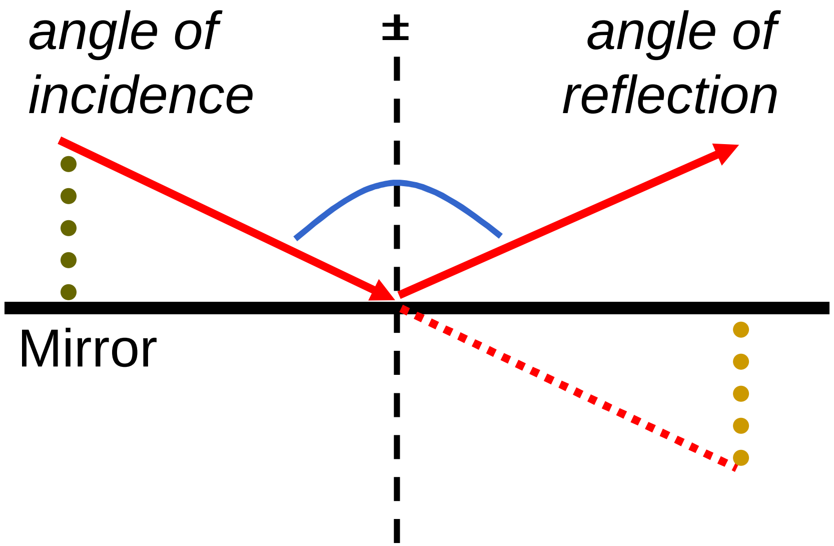
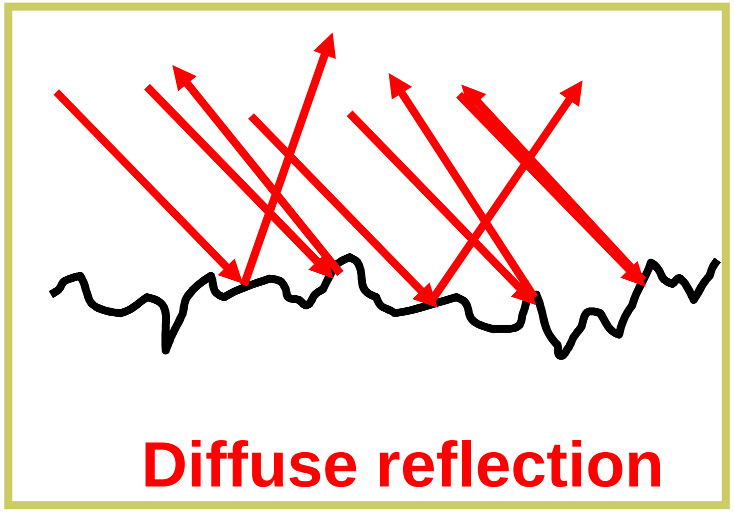
# Reflection

**Law of Reflection:** *When waves are bounced off a smooth surface, the angle of incidence and angle of reflection are the same.*

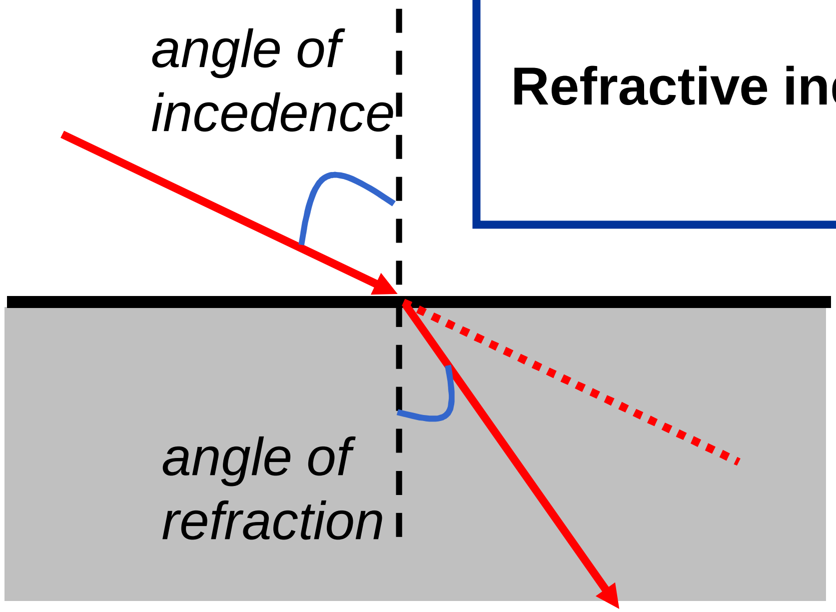



*object distance = image distance*



# Refraction

*When light is travelling through different mediums, it travels at different speeds. When light slows down it appears bent*




**Refractive index (n) =** $\dfrac{\textbf{Speed of light in vacuum}}{\textbf{Speed of light in medium}}$

***Law of Snell:***

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

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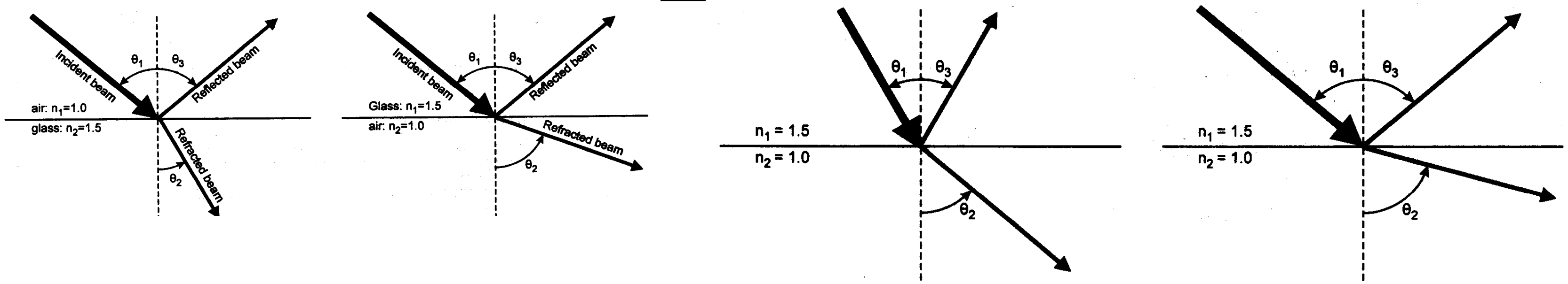
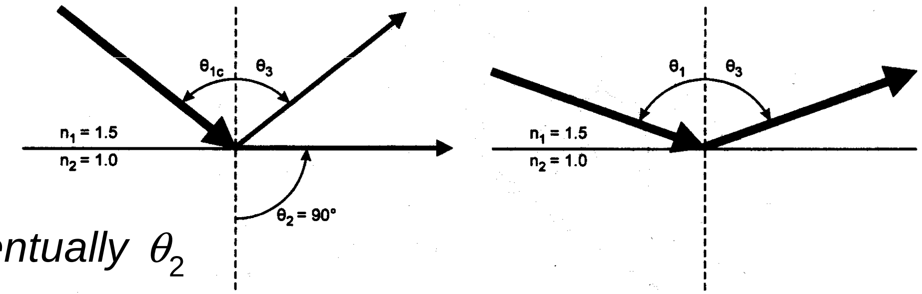
# Total Internal Reflection




*Snells Law* :

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

Re*flection Condition*

$$\theta_1 = \theta_3$$

*When* $n_1 > n_2$ *and as* $\theta_1$ *increases eventually* $\theta_2$ *goes to* 90 degrees *and*

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

$\theta_c$ *is called the Critical angle*

*For* $\theta_1 > \theta_c$ *there is no propagating refracted ray*

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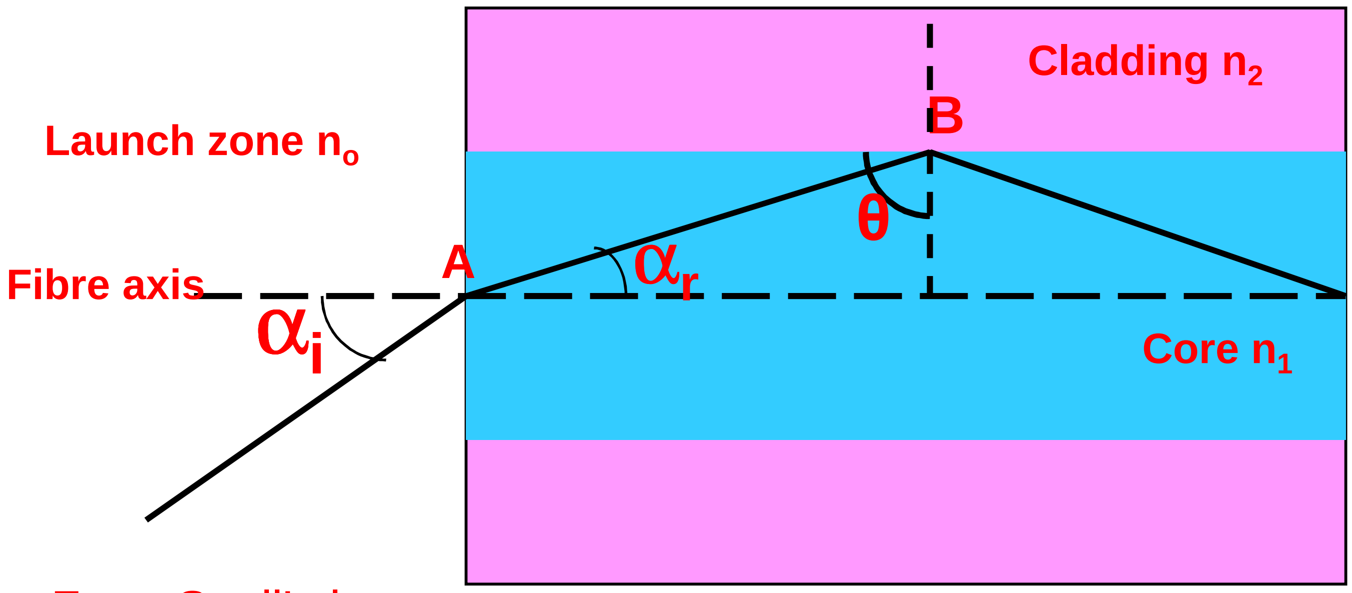



From Snell's law

$$\frac{\sin\alpha_i}{\sin\alpha_r} = \frac{n_1}{n_o}$$

$$\sin\alpha_i = \frac{n_1}{n_o}\sin\alpha_r = \frac{n_1}{n_o}\sin(90-\theta)$$

$$\sin\alpha_i = \frac{n_1}{n_o}\cos\theta$$

$$\sin\alpha_i(\max) = \frac{n_1}{n_o}\cos\theta_c$$

$$\cos\theta_c = \sqrt{1-\sin^2\theta_c}$$

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

$$\sin\alpha_i(\max) = \frac{n_1}{n_o}\frac{\sqrt{n_1^2-n_2^2}}{n_1} = \frac{\sqrt{n_1^2-n_2^2}}{n_o}$$

$$\alpha_i(\max) = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n_o}\right)$$

This maximum angle $\alpha_I$ is called acceptance angle or the acceptance cone angle

Acceptance cone angle can be defined as the maximum angle of launch that a light ray can have with respect to the axis of the fibre at the launch end so that all the rays within this angle propagate through the fibre by total internal reflection.

Light collecting capacity of the fibre is expressed in terms of acceptance angle using the terminology Numerical aperture.

Sine of the maximum acceptance angle is called the numerical aperture (NA) of the fibre.

$$NA = \sin\alpha_i(\max) = \frac{\sqrt{n_1^2 - n_2^2}}{n_o}$$

For most of the fibres $n_1 \cong n_2$

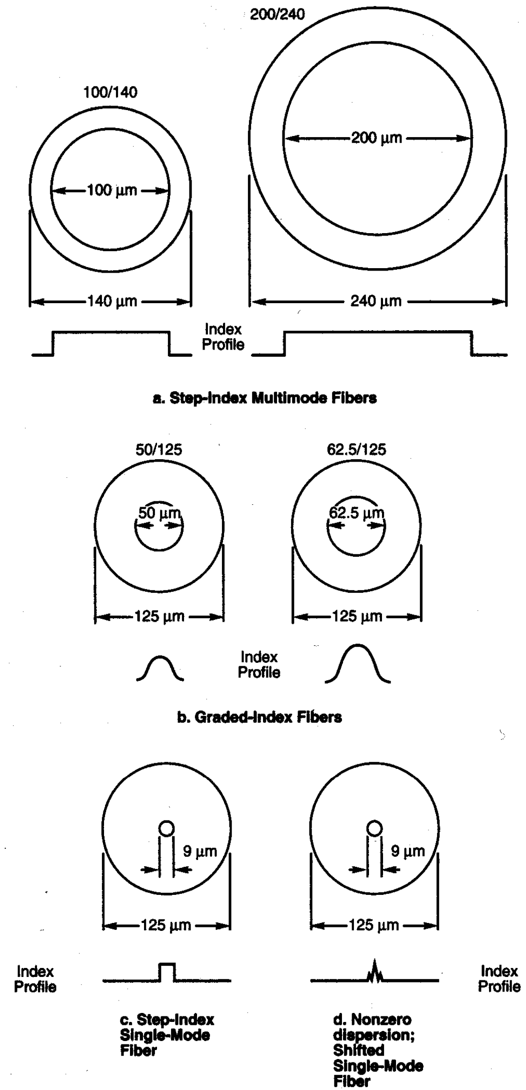
$$\Delta = \frac{(n_1 - n_2)}{n_1}$$

$$n_1^2 - n_2^2 = (n_1 - n_2)(n_1 + n_2) = 2n_1(n_1 - n_2) = \frac{2n_1^2(n_1 - n_2)}{n_1}$$

$$n_1^2 - n_2^2 = 2n_1^2\Delta \qquad \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}$$

$$NA = \frac{n_1\sqrt{2\Delta}}{n_o}$$

# Principal Types of Optical Fiber




**Types of Fibers**

- **Single mode/Multi-mode**
- **Step Index/Graded Index**
- **Silica/fluoride/Other materials**

# Losses in fibres

The power of the light at the output end is found to be always less than the power launched at the input end. The loss is found to be a function of fibre material, wavelength of light and length of fibre

**Mechanisms:**

**Bending loss**

**Absorption**

**Scattering loss**

**dBm refers to a ratio**

**with respect to a**

**signal of 1 mW**

# Bending Loss

**Example bending loss**

1 turn at 32 mm diameter causes 0.5 db loss

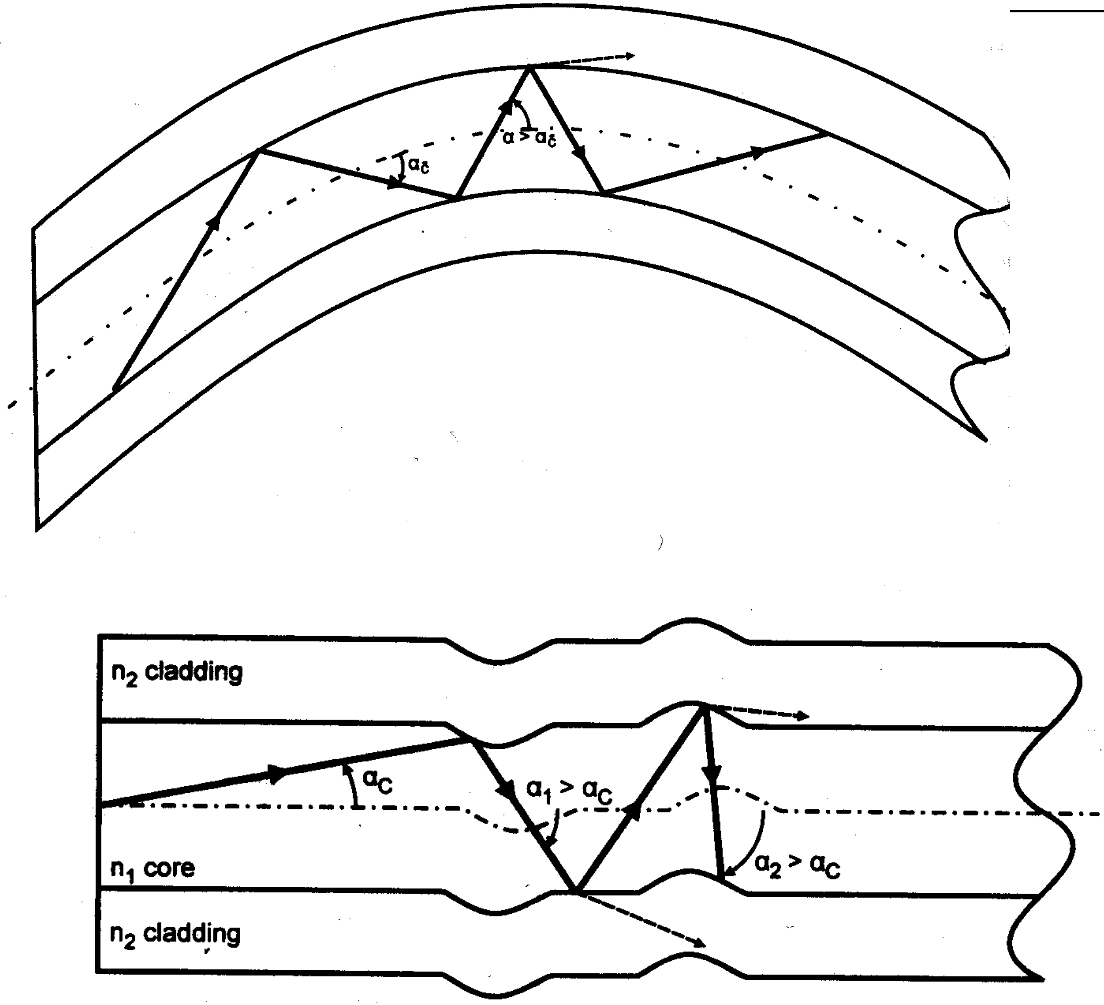
Index profile can be adjusted to reduce loss but this degrades the fibers other characteristics

This loss is ***mode dependent***

Can be used in attenuators, mode filters fiber identifier, fiber tap, fusion splicing

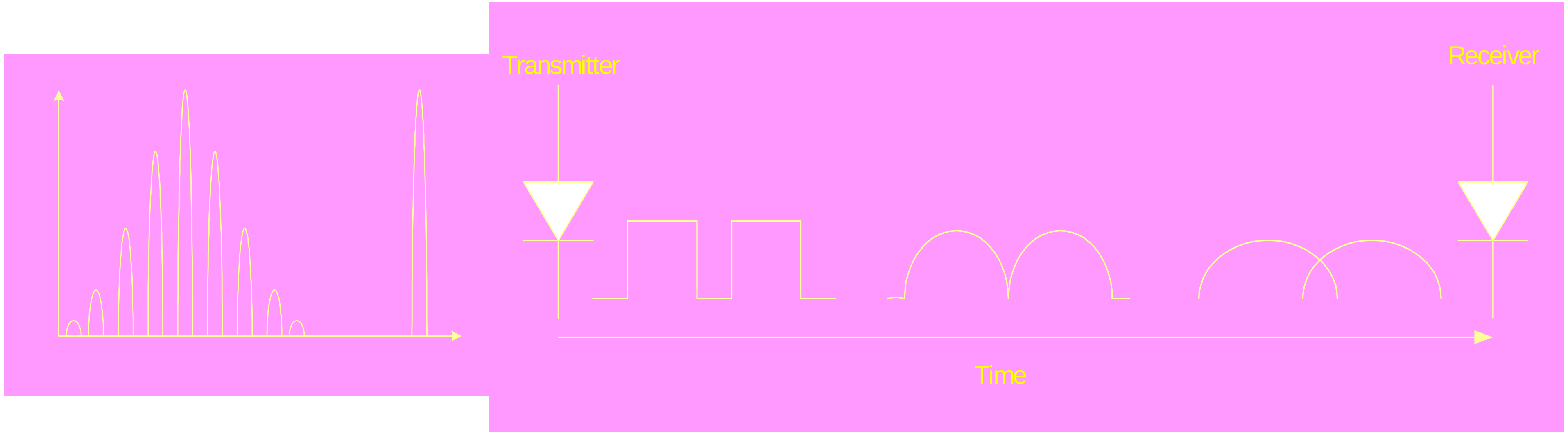
**Microbending loss**

Property of fiber, under control of fabricator, now very small, usually included in the total attenuation numbers



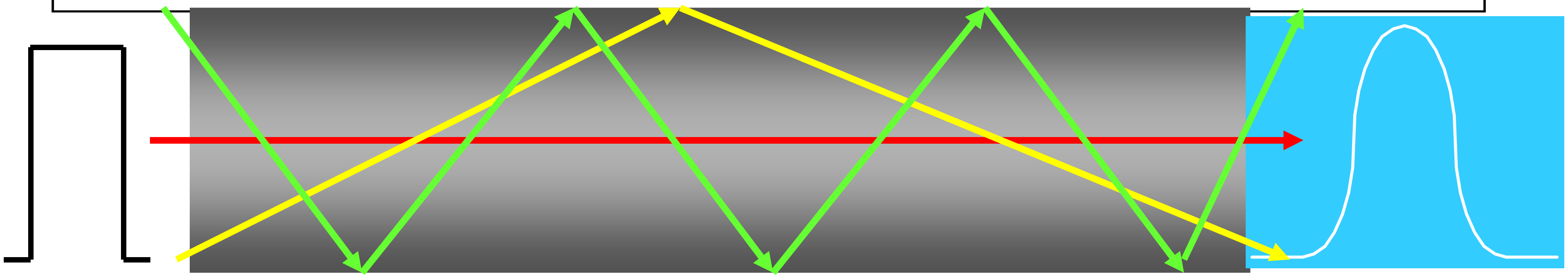

Fiber Optics Communication Technology-Mynbaev & Scheiner

# Dispersion - Single-Mode



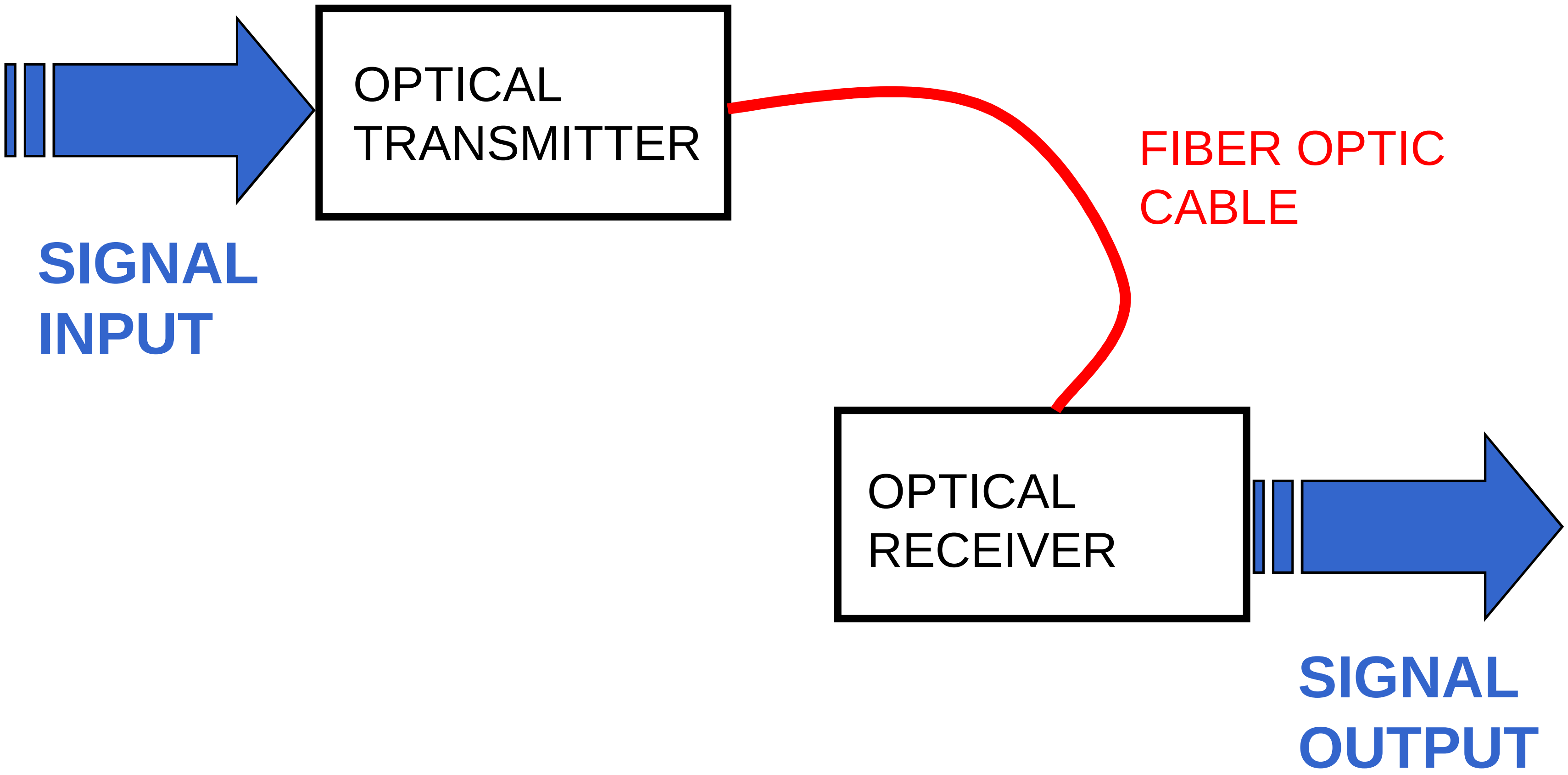

- FP and DFB lasers have finite spectral widths and transmit multiple wavelengths
- Different wavelengths travel at different speeds over fiber
- A pulse of light spreads as it travels through an optical fiber eventually overlapping the neighboring pulse
- Narrower sources (e.g DFB vs. FP) yield less dispersion
- Issue at high rates (>1Ghz) for longer distances (>50Km)

# Dispersion - Multi-Mode Fiber



- Modal Dispersion
- The larger the core of the fiber, the more rays can propagate making the dispersion more noticeable
- Dispersion determines the distance a signal can travel on a multi mode fiber

# Basic Fiber Optic Transmission System



# Operation of the fibre optic system

- In a fibre optic system, there are a few major components to perform the task of communication.
- The Input Modulator is needed; this modulates the incoming signal with a light beam.
- A light emitting device is used; it can be either a light emitting diode (LED) or a semiconductor laser diode.
- A fibre optic cable is used as a transportation medium.
- A fibre optic system converts an electrical signal to an infrared light signal, and then transmits the signal onto an optical fibre.
- An Output Modulator is used to separate the signal from the light beam.
- Special connectors must be used to couple the light from the source to the fibre and from the fibre to the detector.

# Advantages and Disadvantages

**ADVANTAGES**

- Fibre optic cables have a much greater bandwidth than metal cables.
- Fibre optic cable is less susceptible to signal degradation than copper wire.
- Fibre optic cables weigh less than a copper wire cable.
- Data can be transmitted digitally.
- Lower-power transmitters can be used instead of the high-voltage electrical transmitters used for copper wires.
- Unlike electrical signals in copper wires, light signals from one fibre do not interfere with those of other fibres in the same cable.
- Because no electricity is passed through optical cable it is non-flammable, and immune to lightning.
- Impossible to tap into a fibre optics cable, making it more secure

# Advantages and Disadvantages

## DISADVANTAGES

- Fibre optics are that the cables are expensive to install.
- The termination of a fibre optics cable is complex and requires special tools.
- They are more fragile than coaxial cable.

# FIBER OPTIC SENSORS

- DEVICE WHICH CONVERTS ANY FORM OF SIGNAL INTO OPTICAL SIGNAL IN MEASURABLE FORM
- OPTICAL FIBER ARE USED AS GUIDING MEDIA AND HENCE CALLED AS WAVE GUIDES
- OPTICAL SOURCE IS LED / LASER

# TYPES OF SENSORS

- THERE ARE TWO TYPES OF SENSORS.THEY ARE:

1. INTRINSIC OR ACTIVE SENSORS
2. EXTRINSIC OR PASSIVE SENSORS

# ACTIVE SENSOR

- THE PHYSICAL PARAMETER TO BE SENSED DIRECTLY ACTS ON FIBER ITSELF TO PRODUCE CHANGE IN TRANSMISSION CHARACTERESTICS
- Eg: TEMPERATURE / PRESSURE SENSORS

# PASSIVE SENSORS

- IN THIS TYPE OF SENSORS, SEPARATE SENSING ELEMENT IS USED
- OPTICAL FIBER ACTS AS GUIDING MEDIA
- Eg: DISPLACEMENT SENSOR

## ENGG. APPLICATIONS

- COMMUNICATIONS:
  - LONG DISTANCE COMMUNICATIONS
  - CAN HANDLE MORE THAN 1000 OF VOICE CHANNELS
  - USED IN SIGNALLING

## COMPUTER NETWORKS

- USED IN LAN – EACH SYSTEM IS CONNECTED TO REST BY OPTICAL WRITING SCHEME CALLED BUS TOPOLOGY.FOR THIS OPTICAL FIBERS ARE BACK BONE
- USED IN CONNECTING SYSTEM TO PRINTER
- USED IN SIGNAL TRANSMISSION IN MULTIBEAM RADARS