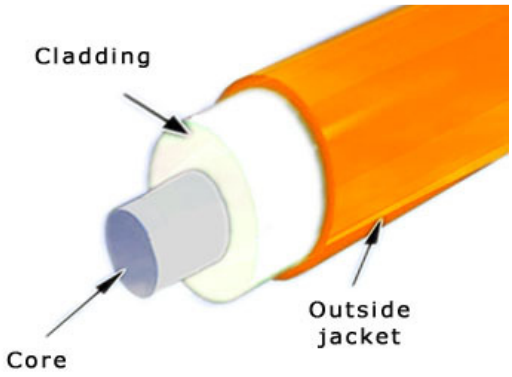
UNIT – III
FIBRE OPTICS

Introduction

Optical fibre is a wave guide which transmits light signals without any loss of energy. The principle involved in optical fibre is total internal reflection.



Critical angle

When a light signal transmitted from a denser medium to a rarer medium, the angle above which the total internal reflection takes place is called as critical angle

$$\theta_C = sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Acceptance angle

The maximum angle below which a light ray enter into an optical fibre and still total internally reflected back into the same medium is called as acceptance angle.

$\theta_0 = \sin^{-1} NA$

Numerical aperture

The light gathering capacity of a fibre is called as numerical aperture also it can be defined as sine of acceptance angle.

$NA = \sin\theta_0$

Propagation of a light ray along an optical fibre

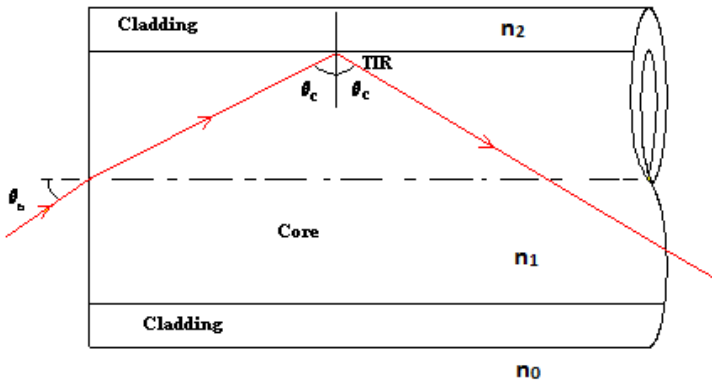
Let us consider a light ray enter into the optical fibre at an angle θ_0 and refracted into the core at an angle θ_1. The refracted ray extends to incident on the core cladding interface at an angle $(90 - \theta_1)$.

$n_0 \sin\theta_0 = n_1 \sin\theta_1$ $\qquad$ $n_0 \sin\theta_0 = n_1\sqrt{1-\cos^2\theta_1}$

$n_2 \sin 90° = n_1 \sin(90-\theta_1)$ $\qquad$ $\cos\theta_1 = \dfrac{n_2}{n_1}$

$n_0 \sin\theta_0 = n_1\sqrt{1-\dfrac{n_2^2}{n_1^2}}$ $\qquad$ $\sin\theta_0 = \dfrac{\sqrt{n_1^2-n_2^2}}{n_0}$

$\theta_0 = \sin^{-1} NA$



Fractional index change or relative refractive index

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

Types of optical fibres:

It can be classified based on three categories material, mode and refractive index.

Based on material

Based on material it can be classified as glass and plastic fibre. The glass fibres are made up of mixed metal oxides with silicon dioxide.

1. Glass /glass fibres (glass core with glass cladding)
2. Plastic/plastic fibres (plastic core with plastic cladding)
3. PCS fibres (polymer clad silica)

Ex. $GeO_2 – SiO_2$ – core, $P_2O_3 – SiO_2$ cladding

Based on modes

Single mode fibre

If only one light mode is transmitted through the fibre then it is called as step index fibre.

It has a small core diameter of the order of 5 – 10 μm. The numerical aperture value is low so laser source alone can be used for illumination of optical fibre.

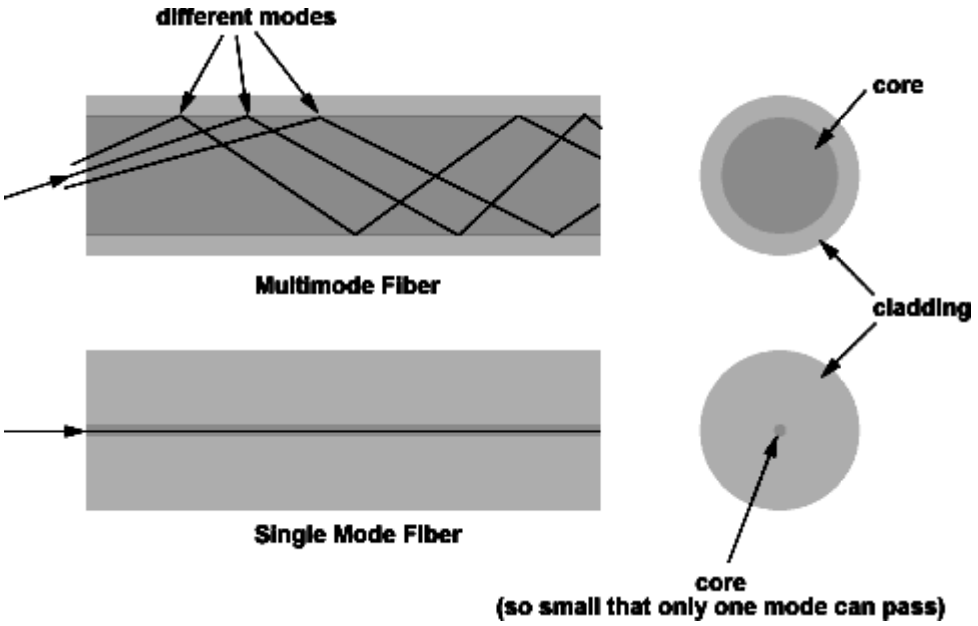
Advantages: there is no intermodal dispersion takes place, bandwidth is high, used for long range communication

Multimode fibre

Here the light signal is transmitted in more than one light modes which means the light ray enter at many angles.

It has large core diameter of the order of 125 – 200 μm. The numerical aperture value is high so LED source can be used for illumination of optical fibre.

Disadvantages: there is intermodal dispersion takes place; bandwidth is low; used for short range communication alone.



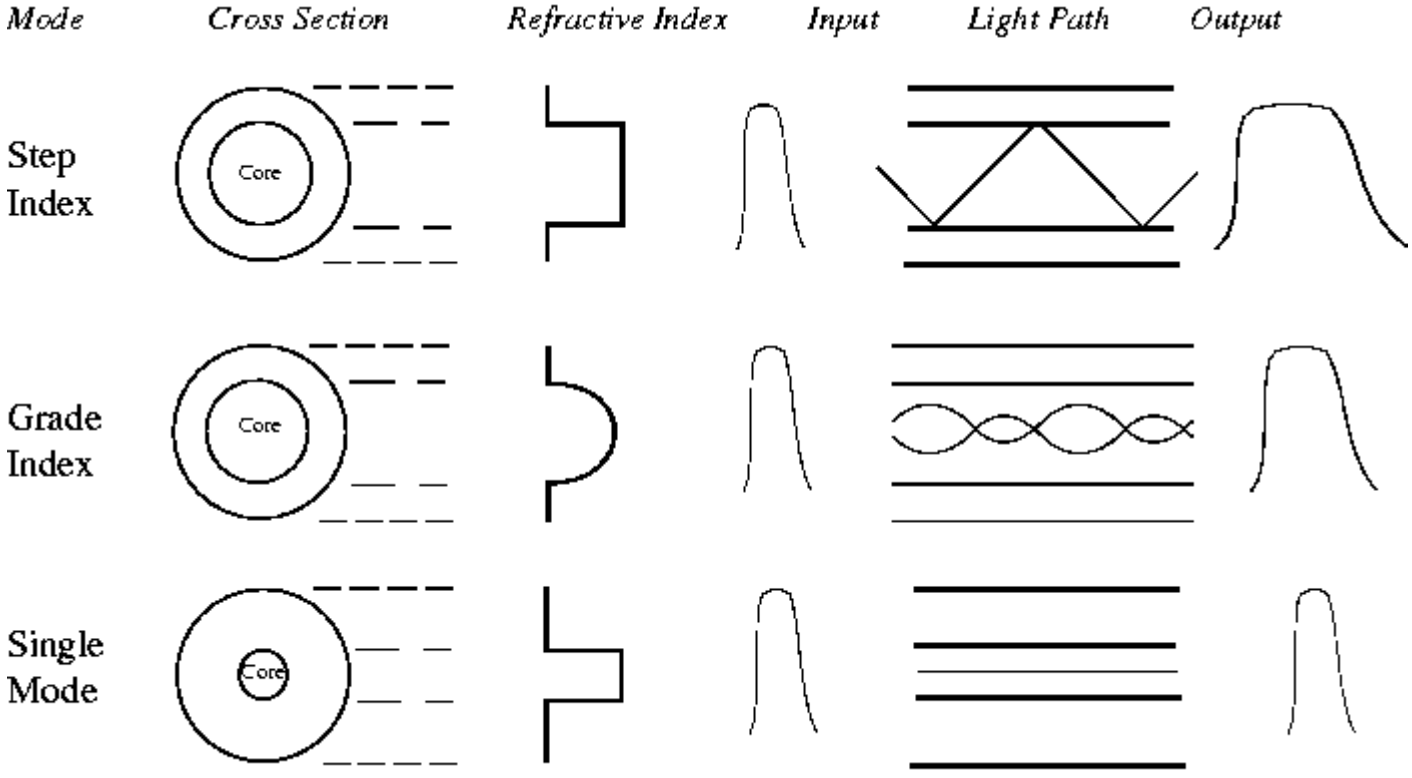
Based on refractive index

Step index fibre

It the core, cladding and air medium refractive indices decreases stepwise then it is called as step index fibre.

Graded index fibre

If the core refractive indices decreases gradually and the cladding and air medium decreases step wise then it is graded index fibre.



Step index single mode fibre

Characteristics

- It has small core diameter
- NA is low
- Laser source can be used

- Very high bandwidth
- Least attenuation

Advantages

- No degradation of signal
- Highly suited for communication
- Low dispersion loss

Disadvantages

- Manufacturing and handling is more difficult
- The fibre is costlier
- Coupling is difficult

Step index multimode fibre

Characteristics

- It has large core diameter
- NA is high
- LED or Laser source can be used
- Low bandwidth
- High attenuation

Advantages

- Less expensive
- LED can be used as source
- Easier to couple with other fibre

Disadvantages

- Has smaller bandwidth
- High attenuation due to intermodal dispersion
- Used for short range communication alone

Graded index multimode fibre

Characteristics

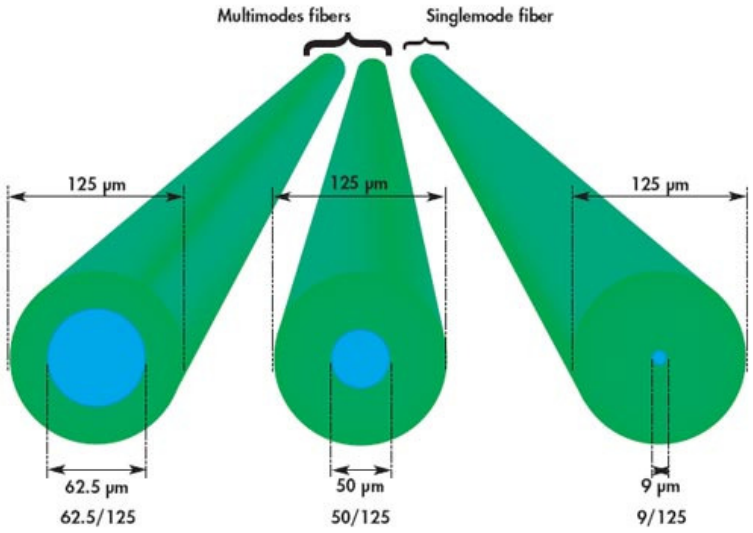
- It has small core diameter
- NA is intermediate
- LED or Laser source can be used
- Intermediate bandwidth
- Intermediate attenuation

Advantages

- Intermodal dispersion can be minimized
- LED or laser can be used

Disadvantages

- Manufacture graded index fibre is more complex.
- Coupling is difficult

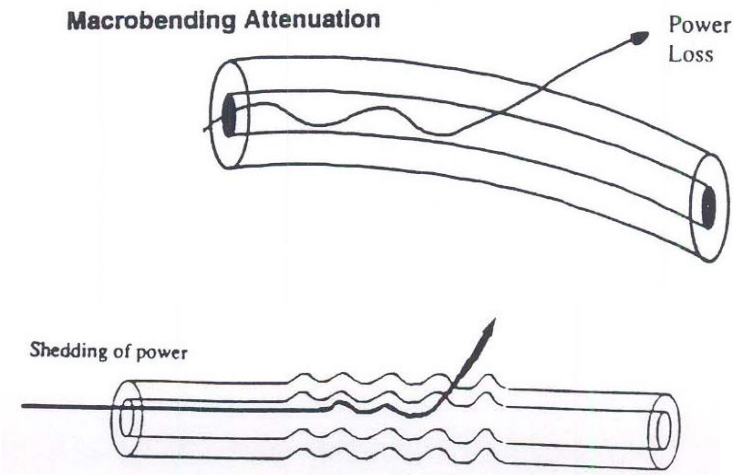


Fibre optic losses

Optical fibre losses can be measured in decibel per km. $\alpha = \frac{10}{L}\log\frac{P_{in}}{P_{out}} dB/km$

Types of losses

1. **Absorption losses** – intrinsic absorption (parent material of fibre absorb light signals), extrinsic absorption (foreign impurities absorb light signal), defect absorption (defects like void spaces etc absorb light signal)
2. **Scattering losses** – local variation in density of the fibre leads to a loss called scattering loss
3. **Bending losses** – macro bending, if the whole fibre is bend during communication leads to bending loss. Micro bending, if the fibre has bendings in the core cladding interface which may be formed during manufacturing



4. **Dispersion losses** – pulse broadening takes place during various modes of transmission

Waveguide dispersion

Wave guide dispersion occurs due to the guiding properties of the fibre. It is mainly due to the angle between the ray and the fibre axis varying with wavelength which subsequently leads to a variation in the transmission times for the rays and hence dispersion.

Chromatic dispersion

A light pulse is a wave packet, composed of group of components of different wavelengths. The different wavelength components will propagate at different speeds along the fibre. The short wavelength components travel slower than long wavelength components, eventually causing the light pulse to broaden. This type of distortion is known as material dispersion or chromatic dispersion.

Intermodal dispersion

Intermodal dispersion occurs as a result of the differences in the group velocities of the modes. The lower order modes (rays reflected at larger angles) travel a greater distance than the higher order modes (lower angle rays). Due to the variation in path length of the rays give rise to dispersion called as intermodal dispersion.

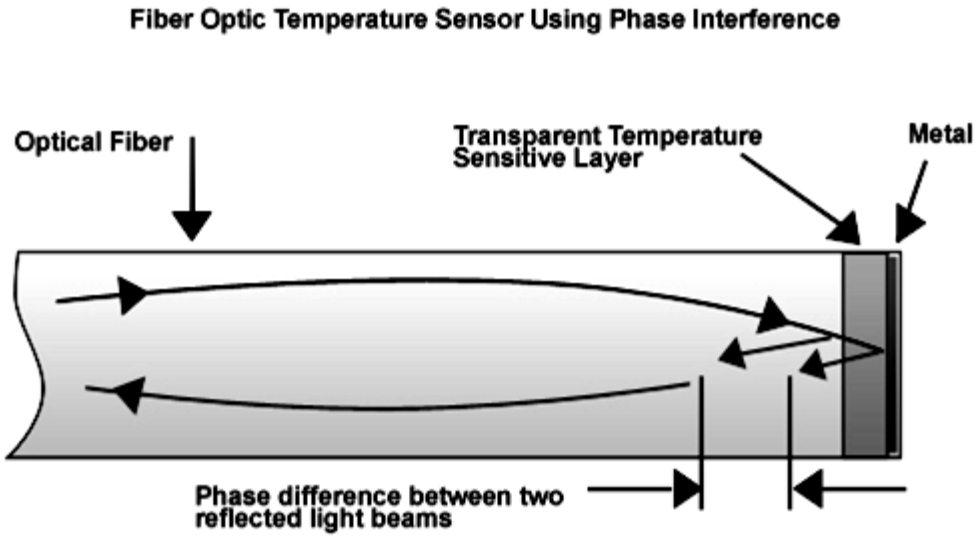
Temperature sensor

Optical fibre can be used as fibre optic sensor. It can used to measure the temperature in a medium. It consist of two fibre coupled to a single fibre.

One fibre transmits the light radiation from source to the silicon layer present in the optical fibre. Another transmits the reflected radiation from the silicon layer to the detector.

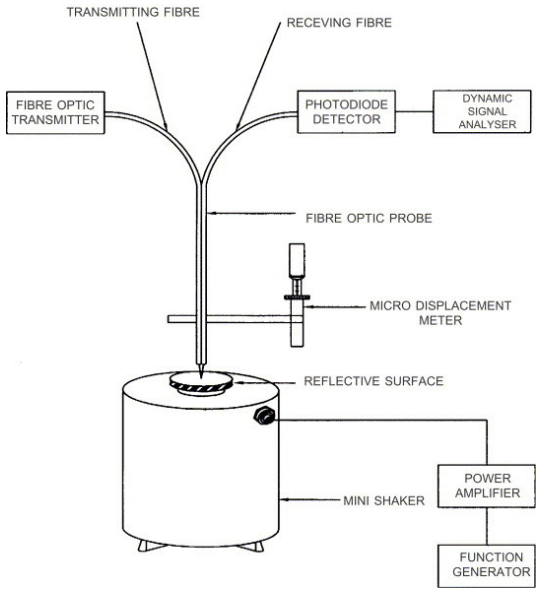
Silicon has a capacity to show variation in absorption of light signal with respect to heating effect.

Thus the reflected intensity varies with respect to heating so it can be measured directly.



Displacement sensor

It consists of two fibre as given in the diagram. The first fibre act as waveguide which transmit the light radiation to illuminate the target and the second fibre receive the reflected radiation from the target. The reflected radiation is sensed using a photodiode which in turn measures the displacement.

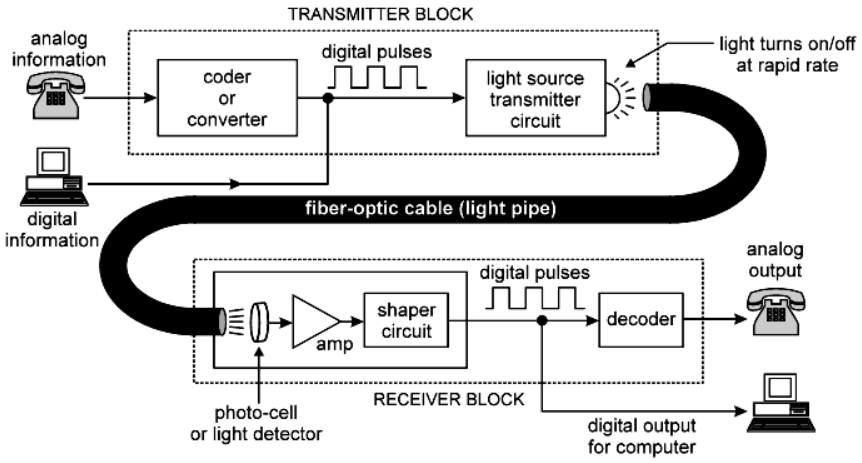


Fibre optic communication system

The optical fibre communication consists of two main regions called transmitting region and receiving region in between the optical fibre serves as wave guide.

The analog signal from the source is sent to the transmitting region where it is converted to digital signal using the AD converter and the light pulse is emitted from the laser source depending on the digital input it receives.

The light pulse is then transmitted through the optical fibre and is received at the receiving region using a photo diode and is then amplified and converted to analog signal using a DA converter.



Endoscopy

Optical fibre along with laser can be used for doing blood less operation or minimum blood loss operation by a method called endoscopy and the apparatus used is called as endoscope

Construction

It consist of thousands of optical fibre bundles where the outer set of fibres transmit light rays to the inner organs and the inner set of fibres takes the reflected light to the screen through detector. Also it consists of lens and prism setup to have better focus on the defect organs and to receive the reflected light pulse from the organs.

Working

The outer fibres are illuminated using a laser source and the light pulses are transmitted to the internal organ which is then reflected to the fibre through the lens arrangement. The light rays are collected by the inner fibre set and it is detected by a photodiode which is then fed to screen through which the operation is done.

To insert the fibre and instruments and for sending some medicine three holes are punched on the body to avoid maximum blood loss. It is a very effective technique where the defect region alone is targeted.