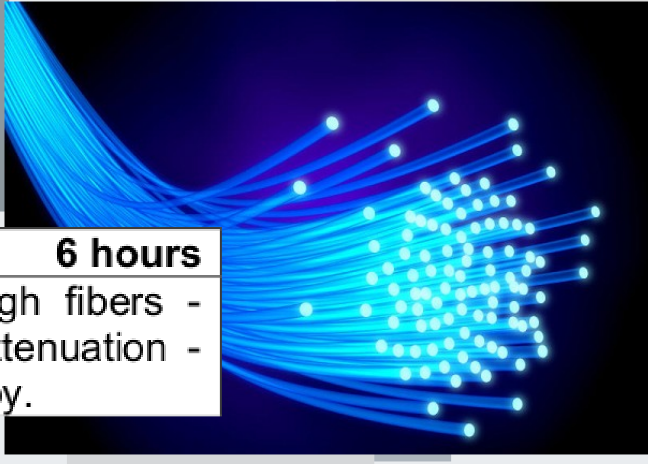
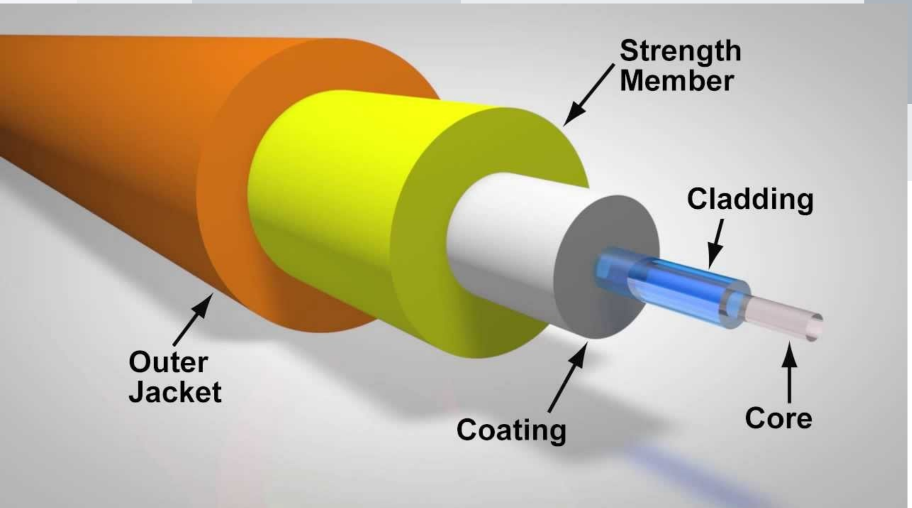
Module – 6



Module:6	Propagation of EM waves in optical fibers	6 hours
Introduction to optical fiber communication system - light propagation through fibers - Acceptance angle - Numerical aperture - V-parameter - Types of fibers – Attenuation - Dispersion-intermodal and intramodal. Application of fiber in medicine - Endoscopy.		

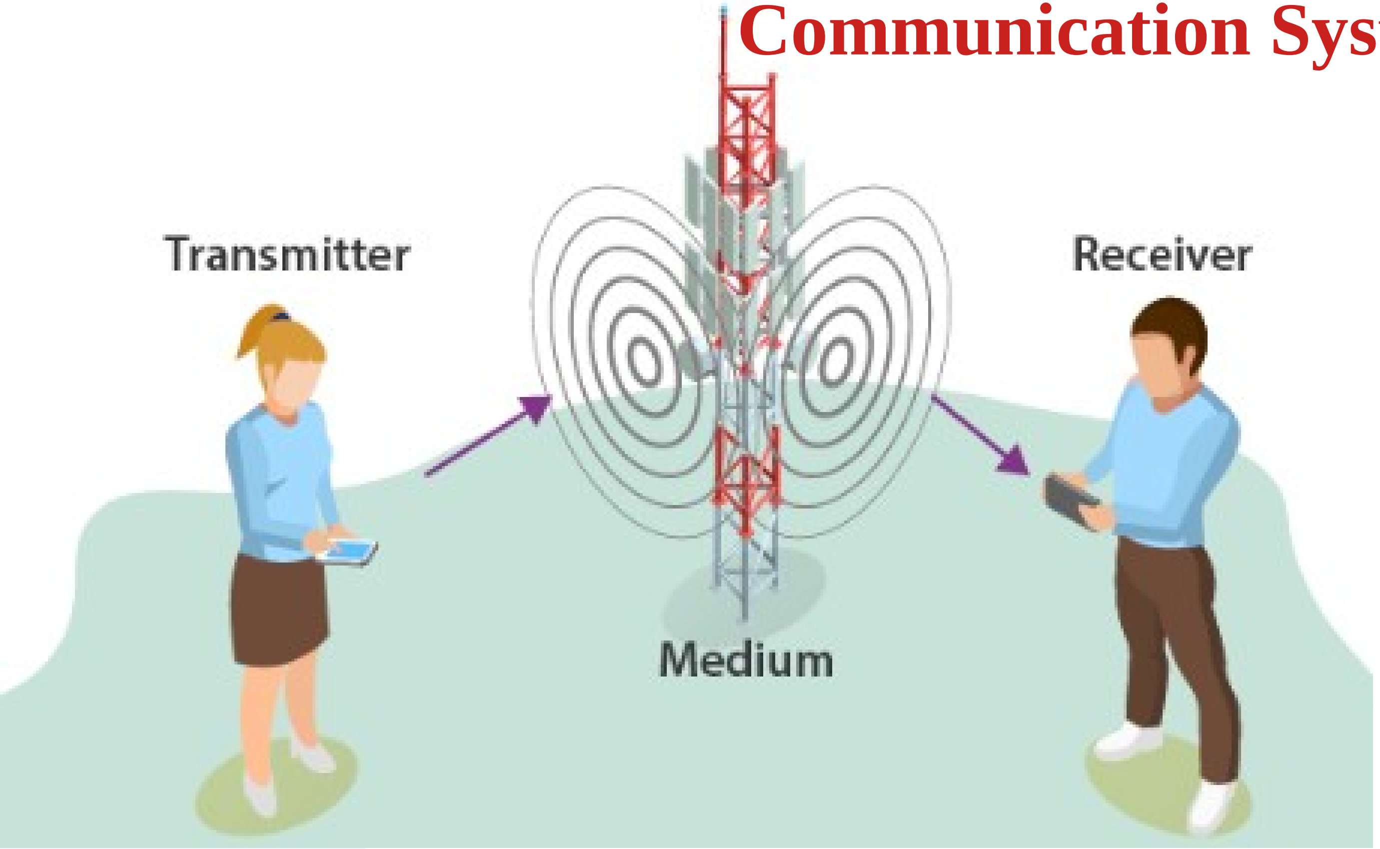
Book:

D. K. Mynbaev and Lowell L. Scheiner, Fiber Optic Communication Technology, 2011, 1st Edition, Pearson, USA



Dr. Pankaj Sheoran
SAS

Communication System

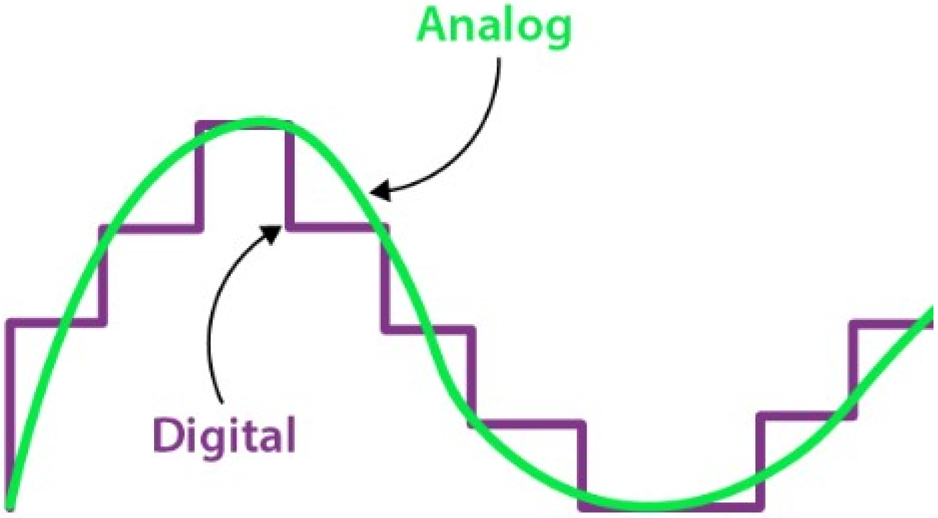


A **communication system** is a system that **specifies the exchange of information between two sites.** Communication refers to the process of transmitting and receiving information. The **primary components of communication** are the *information transmitter*, the *channel or medium of communication*, and *the information receiver*.

The **communication system is categorised** as follows based on **signal specifications** or **technology**:

(1) **Analog:** Analog technology communicates data as *electronic signals of varying frequency or amplitude*. Analog technology is commonly seen in broadcast and telephone communication.

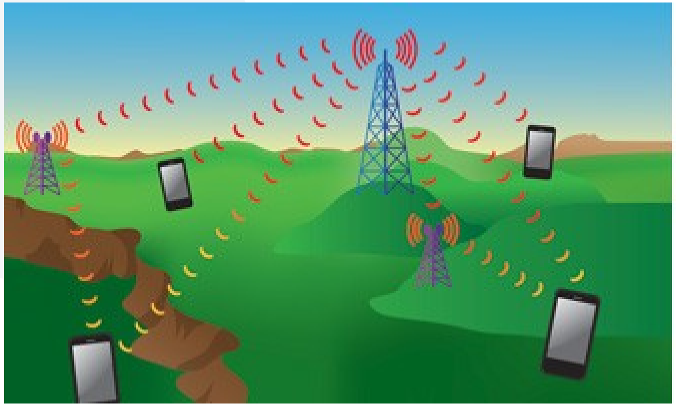
(2) **Digital:** In digital technology, *data is created and processed in two states: **high (expressed as 1) and low (represented as 2)***. (represented as 0). Data in the form of 1s and 0s is stored and transmitted using digital technology.

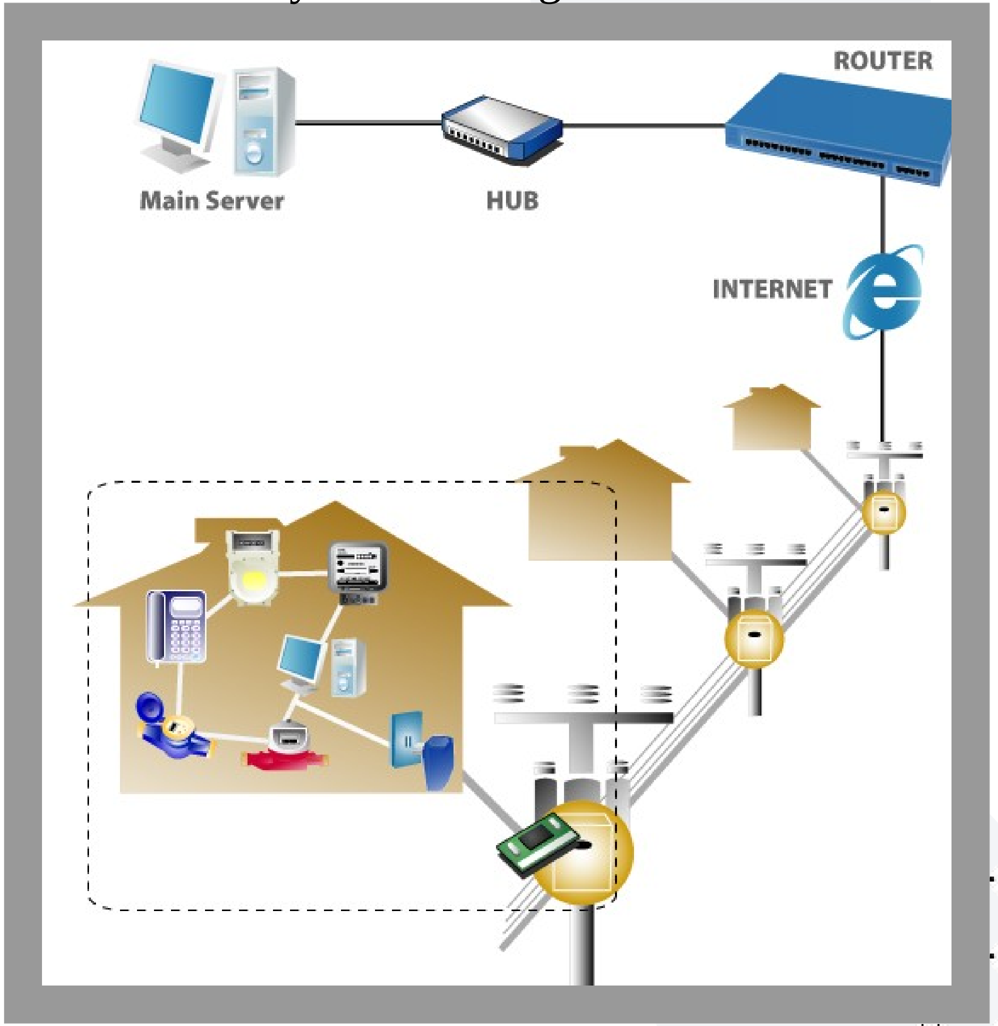


Depending on the communication channel, the communication system is categorized as follows:

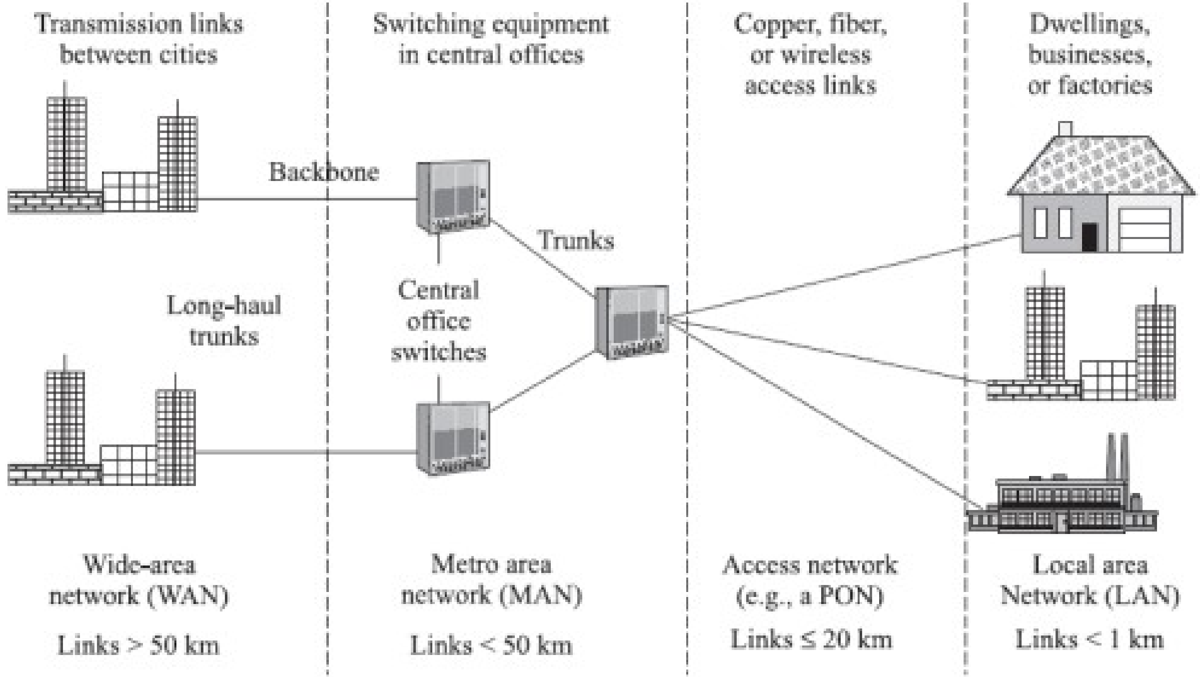
1. Wired (Line communication)
- Parallel wire communication
- Twisted wire communication
- Coaxial cable communication
- Optical fibre communication

2. Wireless (Space communication)
- Ground wave communication
- Skywave communication
- Space wave communication
- Satellite communication



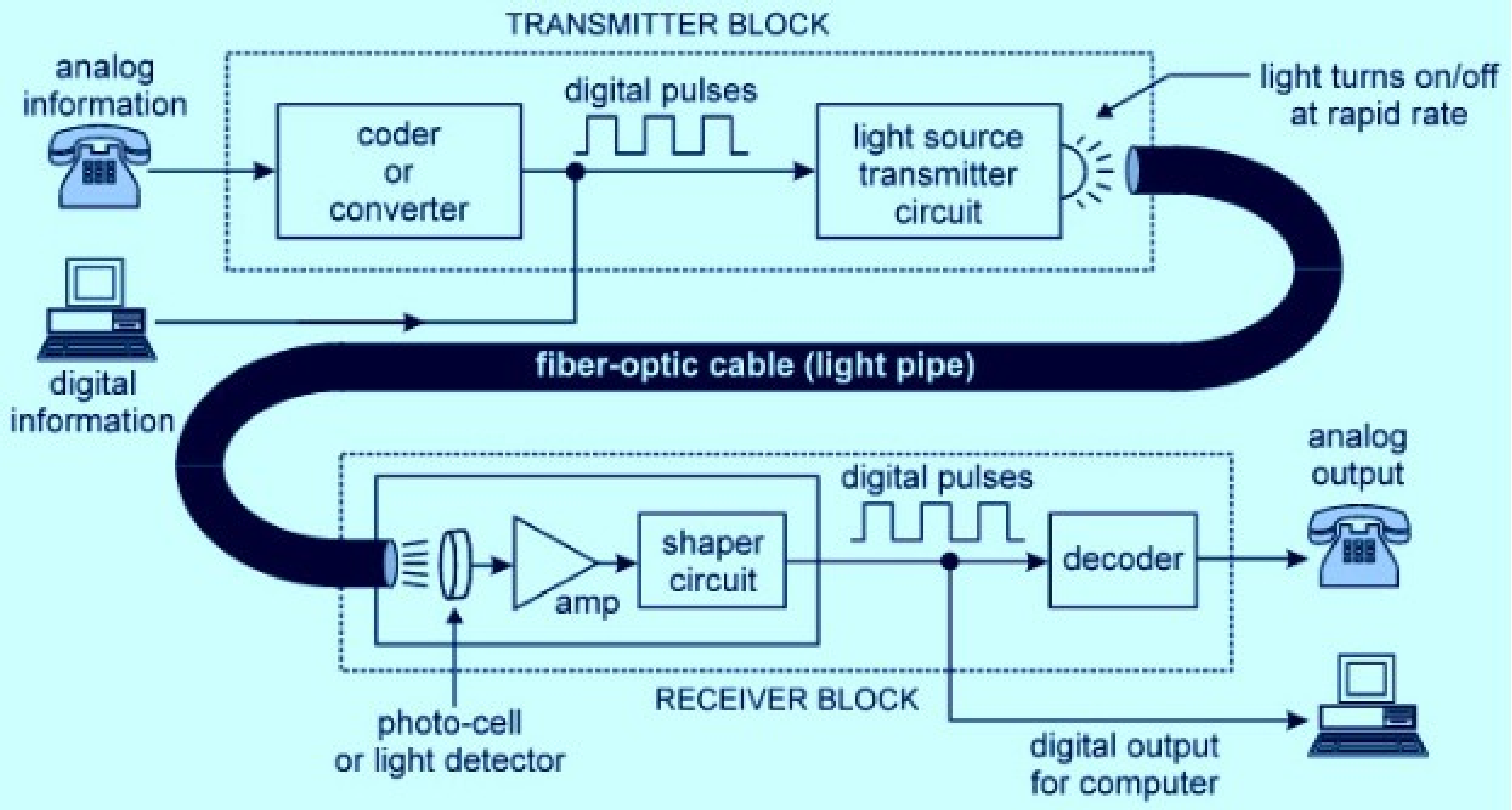


Communication system Network



By combining both LAN/MAN and fiber optic applications, colleges, universities, and businesses can obtain an almost endless stream of information daily. Companies can also use both of these to increase productivity while providing a convenient, safe environment for their employees and customers.

FIBER OPTIC COMMUNICATION SYSTEM



Optical Fiber

An optical fiber is a flexible and transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of human hair, which can transmit light for a long distance by the principle of total internal reflection.

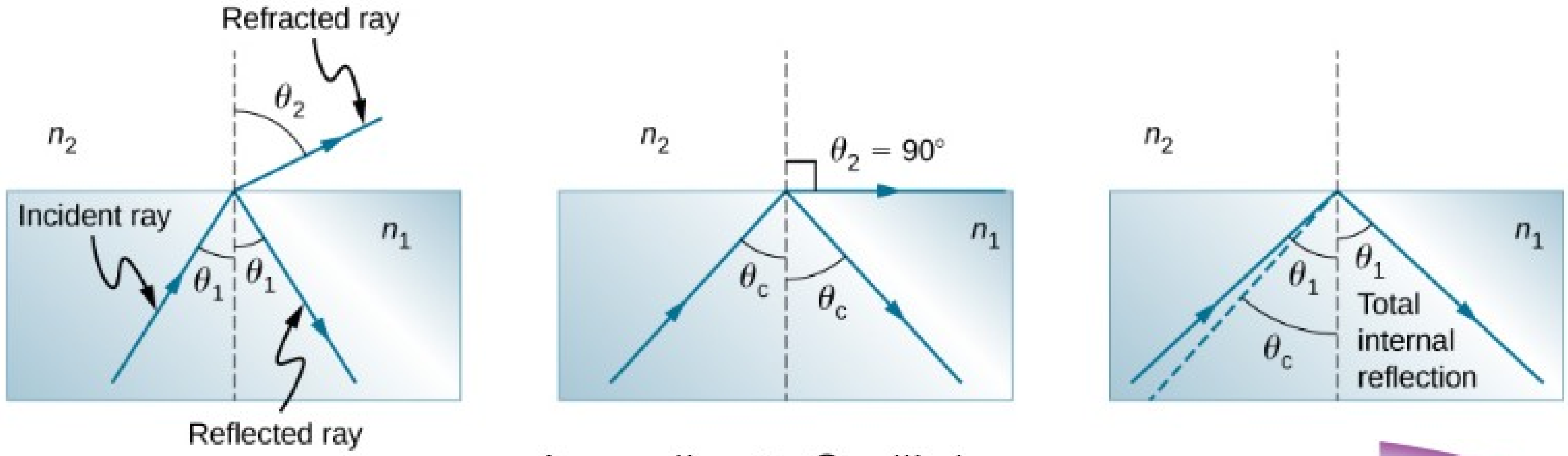
Or

A cylindrical waveguide made of transparent dielectric (glass/clear plastic) which guides light wave along its length by total internal reflection

The significance of optical fibers is:

- Transmit data signals over large distances
- With higher speed and bandwidth than other mediums
- Used to provide internet, telephone, and TV services,
- Made up of glass and plastic, optical fibers **(hence, non-condutive and light weight)**
- Not affected by electromagnetic interference when they transmit data.

Working Principle (Total Internal Reflection)



n_2-Rare Medium

n_1-Denser Medium

$n_1 > n_2$

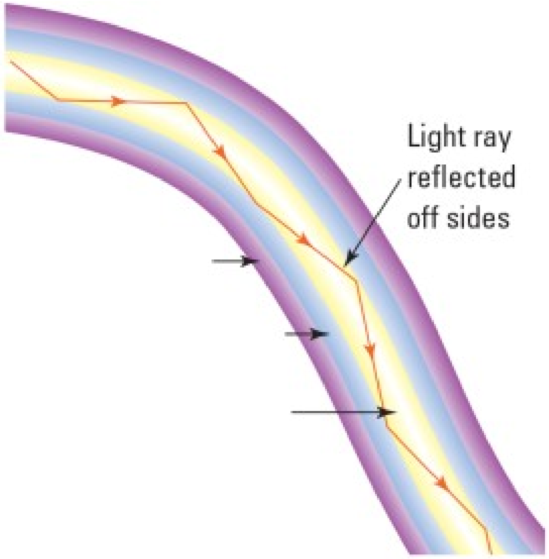
According to Snell's law

$$\Rightarrow n_1 \, Sin\theta_1 = n_2 \, Sin\theta_2$$

At critical angle, $\theta_2 = 90^0$

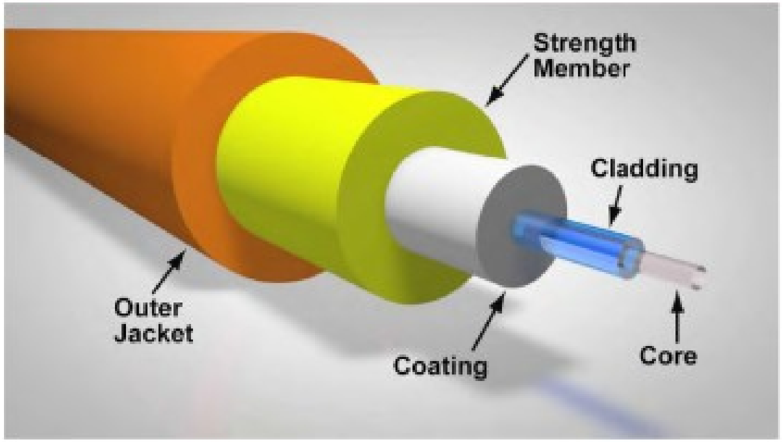
$$\Rightarrow n_1 \, Sin\theta_1 = n_2$$

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



Light must travel from Denser medium to rare medium to have IR

Structure of the Optical fiber



The main components of optical fiber:

- Core (D:10-100 µm)
- Cladding (D:100-400 µm)
- Outer coating

- The transparent **core is surrounded by *cladding*.**
- The cladding has a **lower *refractive index* than the core**. i.e
- This allows the light in the core to experience total internal reflection.
- The jacket surrounds the combination for mechanical strength and support.

$$\boxed{\begin{array}{c} n_{Core} > n_{Cladding} \\ \theta_i > \theta_c \end{array}}$$

Materials used in Optical Fiber

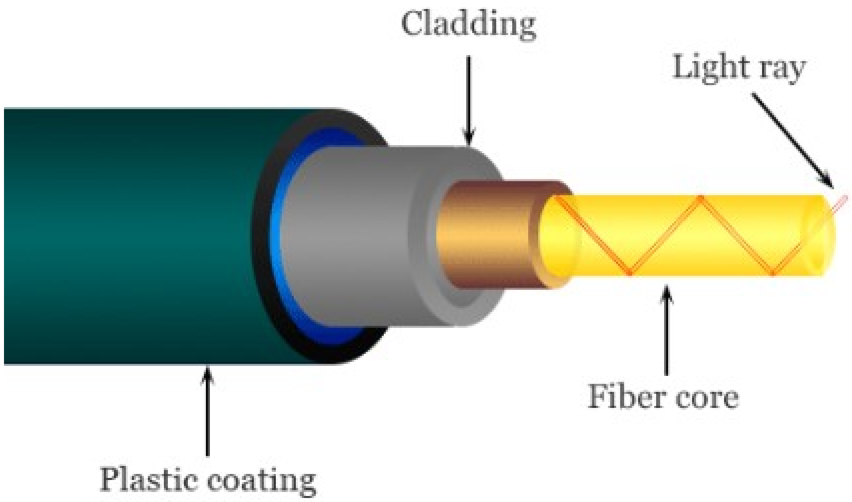
In terms of the materials used, optical fibres are **divided into two categories**:

1)**Glass fiber:**

- **Core:** SiO_2, **Cladding:** SiO_2
- **Core:** $GeO_2 - SiO_2$, **Cladding:** SiO_2

1)**Plastic fiber:**

- **Core:** Polystyrene, **Cladding:** Methyl Methacrylate
- **Core:** Polymethyl Methacrylate, **Cladding:** Co-Polymer



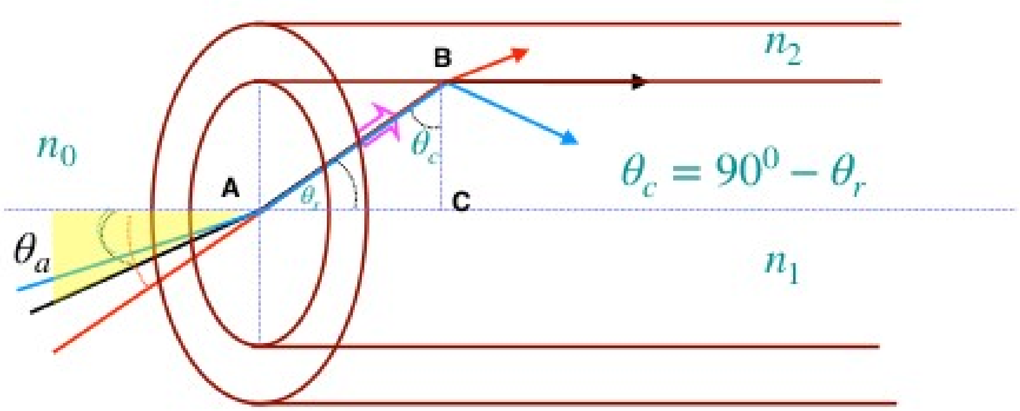
Applicaions include:

•Medical examination of internal organs

•Telecommunications

Acceptance angle in Optical Fibre

Acceptance angle of an optical fiber is the maximum incidence angle of a light ray which can be used for injecting light into a fiber core or waveguide



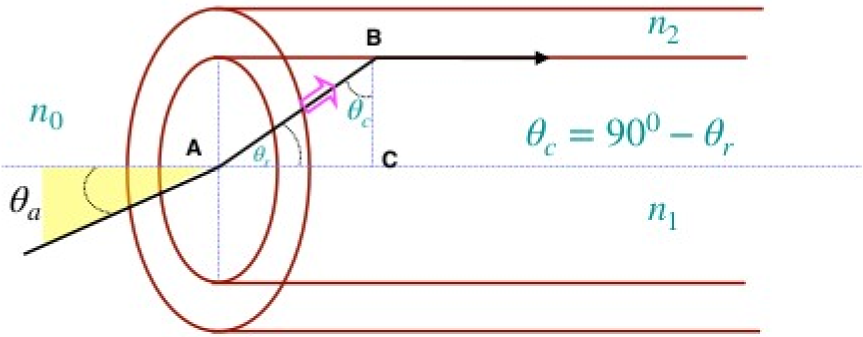
$\Rightarrow \theta_i = \theta_a \quad \Rightarrow$ light will be guided

$\Rightarrow \theta_i < \theta_a \quad \Rightarrow$ light will be guided by TIR

$\Rightarrow \theta_i > \theta_a \quad \Rightarrow$ loss of light

Acceptance angle in Optical Fibre cont'd...

$$\theta_{i_{max}} = \theta_a \text{ and } \theta_c = 90 - \theta_r$$



Applying snell's law at point **A**

$$\Rightarrow \frac{Sin\ \theta_a}{Sin\ \theta_r} = \frac{n_1}{n_0}$$

$$\Rightarrow \frac{Sin\ \theta_a}{Sin\ (90^0 - \theta_c)} = \frac{n_1}{n_0}$$

$$\Rightarrow \frac{Sin\ \theta_a}{Cos\theta_c} = \frac{n_1}{n_0}$$

$$\Rightarrow Sin\ \theta_a = Cos\theta_c \frac{n_1}{n_0} \ldots\ldots (a)$$

Applying snell's law at point **B**

$$\Rightarrow \frac{Sin\ \theta_c}{Sin\ r} = \frac{n_2}{n_1} \quad \Rightarrow \frac{Sin\ \theta_c}{Sin\ 90^0} = \frac{n_2}{n_1} \quad \Rightarrow Sin\ \theta_c = \frac{n_2}{n_1}$$

from equation-a

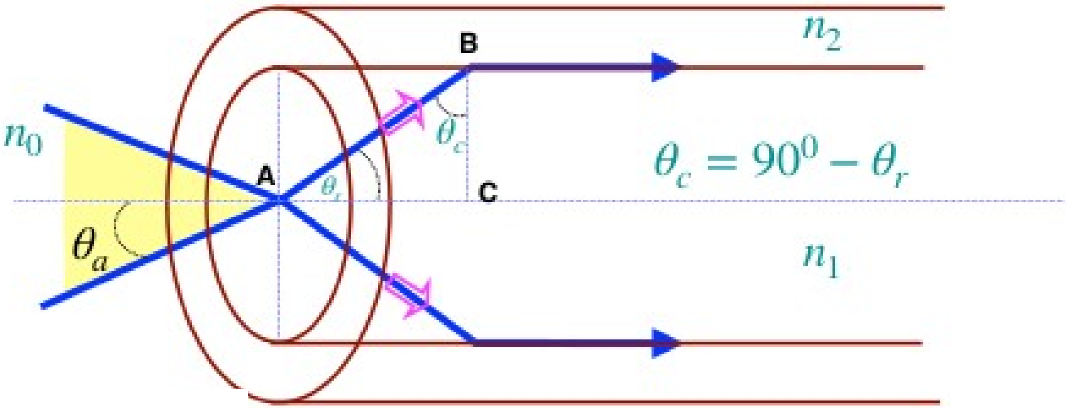
$$Sin\ \theta_a = Cos\theta_c \frac{n_1}{n_0} \quad \Rightarrow \quad Sin\ \theta_a = \sqrt{(1 - Sin^2\theta_c)}\ \frac{n_1}{n_0}$$

using Snell's law from point B

$$Sin\ \theta_a = \sqrt{\left(1 - \frac{n_2^2}{n_1^2}\right)}\ \frac{n_1}{n_0} \quad \Rightarrow \quad \boxed{Sin\ \theta_a = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_0}}$$

Numerical Aperture (NA) of Optical Fibre

The **Numerical Aperture (NA)** of Optical Fibre is defined as the **sine of the largest angle an incident (i.e. $\theta_{i_{max}} = \theta_a$) ray** can have for total internal reflectance in the core.



$$Sin\ \theta_a = \sqrt{\left(1 - \frac{n_2^2}{n_1^2}\right)}\ \frac{n_1}{n_0} \Rightarrow Sin\ \theta_a = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_0}$$

For, $n_0 = 1$, assuming the light travel from air

$$\Rightarrow NA = Sin\ \theta_a = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_0}$$

$$\boxed{NA = Sin\ \theta_a = \sqrt{n_1^2 - n_2^2}}$$

NA depends on the RI of core and cladding only.

Relative Refractive Index/ Fractional Refractive Index

Is defined as the **ratio** of the refractive index difference in **core (n1)** and **cladding (n2)** ***to the refractive index of the core (n1)***.

$$\Delta = \frac{RI_{core} - RI_{cladding}}{RI_{Core}}$$

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

To guide light rays effectively through a fiber, $\Delta \ll 1$ and Δ is of the order of 0.01

Relation b/w NA and Relative Refractive Index

$$NA = Sin\ \theta_a = \sqrt{n_1^2 - n_2^2}$$

$$\Rightarrow NA = \sqrt{(n_1 + n_2)\ (n_1 - n_2)}$$

$$\Rightarrow NA = \sqrt{\frac{n_1(n_1 - n_2)(n_1 + n_2)}{n_1}}$$

$$\Rightarrow NA = \sqrt{n_1\ (n_1 + n_2)\ \Delta}$$

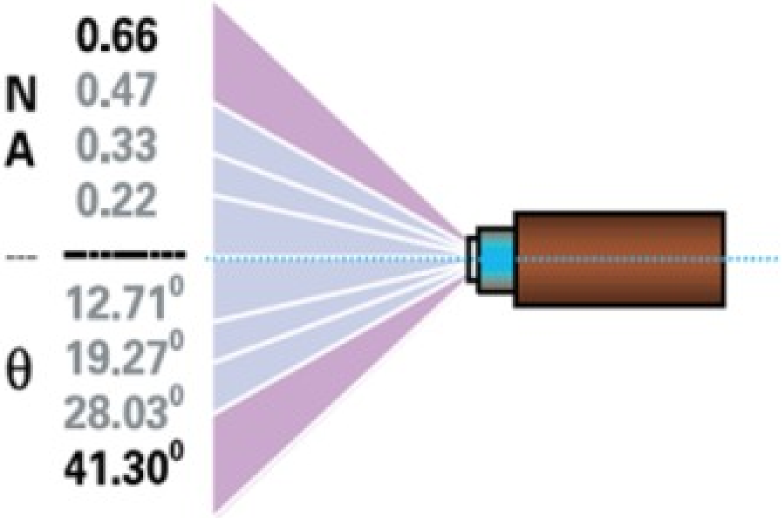
$$\Rightarrow NA = \sqrt{2\ n_1^2\ \Delta}$$

$$n_1 > n_2$$

$$\therefore\ n_1 + n_2 \equiv 2n_1$$

$$\boxed{NA = n_1\sqrt{2\ \Delta}}$$

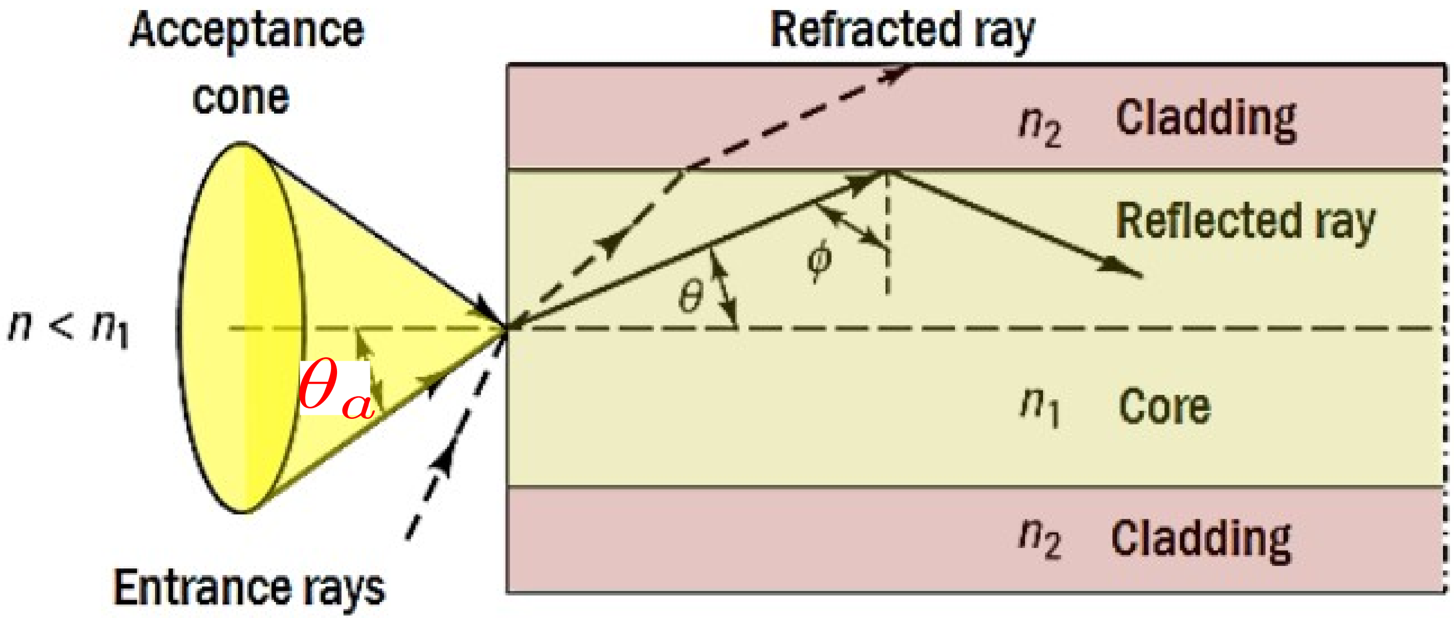
Importance of NA



Numerical aperture determines the **light-gathering ability** of the fiber. *It is a measured amount of light that can be accepted by a fiber.*

Acceptance Cone in Optical Fibre

If we rotate the acceptance angle (θ_a) along the optical axis will form a cone. So the *light incident within this optical cone is going to be guided by the optical fiber.*



V-Parameter in Optical Fiber

V-prameter/V-number determines the ***number of modes supported*** by an ***optical fiber***. An optical fiber is characterized by this important parameter/number and also called as the normalized frequency.

$$\boxed{V = \frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2} = \frac{\pi d}{\lambda} NA}$$

Mathematically Defined as

Where,

d = Diameter of the core

λ = wavelength of light

n_1 = refractive index of core

n_2 = refractive index of cladding

For, V< 2.405, the fiber can support only one mode and is called single-mode fiber (SMF), and if V>2.405, it supports multi modes simultaneously

Sample Numericals

A step-index fiber has a core index of refraction of $n_1 = 1.425$. The cut-off angle for light entering the fiber from the air is found to be 8.5^0.

(a) What is the numerical aperture of the fiber?

(a). NA = Sin θ_a = Sin (8.5^0) = **0.148**

(b) What is the index of refraction of the cladding of this fiber?

(b). $NA = \sqrt{n_1^2 - n_2^2}$.

$n_2^2 = 2.0088$

$n_2 =$ **1.417**

(c) If the fiber were submersed in water (n=1.33), what would be the new numerical aperture and cut-off angle?

(c). NA = **0.148**.

$\sin \theta_a = NA/n_0$

$\theta_a = \sin^{-1}(NA/n_0) = \sin^{-1}(0.1479/1.33) = = \sin^{-1}(0.1112) =$ **6.38^o**

Calculate the numerical aperture of an optical fiber whose core index is 1.48 and relative index is 0.02

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

$$NA = Sin\ \theta_a = \sqrt{n_1^2 - n_2^2}$$

$$\Rightarrow NA = \sqrt{n_1\ (n_1 + n_2)\ \Delta}$$

$$\Rightarrow NA = \sqrt{2\ n_1^2\ \Delta}$$

$$\boxed{NA = n_1\sqrt{2\ \Delta}}$$

$n_1 > n_2$

$\therefore\ n_1 + n_2 \equiv 2n_1$

We know, $NA = n_1 \sqrt{2\Delta}$

Given data: $n_1 = 1.48$ and $\Delta = 0.02$

$$\therefore \quad NA = 1.48 \sqrt{2 \times 0.02}$$

$$NA = 0.296$$

. For single-mode step-index fiber with n_1=1.482 and n_2=1.474 operating at 820 nm, then

a. Find the radius of the core

b. What is this fiber's numerical aperture and acceptance angle?

Given:

λ = 820 nm, n_1=1.482, n_2=1.474, V = 2.405 (single mode step index)

$$V = \frac{2\pi a(N.A)}{\lambda}$$

$$2.405 = \frac{2\pi * a * 0.153}{820 * 10^{-9}}$$

a = 2.051μm

$$\boxed{Core \ \ radius \ \ (a) = 2.051\mu m}$$

Solution: - $N.A = \sqrt{n_1^2 - n_2^2} = \sqrt{1.482^2 - 1.474^2}$ - N.A= 0.153

$$\boxed{Numerical\ aperture\ (N.A) = 0.153}$$

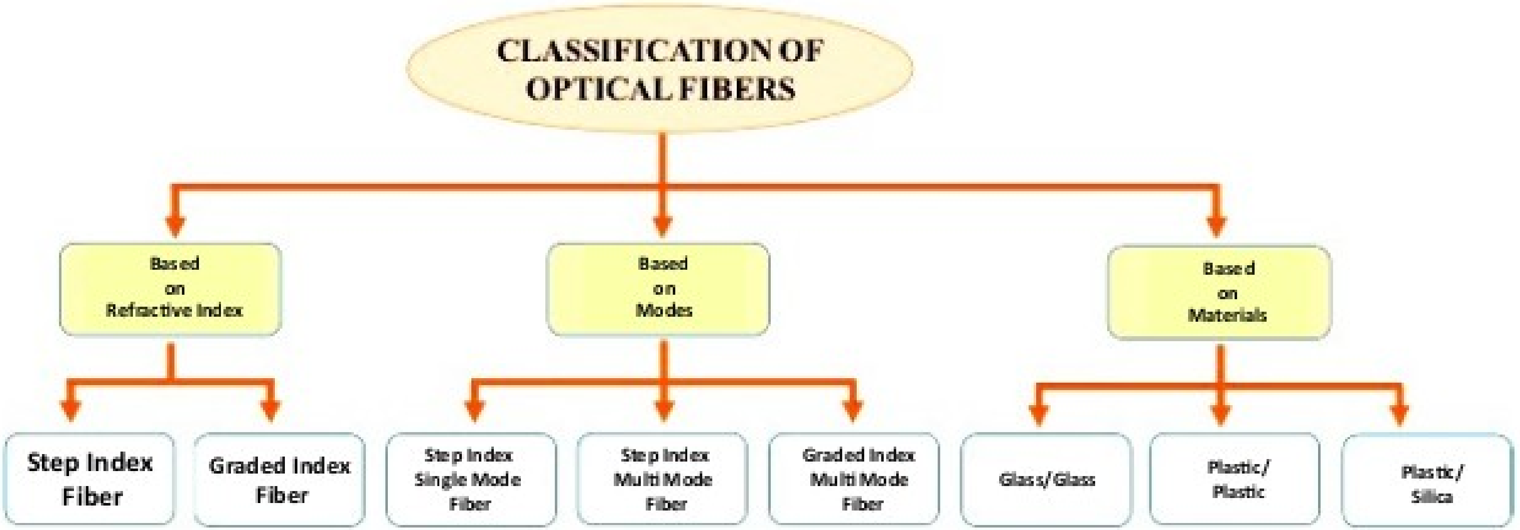
N.A = sin Θ_a

0.153=sin Θ_a

Θ_a = 8.8° $\boxed{Acceptance\ angle\ (\Theta_a) = 8.8^\circ}$

Classification of Optical Fiber

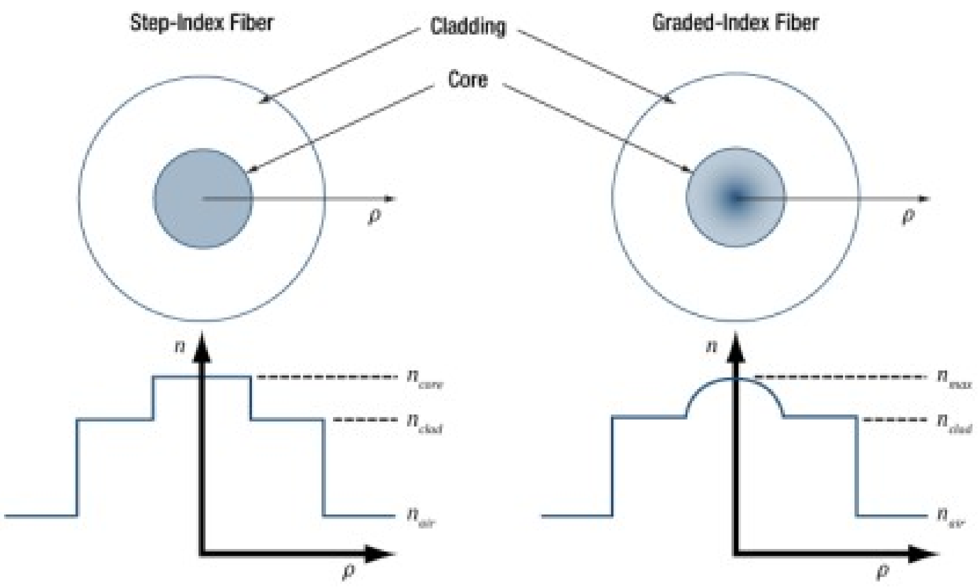
The optical fibres are classified into three types based on their mode of propagation and refractive index and the materials used in optical fiber.



Optical Fiber based on Referactive Index

Based on the **refractive Index**, they are classified into two types:

- Step Index Fiber
- Graded Index Fiber



Step index fibres: The **refractive index of the core is constant** along the radial direction and sudden falls to a lower value at the cladding and core boundary

Graded index(GRIN) fibres: The refractive index of the core is not constant but varies smoothly over the diameter of the core.

- It has a maximum value at the centre and decreases gradually towards the outer edge of the core.
- At the core-cladding interface the refractive index of the core matches with the refractive index of the cladding
- The refractive index of the cladding is constant.

Optical Fiber based on Modes

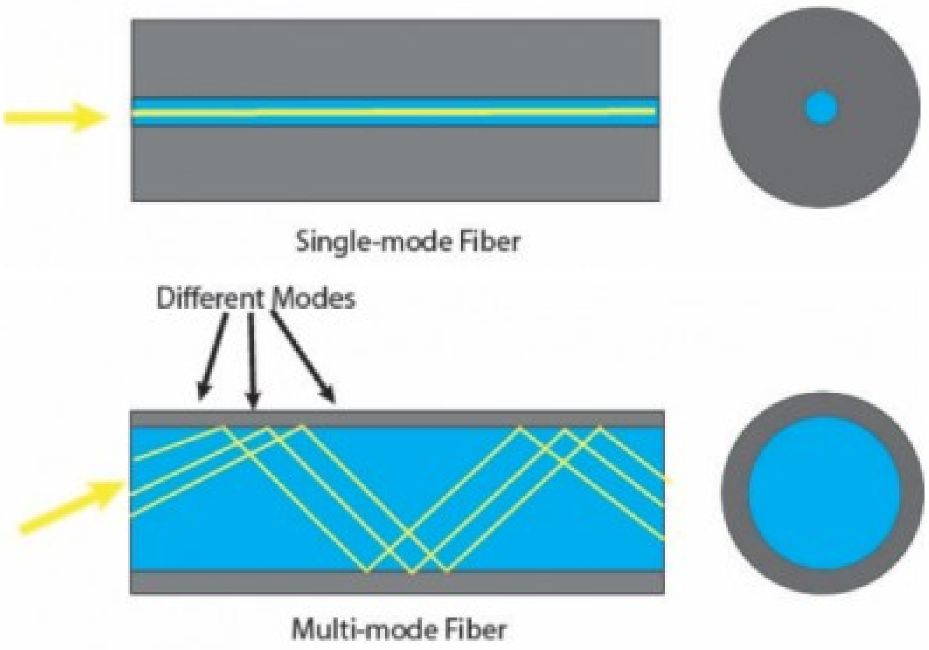
Based on **Modes of propagation**, they are classified into two types:

- Single Mode Fiber (SMF)
- Multi Mode Fiber (MMF)

Single-mode fibre (SMF): has a smaller core diameter and can support only one mode of propagation

Multimode fiber (MMF): A multimode fiber has a larger core diameter and supports a number of modes.

- There is one more mode which is also multimode is the Graded index(GRIN) fiber



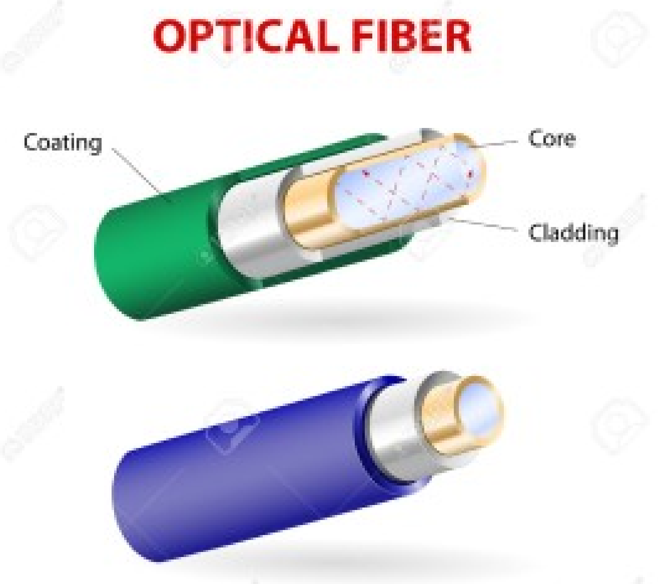
Optical Fiber based on Materials

This classification deals with the materials used for core and cladding.

The optical fibres, under this consideration are classified in to three categories.

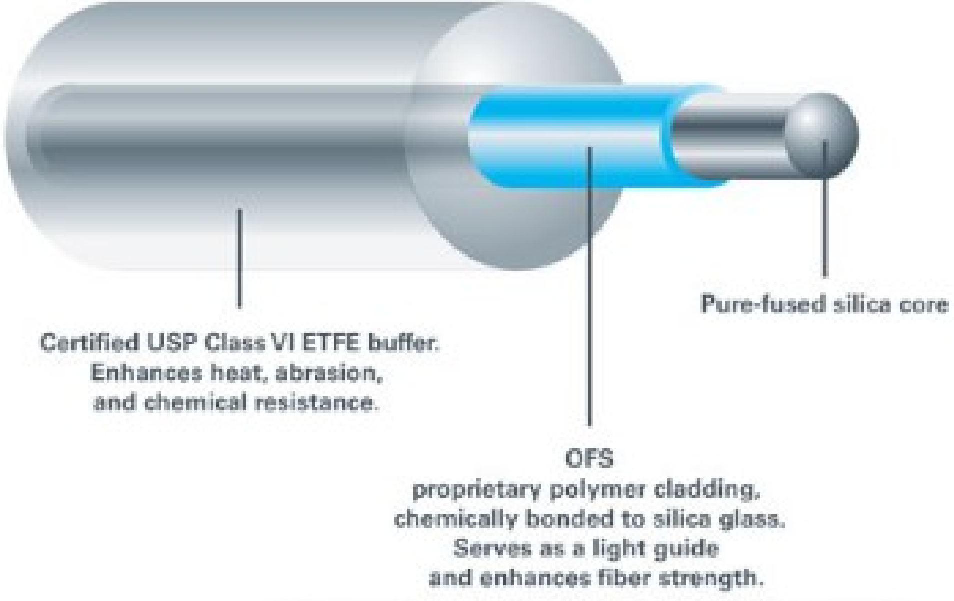
1. Glass/glass fibres (glass core glass cladding)
2. Plastic/plastic fibres (plastic core with plastic cladding)
3. PCS fibres (polymer clad silica)

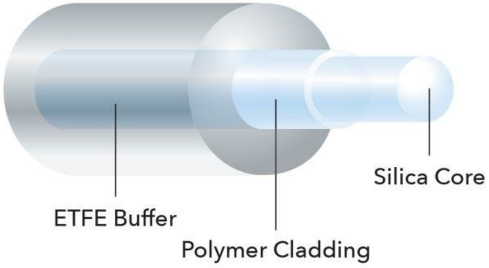
- **Glass fiber (RI-1.458 at λ=850nm):**
  - **Core**: SiO_2 ,**Cladding**: SiO_2
  - **Core**: GeO_2- SiO_2, **Cladding**: SiO_2
  - SiO_2 **core** – $B_2O_3.SiO_2$ **cladding**
  - $GeO_2.SiO_2$ **core** – SiO_2 **cladding**
- **Plastic fiber (RI-1.49-1.59):**
  - **Core**: Polystyrene : **Cladding**: Methyl Methacrylate
  - **Core**: Polymethyl Methacrylate : **Cladding**: Co-Polymer



- large NA of the order of 0.6
- large acceptance angles up to 77°
- advantages of plastic fibres are low cost and higher mechanical flexibility
- mechanical flexibility allows the plastic fibres to have large cores of diameters ranging from 110 to 1400 μm
- They are temperature sensitive and exhibit very high loss

Optical Fiber: PCS





Ethylene tetrafluoroethylene (ETFE)

- The plastic-clad silica (PCS) fibers are composed of silica cores surrounded by a low refractive index transparent polymer as cladding.
- The core is made from high-purity quartz.
- The cladding is made of a silicone resin having a refractive index of 1.405 or per fluorinated ethylene propylene (Teflon) having a refractive index of 1.338.
- Plastic claddings are used for step-index fibres only.
- The PCS fibres are less expensive but have high losses. Therefore, they are mainly used in short-distance applications.

Cut-Off wavelength (λ_c) of an Optical Fiber

The wavelength below which multiple modes of light can be propagated along a particular fiber.

$$\boxed{\lambda_c = \frac{\pi\, d}{2.405} NA}$$

If,

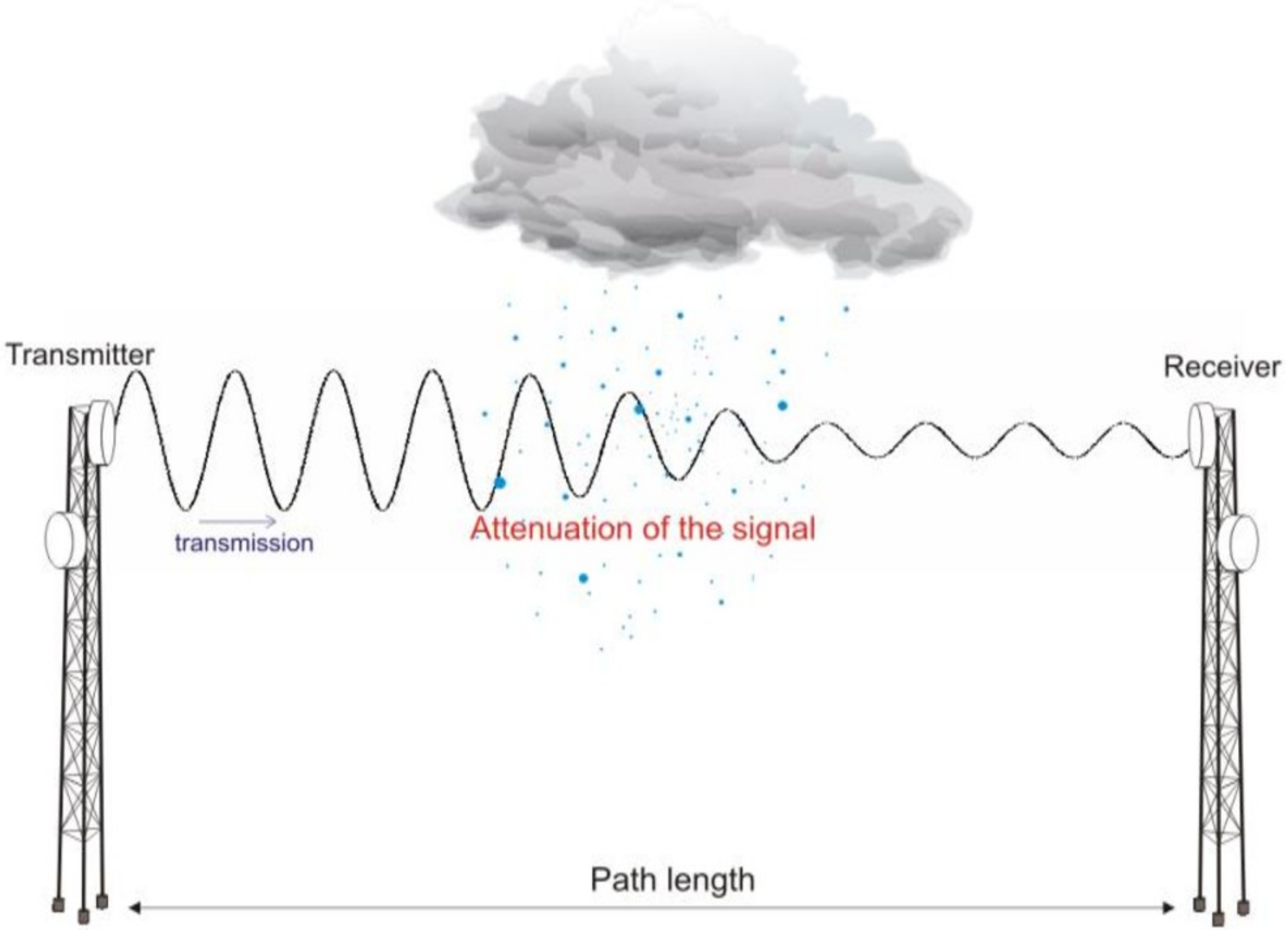
$$\lambda < \lambda_c \quad = \text{Single Mode}$$

$$\lambda > \lambda_c \quad = \text{Multi- Mode}$$

Attenuation in Communication System

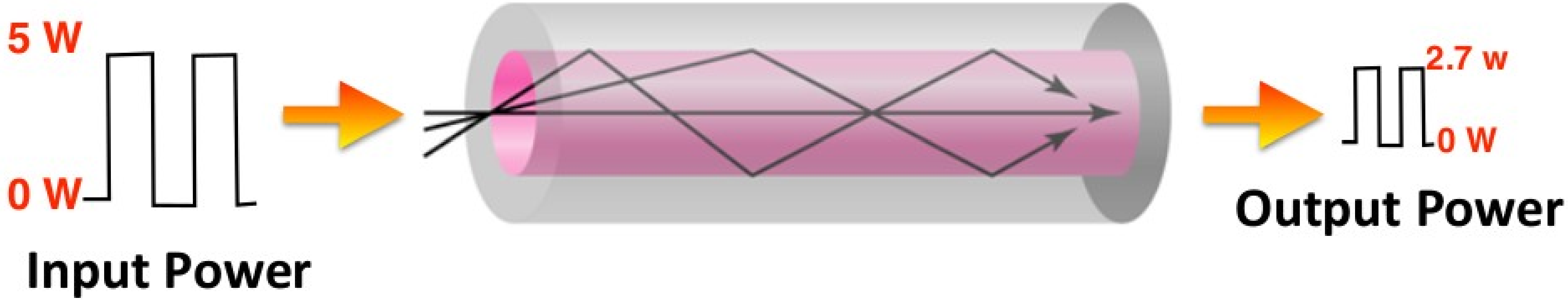
It is defined as the **reduction in the strength of a signal** (Electrical, optical, optoelectrical.. any form) as it is transmitted.

Means the reduction of the **amplitude** of a signal, electric current, or other oscillation.



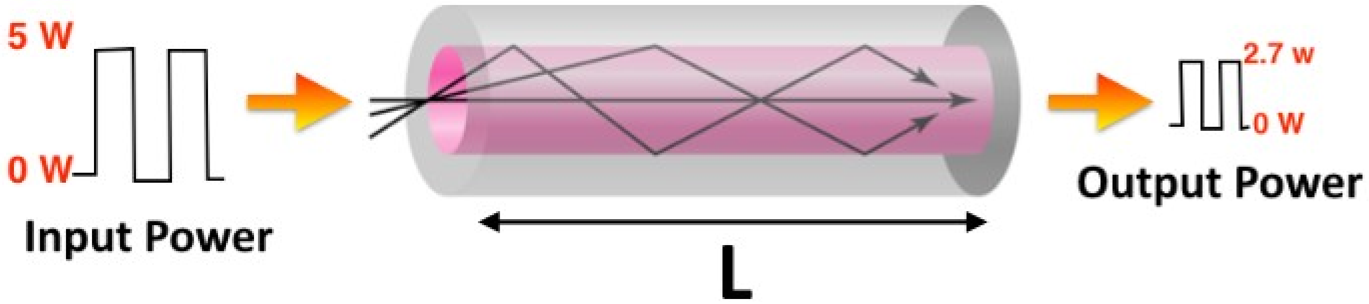
Optical Fibre: Attenuation

measures the **amount of light lost between input and output.**



Attenuation is the ***reduction in*** *the* ***power*** *of the light signal as it is transmitted*. This attenuation can be **calculated by** taking the **ratio** between the **optical input power** (P_i) and the **optical output power** (P_0). Attenuation is basically **measured in decibels (dB)**. *It **also depends** on the **length of the optical fiber** in which light travels.*

Optical Fibre: Attenuation cont'd...



This attenuation loss α_L (dB)

$$\boxed{\alpha_L = 10 \log \frac{P_i}{P_o}}$$

Where,

α_L = Attenuation loss in dB

P_i = Input power

P_o = Output power

attenuation coefficient α (dB/Km)

$$\boxed{\alpha = \frac{10}{L} \log \frac{P_i}{P_o}}$$

Where,

α = Attenuation coefficient (dB/Km)

P_i = Input power

P_o = Output power

L = Length of optical fiber

Numericals

A low loss fiber has average loss of 3 dB/km at 900 nm. Compute the length over which –

Power decreases by 50 %

1 km

The input power to an optical fiber is 2 mW while the power measured at the output end is 2 µW

. If the fiber attenuation is 0.5 dB/km, calculate the length of the fiber.

60 km

For a 30 km long fiber attenuation 0.8 dB/km at 1300nm. If a 200 µwatt power is launched into the fiber,

, find the output power.

P(z)=0.7962 μW

Solution : $\alpha = 3$ dB/km

a) Power decreases by 50 %.

$\Rightarrow \quad \frac{P(0)}{P(z)} = 50\ \% = 0.5$

α is given by,

$$\boxed{\alpha = 10 \cdot \frac{1}{z} \log \left[\frac{P(0)}{P(z)}\right]}$$

$$3 = 10 \cdot \frac{1}{z} \log [0.5]$$

$\therefore$ $z = \mathbf{1\ km}$

Solution : Given : $P(0) = 2$ mwatt $= 2 \times 10^{-3}$ watt

$P(z) = 2$ μwatt $= 2 \times 10^{-6}$ watt

$\alpha = 0.5$ dB/km

$$\boxed{\alpha = 10 \times \frac{1}{z}\left[\frac{P(0)}{P(z)}\right]}$$

$$0.5 = 10 \times \frac{1}{z}\log\left[\frac{2 \times 10^{-3}}{2 \times 10^{-6}}\right]$$

$$0.5 = \frac{1}{z} \times 3$$

$$z = \frac{3}{0.05}$$

$$z = \mathbf{60\ km}$$

Solution : $z = 30$ km

$\alpha = 0.8$ dB/km

$P(0) = 200\ \mu W$

Attenuation in optical fiber is given by.

$$\boxed{\alpha = 10 \times \frac{1}{z} \log \left[\frac{P(0)}{P(z)}\right]}$$

$$0.8 = 10 \times \frac{1}{30} \log \left[\frac{200\ \mu W}{P(z)}\right]$$

$$2.4 = 1(\quad og \left[\frac{200\ \mu W}{P(z)}\right]$$

using identity:

$y = log_b(x)$

$b^y = x$

for our case

$2.4 = log_{10} \frac{200\mu W}{P_0}$

$10^{2.4} = \frac{200\mu W}{P_0}$

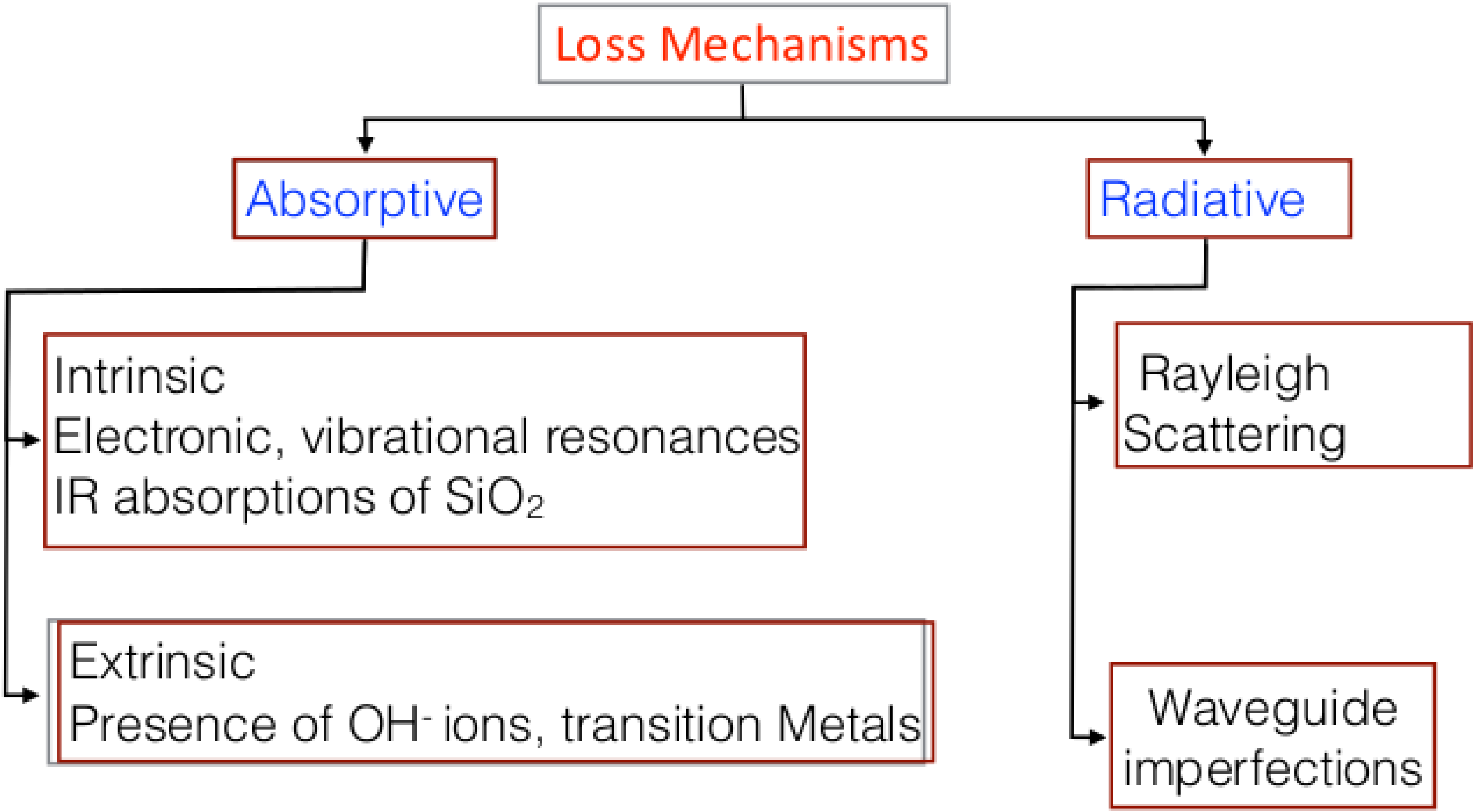
$P_0 = \frac{200\mu W}{10^{2.4}}$

$P_0 = \frac{200\mu W}{251.188}$

$P_0 = 0.7962\mu W$

P(z)=0.7962 μW

Attenuation/ Loss Mechanism



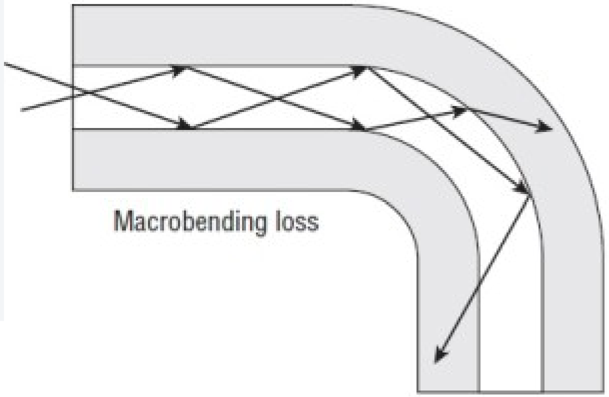
Losses due to the Bending of optical fiber

Radiative losses occur whenever an optical fiber undergoes a bend of finite radius of curvature ***are known as bending losses***. These losses are classified as **two types**:

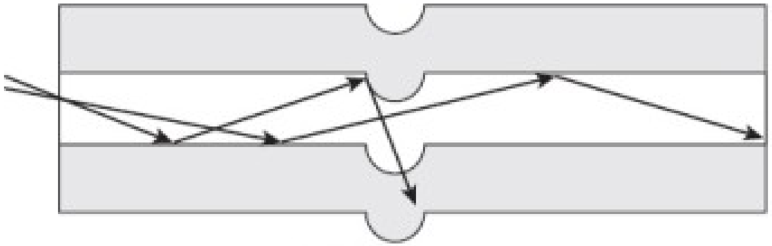
Macrobending losses are due to the Physical bends in the fiber that are large in relation to the diameter.

- Loss proportional to $e^{-\frac{R}{R_c}}$, R is the radius of curvature, R_C is constant
- Bending loss is negligible if R> 5 mm

Microbending losses are due to the microscopic fiber deformation in the core-cladding interface caused by induced pressure on the glass (local stress in glass formation).



Macrobending loss



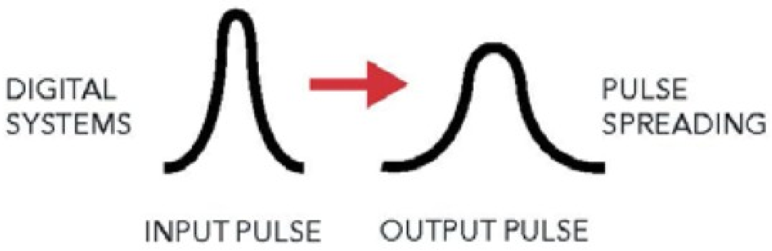
Microbending loss

Ways to reduce Attenuation/Losses in an optical fiber

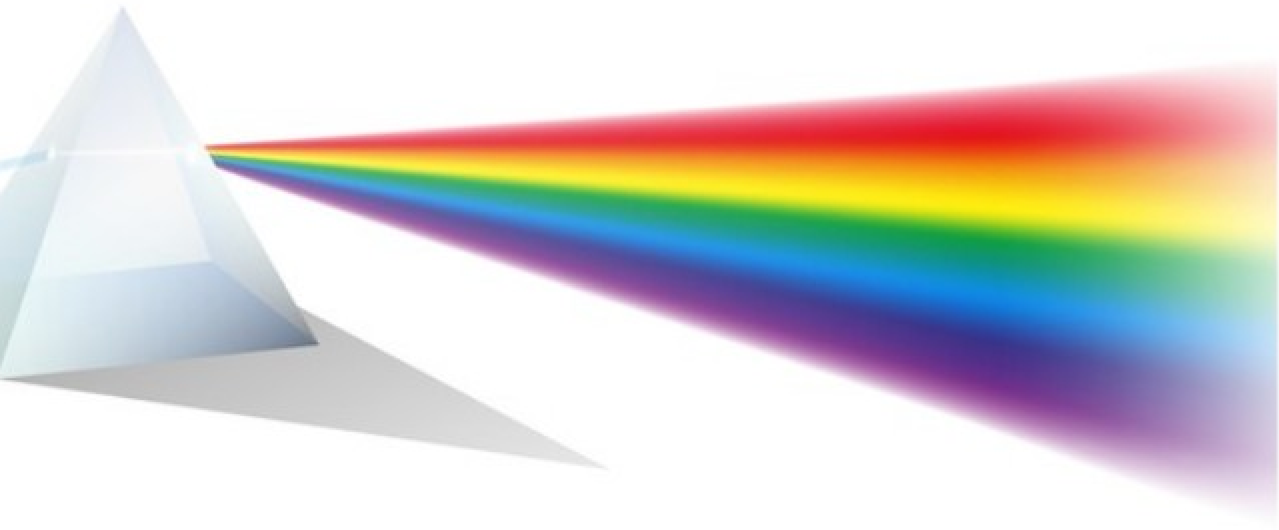
- **Better manufacturing** Process: **Fewer impurities**
- Scattering wavelength in **low-loss frequency windows**
- **Prevent macro bend loss**: minimising physical damaging
- **Proper connection** with 0 dB loss
- **Use graded index multimode fiber** instead of a step-index fiber

Losses **due to the** ***Dispersion of light*** in Optical Fiber

Dispersion causes the ***pulse to spread out over time*.**

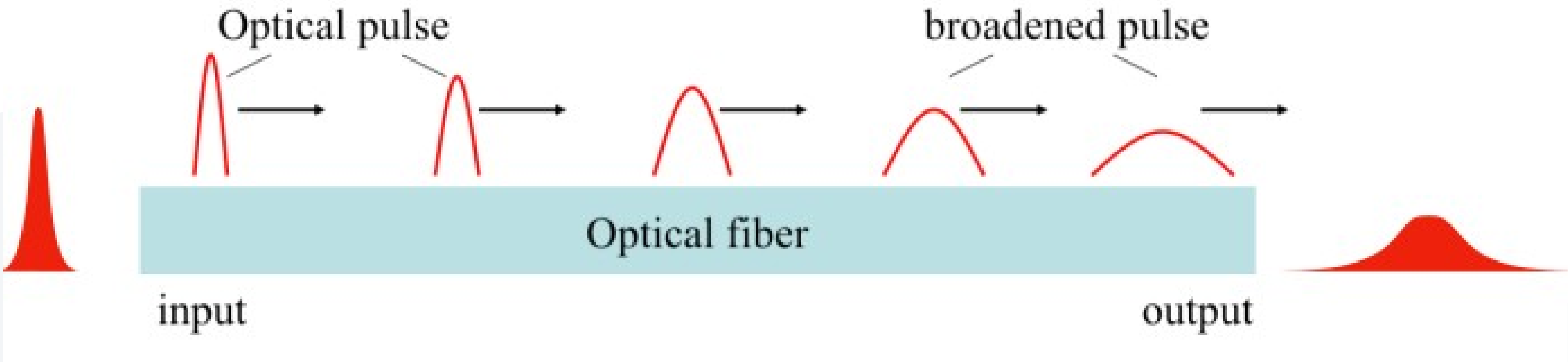


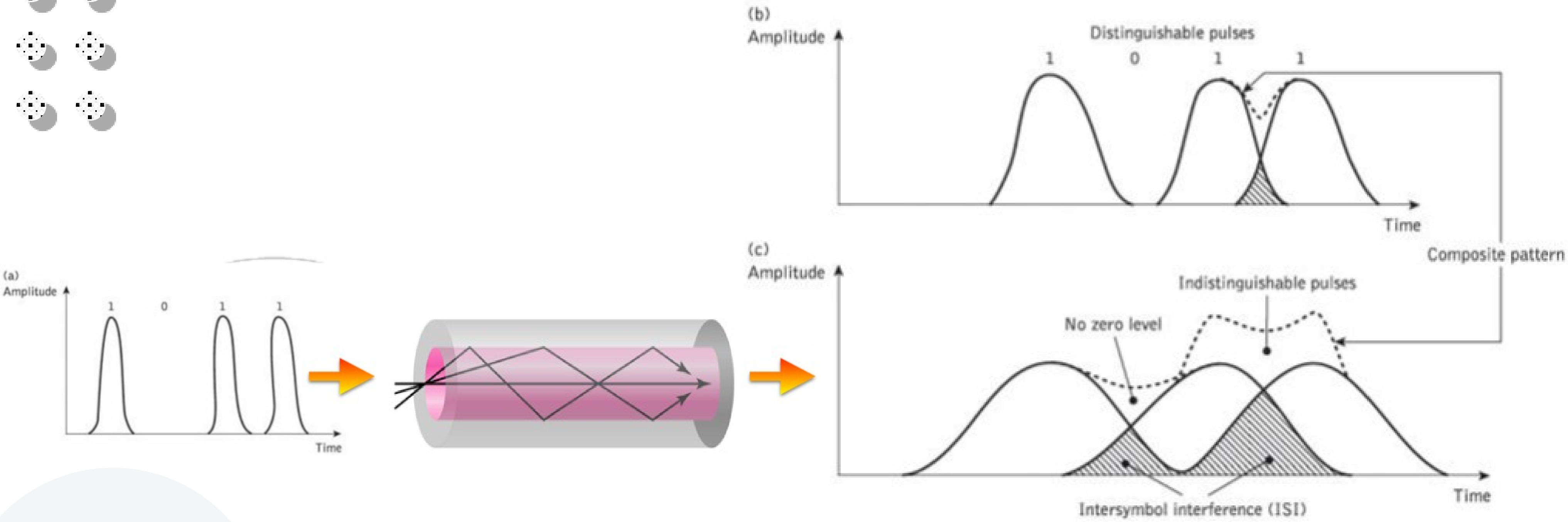
In optics, it **separates** the **wavelength** of light **of different frequencies.**

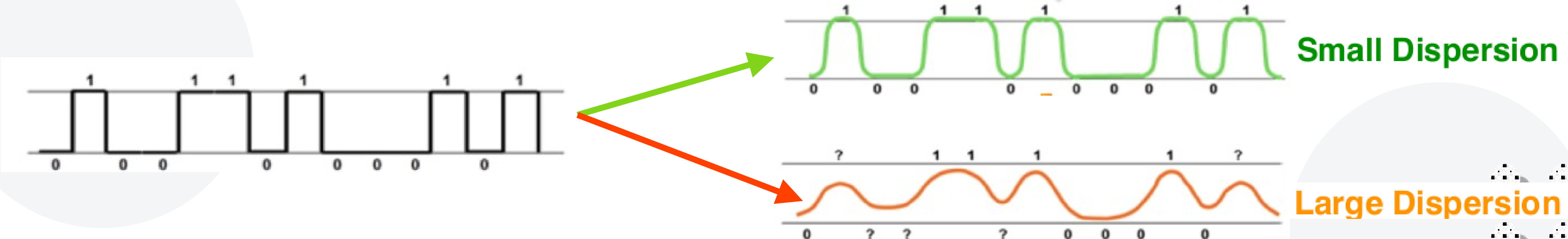


Dispersion Loss in Optical Fiber:

Dispersion causes the pulse to spread out over time. This **limits the information carrying capacity of the fiber**, *reduces the communication bandwidth*.







Input Signal

Output Signal

Types of Dispersion in Optical Fiber

Intramodal dispersion
(Chromatic dispersion**)**

Intramodal dispersion **occurs in all types fibers.**

Materials dispersion

Waveguide dispersion

Intermodal dispersion

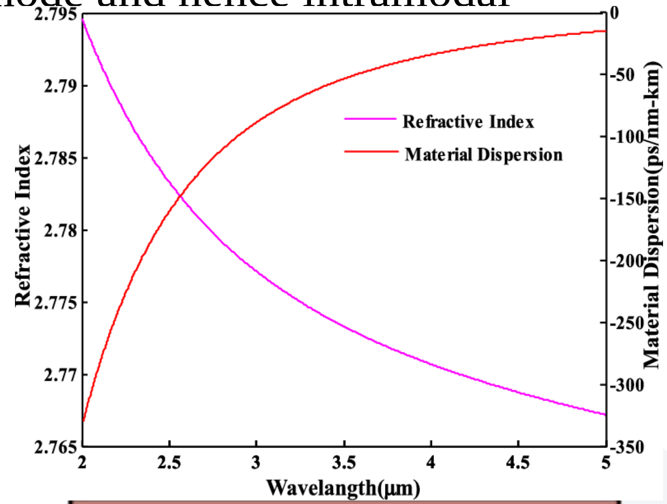
Intermodal dispersion **occurs** only in **multimode fibres.**

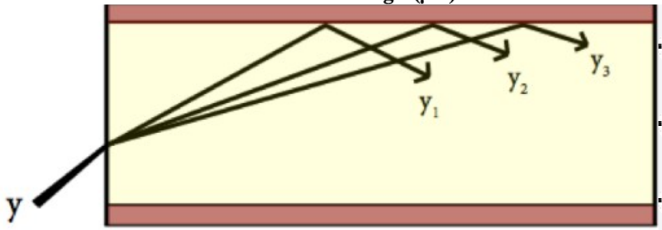
Intramodal dispersion

- In **chromatic/intramodal dispersion**, the delay effect **primarily depends on the fiber materials.**
  - Optical sources do not emit just a single frequency but a band of frequencies.
  - There will be propagation delay differences between the different spectral components of the transmitted signal. This causes the broadening of each transmitted mode and hence intramodal dispersion.

a) Materials dispersion:

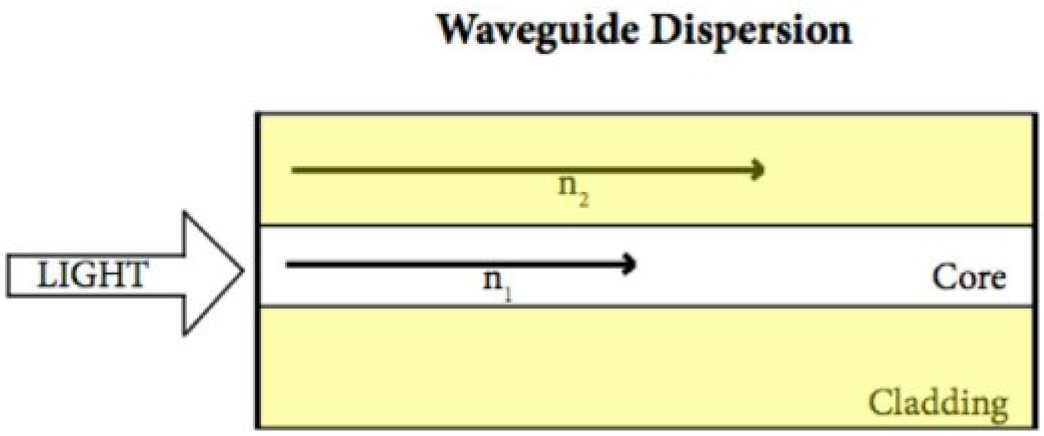
- Different wavelengths of light travel at different speeds inside the fiber.
- Longer wavelengths travel faster than shorter wavelengths (higher frequencies). Hence, will arrive at the end of the fiber ahead of the shorter ones.
- Reach at a different time at the output end.
- This leads to a broadening/delay effect or a dispersion
- Mainly caused by the wavelength dependence of the refractive index on the fiber core material.

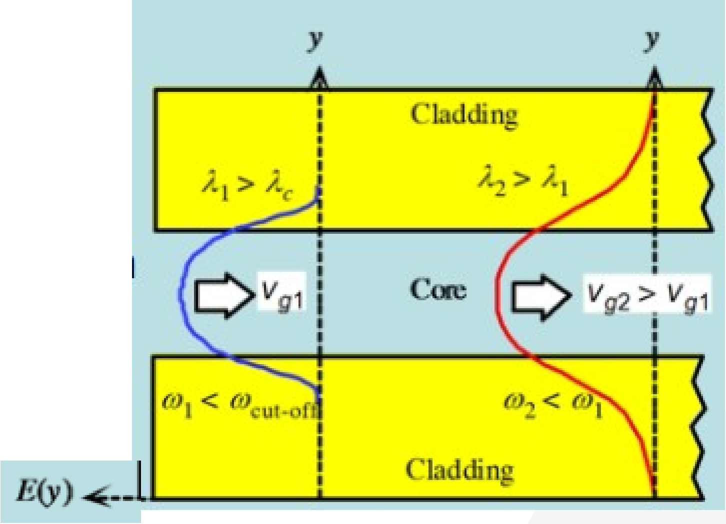




b. Waveguide dispersion:

- The light is guided in an optical fiber by core and cladding
- Some light travels in the core, and some will travel in cladding
- Different speed of light in core and cladding due to different refractive index leads to a delay effect/spreading of signals
- It is seen prominently in SMF than a MMF
- Waveguide dispersion in SMF is relatively small than material dispersion in SMF

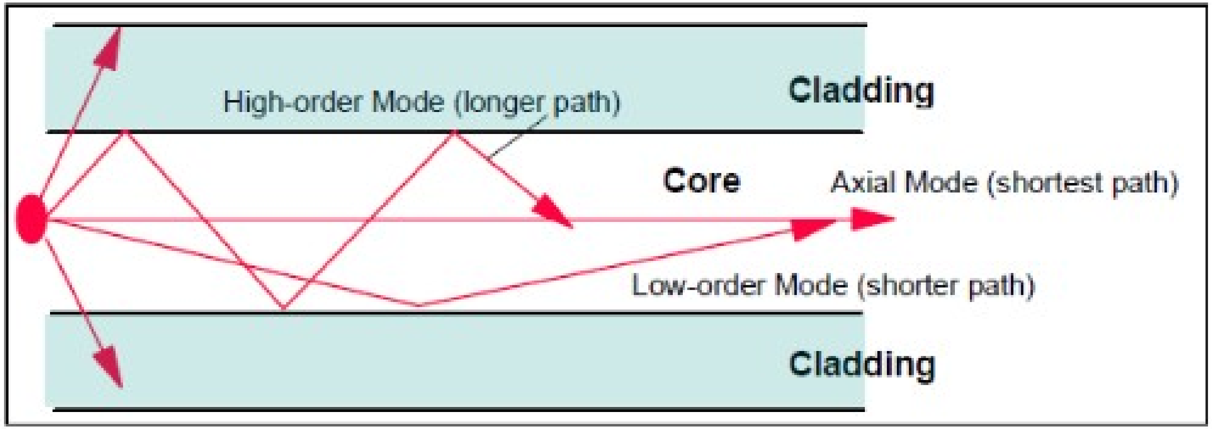




- The **higher the wavelength** (lower the frequency), **the greater the penetration** into the cladding.
- **Greater portion of light is carried** by the cladding in which the phase velocity is higher.

Intermodal Dispersion

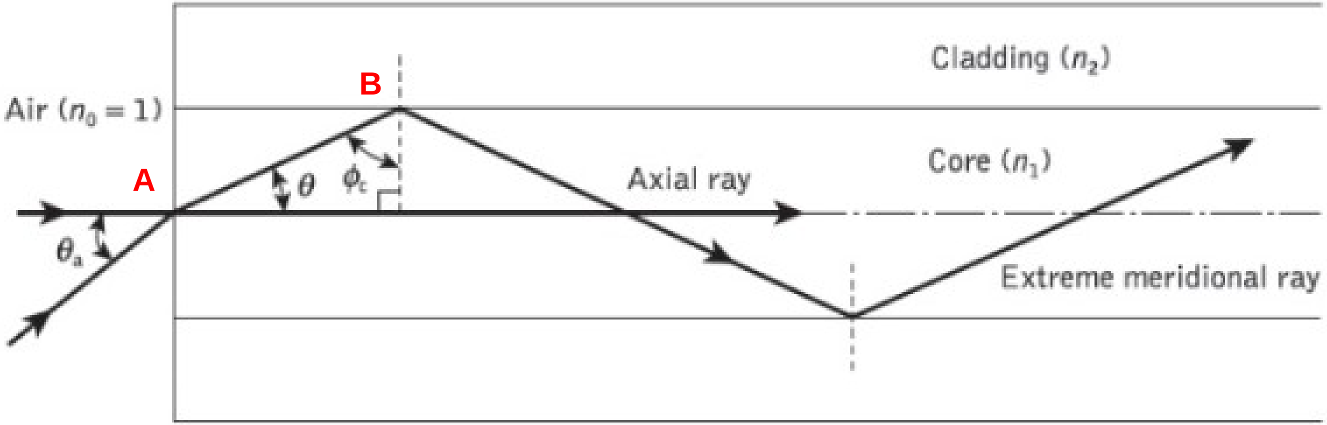
It is some times referred to simply as modal or mode dispersion results from the propagation delay differences between modes within a multimode fiber.



- In a simple terminology, ***Mode** is the path of each light ray travel in optical fiber.*
- Some of these *light rays will travel straight through the center of the fiber known as* ***axial mode***.
- Others will repeatedly bounce off the cladding/core boundary to zigzag their way along the waveguide.
- The *modes that enter at sharp angles are called* ***high-order modes.*** These modes take much longer to travel through the fiber than the low-order modes
- These **time difference** leads to ***modal dispersion.***

Measurement of Intermodal Dispersion

- Let the optical fiber of length L, the core having refractive index n_1 and cladding refractive index n_2. θ is the critical angle for maximum path covered and ϕ_c is the critical incident angle at core-cladding interface



Time taken for the zero mode to complete path L is:

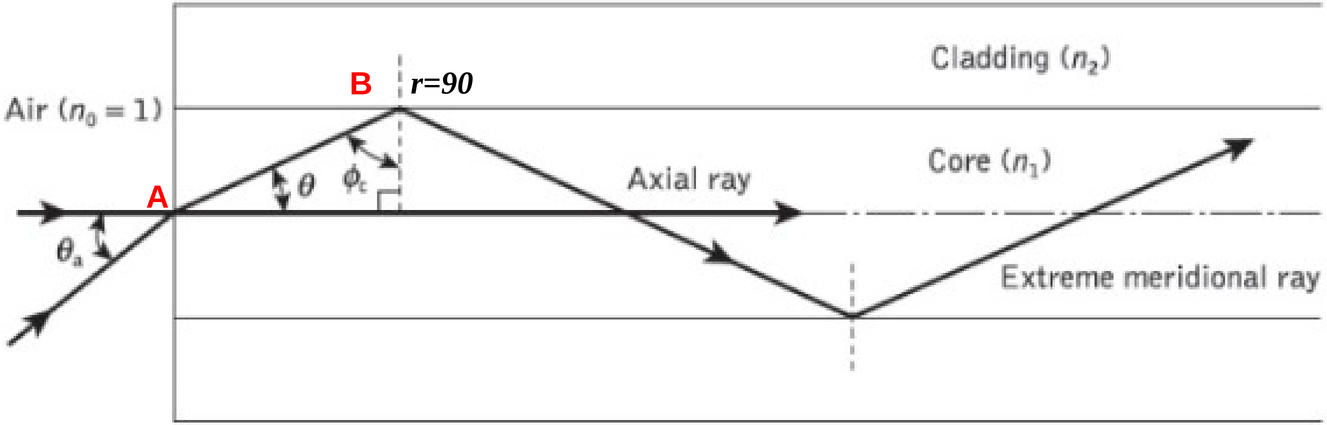
$$t_0 = \frac{L}{v} \qquad \text{----(1)}$$

Time taken for the highest mode is:

$$t_m = \frac{L/cos\theta}{v} = \frac{L}{vcos\theta} \qquad \text{---(2)}$$

the Time difference between these is due to the intermodal dispersion, is

$$\Delta t = t_m - t_0$$



Using Eq. (1) and (2),

$$\Rightarrow \Delta t = \frac{L}{vCos\theta} - \frac{L}{v}$$

$$\Rightarrow \Delta t = \frac{L}{v}\left[\frac{1}{cos\theta} - 1\right]$$

Now,

Applying snell's law at point **B**

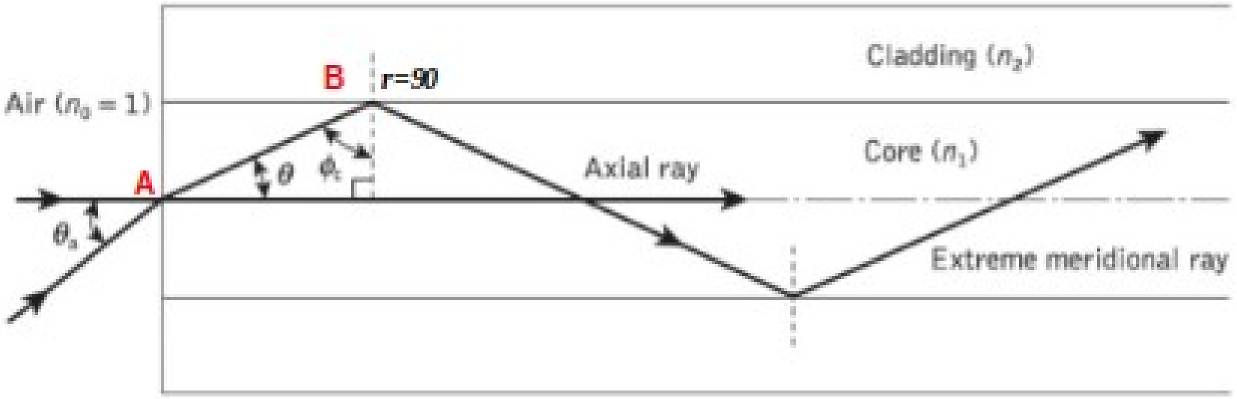
$$\Rightarrow \frac{Sin\ \phi_c}{Sin\ r} = \frac{n_2}{n_1} \Rightarrow Sin\ \phi_c = \frac{n_2}{n_1} \Rightarrow Sin(90-\theta) = \frac{n_2}{n_1} \Rightarrow Cos\theta = \frac{n_2}{n_1}$$

$$\Rightarrow \Delta t = \frac{L}{v}\left[\frac{n_1}{n_2} - 1\right]$$

$$\Rightarrow \Delta t = \frac{Ln_1}{c}\left[\frac{n_1}{n_2} - 1\right]$$

$$\Rightarrow \Delta t = \frac{Ln_1}{c}\left[\frac{n_1 - n_2}{n_2}\right]$$

Refractive index is also equal to the velocity of light c of a given wavelength in empty space divided by its velocity v in a substance, or $n = c/v$.



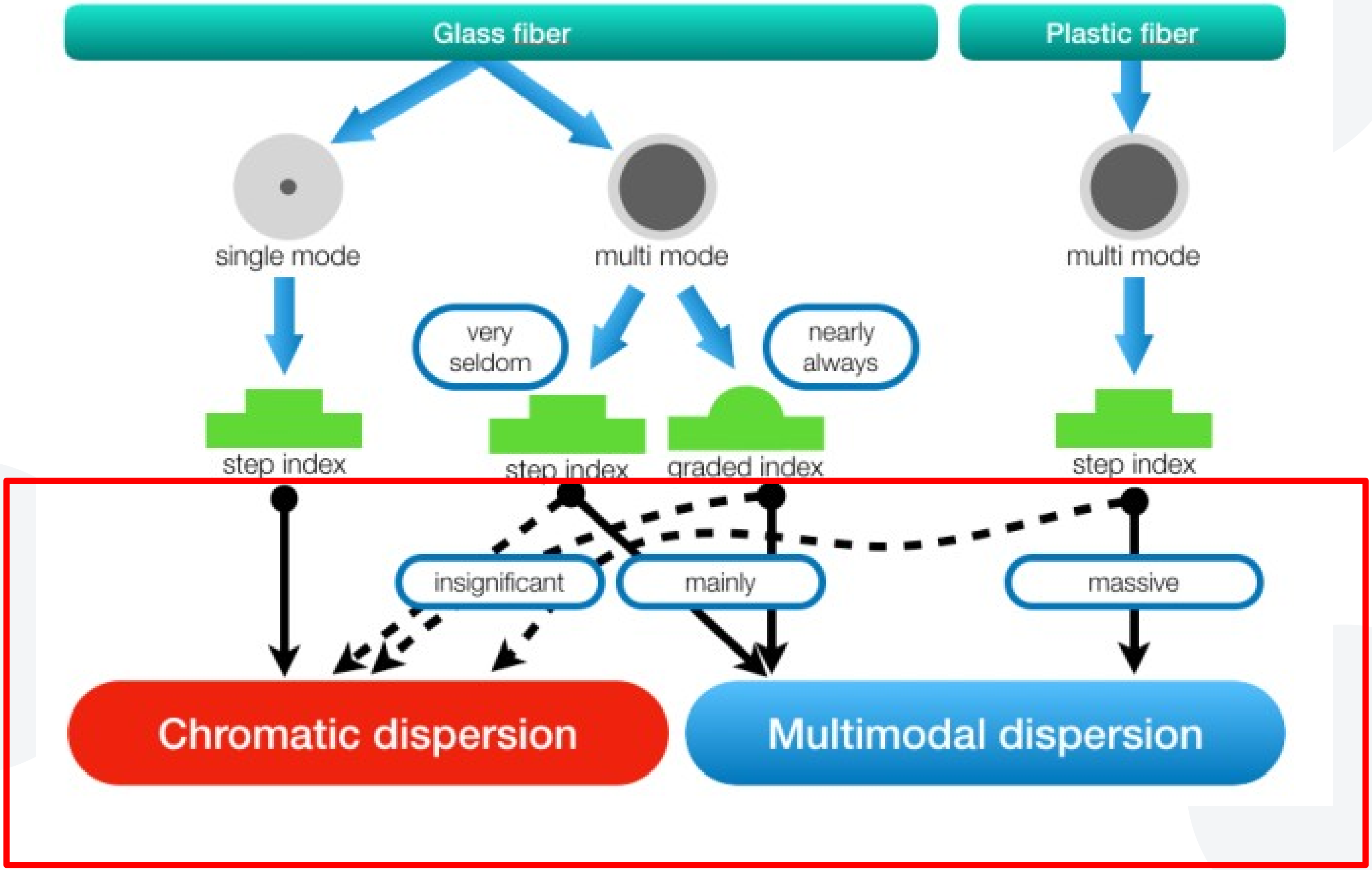
As

$$\boxed{NA = n_1\sqrt{2\,\Delta}}$$

$$\Delta = \frac{NA^2}{2n_1^2}$$

$$\Rightarrow \quad \Delta t = \left(\frac{Ln_1}{c}\right)\,\Delta$$

$$\boxed{\Delta t = \left(\frac{L}{2cn_1}\right)NA^2}$$

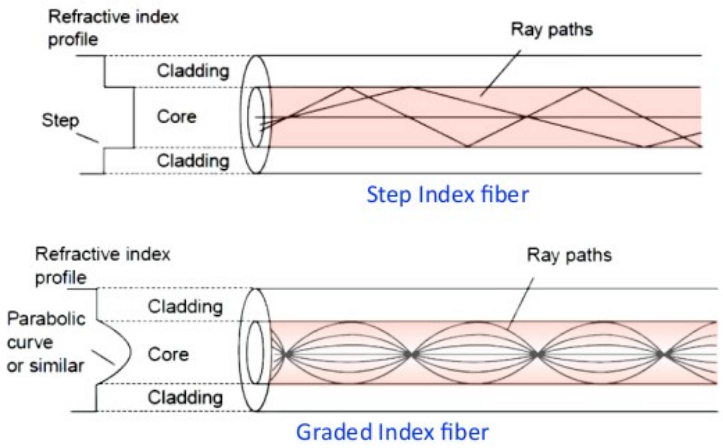


Glass fiber
Plastic fiber
single mode
multi mode
multi mode
very seldom
nearly always
step index
step index
graded index
step index
insignificant
mainly
massive
Chromatic dispersion
Multimodal dispersion

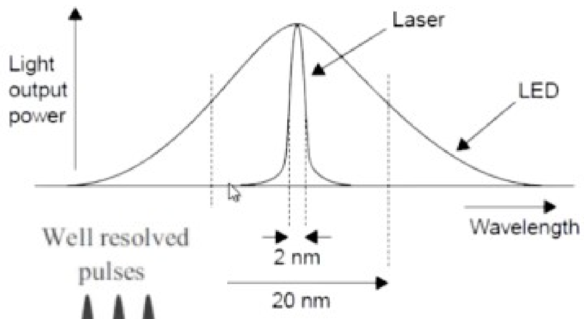
Ways to reduce the intermodal Dispersion

- Use **multi-mode graded index fiber instead of multi-mode step index fiber.**

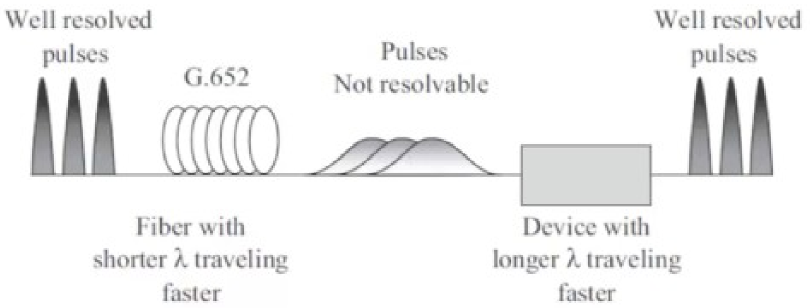
- Modal dispersion can be further decreased by **selecting a smaller core size** (less than 5–10 μm) and forming a single-mode step index fiber.



- By **choosing a proper source**, we can reduce the chromatic dispersion.



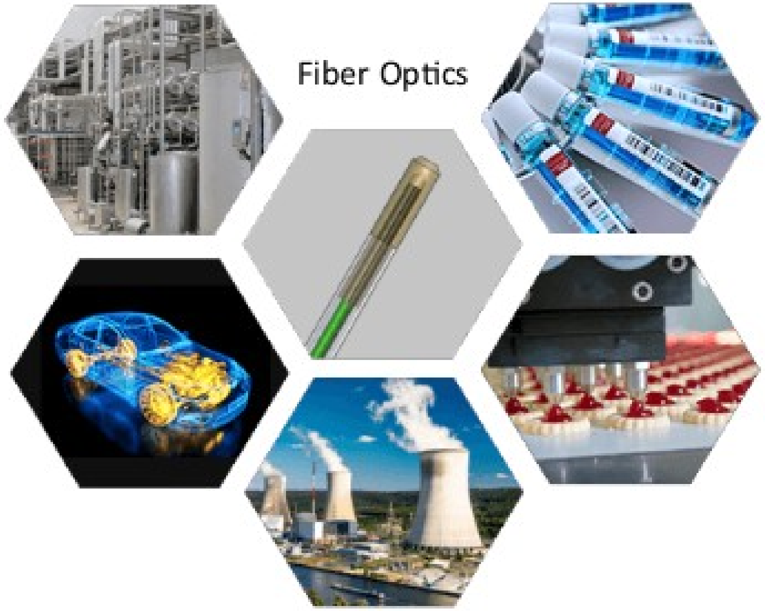
- By using a **chromatic compensator.**



Applications of Optical Fibre

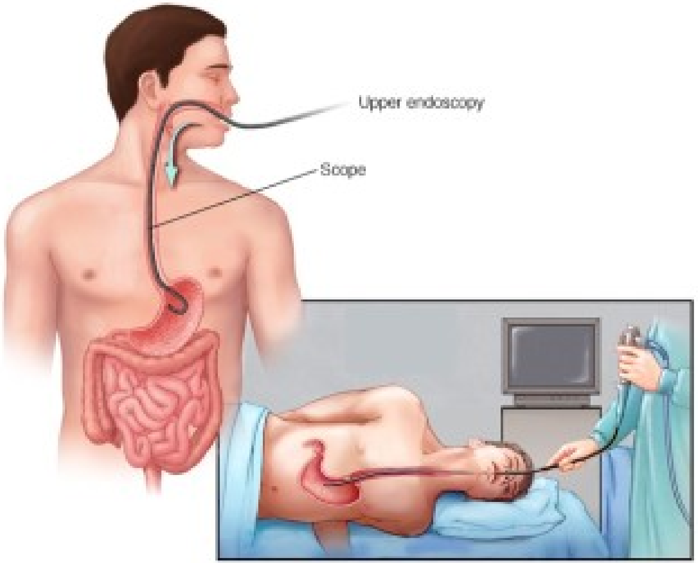
We are living in an information society, where the efficient transfer of information is highly relevant to our well-being. owing several advantages, fiber optics has many applications in:

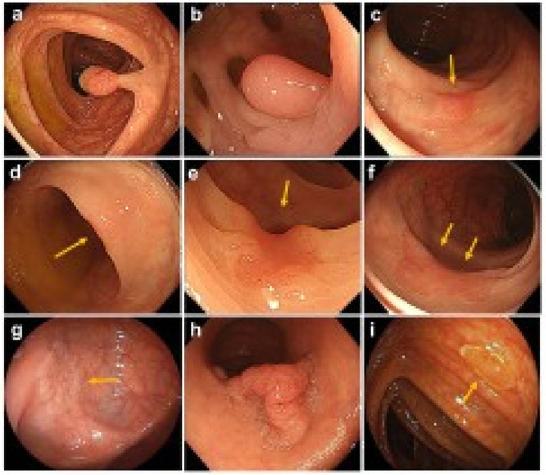
- Communications
- Pharmaceuticals
- Spectroscopy
- Biological and Biomedical Sciences
- Petrochemicals
- Food and Beverage industry
- Plastic Industry
- Study of Soil sample
- Understanding the basics chemical reaction
- Energy and miliyarty services



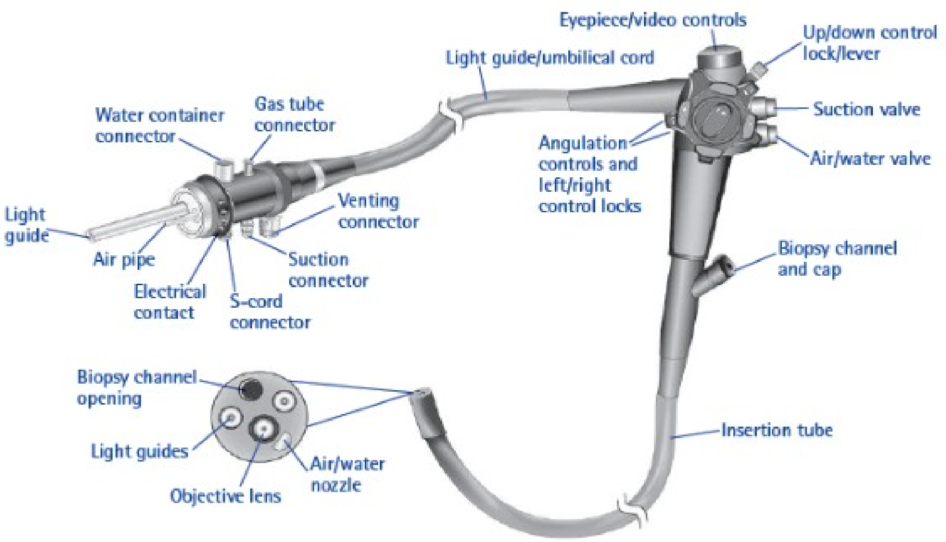
Applications of Optical Fibre: Endoscopy

An endoscopy is a test to look inside your body. A long, thin tube with a small camera inside, called an endoscope, is passed into your body through a natural opening such as your mouth. “**Endo**” means **inside**, and “**Scop**e” means the **device to look/see**.





Components & Working Principle of Endoscope



Components:

- An eyepiece with camera attachment at the focus
- Distal tip control, capable of rotating by 120 º
- Operational channel valve that controls the entry of catheters, electrode, biopsy, and other flexible devices
- valve control for application of water and air irrigation through the channel
- A connection with an umbilical tube for the control of the light transmission.

Working Principle:

- The flexible shaft is inserted into our body, and the distal tip is positioned correctly to study the inter-organ of our body.
- The light is transmitted by the optical fiber.
- The reflected light from the organs/interior body is collected and viewed as image