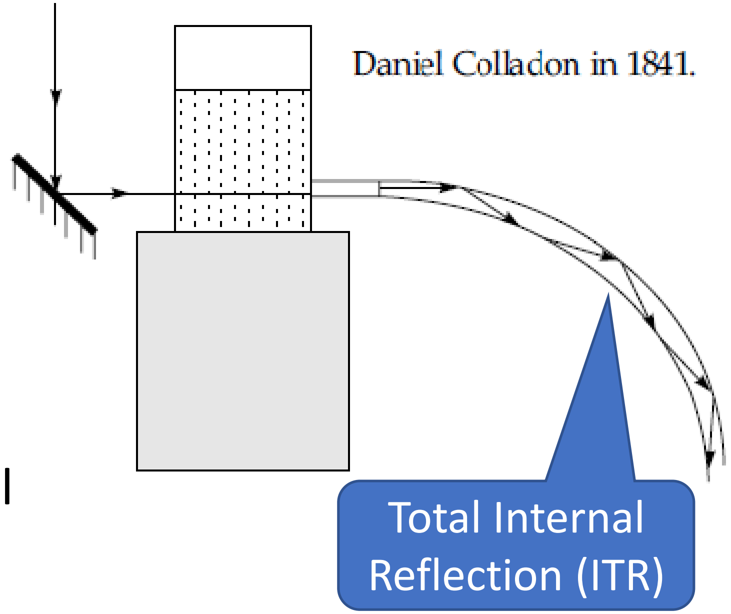
Fibre Optics: Wave guides:

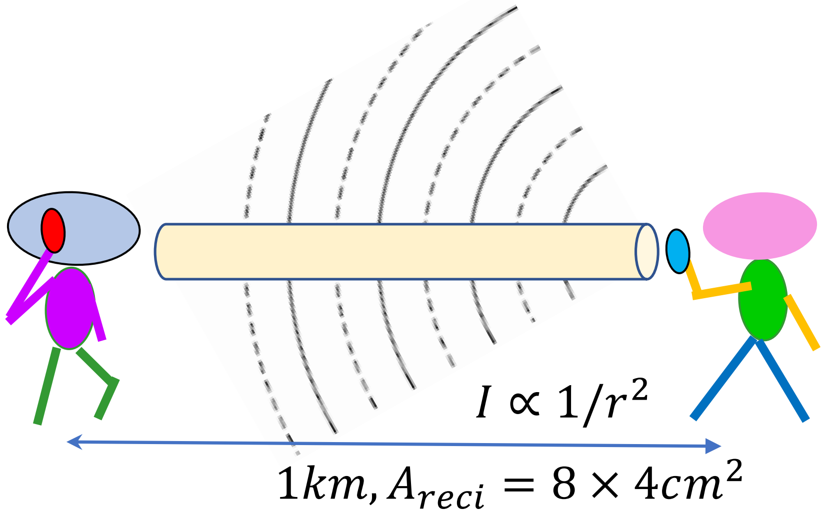


Optical fibre is dielectric waveguide that operate that operate in optical frequency. It is use for transmitting information over a long distance

$$\frac{sin\theta_i}{\sin\theta_r} = \frac{n_2}{n_1}$$

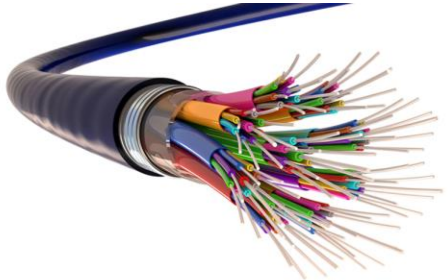
$$\theta_c = \sin^{-1}\{\frac{n_2}{n_1}\}$$

$$For\ ITR:\ \theta \geq \theta_c$$

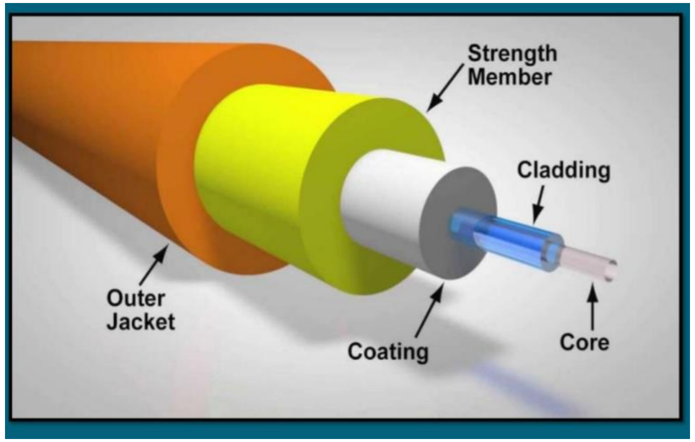


Glass?

- Available in pure form and being used since long back reliably for applications.
- Wide range of accessible temperatures where its viscosity is variable. Does not solidify at a discrete freezing temperature but gradually becomes stiffer.
- Intrinsic strength of glass. Its strength ($2 \times 10^6 lb/in^2$). A glass fiber a diameter (125 mm) of can support a load of $40lb$.



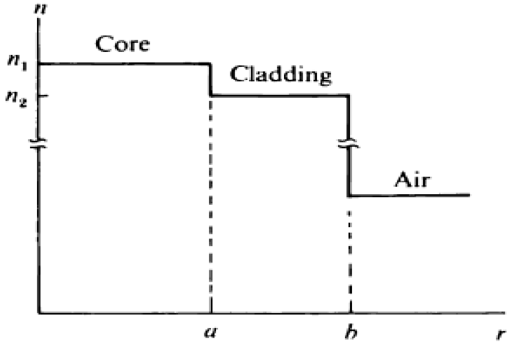
Optical Fibre



Core: Central tube of very thin size made up of optically transparent dielectric medium and carries the light from transmitted to receiver. The core dimeter can vary from about $5\mu m - 100\mu m$

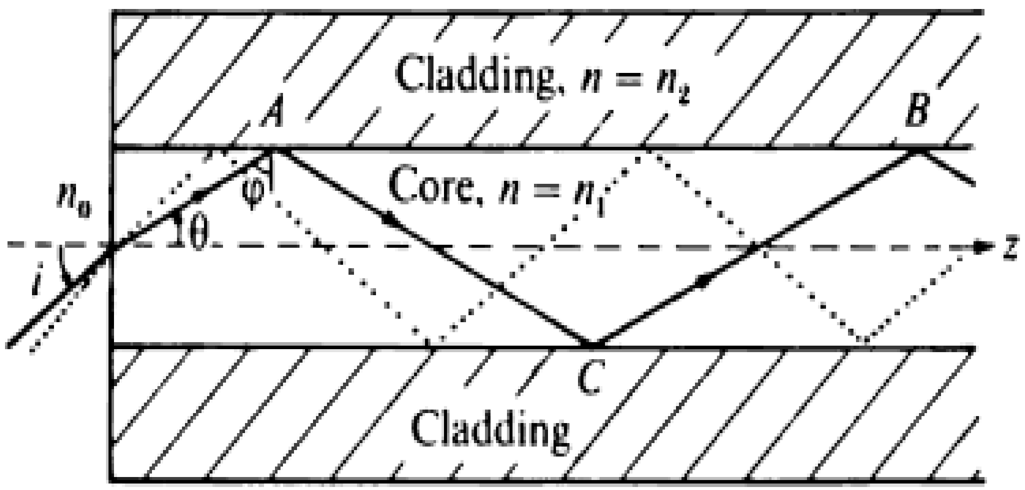
Cladding- outer optical material surrounding the core having reflecting index lower than core. It helps to keep the light within the core throughout the phenomena of total internal reflection.

Buffer coating: plastic coating that protects the fibre made of silicon rubber. The typical dimeter of fibre after coating is $250\mu m$-$300\mu m$



$$n(r) = \begin{cases} n_1; & r < a \\ n_2; & r > a \end{cases}$$

$n_1 > n_2$



$$\frac{sin\theta_i}{sin\theta} = \frac{n_1}{n_0}, \qquad \phi = \frac{\pi}{2} - \theta$$

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

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

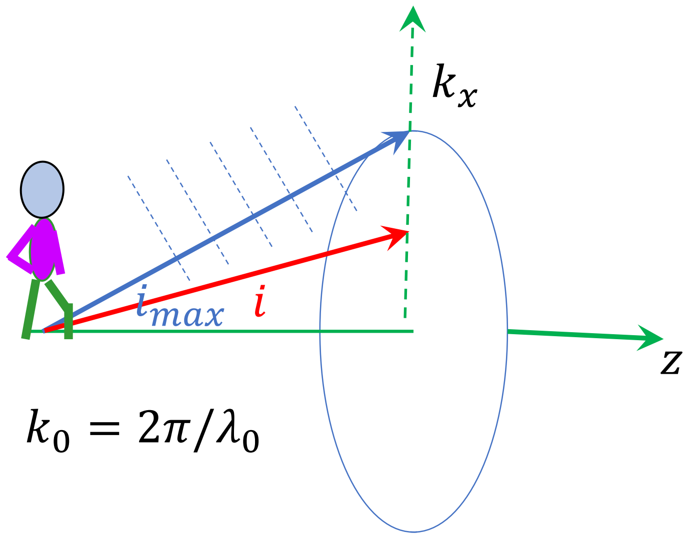
$$\sin i_c = \frac{n_1}{n_0}\sqrt{1 - \left(\frac{n_2}{n_1}\right)^2} = \left(\frac{n_1^2 - n_2^2}{n_0^2}\right)^{\frac{1}{2}}$$

$n_0 = 1,$
for air

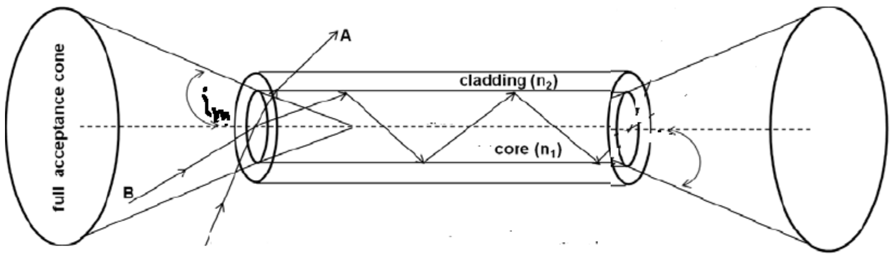
$$i > \sin^{-1}\left\{\sqrt{n_1^2 - n_2^2}\right\}$$

TPS

Wave guides:



$k_0 = 2\pi/\lambda_0$



Specifications of the optical fiber

- **Numerical Aperture:** Light gathering ability
- **Attenuation:** Loss of signal in dB
- **Dispersion:** Blurring of a signal
- **Band-width:** Number of bits/s be transmitted

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

Thus, if a cone of light is incident on one end of the fibre, it will be guided through it provided the semi angle of the cone is less than $\boldsymbol{i_m}$. This angle is a measure of light gathering power of the fibre. The numerical aperture (NA) of the fibre is a measure of light gathering power of the fibre.

$$Acceptance\ angle = 2i_m$$

V- number determine how many modes a fibre can support.
It define as

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

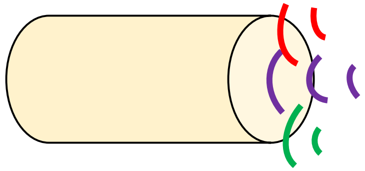
$d \rightarrow diameter$
$\lambda \rightarrow wavelength\ of\ light$

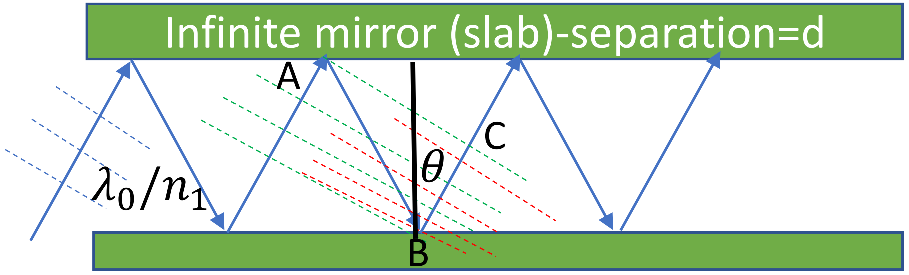
Fiber Optics: Wave guides:

https://www.youtube.com/watch?v=9-1717Poco

Dispersion:
distortion

Where is the wave injected in WG:
Mode Profile





If meets in opposite phase→ die out
Same phase→ constructive (Amp-2times). In this way A-2,4,8,..

How to make constructive?
Same phase→ constructive (Amp-2times). In this way A-2,4,8,..

$$\Delta\Phi = 2\pi m, \qquad m = 0,1,2,3,\ldots.$$

$$\Delta\Phi = kL = \frac{2\pi n_1}{\lambda_0}(AB + BC)$$

$$= \frac{2\pi n_1}{\lambda_0}\left(\frac{d}{\cos\theta} + AB\cos(2\theta)\right)$$

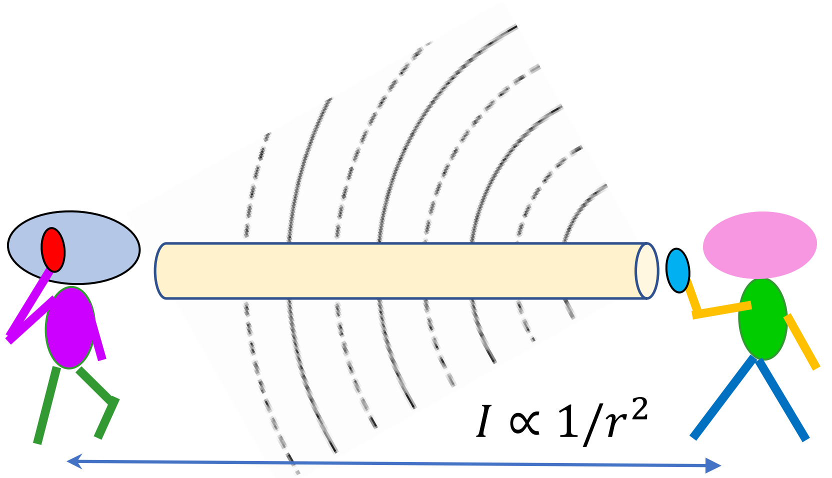
$$AB = \frac{d}{\cos\theta}, \; AC = AB\cos(2\theta)$$

$$2\pi m = \frac{2\pi n_1}{\lambda_0}\frac{d}{\cos\theta}(1 + \cos(2\theta))$$

$$m = \frac{n_1}{\lambda_0} d \, 2\cos\theta$$

$$\boxed{\cos\theta = \frac{\lambda_0}{2dn_1} m}$$

Optical Fiber condition



TPS

Wave guides:

$$k = k_0 n_1 = n_1 2\pi/\lambda$$

Incident wave

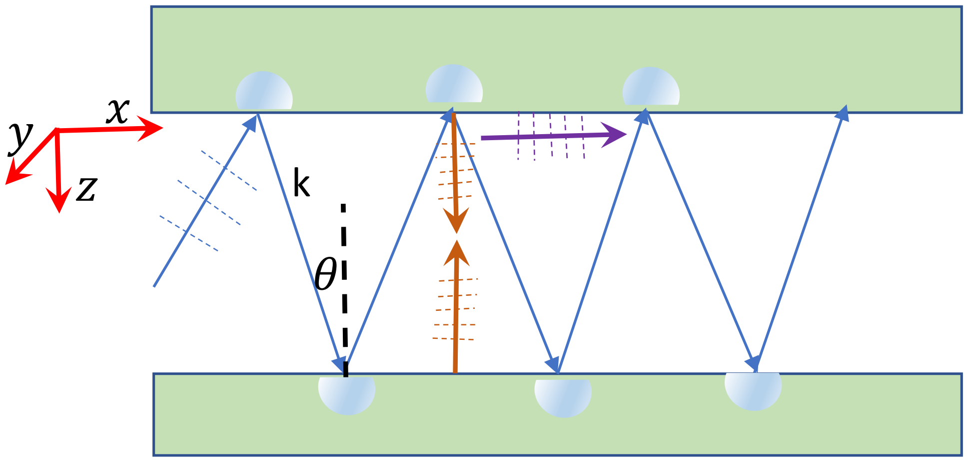
$$k_x = k sin\theta$$

$$k_z = k cos\theta$$

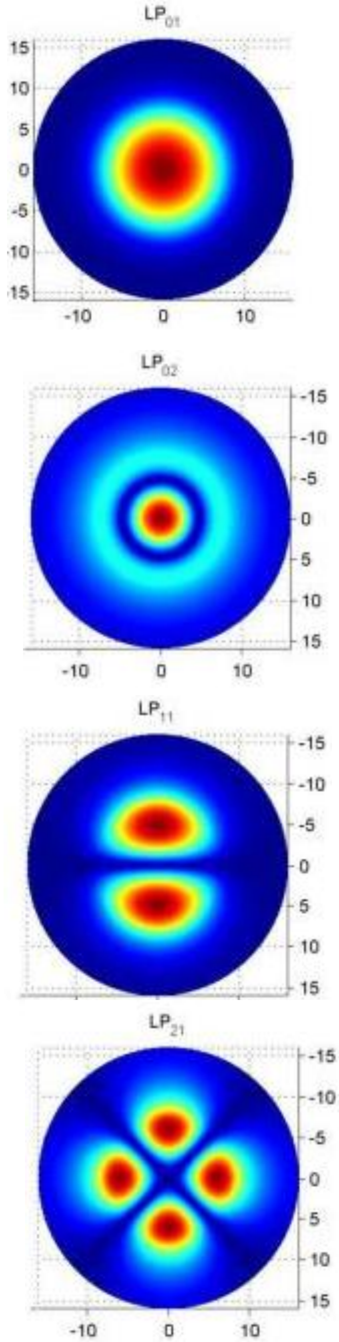
Reflected wave

$$k_x = k sin\theta$$

$$k_z = -k cos\theta$$



For TE mode, $E_z = 0, \mathrm{E_x} = 0$



$$\vec{E} = \hat{j}E_0 e^{\{i(\omega t - k_x x - k_z z)\}} + \hat{j}E_0 e^{\{i(\omega t - k_x x + k_z z)\}}$$

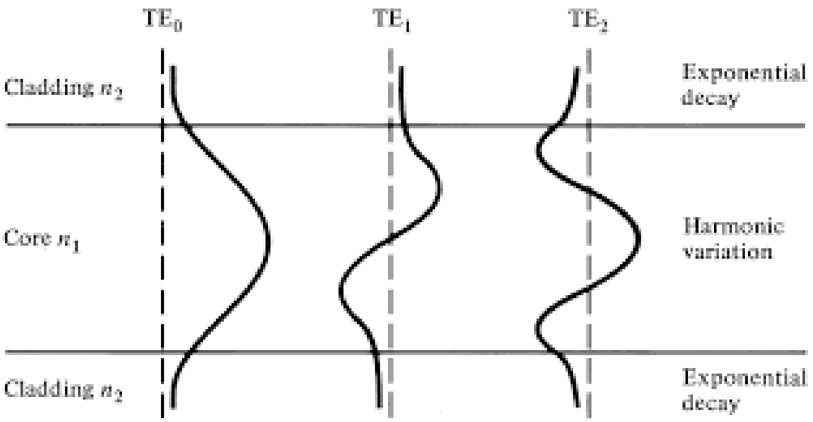
$$\vec{E} = \hat{j}E_0 e^{\{i(\omega t - k_x x)\}}(e^{-ik_z z} + e^{ik_z z})$$

$$\vec{E} = \hat{j}2E_0 \cos(k_z z) e^{\{i(\omega t - k_x x)\}}$$

Standing

Moving along y-direction

Evanescent field



$\psi(z,t) = 0,\ for\ k_z z = (n + \frac{1}{2})\pi,\ ie, z = \frac{(2n+1)\lambda}{2k_z}$ => NODES

Classification of optical fibre

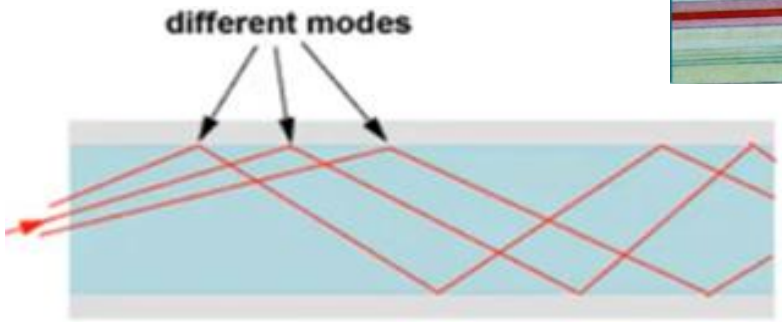
Sl no	Single Mode (SMF)	Multimode (MMF)
1	Only one mode is transmitted	Many modes (more than one) can be transmitted
2	Smaller core diameter (5-10mm)	Larger core diameter (50-200mm-SI)
3	$n_1 - n_2 \Rightarrow small$	$n_1 - n_2 \Rightarrow large$
4	Fabrication is difficult and hence costly	Fabrication is less difficult and hence cheaper

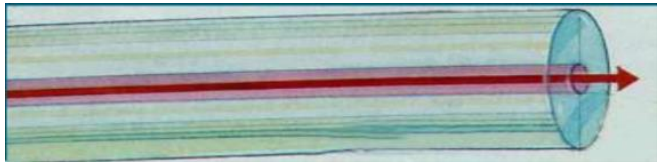
Single mode Fibre (SMF):

- It allow only one mode of light wave propagation
- It has very small core diameter of 8 to 10μm
- only light ray at $0°$ incident angle can pass through the length of fibre
- It is designed for use in the near infrared (the most common are 1310nm and 1550nm)
- Uses laser light source
- Higher bandwidth, high data rate
- Used for long communication
- Fabrication is difficult and costly
- No dispersion

Multi mode fibre (MMF):

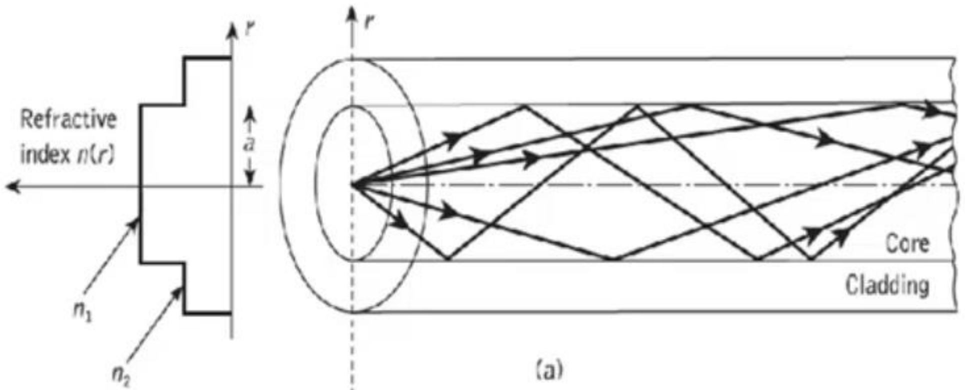
- Carries more than on mode
- Large core diameter around 50 to 100 μm
- The most prevalent size is 62.5μm
- Use for short communication
- Use LED light source
- Easy to install and maintain
- Fabrication is easy
- Significant loss and dispersion

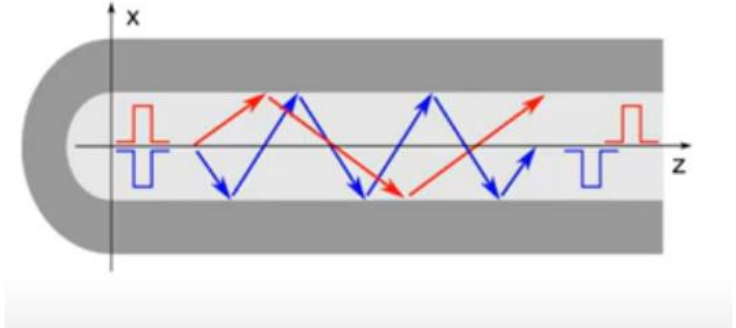




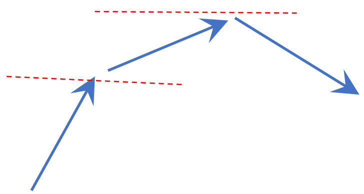
Step index fibres

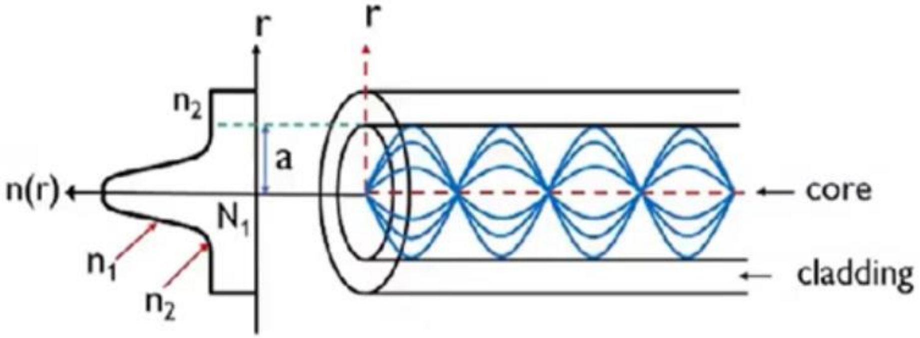
Step index fibres: If the refractive index of core remains the same from the centre of core to core-cladding interface and a sharp decrease in refractive index (make a step at core cladding boundary) at the core-cladding interface so that the cladding is of lower refractive index

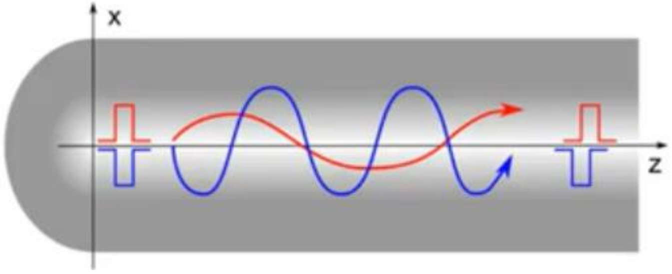




Graded index fibres: These type are made of varying refractive index of core material . Therefore, the refractive index changes with distance from centre of fibre to core-cladding interface







Combination of optical fibres

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

The refractive index of core and mode of propagation of light in optical, fibre is used to form combination types of optical fibre

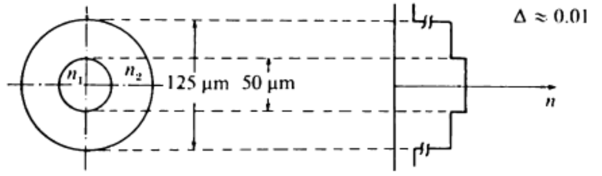
- Step index –single mode fibre
- Step index-multimode fibre
- Graded index –single mode fibres
- Graded index –multi mode fibres

If V ≤ 2.405, then the fibre is single mode fibre (SMF)
If V > 2.405, then the fibre is multimode fibre (MMF)

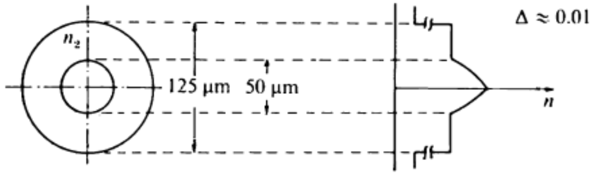
Number of Modes traveling in Fibre depends on the V – Number and is related as (for V > 20)):

For Step Index Fibre: $\boldsymbol{N} = \frac{V^2}{2}$

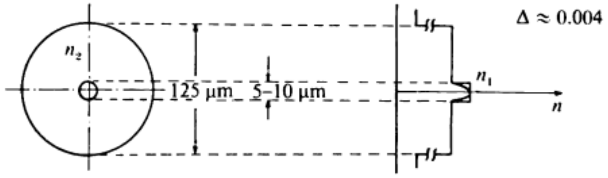
For Graded Index Fibre: $\boldsymbol{N} = \frac{V^2}{4}$



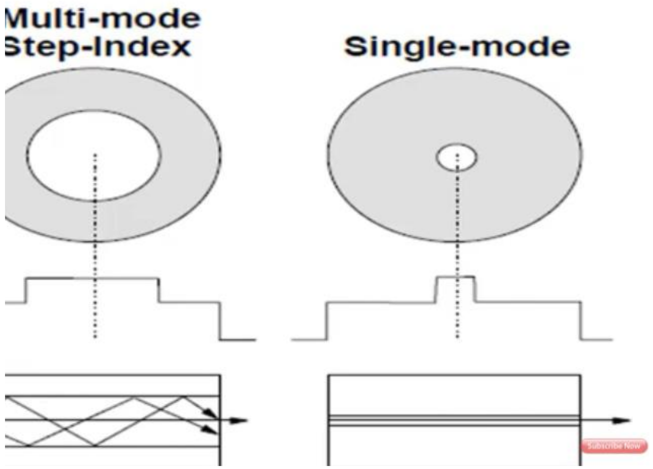
(a) Multimode step index



(b) Multimode (near parabolic)

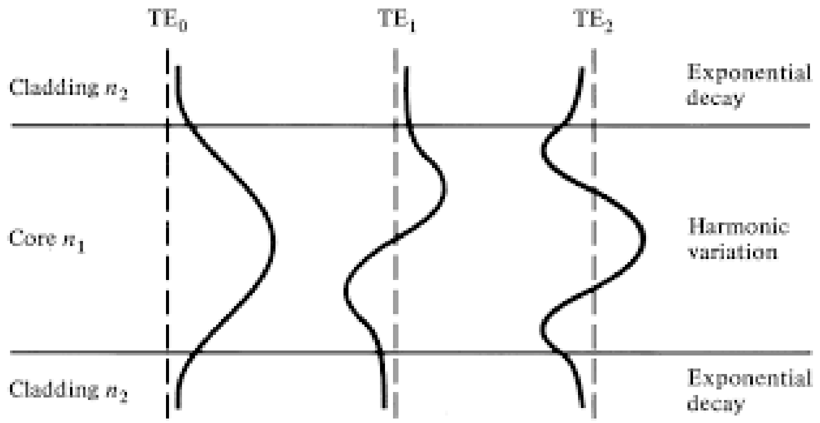


(c) Single mode (step/graded index)

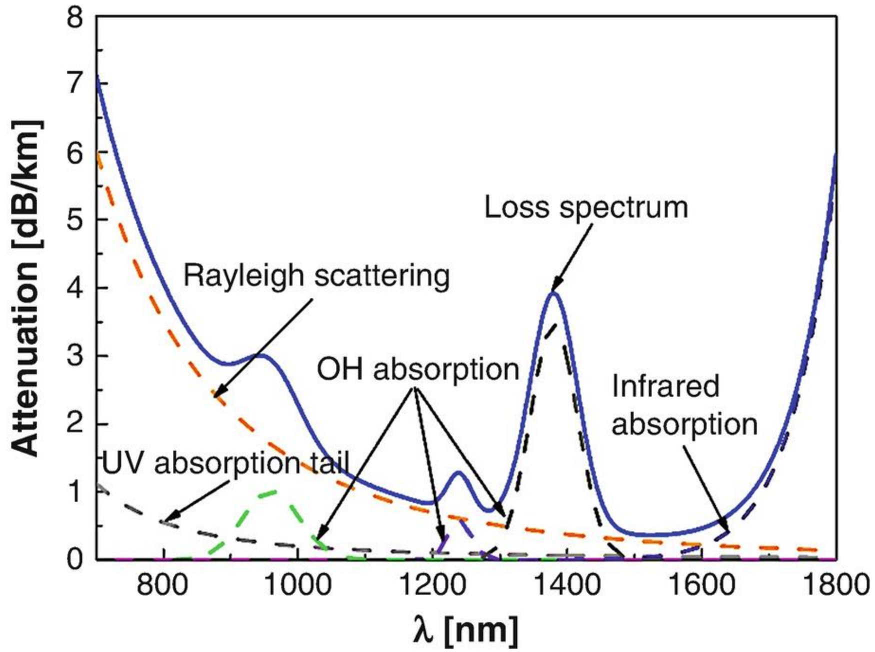


The ***cutoff wavelength*** for any mode is defined as the *maximum* wavelength at which that mode propagates. It is the value of $\lambda_c(lm)$ that corresponds to $V_c(lm)$ for the mode concerns. For each LP mode, the two parameters are related $\lambda_c = \frac{\pi d}{V_c}\sqrt{n_1^2 - n_2^2}$. The range of wavelengths over which mode *l*m will propagate is thus $0 < \lambda < \lambda_c(lm)$).

Attenuation:



1. Evanescent field loss
2. Rayleigh Scattering
3. Material absorption:
4. Bending loss:



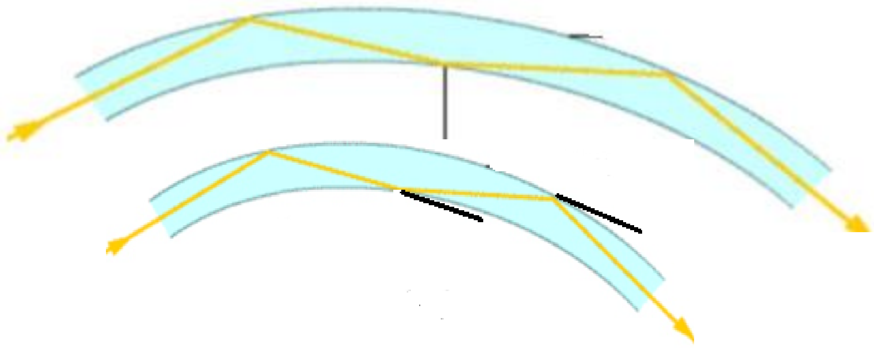
Optical power loss:

$$dB = 10log\left(P_{in}/P_{out}\right)$$

0=0 dB
50%= 3dB
90%=10dB
99%=20dB

$$P_{out} = P_{in}e^{-\alpha L/10}$$

$$\boxed{\alpha = \frac{10}{L}log\left(P_{in}/P_{out}\right)}$$



Dispersion:

The spreading of the optical pulse as it travels along the fiber limits the information carrying capacity of the fiber

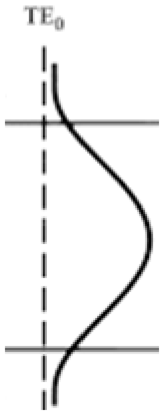
Intramodal(chromatic) dispersion: Pulse broadening within a single mode.The causes are as follows:

>> Material dispersion:

- It is the pulse spreading due to the dispersive properties of material.
- It arises from variation of refractive index of the core material as a function of wavelength.

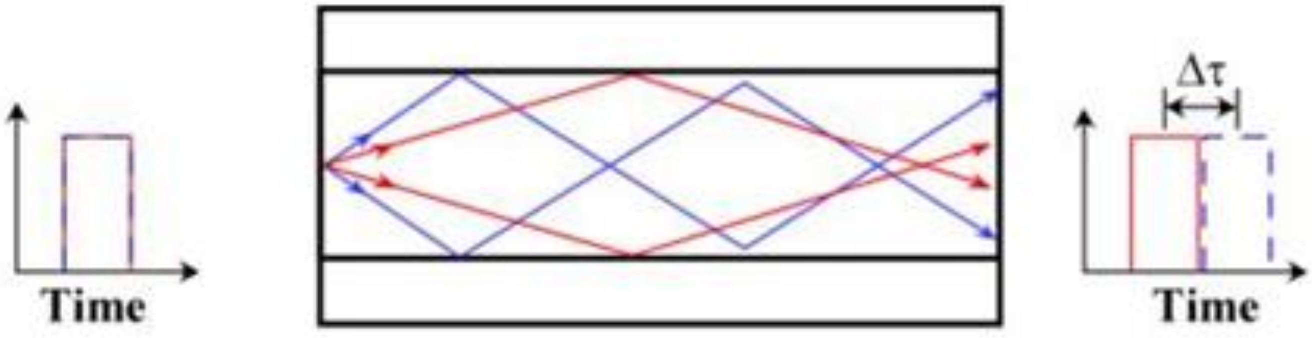
>>Waveguide dispersion:

- It occurs because a single mode fiber confines only about 80% of the optical power to the core.
- Dispersion thus arises since the 20% light propagating in the cladding travels faster than light confined to the core.



Intermodal dispersion: Dispersion caused by multipath propagation of light energy

- When the light pulse enters fiber it is breakdown into small pulses carried by individual modes.
- At the output individual pulses are recombined and since they are overlapped receiver sees a long pulse causing pulse broadening.



Temporal pulse separation:

$$\Delta t = \Delta L / v_g$$

Band width:

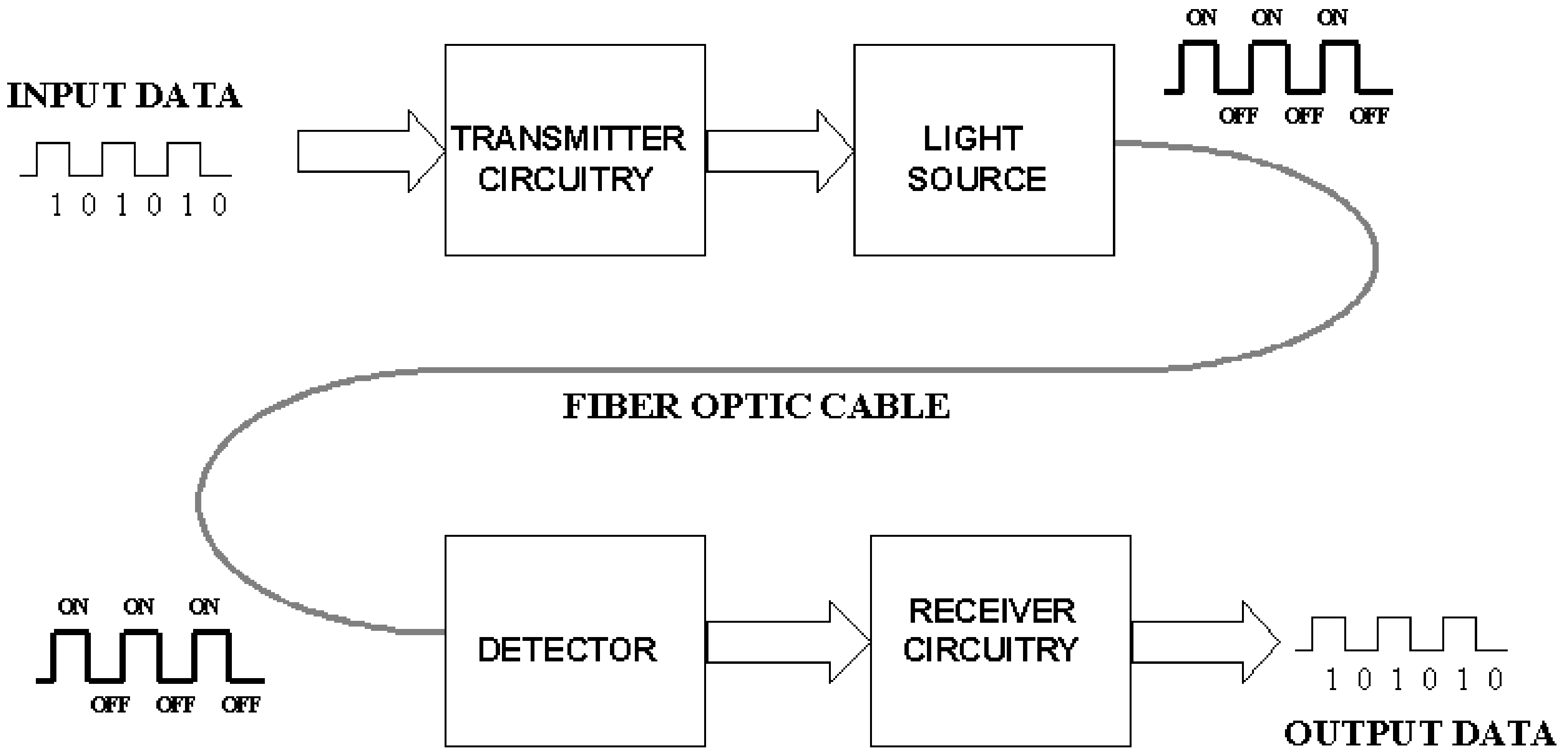
Bandwidth measures the data-carrying capacity of an optical fiber and is expressed as the product of the data frequency and the distance traveled (MHz-km or GHz-km, typically). For wideband communications we need single mode (multimode will have loss/dispersion)

For example, a fiber with a 400-MHz-km bandwidth can transmit 400 MHz for a distance of 1 km, or it can transmit 20 MHz of data for 20 km. The primary limit on bandwidth is pulse broadening, which results from modal and chromatic dispersion of the fiber. $Bandwidth \times distance = constant$

Typical values for different types of fiber follow,

Fiber Type	Bandwidth
Single Mode	100 GHz-km
Graded Index	500 MHz-km at 1300 nm 160 MHz-km at 850 nm
Step Index	20 MHz-km

Basic fiber optic communication System:



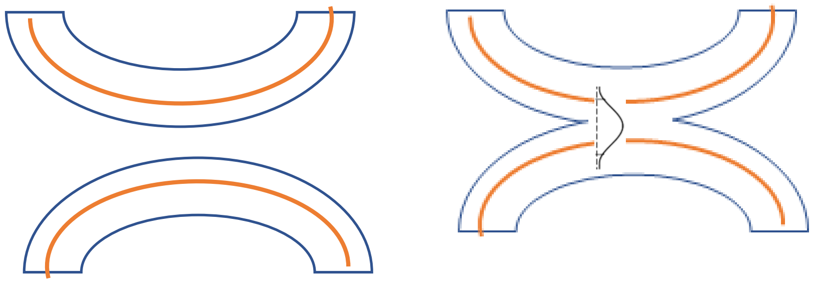
At the transmitter an electrical input is converted into an optical output from a laser diode or LED and this modulated light energy is fed into the Optical Fiber. The light is ultimately coupled to a receiver (detector) where this light energy is made incident on photo-sensors converts the light into an electrical signal.

Components:

- Directional coupler
- Phase modular
- Polariser
- Polarization controller
- Frequency shifter

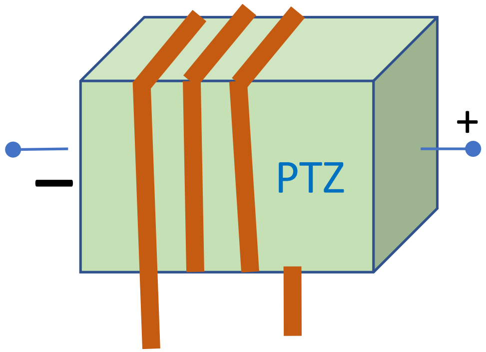
Directional coupler:

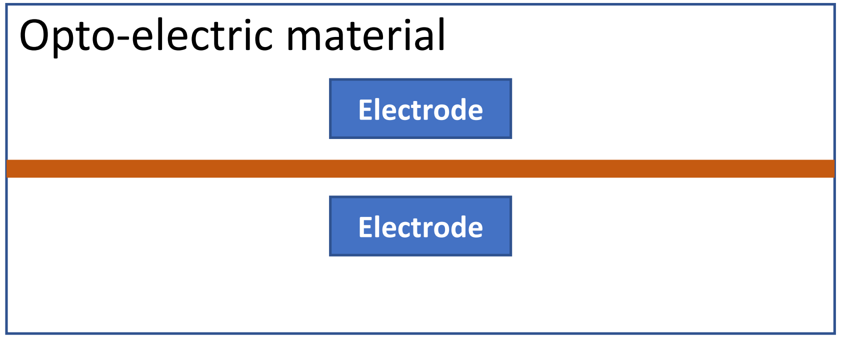
Splitting light in a desired ratio (50:50, 60:40, even 0:100,etc) by adjusting the interaction length (L_{int}) and distance between cores (d_{core}).



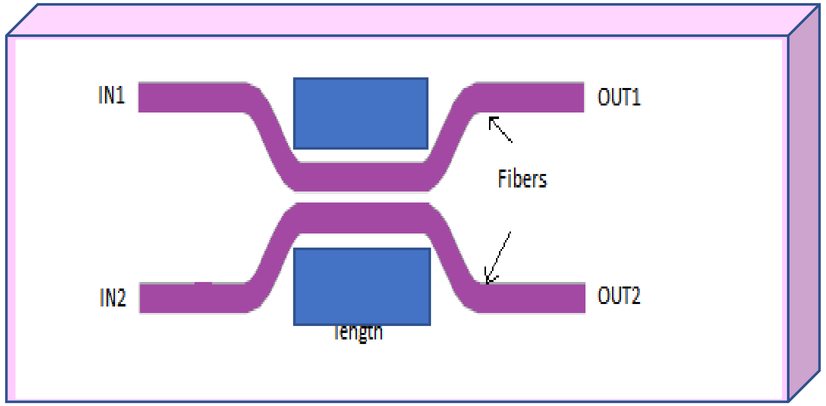
Phase modular

$$\Delta\phi = \frac{2\pi}{\lambda} n\Delta L + \frac{2\pi}{\lambda} \mathrm{L}\Delta\mathrm{n}$$





V changes the n and hence the phase (even frequency) get changed



Special Fibres and Applications:

1. Polarization maintaining fibre: polarization will sustain whatever was launched in the fibre

2. Single polarization fibre: allows one polarization and others will be blocked

3. Coated fibre: coated with special materials (metal: temp, PTZ : pres/electric field/sound) which responds to the particular change in the environment and hence modulate the signal.

4. Jacketed fibre: similar to 3

5. Doped: Indium doping and pump with laser (semiconductor) to get different types of lasers.

6. Exposed fibre: tail of the evanescent field are exposed to interact with environ. (gas etc).

7. Twin-core fibre: temp/stress etc