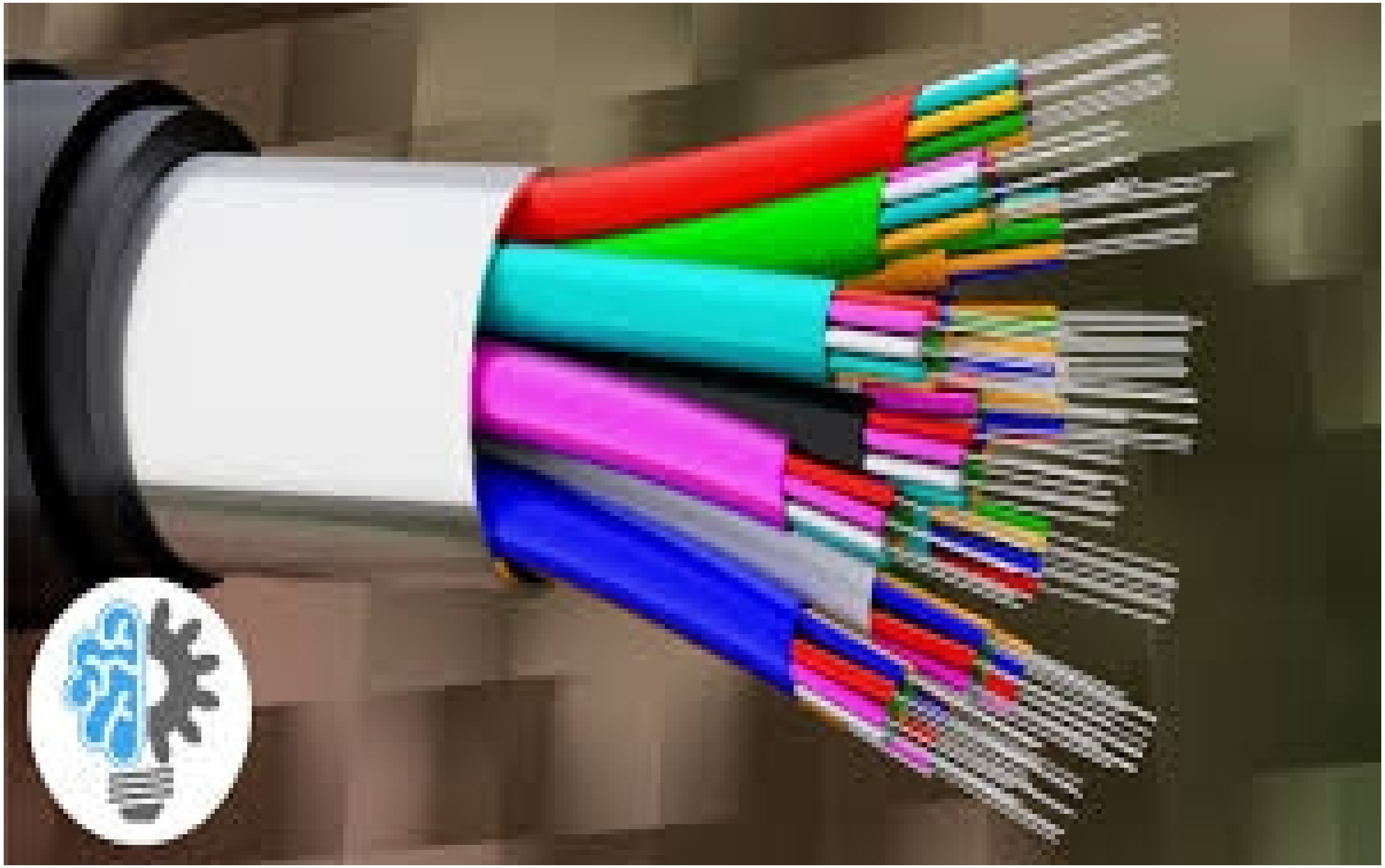
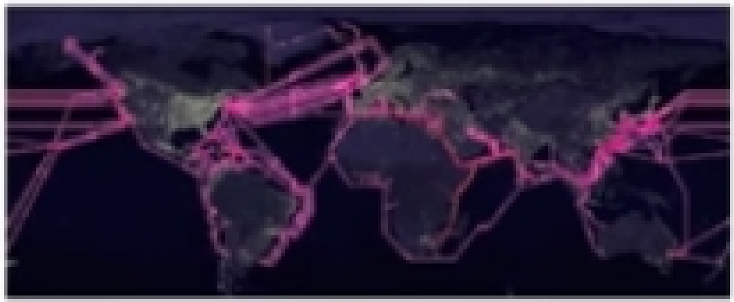
FIBRE OPTICS

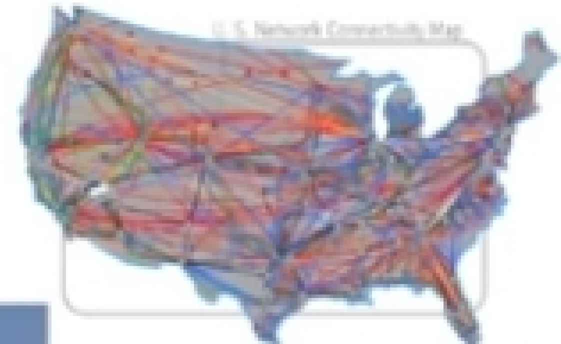


Fibre optics:
Principle
Propagation of light .
Optical fibre.
Numerical aperture and acceptance angle.
Types of optical fibers
(material, refractive index, mode).
Applications

Fiber Is Everywhere!

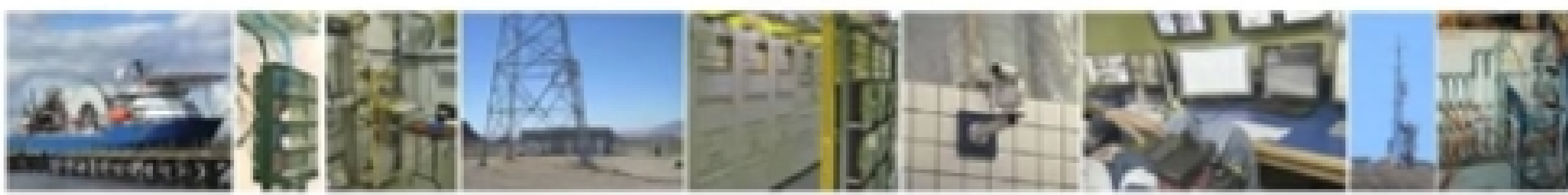


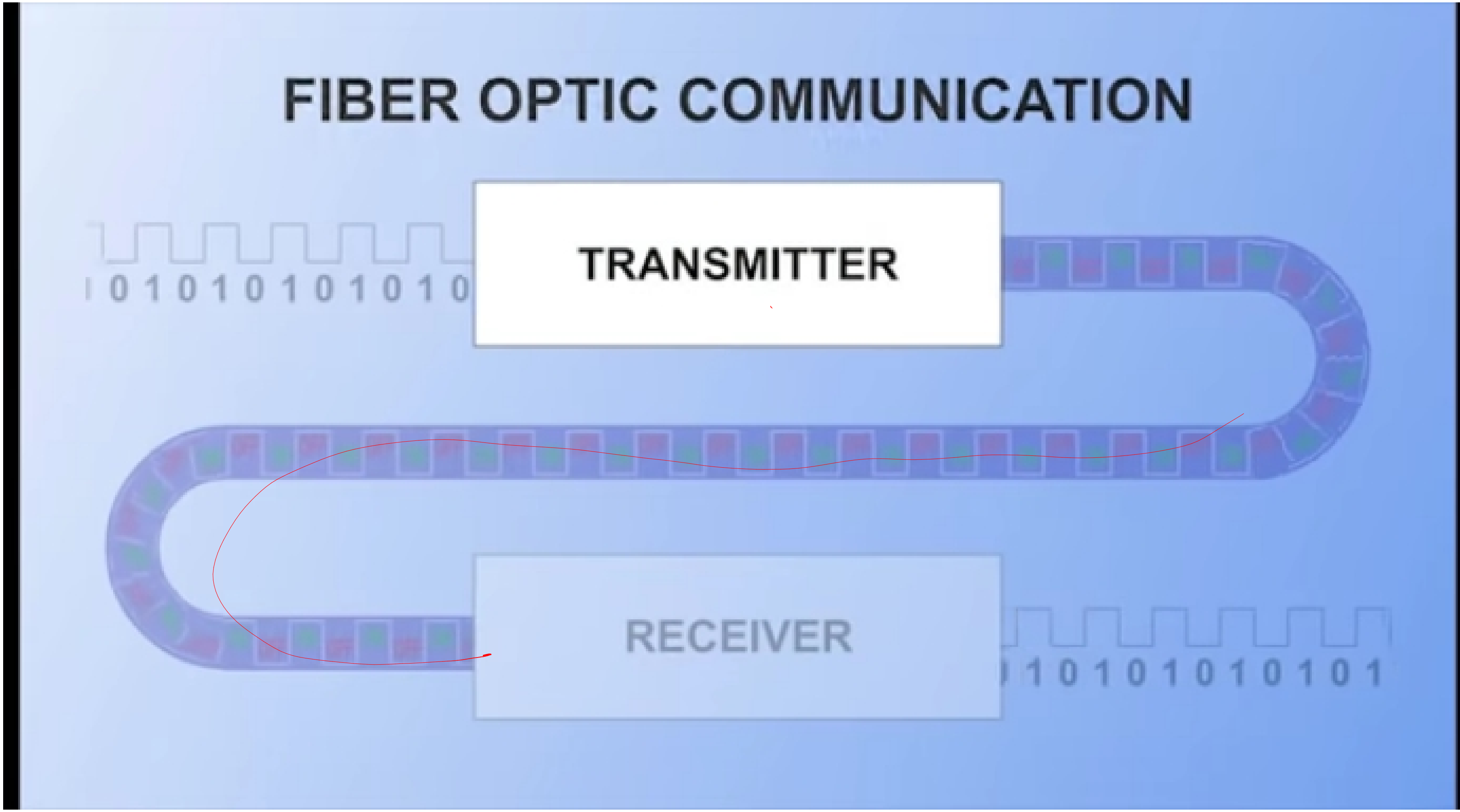
Submarine



Landlines

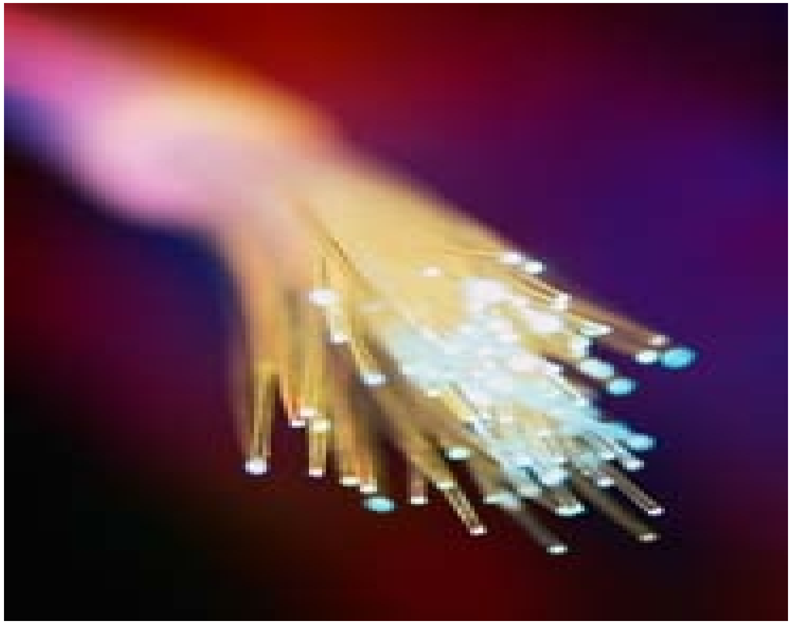
Connecting Wireless




FIBER OPTIC COMMUNICATION
TRANSMITTER
0 1 0 1 0 1 0 1 0 1 0
RECEIVER
1 0 1 0 1 0 1 0 1 0 1

Introduction

- EM waves are guided through media composed of transparent material
- Without using electrical current flow
- Uses glass or plastic cable to contain the light wave and guided them
- Infinite bandwidth – carry much more information



History

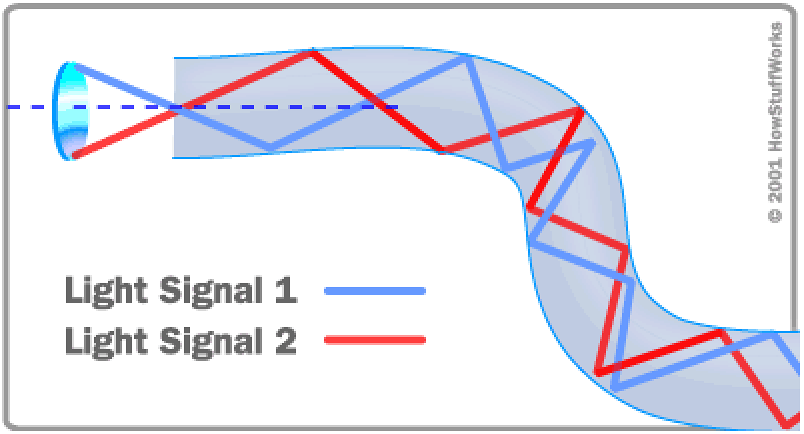
- 1951 – light transmission via bundles of fibers – leads to fiberscope – medical field
- 1958 – light amplification – stimulated emission
- 1960 – laser invention
- 1967 – fiber cable with clad
- 1970 – low loss optical cable. < 2 dB/km
- 1980 – optical cable refined – affordable optical communication system
- 1990 – 0.16dB/km loss
- 1988 – long haul transmission system

light propagation

- Refraction
  - Occurs when the light travels between two different material density and changes it speed based on the light frequency
- Refraction Index
  - the ratio of the velocity of propagation of a light ray in a given material

Refractive Index

$$n = \frac{c}{v}$$



n = refractive index

c = speed of light

v = speed of light in a given material

Refractive Index

Material	Index of Refraction[a]
Vacuum	1.0
Air	1.0003 (≈1)
Water	1.33
Ethyl alcohol	1.36
Fused quartz	1.46
Glass fiber	1.5–1.9
Diamond	2.0–2.42
Silicon	3.4
Gallium-arsenide	2.6

Index of refraction and speed of light for various materials.

	Index of Refraction	Speed of Light
Free space (vacuum)	**1.0**	**3×10^8 m/s**
Air at sea level	**1.003**	**2.99×10^8 m/s**
Ice	**1.31**	**2.29×10^8 m/s**
Water	**1.33**	**2.26×10^8 m/s**
Glass (minimum)	**1.45**	**2.07×10^8 m/s**
Glass (maximum)	**1.80**	**1.67×10^8 m/s**
Diamond	**2.42**	**1.24×10^8 m/s**

Refraction with Snell's Law

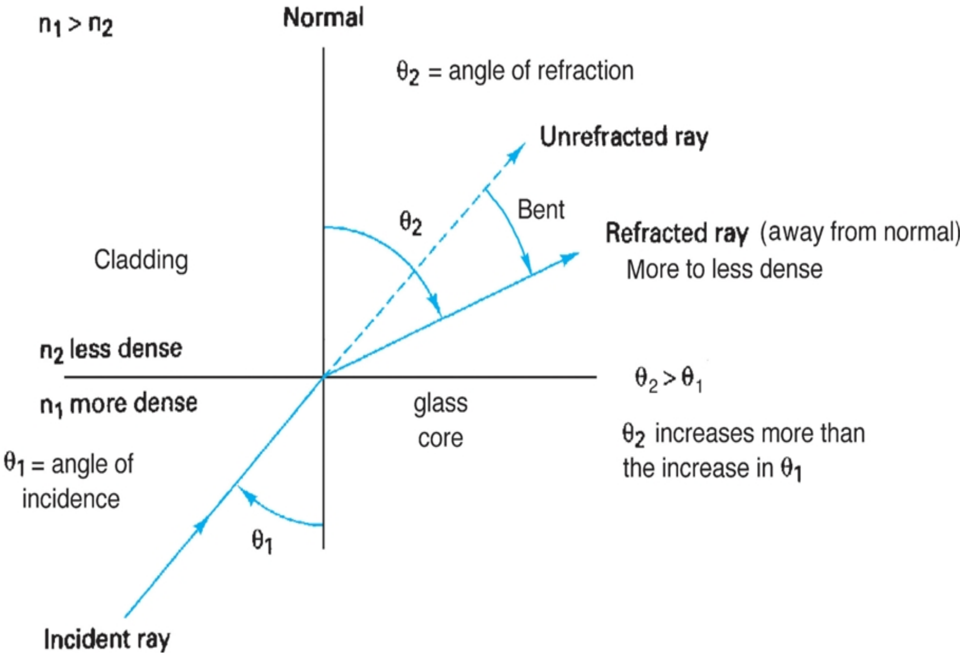
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

n_1 = refractive index material 1

n_2 = refractive index material 2

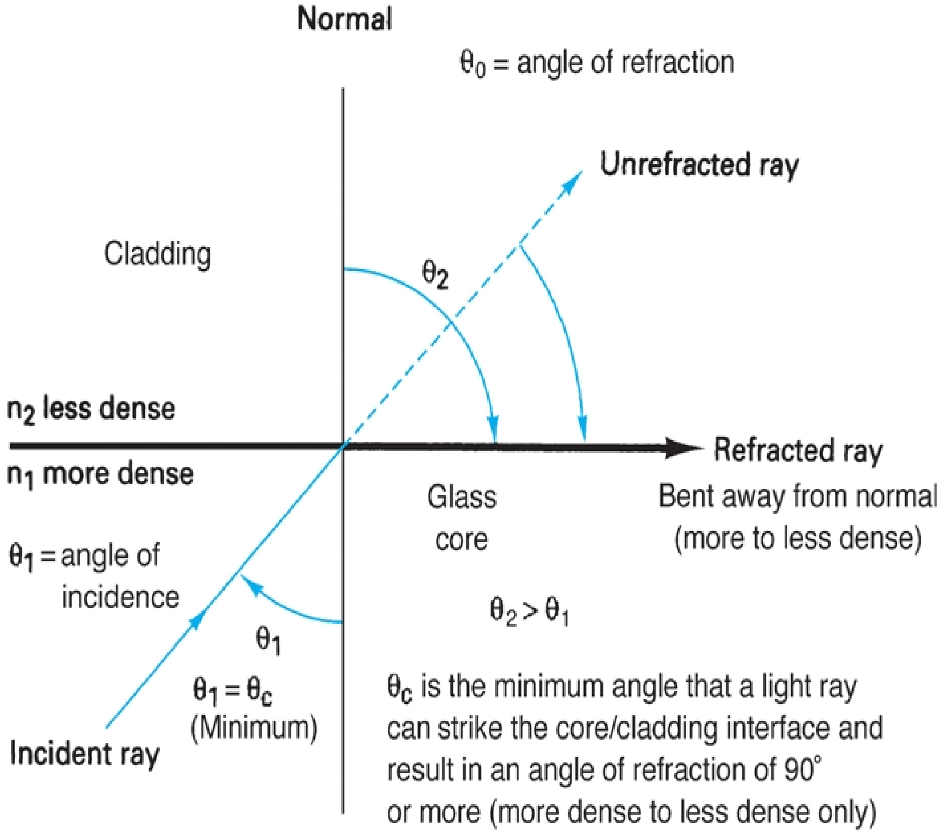
θ_1 = angle of incidence

θ_2 = angle of refraction

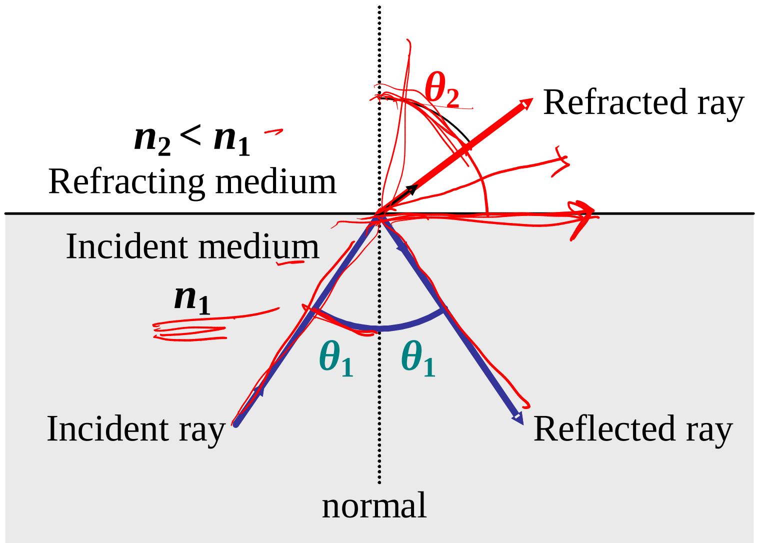


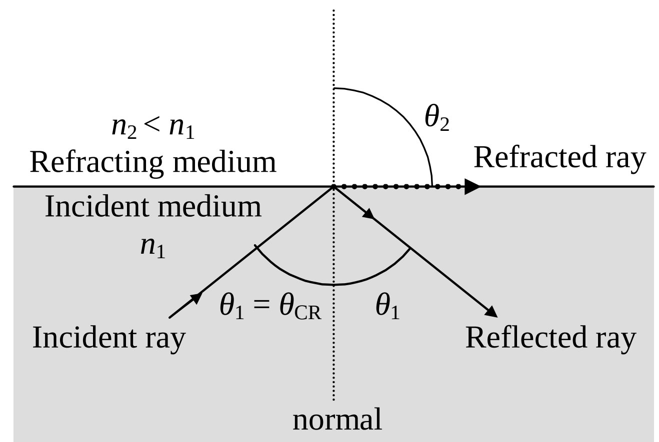
Critical Angle

- the minimum angle of incident at which the refracted angle is 90° or greater
- the light must travel from higher refractive index to a lesser refractive index material



Total internal reflection





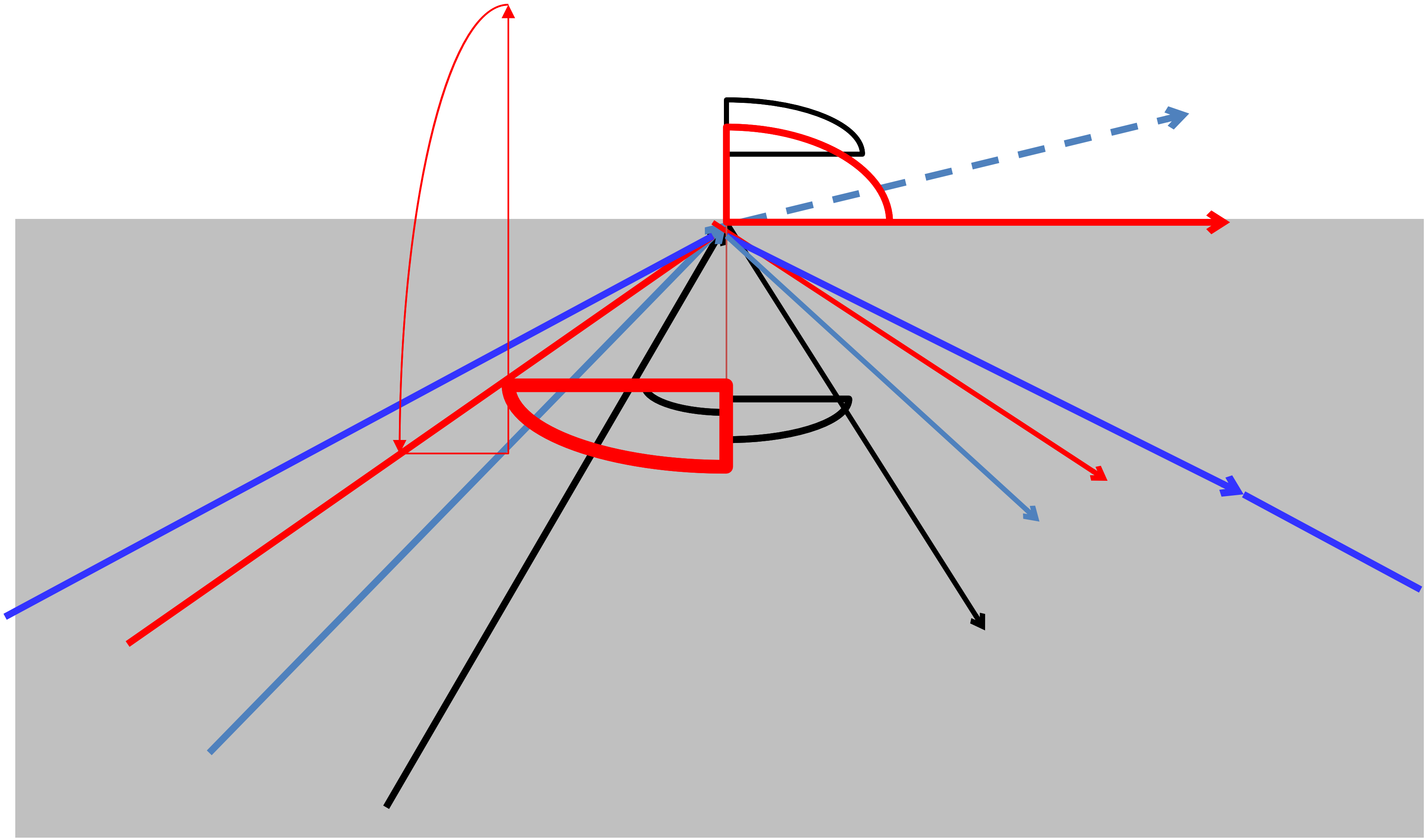
$\theta_1 < \theta_c$

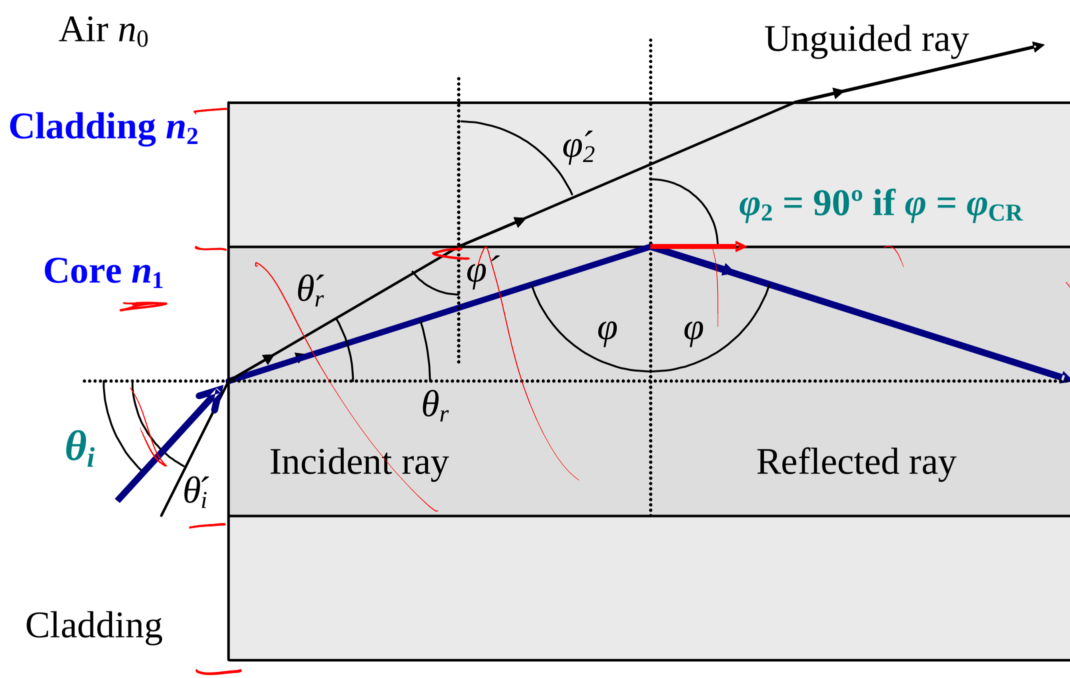
$\theta_1 = \theta_c$

$\theta_1 > \theta_c$

Total internal reflection

Critical angle refraction=90





1. $n_1 > n_2$

2. Angle of incident rays at core-cladding boundary must be greater than critical angle of incidence

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

$\theta_i = \theta_c$, $\theta_r = 90^\circ$

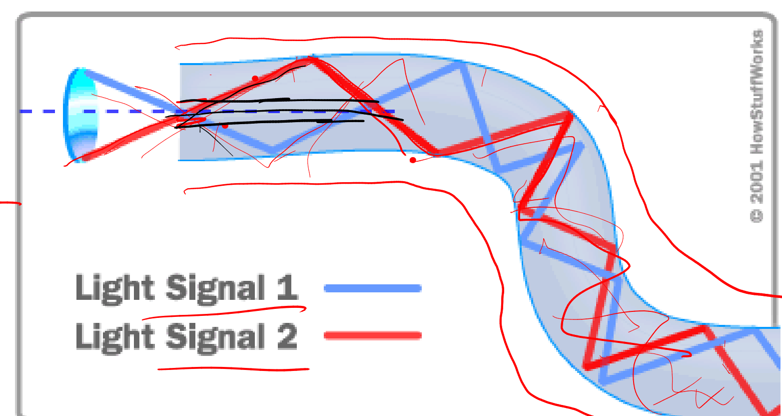
$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\boxed{\sin \theta_i > \frac{n_2}{n_1}}$$

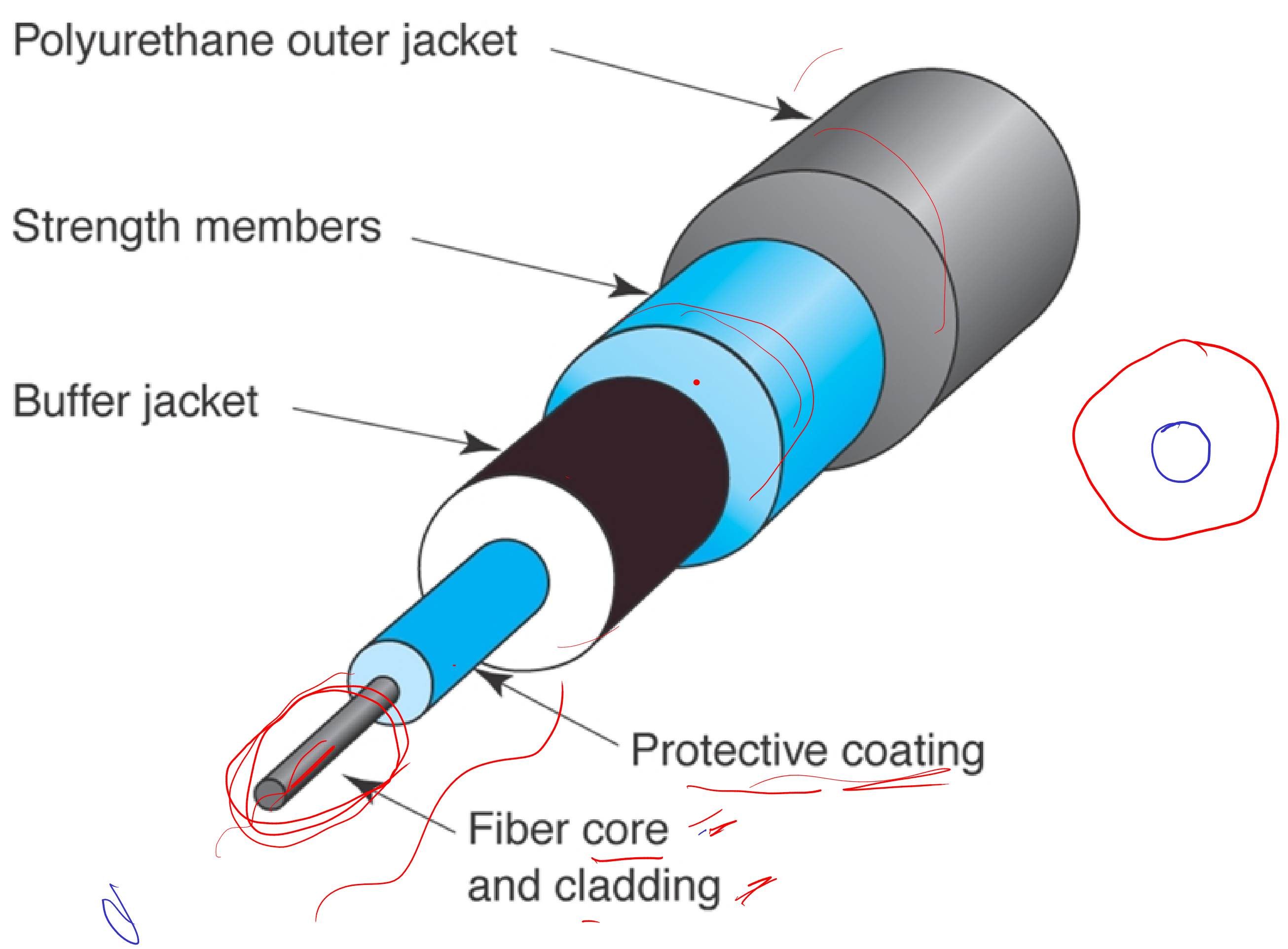
$\theta_i > \theta_c$

$\sin \theta_i > \sin \theta_c$

number of modes $\propto$ diameter



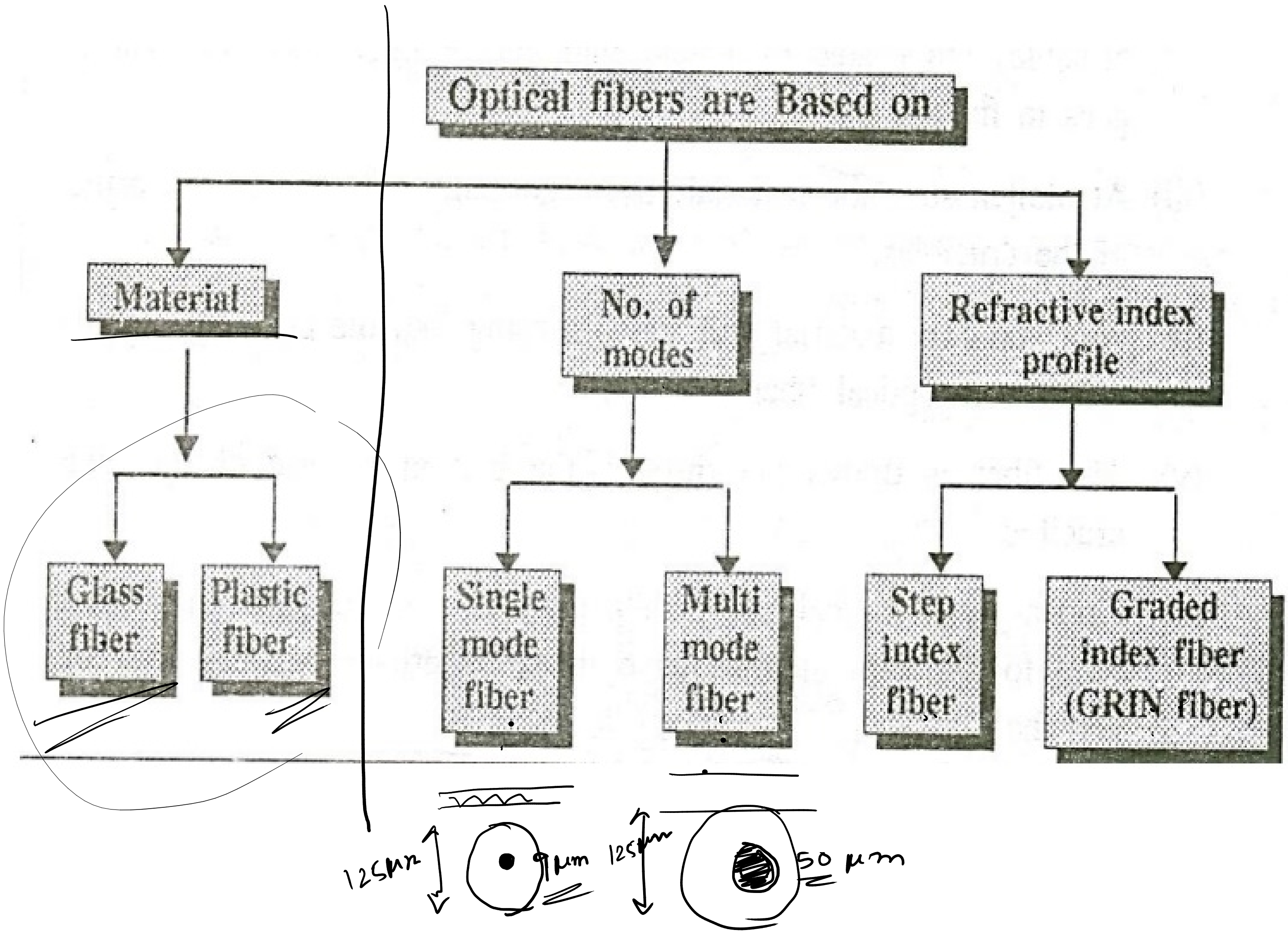
The structure of Optical Fibre



The structure of Optical Fibre

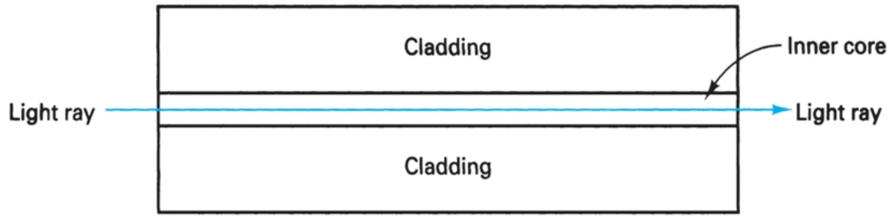
- Optical fiber construction
  - special lacquer, silicone, or acrylate coating – outside of cladding – to seal and preserve the fiber's strength, protects from moisture
  - Buffer jacket – additional cable strength against shocks
  - Strength members – increase a tensile strength
  - Outer polyurethane jacket

Types of fiber optics

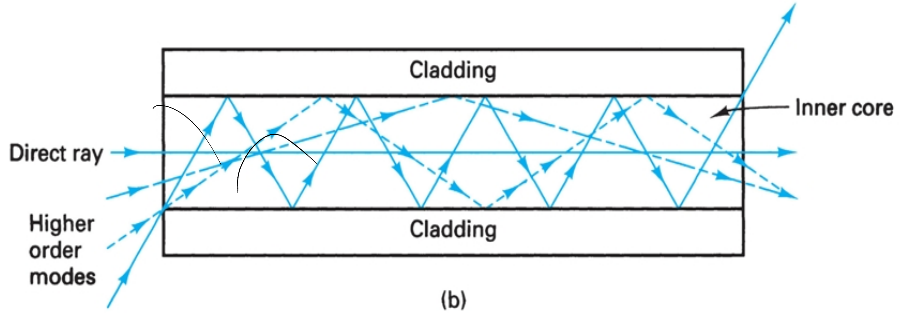


Types of optical fibre (propagation)

- Mode of propagation
  - single mode
    - only one path for light rays down the fiber
  - multimode
    - many higher order path rays down the fiber



(a)

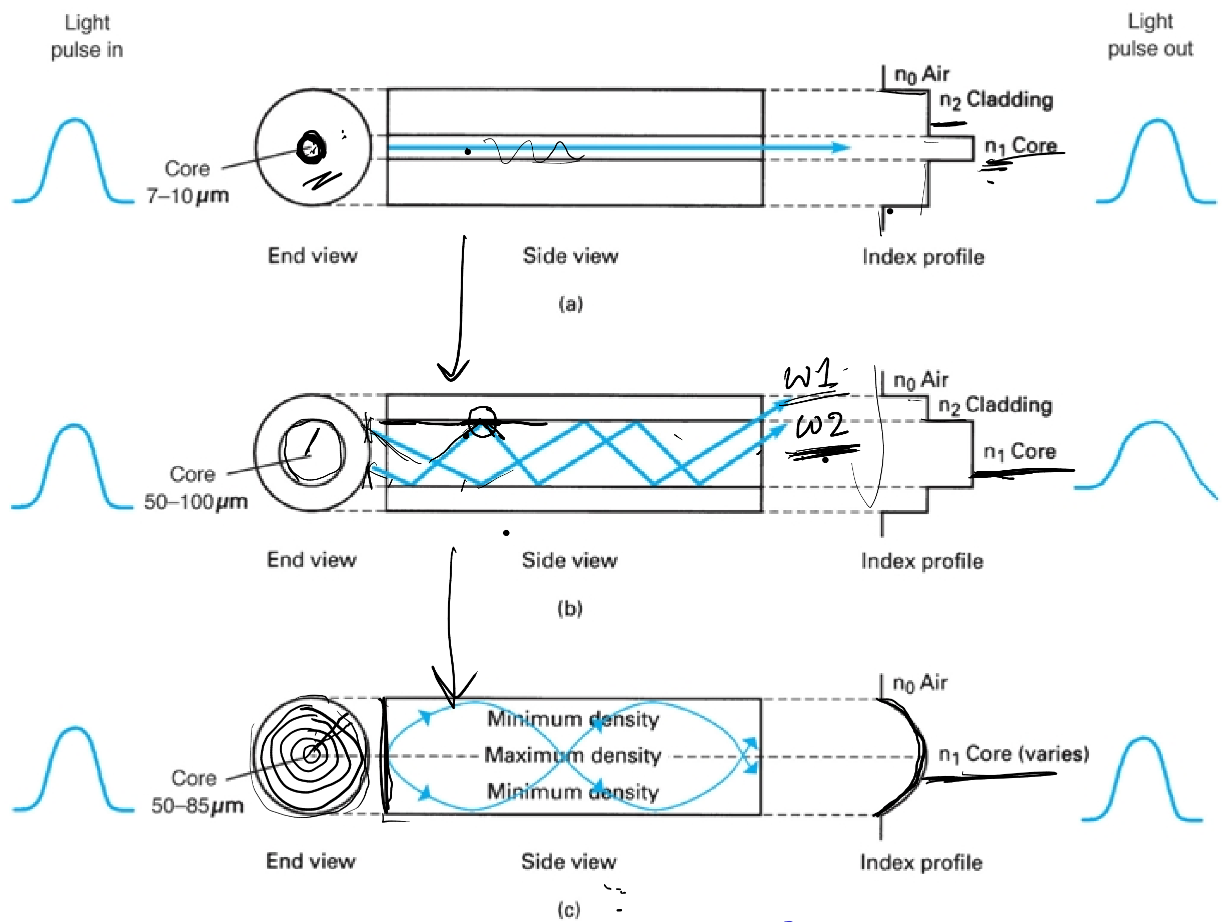


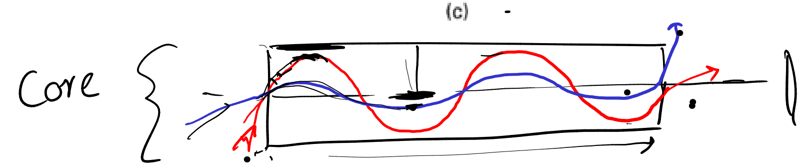
(b)

Types of optical fibre (Index Profile)

$n_1 > n_2$

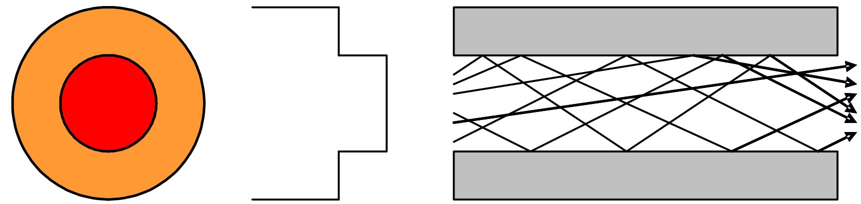
- step index – single mode
- step index – multimode
- graded index - multimode





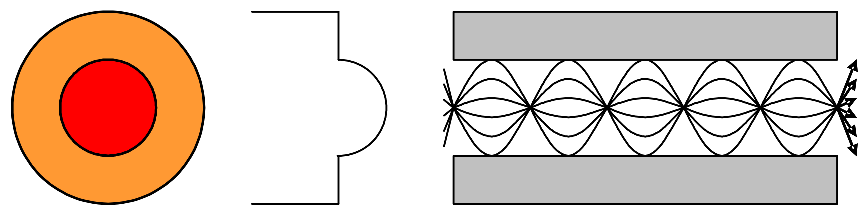
Types of optical fibre (propagation)

- multimode step index



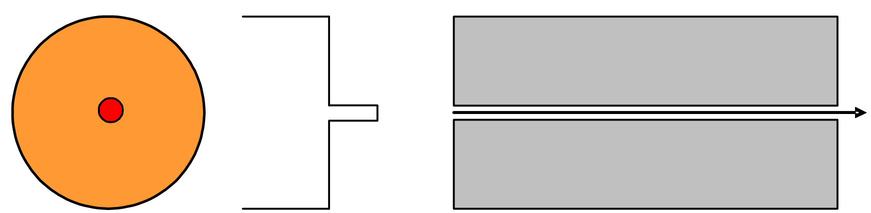
(a) Multimode step index fiber

- multimode graded index



(b) Multimode graded index fiber

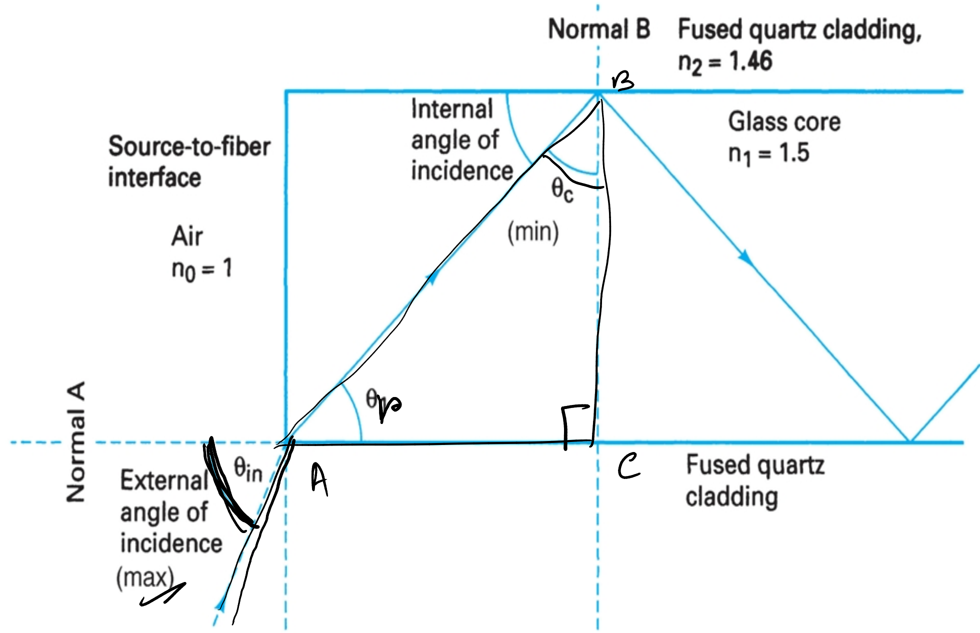
- single-mode step index



(c) Single-mode fiber

Acceptance Angle

- the maximum angle in which external light rays may strike the air/glass interface and still propagate down the fiber



ΔABC

$\sin\theta_r = \sin(90-\theta) = \cos\theta$

$\sin\theta_c = \dfrac{\mu_2}{\mu_1}$

$$\frac{\sin\theta_{in}}{\sin\theta_r} = \mu_1$$

$$\Rightarrow \sin\theta_{in} = \mu_1\cos\theta$$

$$\theta_{in} = \theta_{in,max}, \quad \theta = \theta_c$$

$$\sin\theta_{in,max} = \mu_1\cos\theta_c$$

$$= \mu_1\sqrt{1-\sin^2\theta_c}$$

$$\sin \theta_{in,max} = \mu_1 \sqrt{1 - \sin^2 \theta_c}$$

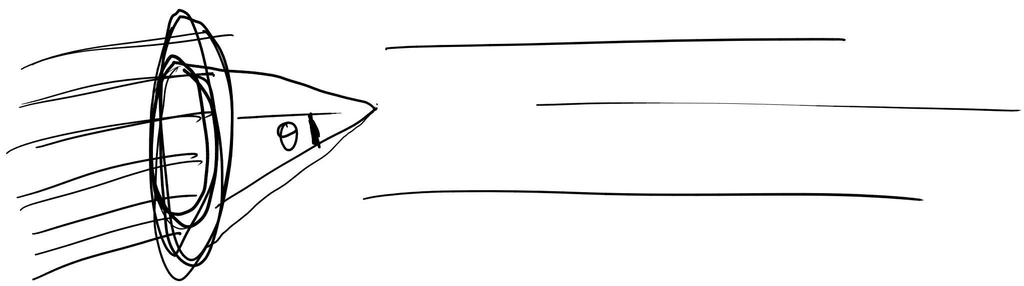
$$= \mu_1 \sqrt{1 - \left(\frac{\mu_2}{\mu_1}\right)^2}$$

$$\boxed{\sin \theta_{in,max} = \sqrt{\mu_1^2 - \mu_2^2}}$$

$\theta_{in,max} \rightarrow$ Acceptance Angle

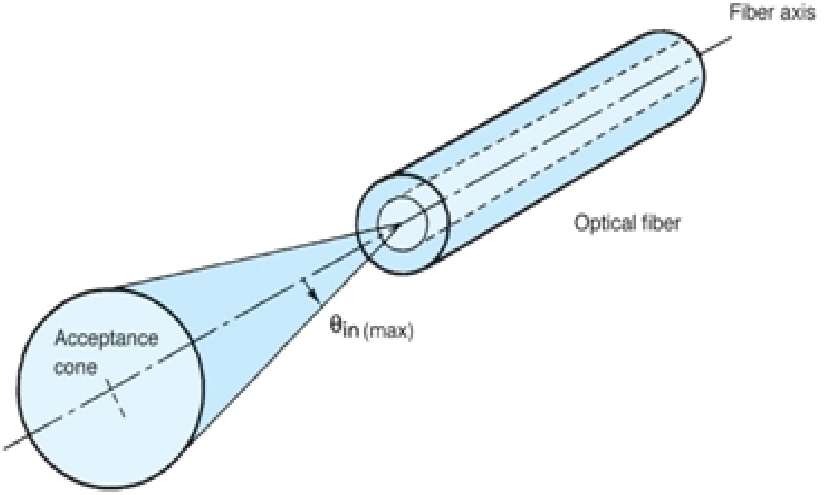
$\sin \theta_{in,max} \rightarrow$ Numerical Aperature

$$NA = \sqrt{\mu_1^2 - \mu_2^2}$$



Acceptance Angle

$$\theta_{in(\max)} = \sin^{-1}\frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$



$\theta_{in(\max)}$ = acceptance angle

n_0 = refractive index of air

n_1 = refractive index of fiber core

n_2 = refractive index of fiber cladding

$$\theta_{in(\max)} = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

Numerical Aperture - NA

To measure the magnitude of the
acceptance angle

- describe the light gathering or light-collecting ability of an optical fiber
- the larger the magnitude of NA, the greater the amount of external light the fiber will accept

Numerical Aperture - NA

$$NA = \sin \theta_{in}$$

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

$$\theta_{in} = \sin^{-1} NA$$

θ_{in} = acceptance angle

NA = numerical aperture

n_1 = refractive index fiber core

n_1 = refractive index fiber cladding

- Calculate the numerical aperture of an optical fibre hose core and cladding are made of materials of refractive index 1.6 and 1.5 respectively.

- Calculate the numerical aperture of an optical fibre hose core and cladding are made of materials of refractive index 1.6 and 1.5 respectively.

Numerical aperture =

- $\sqrt{n1^2 - n2^2} = 0.55677.$

NA = 0.5, core refractive index = 1.54

Find i) r.i of Cladding = 1.45

ii) Acceptance Angle $\approx 30^{\circ}$

$\boxed{\mu_1 , \mu_2 , NA , \theta}$

Advantages of Optical Fibre

<u>1. Wide bandwidth</u>: Fiber optic system uses light as a carrier with **1013 to 1014 Hz**. Radio waves are **106 to 1010 Hz**. Electrical signals have frequencies up to **108 Hz**. The maximum bandwidth of the transmitted signals is **10%** of the carrier. **Bandwidth** describes the maximum data transfer rate of a network

<u>2. Low loss</u>: The typical attenuation of a 1 GHz bandwidth digital signal in an optical fiber is **0.1 dB per km**. A 100 MHz bandwidth signal in RG-58/U coaxial cable has attenuation of **130 dB per km**.

Advantages of Optical Fibre

3. Electromagnetic immunity: Electrical fields do not affect light signals.

4. Light weight and small size: 1 km of optical fiber cable weighs about 10 kilograms. A 1 km copper wire with the same signal carrying capacity would weigh 700 kg.

Advantages of Optical Fibre

5. Safety: There is no possibility of a short circuit in a fiber optic system, eliminating the hazard of sparks in an electrical cable.

6. Security: Optical fiber is harder to tap than electrical wire. Unwanted tapping over the length of the fiber can usually be detected.

Disadvantages

- Interfacing cost
  - Optical cable – transmission medium
  - Needs to be connected to standards electronics facilities – often to be expensive
- Strength
  - lower tensile strength
    - can be improved with kevlar and protective jacket
  - glass – fragile – less required for portability
- Remote electrical power
  - need to be include electrical line within fiber cable for interfacing and signal regeneration

Disadvantages

- Loss due to bending
  - bending causes irregularities in cable dimension – the light escapes from fiber core – loss of signal power
  - prone to manufacturing defect
- Specialized tools, equipment and training
  - tools to splice, repair cable
  - test equipment for measurements
  - skilled technicians

Some of the applications of fiber optic

- Long haul, backbone public and private networks
- Local loop networks
- Fiber backbone networks (LAN connectivity)
- High resolution image and digital video
- Computer networks, wide area and local area
- Shipboard communications
- Aircraft communications and controls
- Interconnection of measuring and monitoring instruments in plants and laboratories