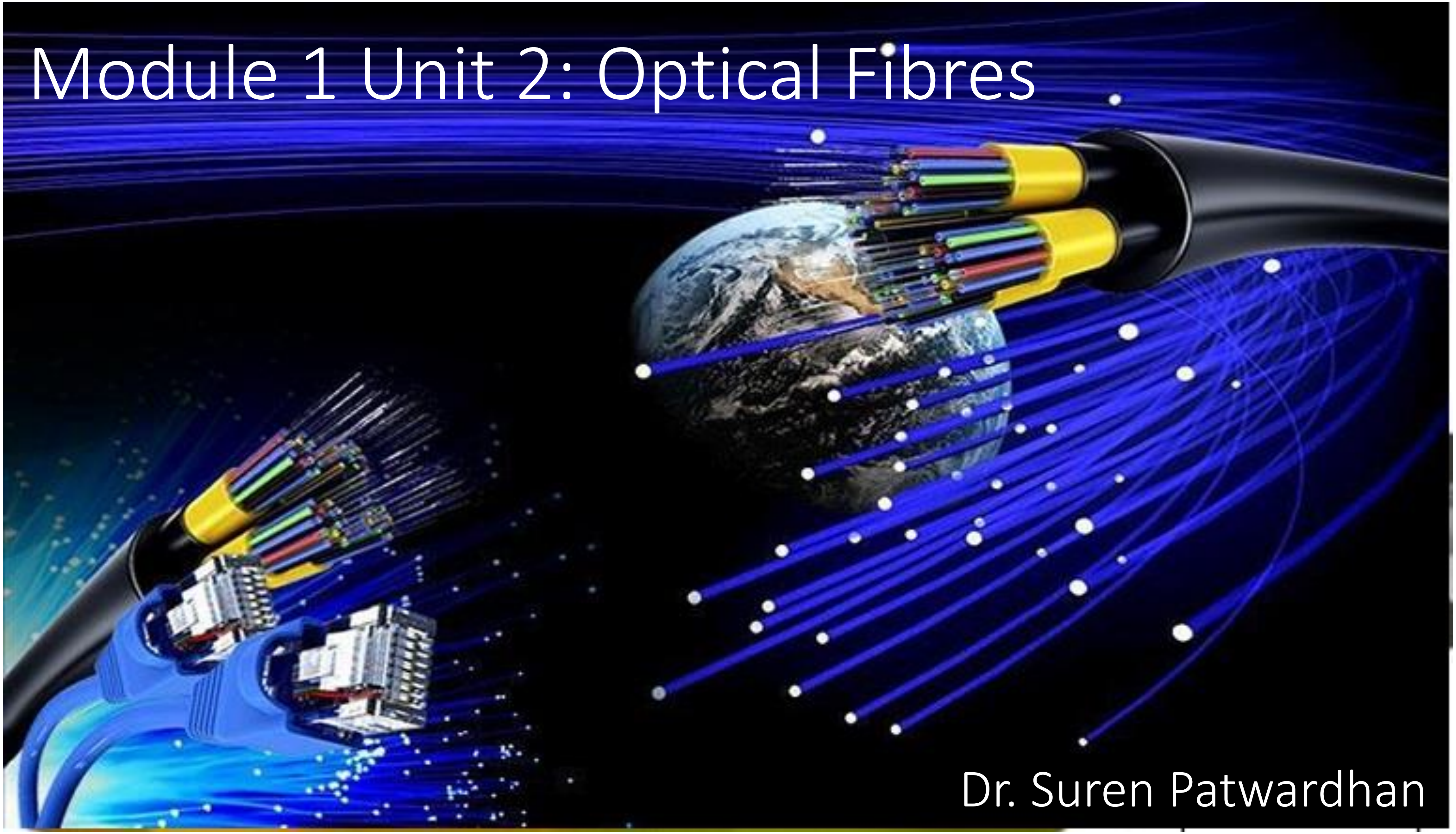
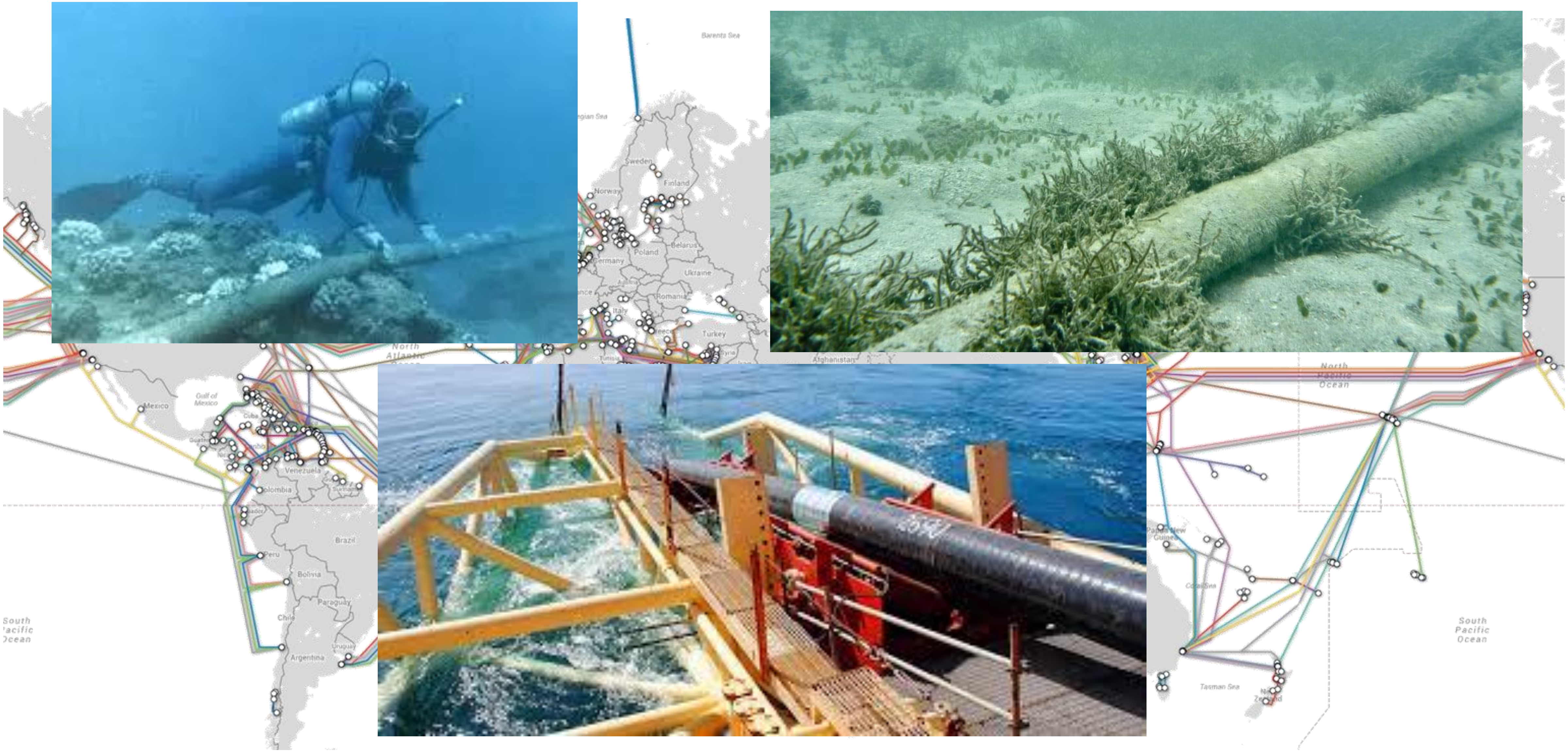
Module 1 Unit 2: Optical Fibres



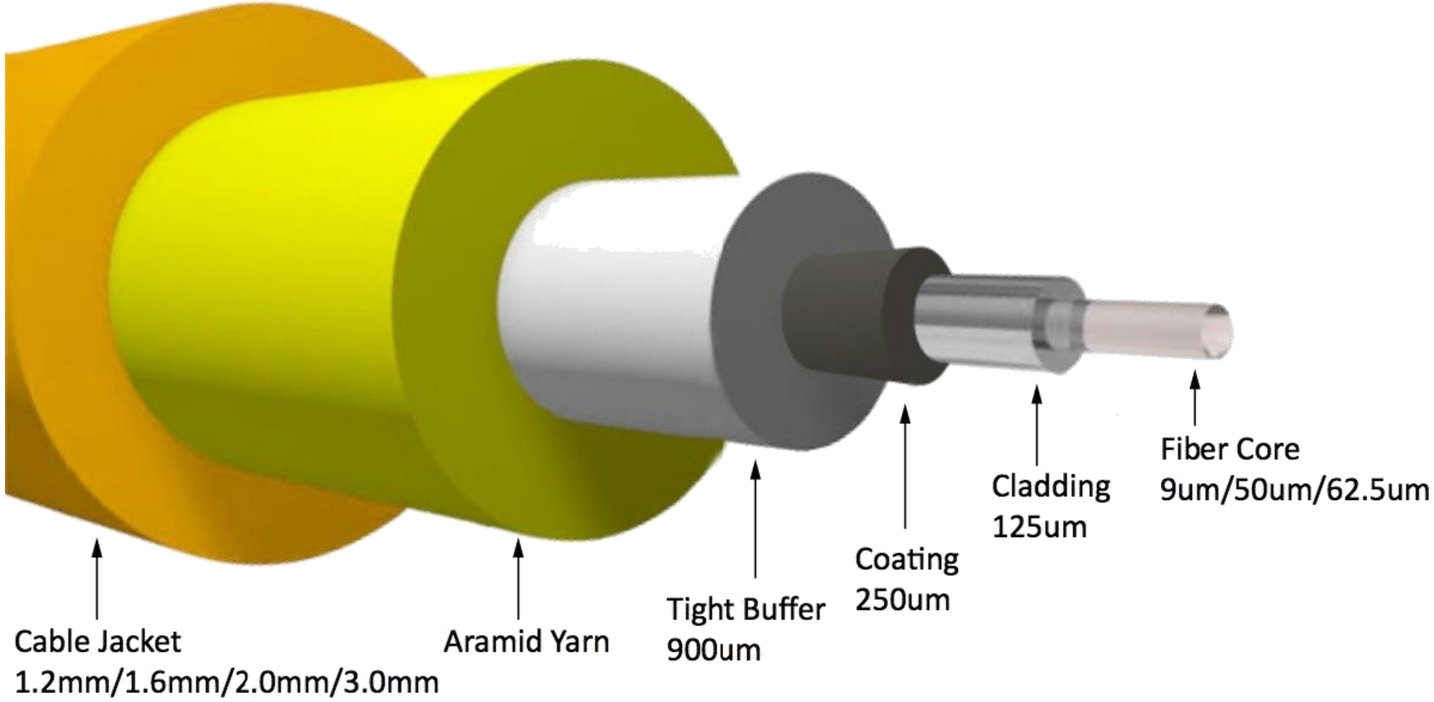
Dr. Suren Patwardhan

Contents

Global Fibre Optic Network

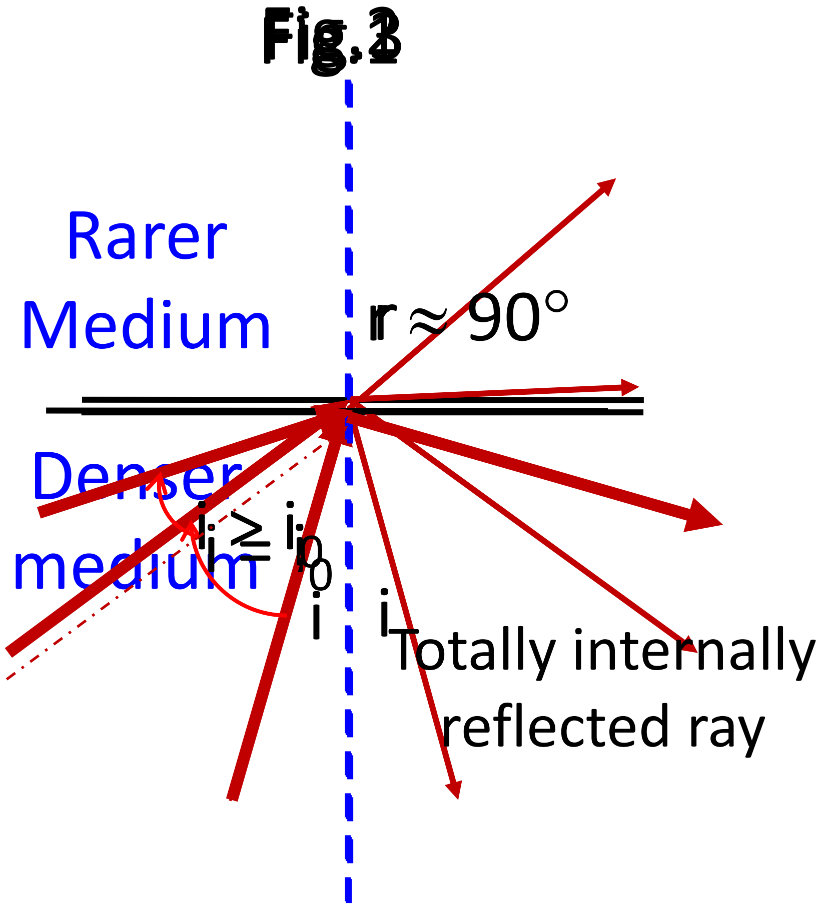


Structure of an Optical Fibre



- Main two parts: core and cladding
- Core has slightly higher refractive index
- Light is fed into the core region

Principle of Working – Total Internal Reflection

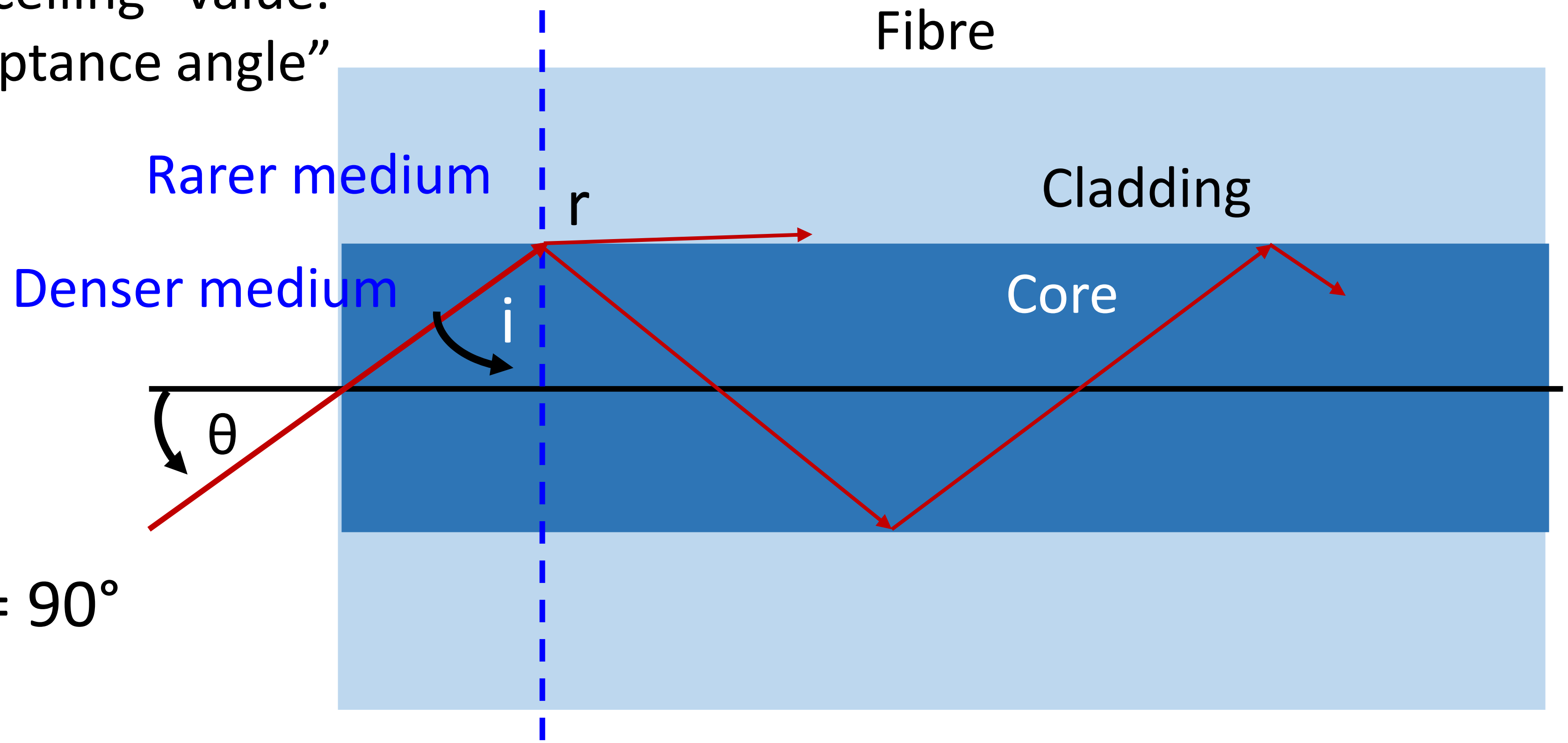


Total Internal Reflection and Acceptance Angle

But for TIR, $i \geq i_0$

$\Rightarrow \theta$ should have some "ceiling" value.

This value is called "acceptance angle"

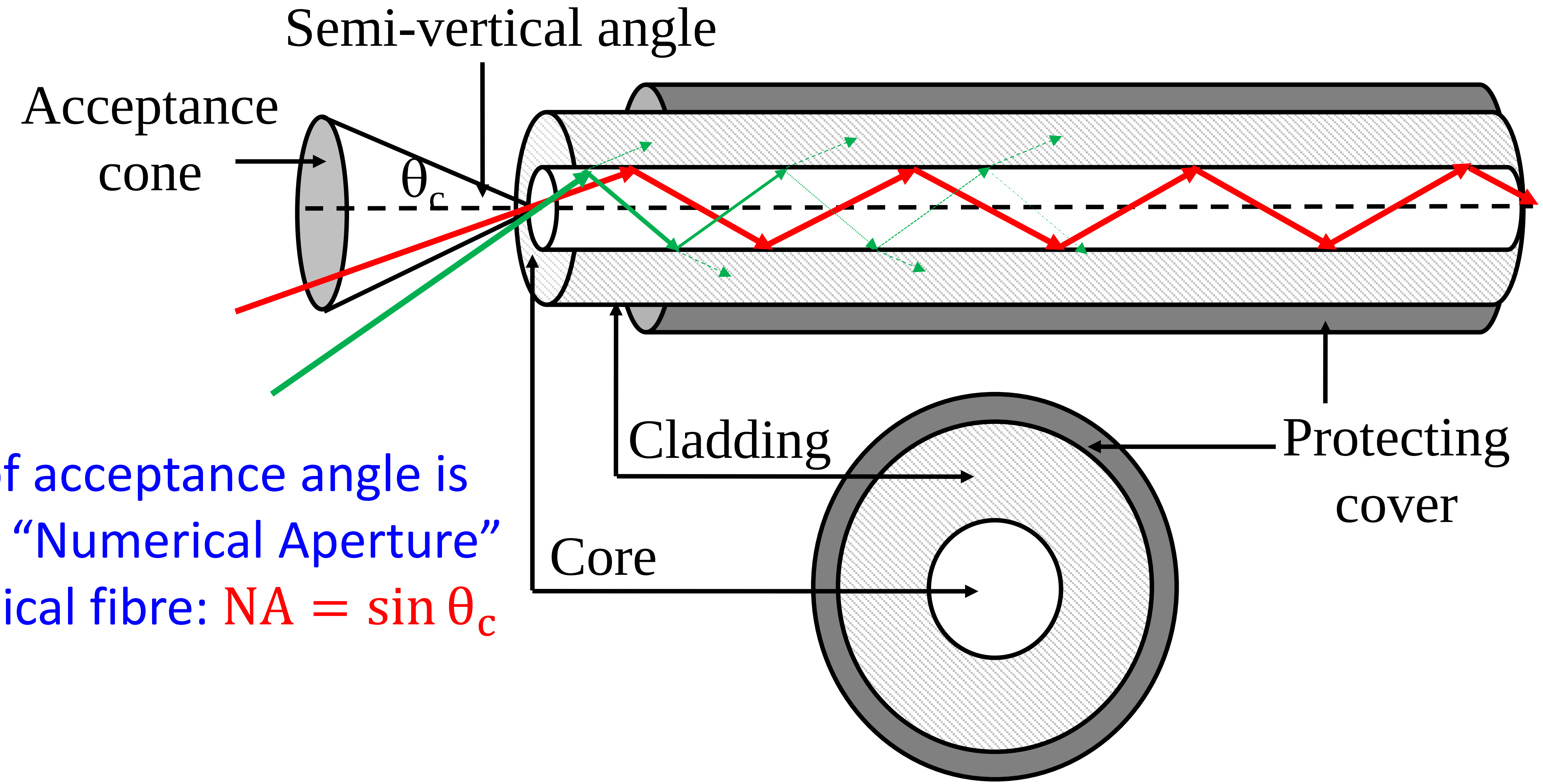


condition for TIR:

$\theta \leq \theta_C$

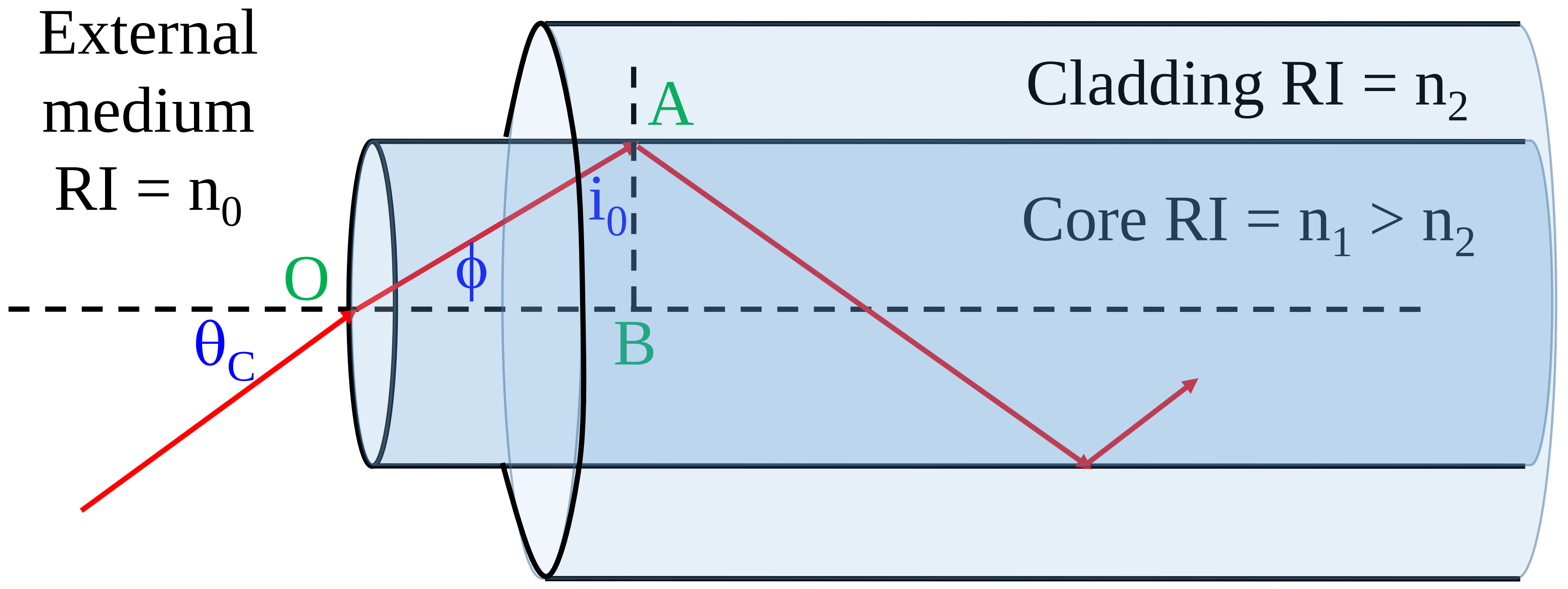
At $\theta = \theta_C$, $i = i_0$ and $r = 90°$

Optical Fibre – Cross Sections and Acceptance Cone



Sine of acceptance angle is called "Numerical Aperture" of optical fibre: $NA = \sin\theta_c$

Numerical Aperture of an Optical Fibre



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

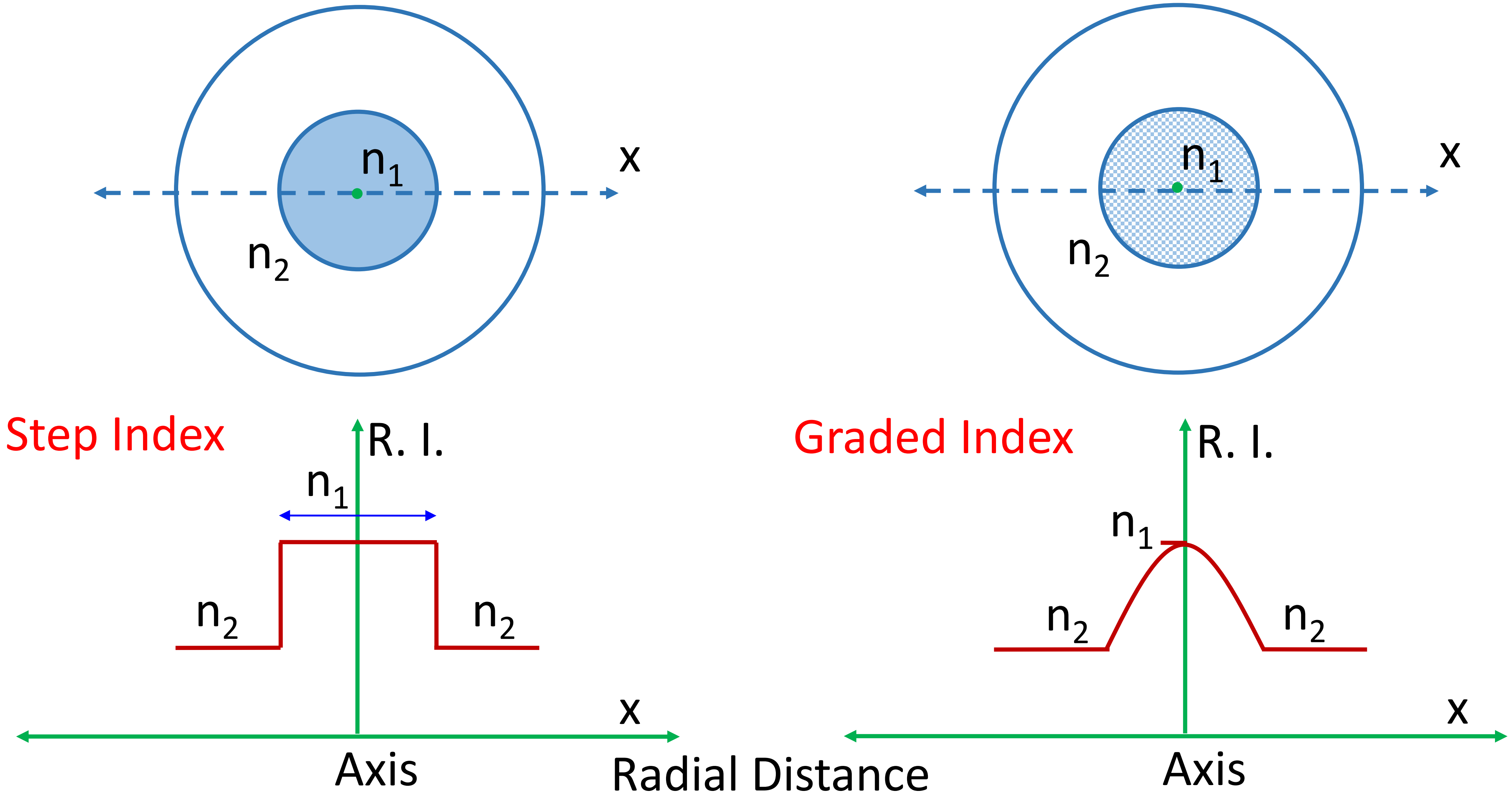
$$NA \approx n_1\sqrt{2\Delta}$$

Types of Fibres

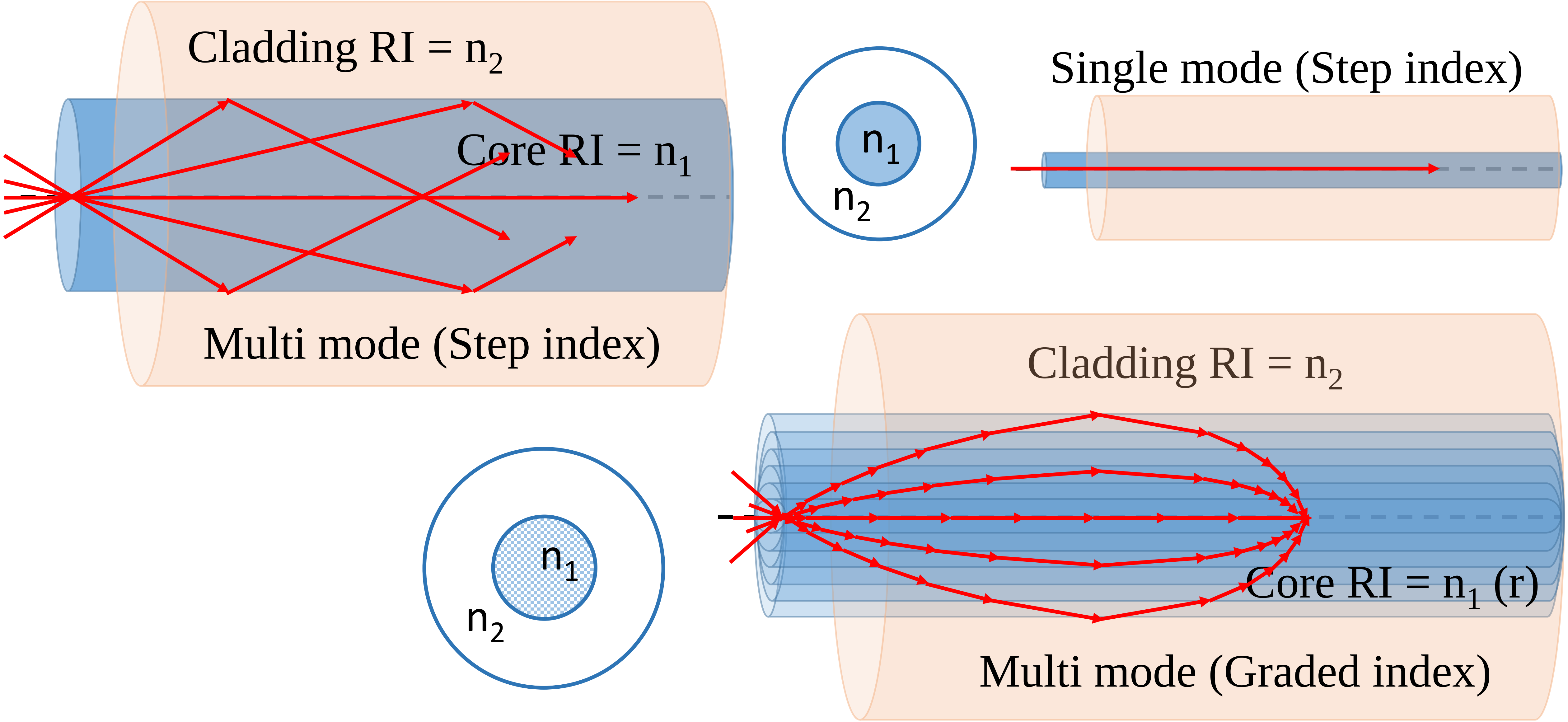
Based on →

- **Material**
  - All-glass
  - All-plastic
  - PCS
- **Refractive index profile**
  - Step index
  - Graded index
- **Modes of Propagation**
  - Single mode
  - Multi mode

Refractive Index Profile

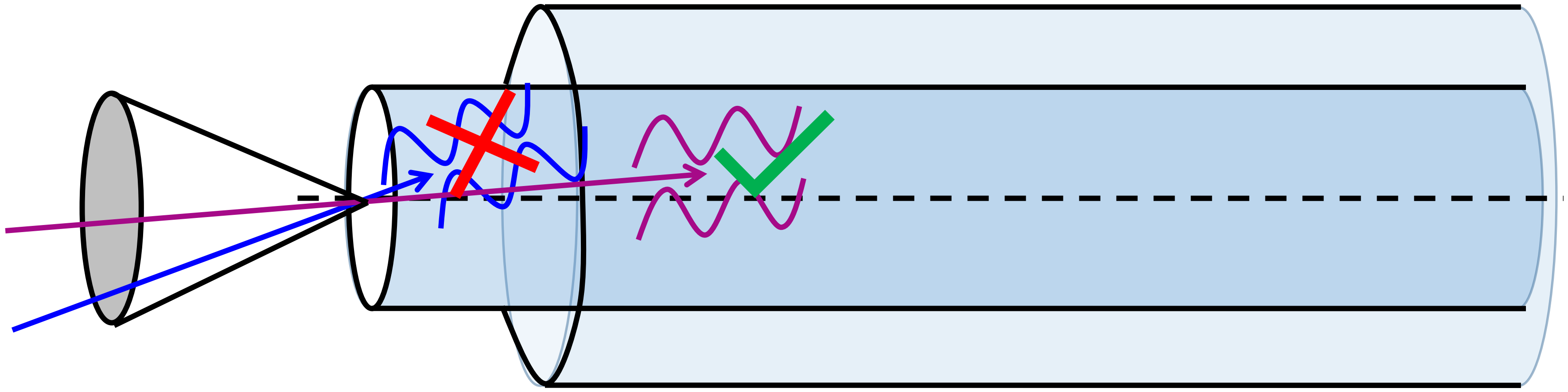


Ray Propagation in Different Types of Fibres



Mode of Propagation - Concept

- <u>Defined as "allowed" directions for light entering optical fibre</u>
- Fibre does not guide all light even though it is launched within acceptance cone
- Due to restricted space, light undergoes diffraction
- Light waves are in phase only along certain paths
- These paths are the "allowed" directions and called "modes of propagation"



V-number and Number of Modes

- An optical fibre is characterized by another important parameter called as the V-number or normalized frequency. It is given by,

$$V = \frac{2\pi a}{\lambda} \times NA$$

a: radius of core, λ: wavelength of light, NA: numerical aperture

- The maximum number of modes supported by the fibre is given by,

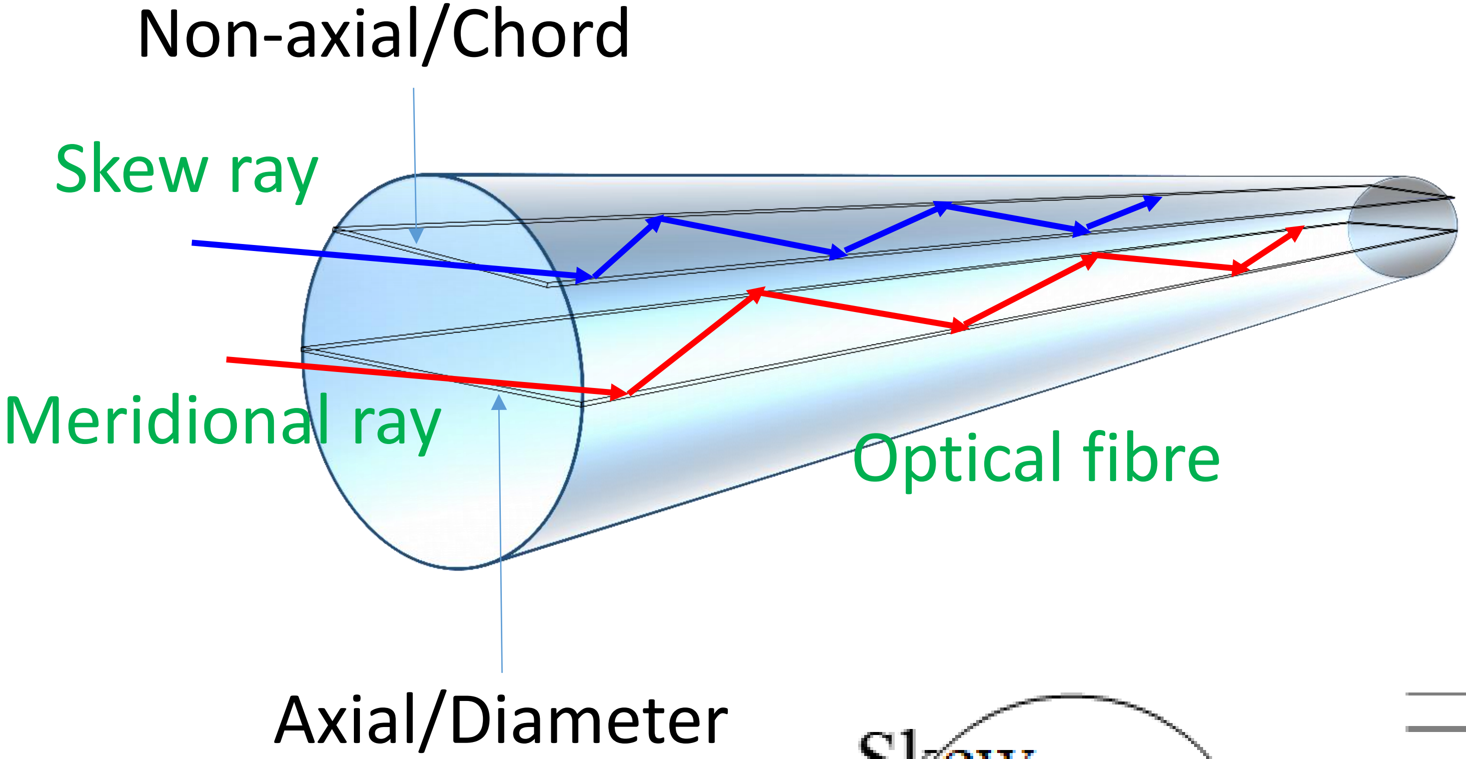
$$N_m = \frac{V^2}{2}; \qquad \text{SI}$$

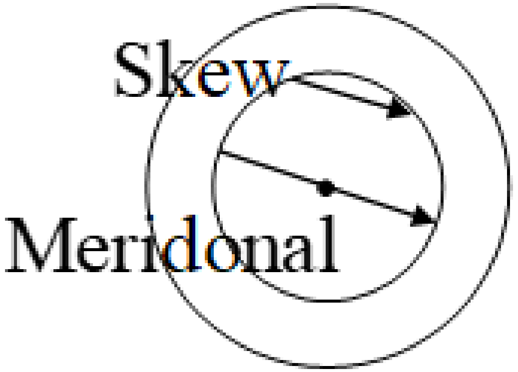
$$= \frac{V^2}{4}; \qquad \text{GI}$$

- From electromagnetic theory, it is deduced that

$$V < 2.405; \qquad \text{SM}$$

Various Modes of Propagation





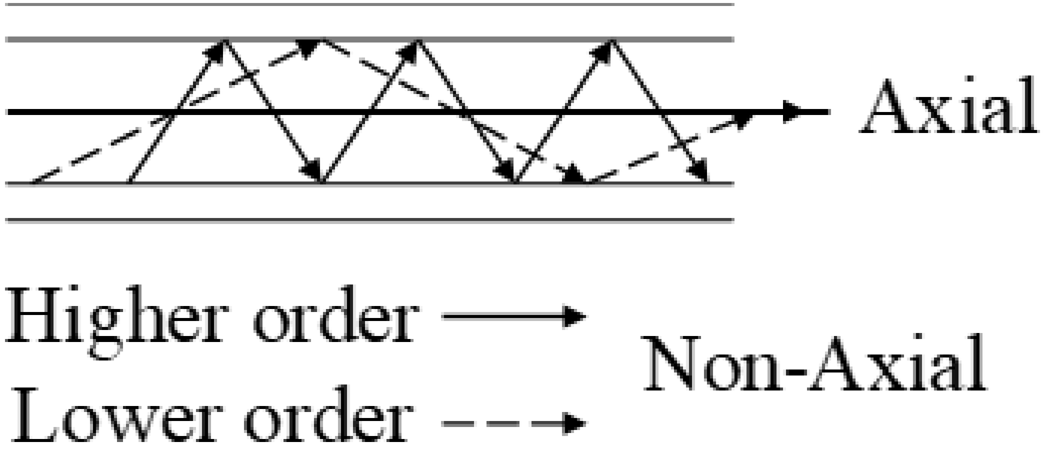
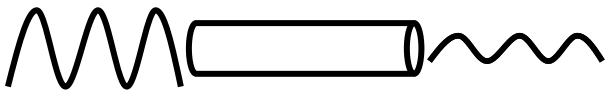


Figure of Merits for an Optical Fibres

Fibre Losses

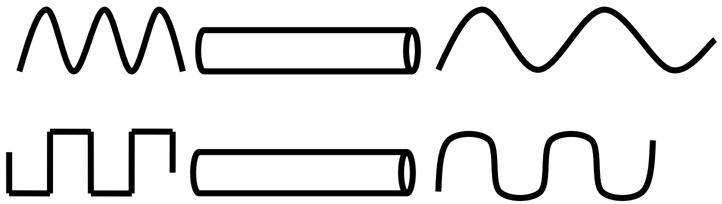
Attenuation

- Loss of amplitude
- Signal becomes weaker
- Measured in dB/km
- Typical: 0.2-0.3 dB/km



Dispersion

- Loss of synchronization
- Signal is distorted
- Measured in ps/km
- Typical: 100 ps/km



Causes of Attenuation in Fibres

Absorption

- By impurities in fibre (Na, Fe, OH^-, Cr)
- By fibre itself (intrinsic absorption)

Scattering

- Due to non-uniform density of glass (Rayleigh scattering)

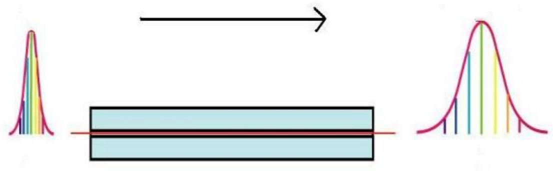
Geometric

- Bending of fibre into tighter loops
- Micro-kinks inside fibre

Can be reduced using a highly-controlled manufacturing process

Causes of Dispersion in Fibres

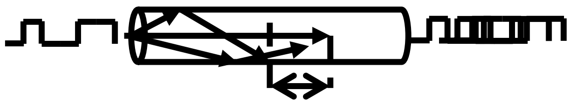
Chromatic Dispersion



- Occurs if light of broad spectrum is used

Can be reduced using a laser source

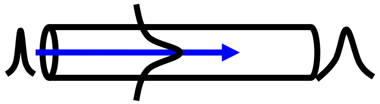
Intermodal Dispersion



- Occurs due to loss synchronization between light waves

Can be reduced using GI or SM fibre

Waveguide Dispersion

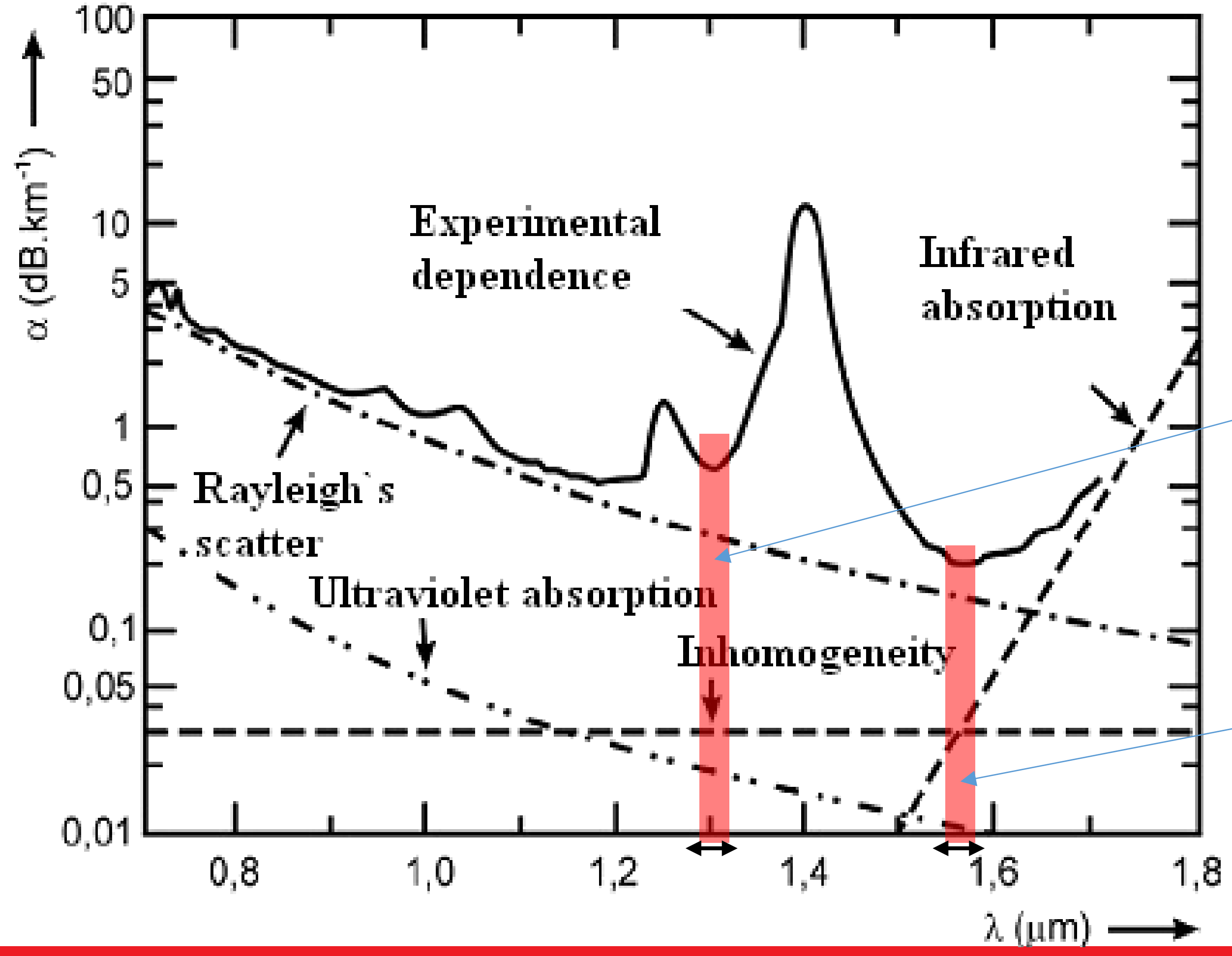


- Occurs due to induced electric field in cladding

Can be reduced by increasing core diameter

Wavelength of the Internet

Attenuation coefficient: $\alpha = \frac{1}{L} 10 \log\left(\frac{P_{in}}{P_{out}}\right)$ dB/km



1.3 µm
Optical window 1

1.55 µm
Optical window 2

Pulse Dispersion and Bit Rate

Intermodal dispersion for SI: $\tau_{\mathrm{i}} = \frac{n_1 \mathrm{L}}{\mathrm{c}} \Delta$

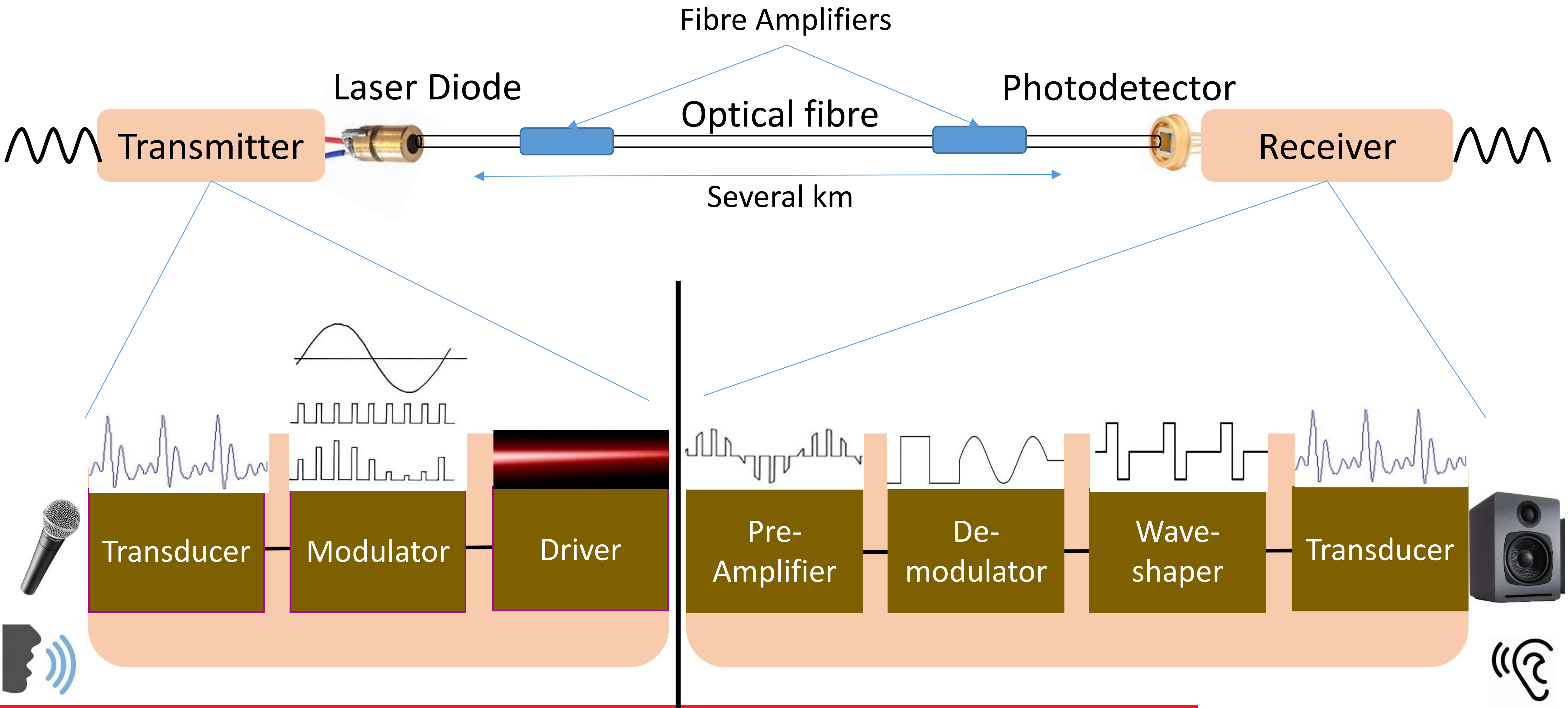
Intermodal dispersion for GI: $= \frac{n_2 \mathrm{L}}{2\mathrm{c}} \Delta^2$

Total dispersion (intermodal + material): $\tau = \sqrt{\tau_{\mathrm{i}}^2 + \tau_{\mathrm{m}}^2 + \tau_{\mathrm{w}}^2}$

Usually, τ_{w} is small compared to other two and ignored

Bit Rate: $\mathrm{B} \approx \frac{0.7}{\tau}$ usually expressed in "MBPS"

Fibre Optic Communication System



Fabrication of Optical Fibres

References

- Optics – Ghatak, 6th edition 2017, Mc-Graw Hill India
- Wikipedia (images on slide # 1, 3, 5, 11, 13, 18 and 20)