Optical fiber

- **Topics**
- Optical Fibers Historical background.
- Optical fiber attenuation curve versus wavelength.
- Typical block diagram of optical fiber communication (OFC) system.
- The units distinguish OFC system from electrical communication system.
- Erbium doped fiber amplifier (EDFA)

Optical fiber

Topics

- How light propagate via optical fiber?
- Optical parameters calculations.

Optical Fibers Historical background

In early **1960s**, the attenuation in optical fiber was 100 dB/km. Thus, optical fiber was impractical for communication.

In **1966**, **Charles K. Kao** and **George A. Hockham** found that attenuation of fibers was caused by impurities, which could be removed by purifying glass. Thus, losses can be reduced.

Optical Fibers Historical background

- In **1970**, single mode Fibers with less than 20dB/km was reached by researchers at **Corning Glass Works**, now **Corning Inc**. and started the **era of fiber-optic communications**
- In **Nowadays**, a fiber with loss of only 0.2 dB/km. The availability of low-loss fibers led to a revolution in the field of light wave technology**.**
- In **2009** Nobel Prize in material science was granted to **Charles K. Kao.**

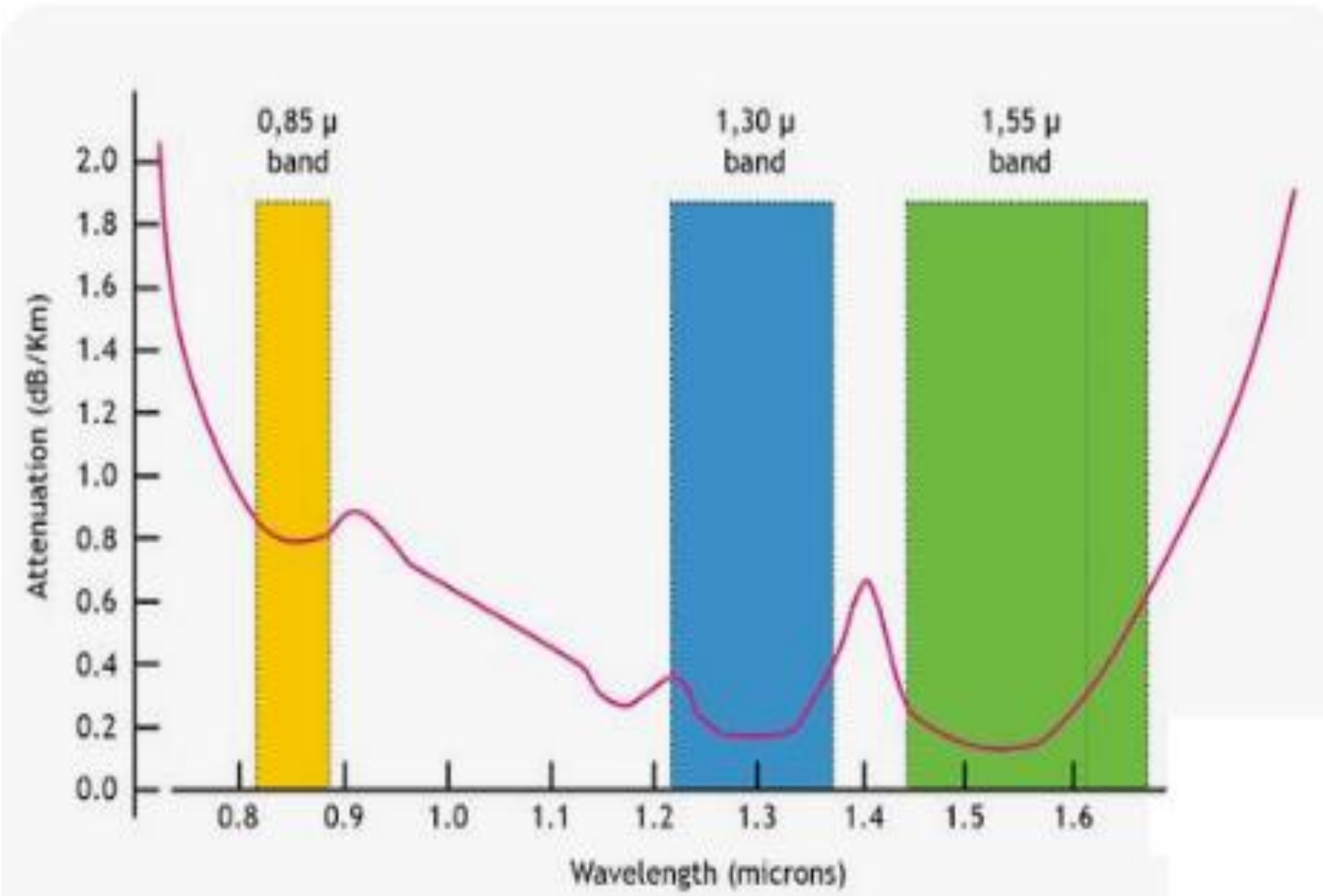
Optical fiber attenuation curve versus wavelength

In early glass optical fiber, there are three windows:

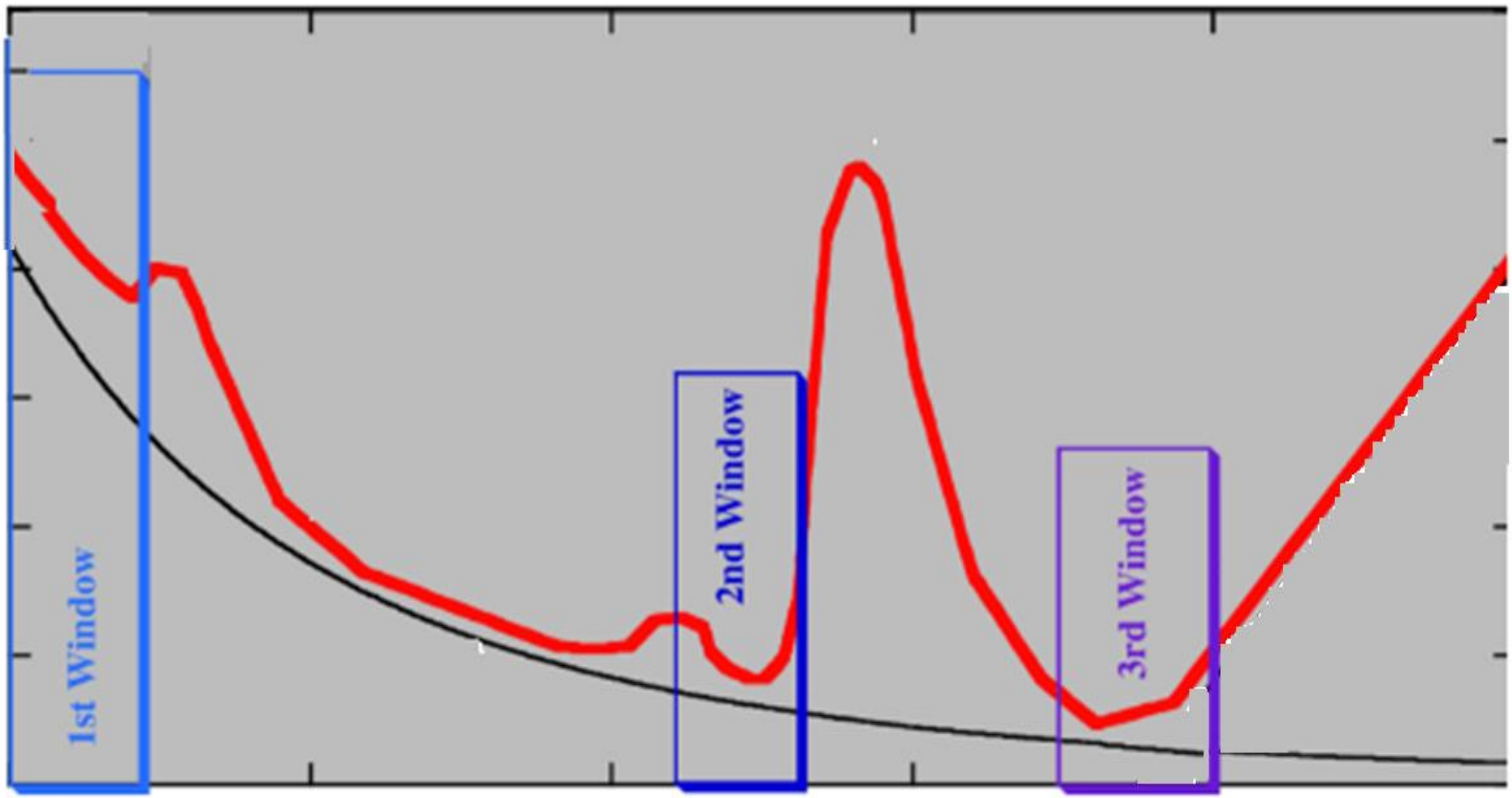
- **Window I:** at 850nm, the attenuation 3dB /km
- **Window II**: at 1300nm, attenuation 0.5 dB /km.
- **Window III**: at 1550 nm, the attenuation 0.2 d B /km.

Nowadays **all wave fiber** is manufactured.

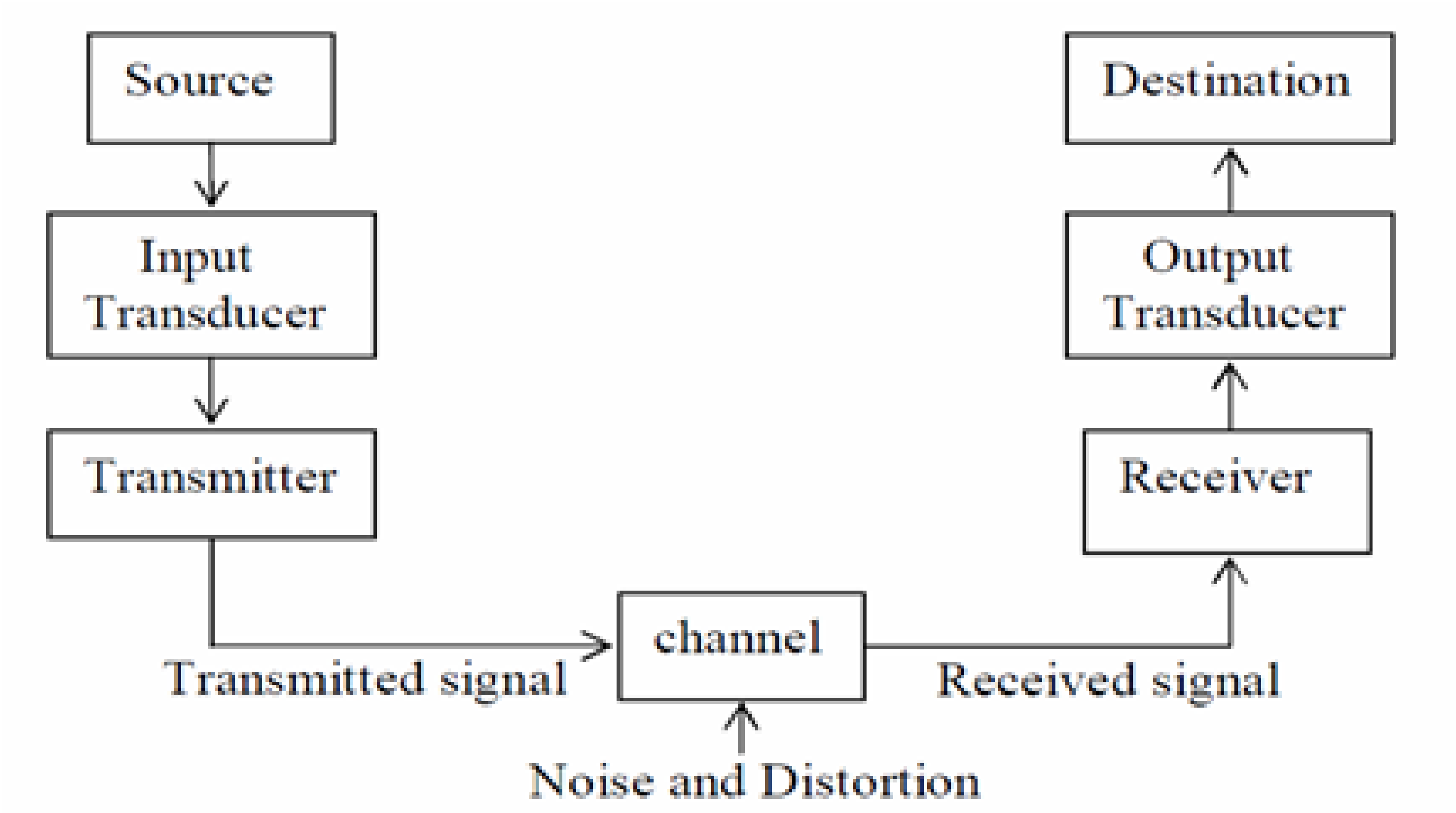
Optical fiber attenuation curve versus wavelength



Optical fiber attenuation curve versus wavelength



Typical block diagram of electrical communication system



Typical block diagram of optical fiber communication system

Optical fiber communication system consists of the following:

Information source: The input signal such as a data from the **keyboard** or human voice from **mouth** or **still image** or **moving picture**.

Input transducer: It is responsible for converting the message from the non-electrical form into electrical form to be processed to the transmitter such as a **microphone** or **keyboard** of a computer or **T.V camera**.

Typical block diagram of optical fiber communication system

Transmitter: It modifies the message to a form suitable for being transmitted via communication medium efficiently.

(1)Light source or **photo sources or electrical to the optical (E/O) converter** that converts electrical signal into light signal**.** It is at the end of the transmitter such as **light emitting diode (LED)** or **injection laser diode (ILD).**

Typical block diagram of optical fiber communication system

Communication medium: It is the medium or the channel which is responsible for connecting the message from the transmitter to the receiver. **It is optical fiber cable. It carries the light signal.**

Receiver: It receives the transmitted signal and recovers the original message from this signal.

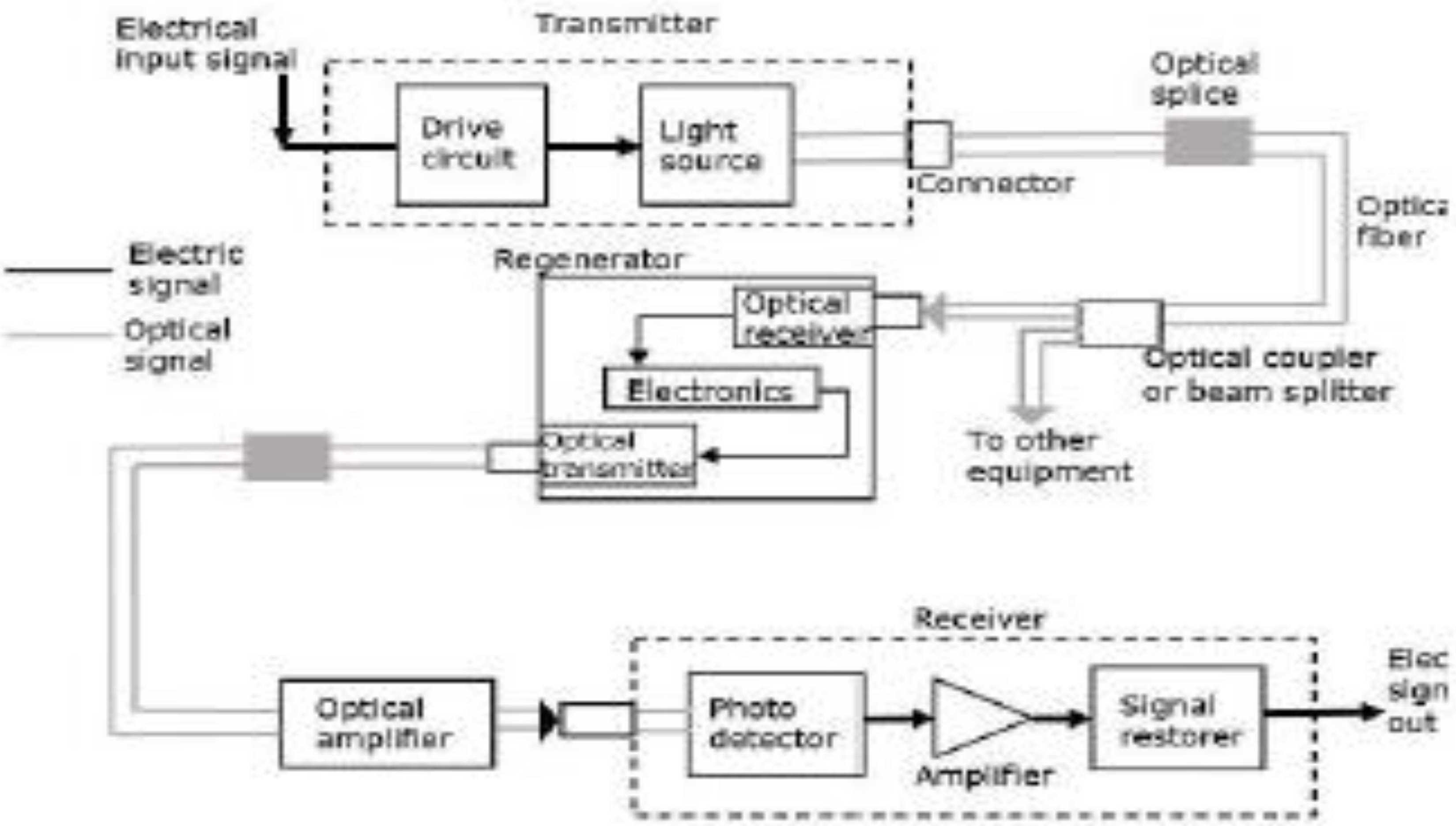
(2)At the beginning of receiver, there is **photo detector(PD)** or **optical to electrical converter(O/E)** that converts light signal into electrical signal such as **avalanche photo detector (APD),PIN (P-type Intrinsic N- type)PD**

Typical block diagram of optical fiber communication system

Output transducer: It converts the electrical signal into non-electrical signal such as **earphones** or **loudspeakers** in case of voice or **displays unit** or **monitor** or **printer**.

Information destination (sink): It is the unit the information is sent or communicated for such as **a human ears**, or **human eye** or **computer**. …etc

Typical block diagram of optical fiber communication (OFC)system



The units distinguish OFC system from electrical communication system

(1)Electrical to the optical converter (E/O): it is at the end of the transmitter and is called **photo sources(PS) or light source** such as **LED or ILD**.

(2)Optical to the electrical converter (O/E): it is at the beginning of the receiver and is called photo detector (PD) such as **Avalanche photodetector (APD) and P-type intrinsic N –type photodetector(PINPD).**

The units distinguish OFC system from electrical communication system

(3)Connector: it is a loose or demountable joint.

(4)Splice: it is a permanent joint.

(5)Splitter or combiner or coupler.

(6)Optical fiber: it is the communication medium.

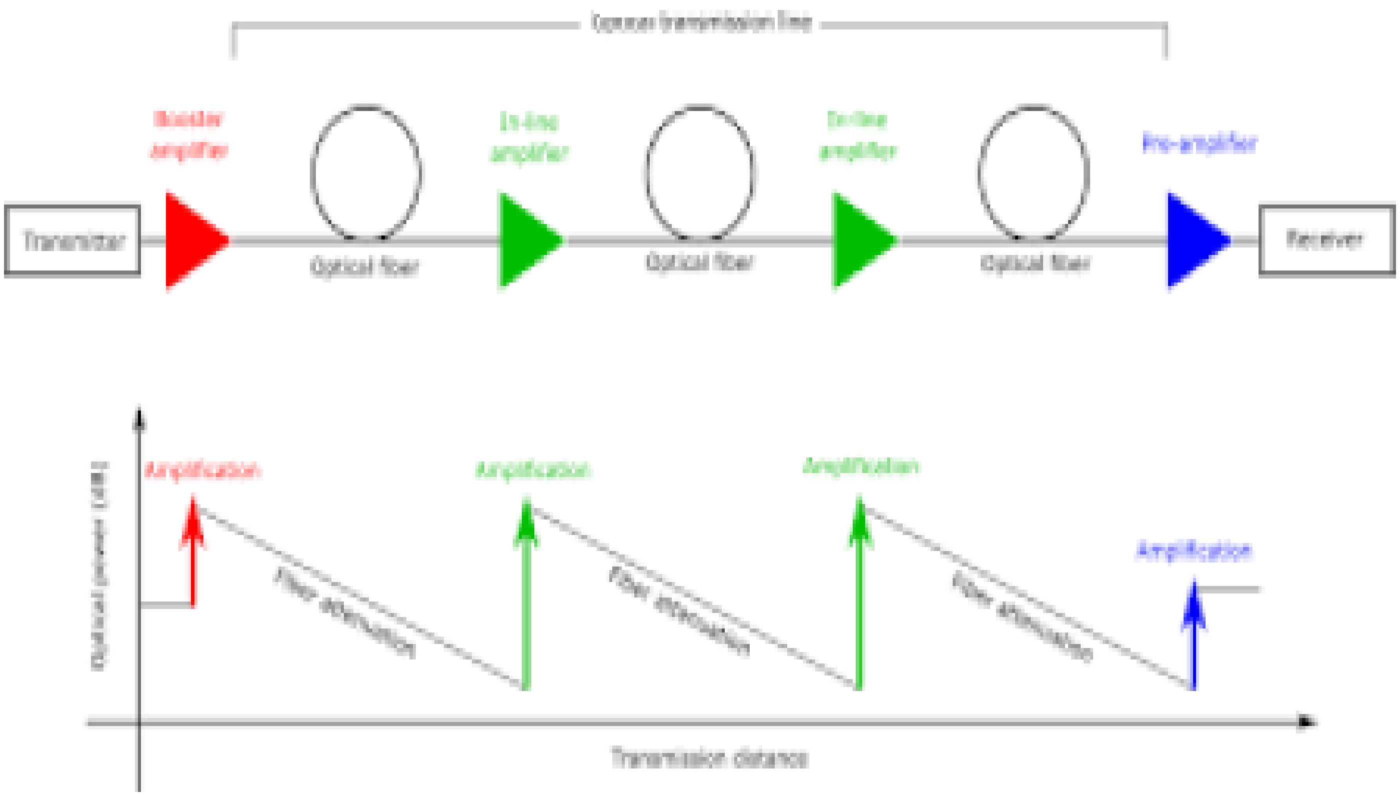
(7)Classical (or conventional) repeater.

(8)optical amplifier

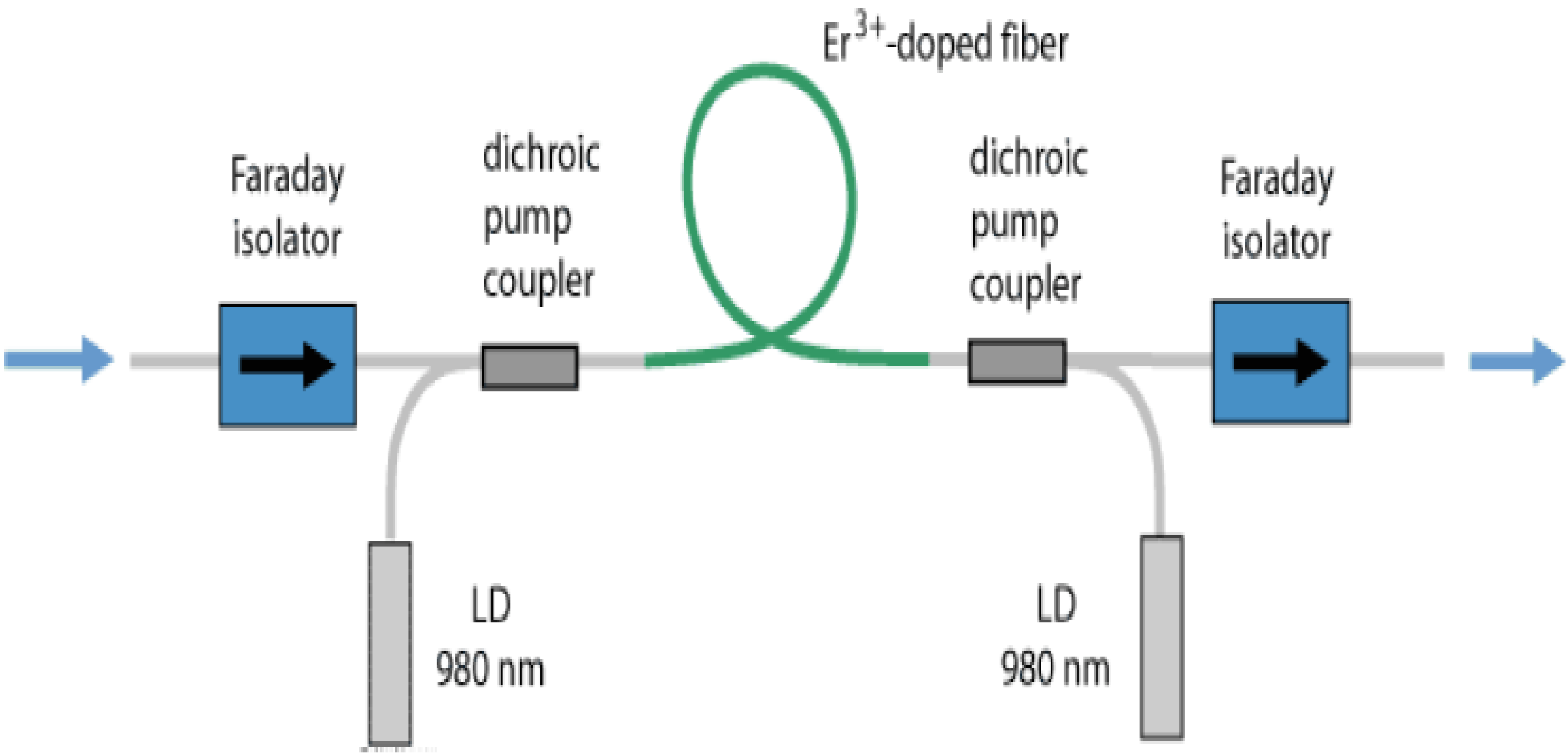
Erbium doped fiber amplifier (EDFA)

It is a piece of optical fiber about ten meters or less of single mode fiber (SMF). The core is doped by trivalent rare earth element Erbium (Er^{+3}). It amplifies the optical signal directly without need to first convert it to an electrical signal. Thus, it is called an optical amplifier

Erbium doped fiber amplifier (EDFA)



Erbium doped fiber amplifier (EDFA)



Erbium-doped Fiber Amplifiers

Erbium doped fiber amplifier (EDFA)

The fiber is "**pumped**" with light from **two laser diodes(LDs)**. The pump light might has a wavelength in the range of 980 nm excites the erbium ions (Er^{3+}).This range can amplify light in stimulated emission at the 1.5-μm wavelength area changing to the ground-state manifold.

Erbium doped fiber amplifier (EDFA)

Two optical isolators called "pig-tailed". The **isolator at the input** prevents light from disrupting any previous stages induced by amplified spontaneous emission, while the **isolator at the output** suppresses lasing when the output light is reflected back to the amplifier. Fiber amplifiers without isolators can be prone to back-reflections

Erbium doped fiber amplifier (EDFA)

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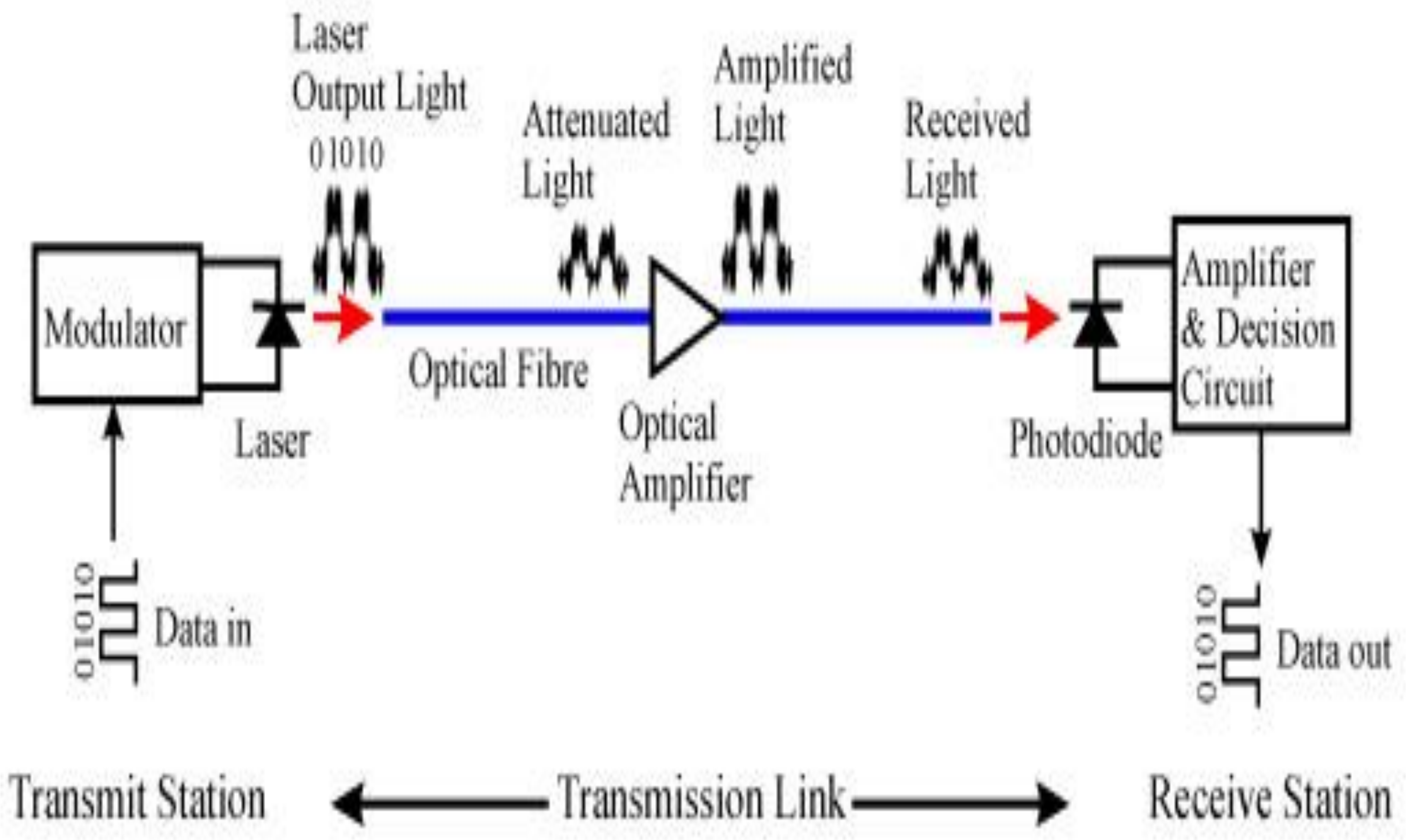
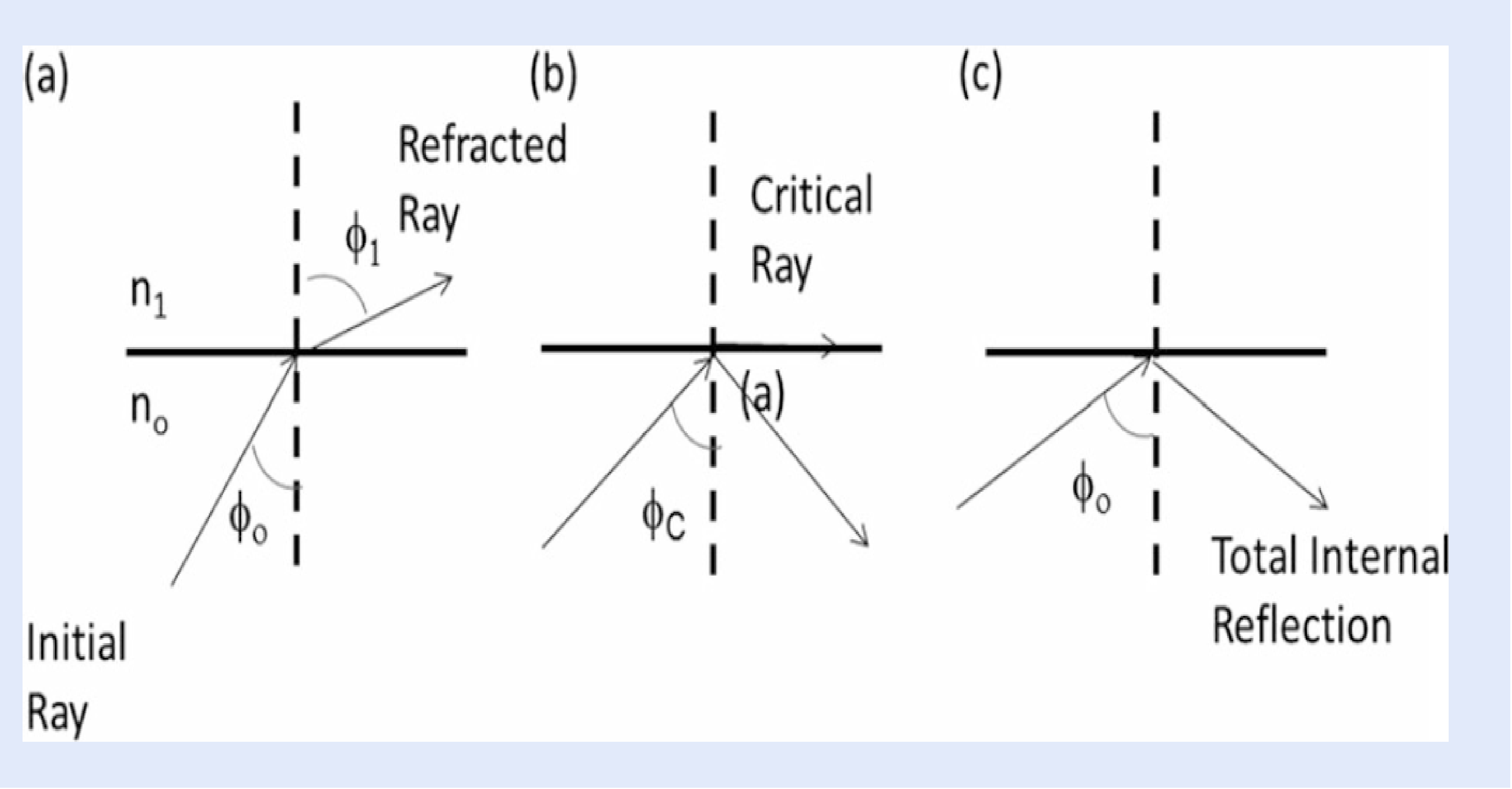
Optical amplifier

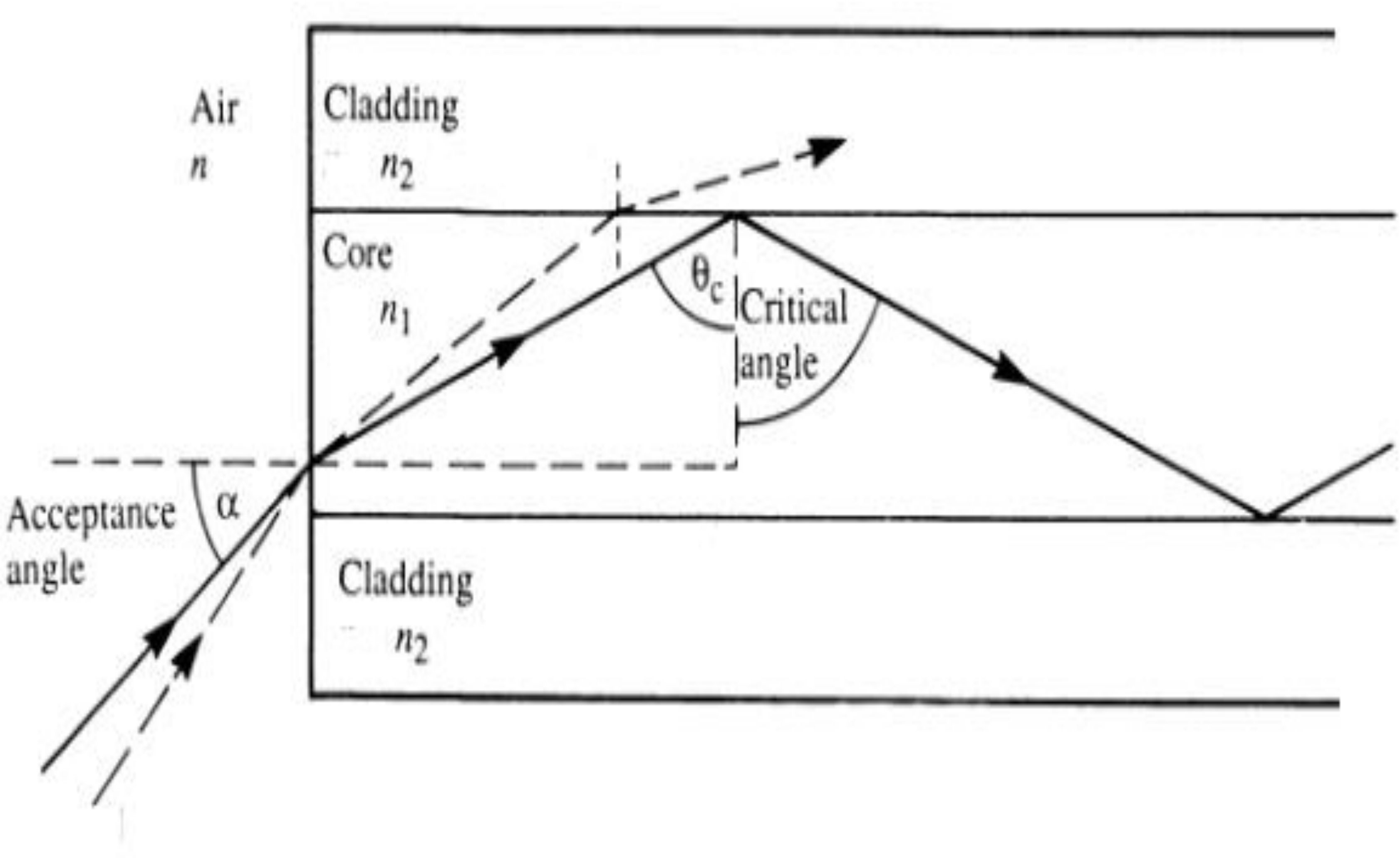


How light propagate via optical fiber?



Light reflection and refraction between two media with different indices of refraction

How light propagate via optical fiber?



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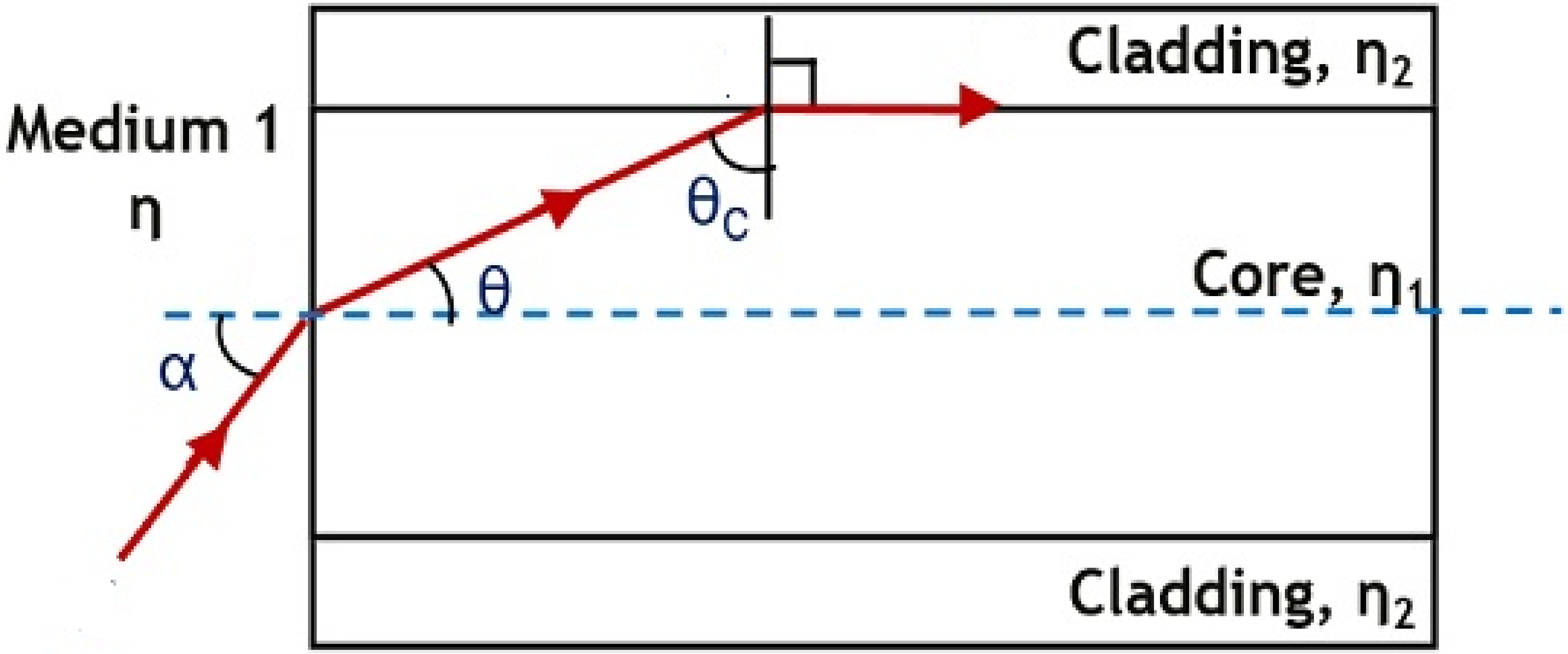
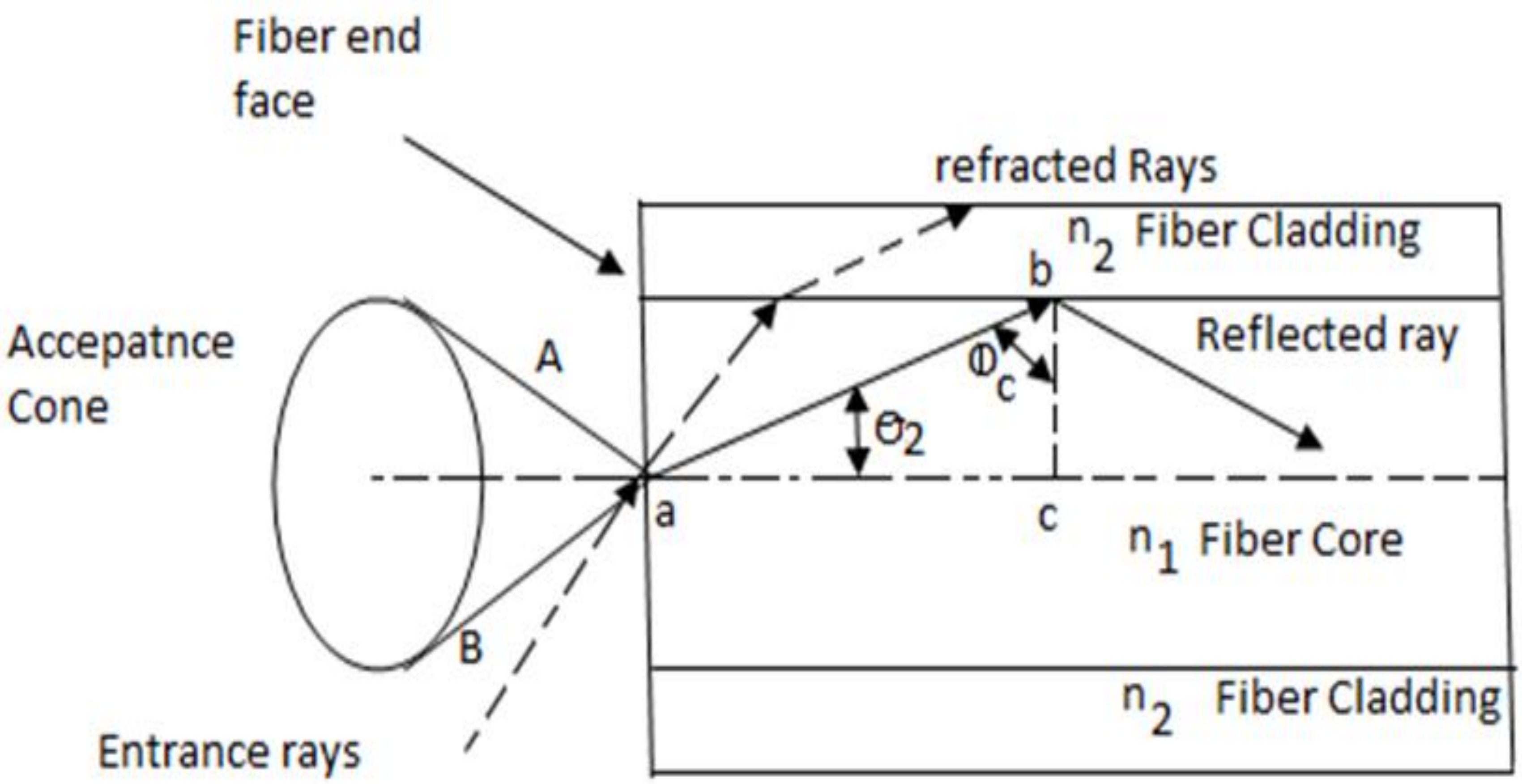
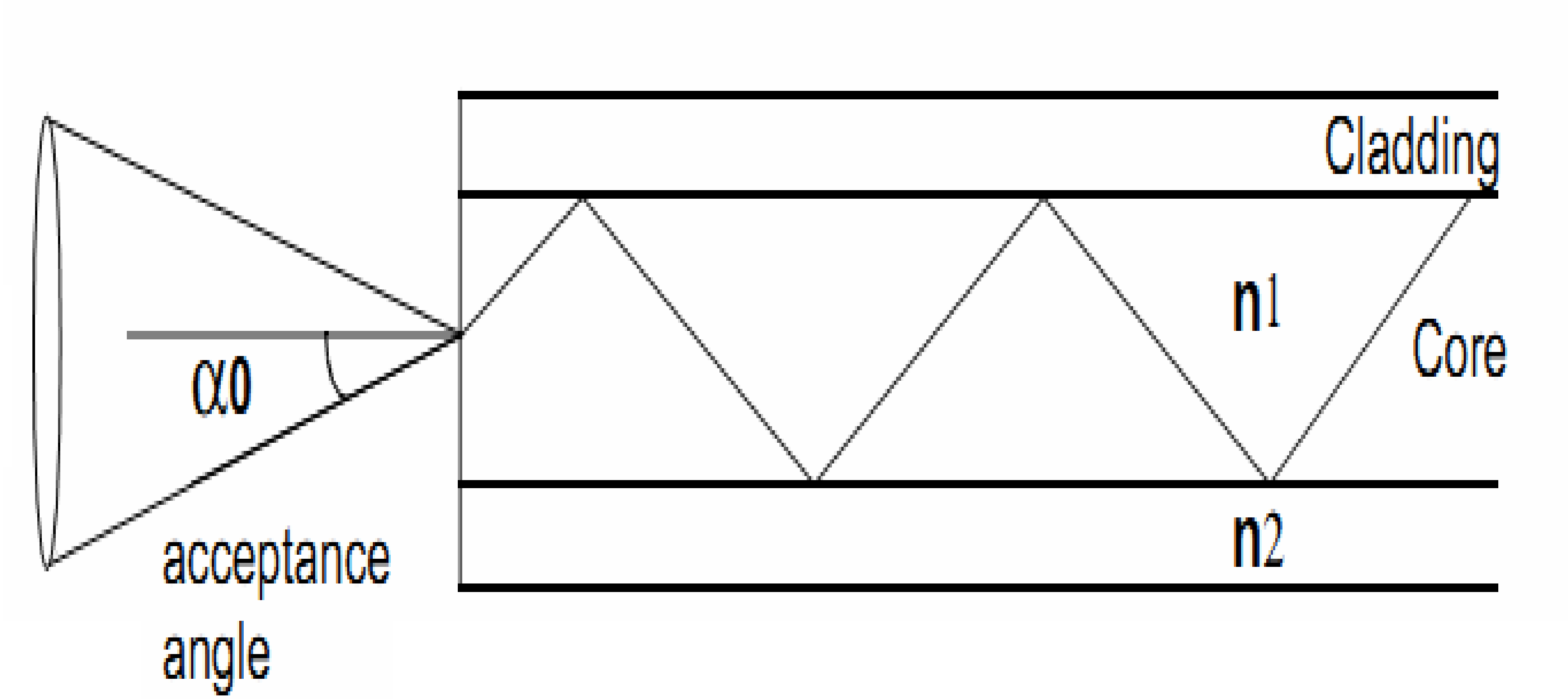


Ray propagation through Optical Fiber

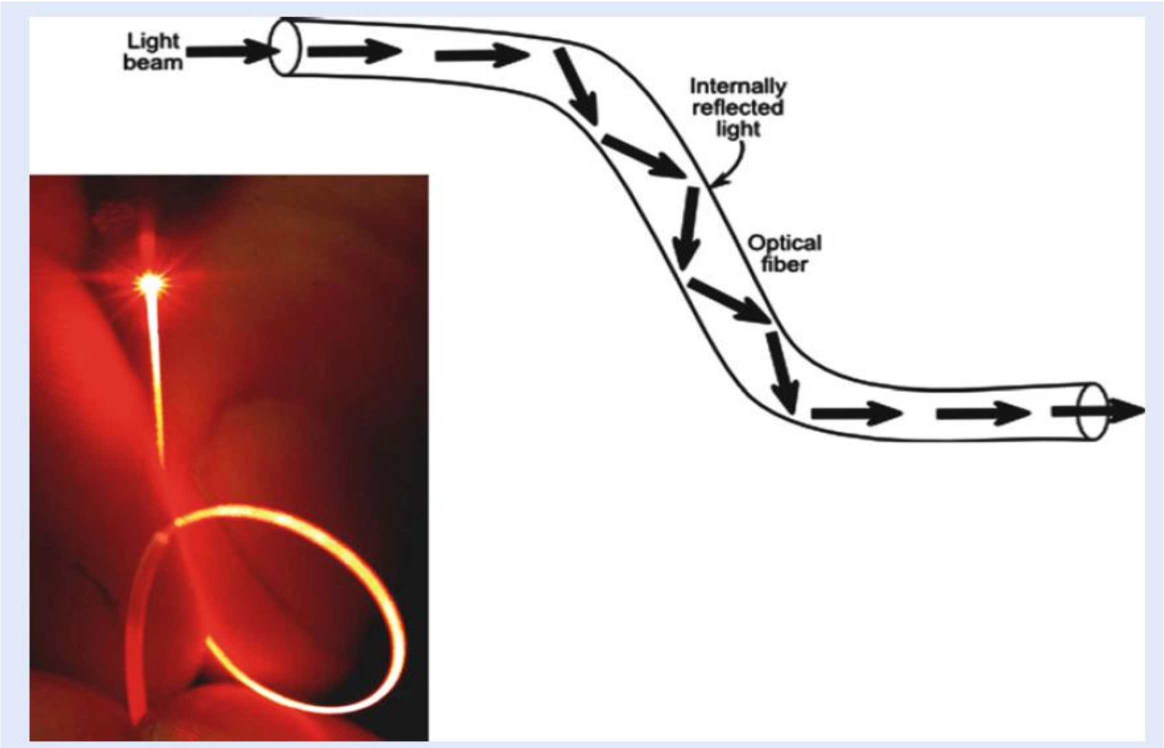
How light propagate via optical fiber?



Acceptance angle

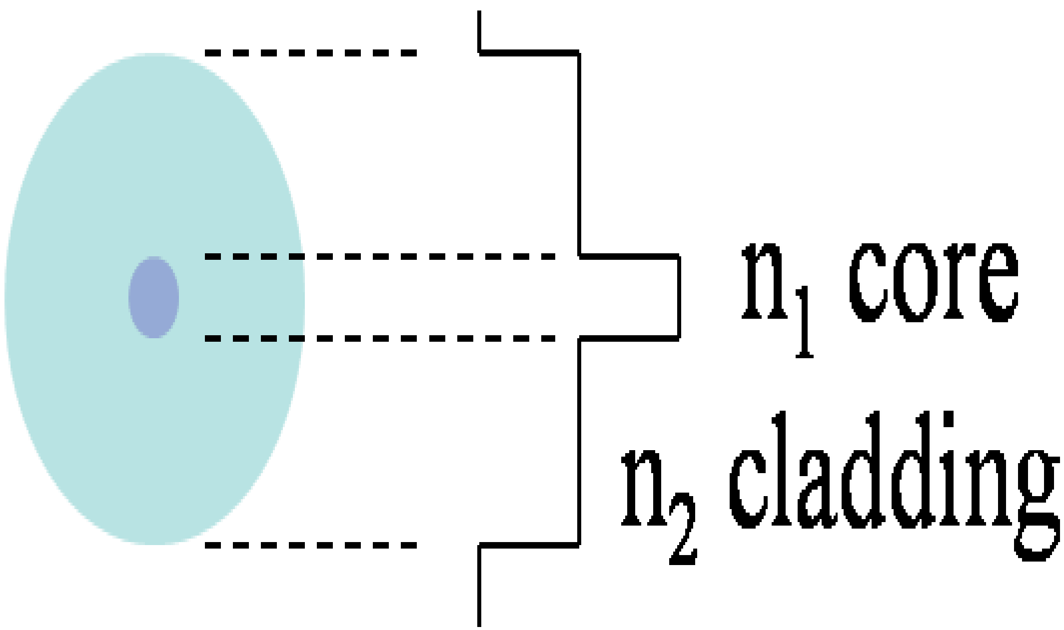


Total internal reflection (TIR)



Conditions of light propagate in optical fiber

(1)The refraction index of the core (n1) is greater than refraction index of cladding (n2).



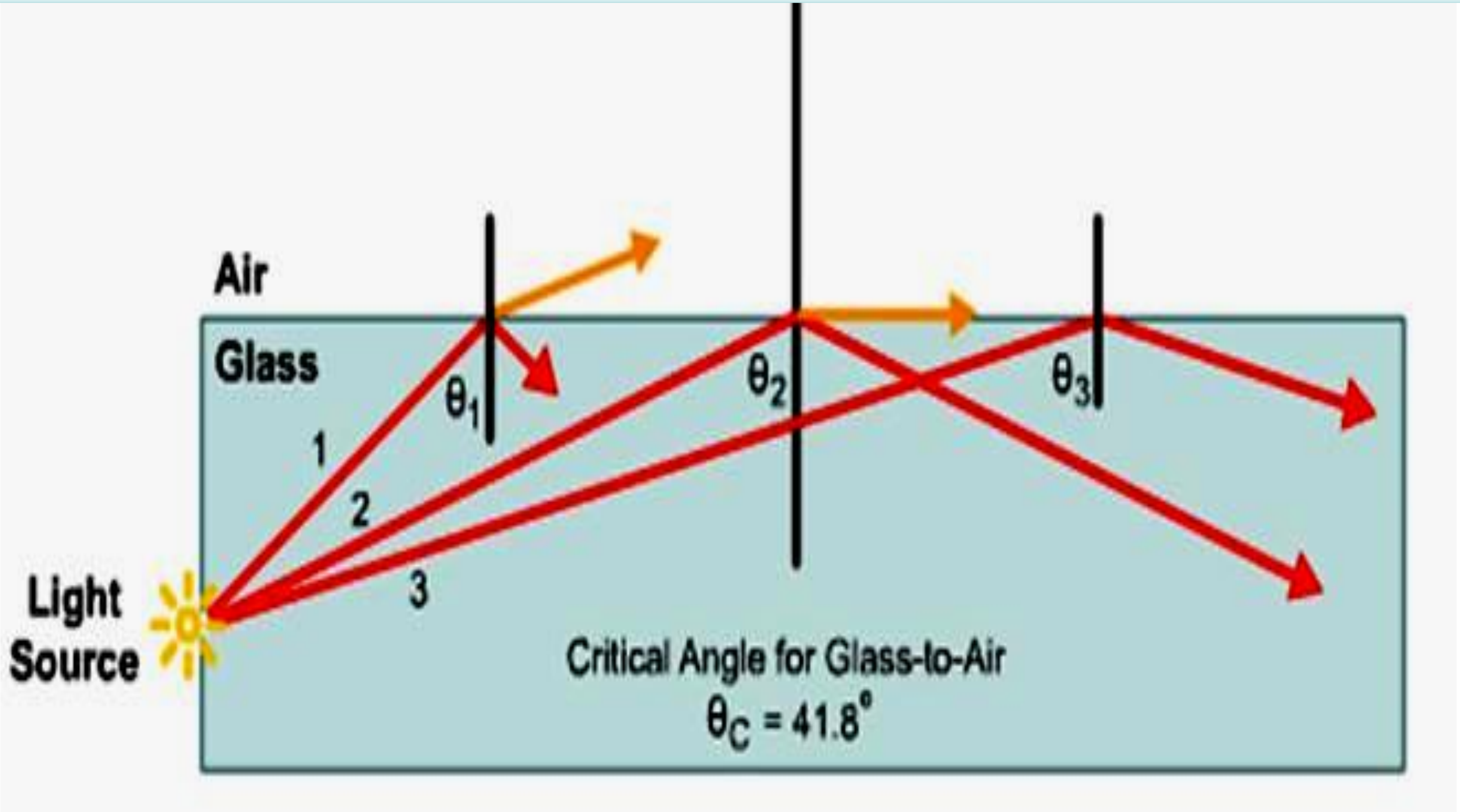
Conditions of light propagate in optical fiber

Optical fiber made of glass i.e. silica with **cladding** with a material of a little lower refractive index. The refractive index of the **core** is increased by doping the silica with GeO2. The cladding is pure silica. A plastic **cover** is utilized to protect the fiber from moisture and abrasion.

(2)Total internal reflection (TIR)

- Light incident at any angle **smaller than or equal to** the **critical angle** is not totally reflected. Some of the energy in the incident ray exits the glass.
- Light incident at any angle **greater than** the **critical angle** is totally reflected . All the energy of the incident ray stays in the glass.

Ray1: $\theta_1 < \theta_c$, so ray reflects and refracts.
Ray2: $\theta_2 = \theta_c$, so ray reflects and refracts.
Ray3: $\theta_3 > \theta_c$, so ray is totally internally reflected.



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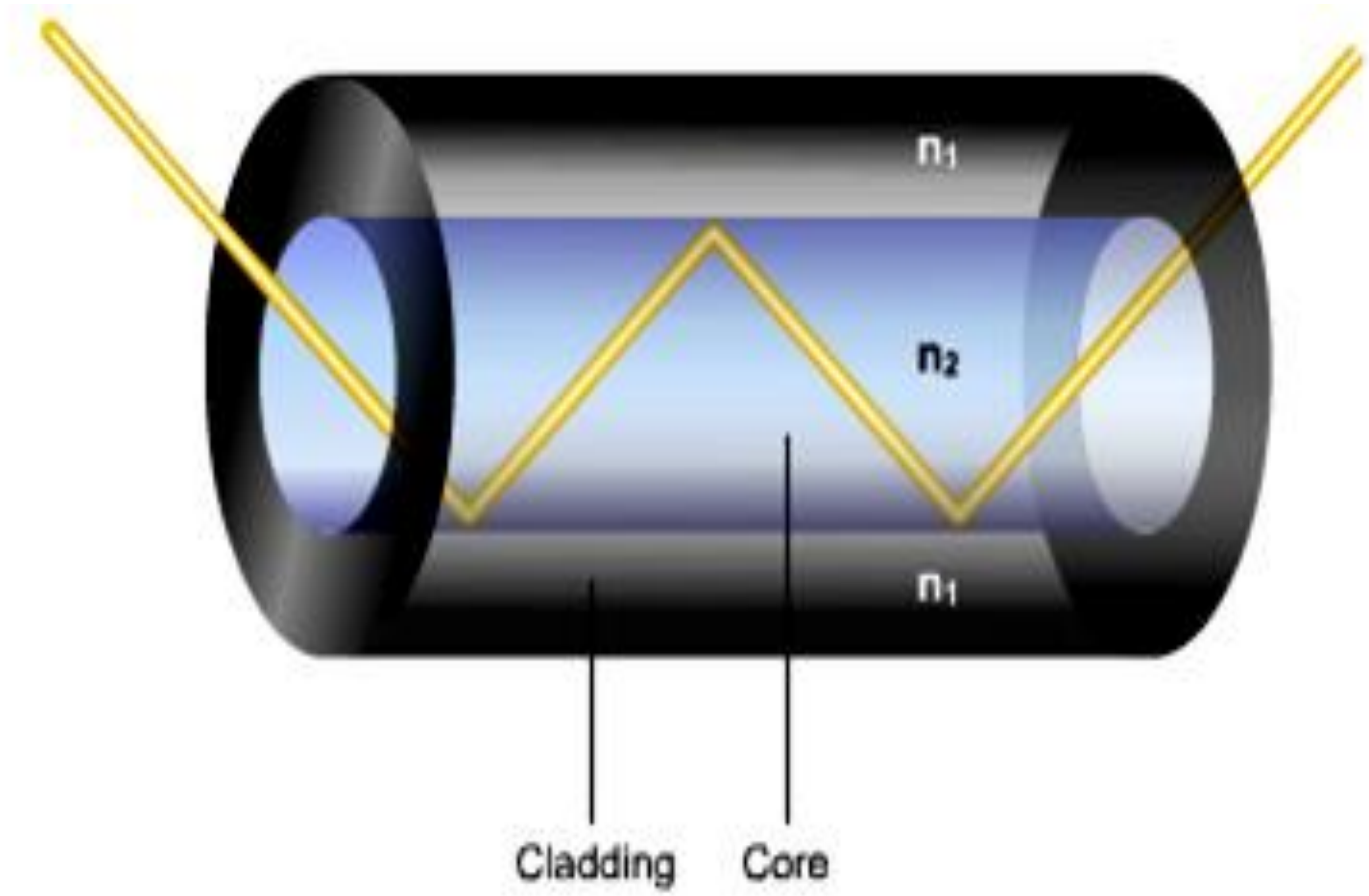

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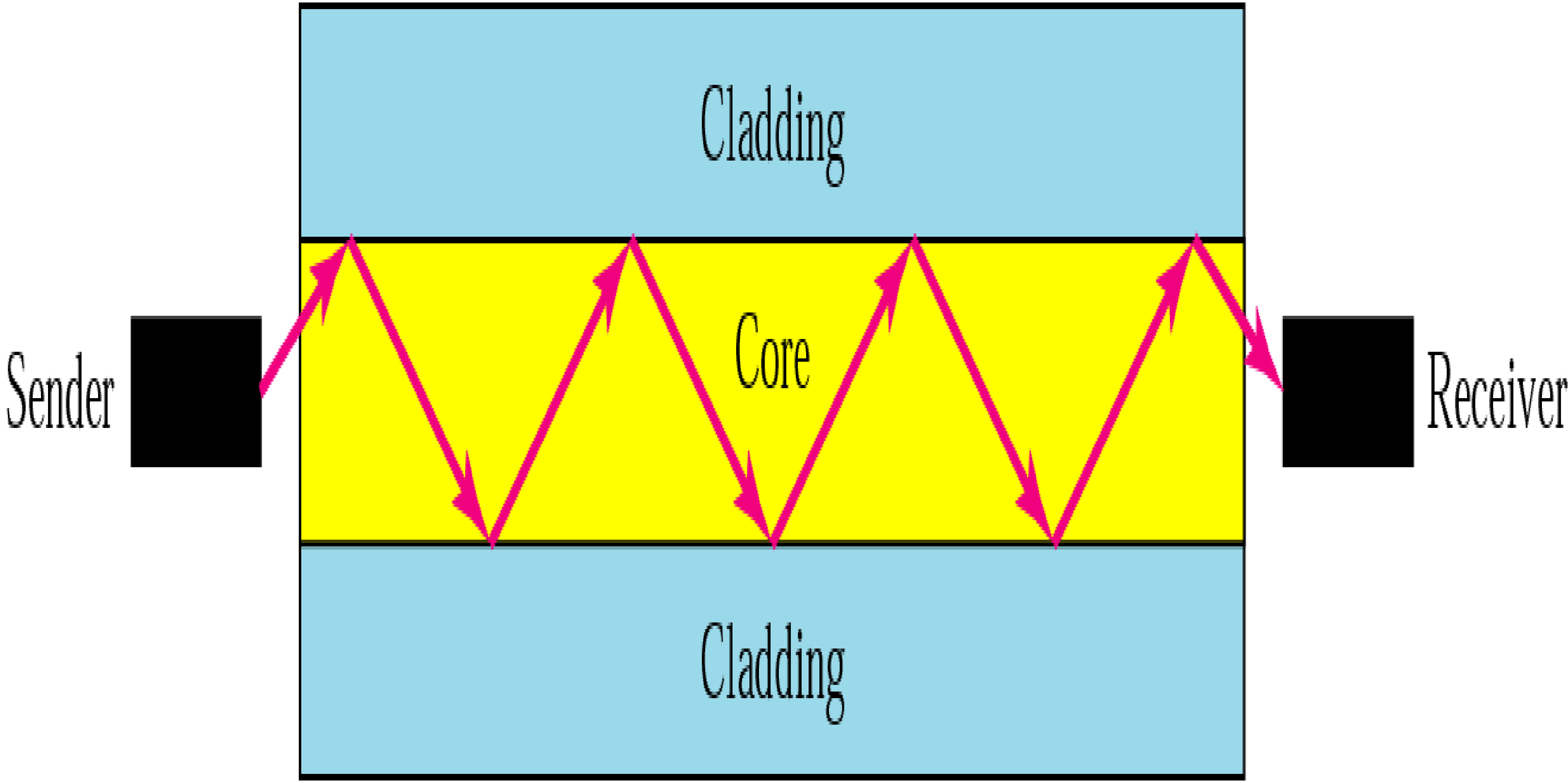


Optical fiber parameters calculations

Numerical Aperture (NA): It is a figure of merit describes the light gathering or light collecting ability of optical fibers. The light propagates via optical fiber via total internal reflection (TIR).It is a dimensionless number.Let n1 is core refractive index, n2 cladding refractive index and Δ: is fractional difference between core and cladding refractive index.

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

$$NA = n1\sqrt{2\Delta}$$

$$\Delta = \frac{n1-n2}{n1}$$

Acceptance angle

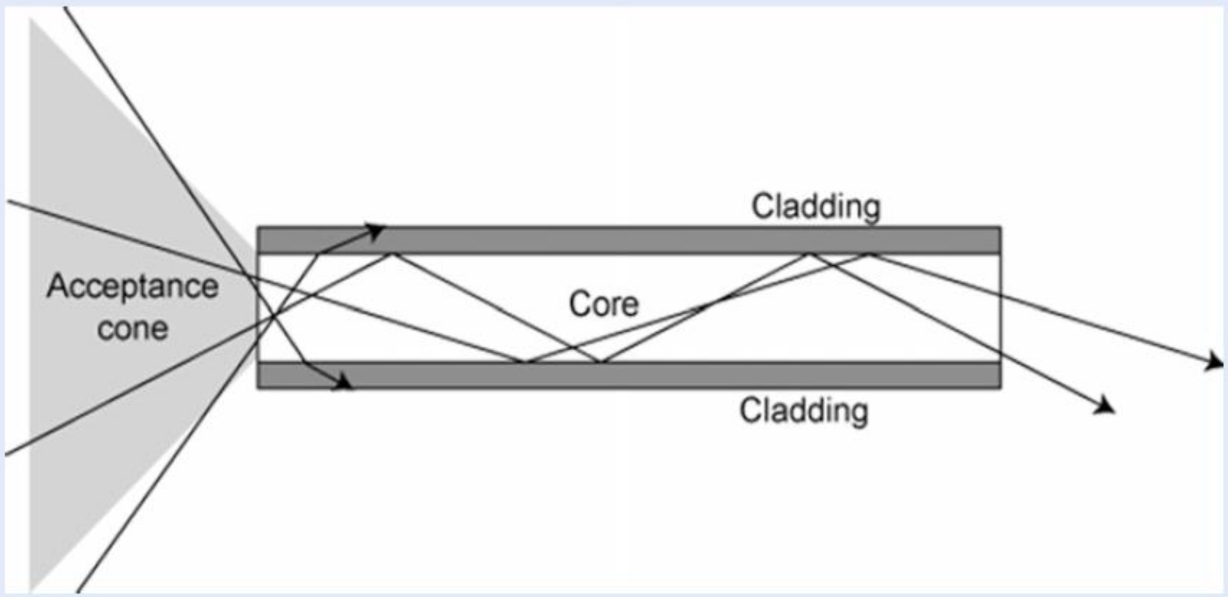
It is the maximum angle at which light may enter the fiber in order to get propagated. It is the angle between **the incident ray** and **the fiber axis**. The angle of incident ray should be greater than the critical angle. The ray is refracted, if the incident angle is less the critical angle then reflected.

θmax = sin-1 (n2/n1).

$$NA = \sin^{-1}(\theta max)$$

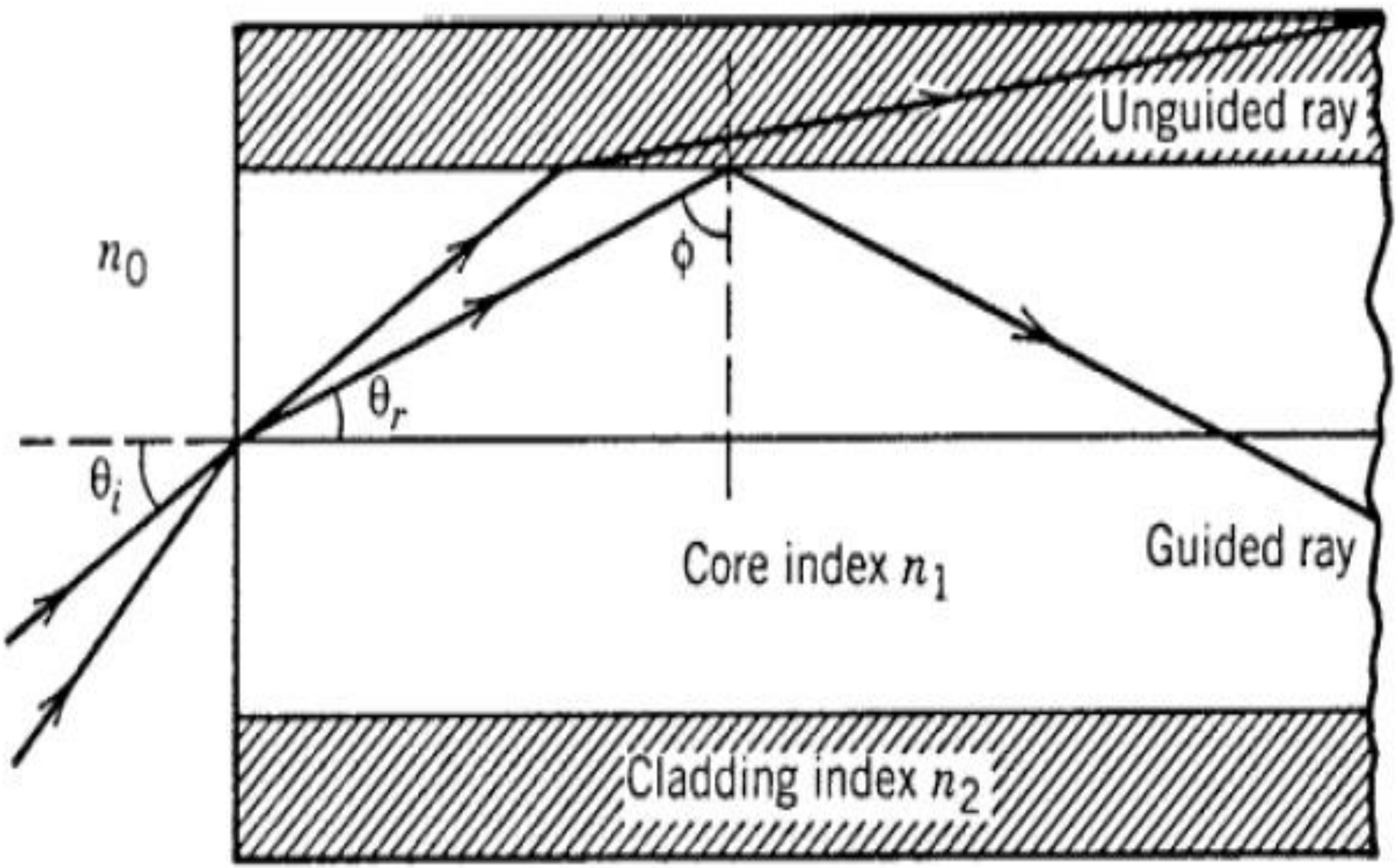
$$\theta max = \sin^{-1}(NA)$$

Acceptance angle

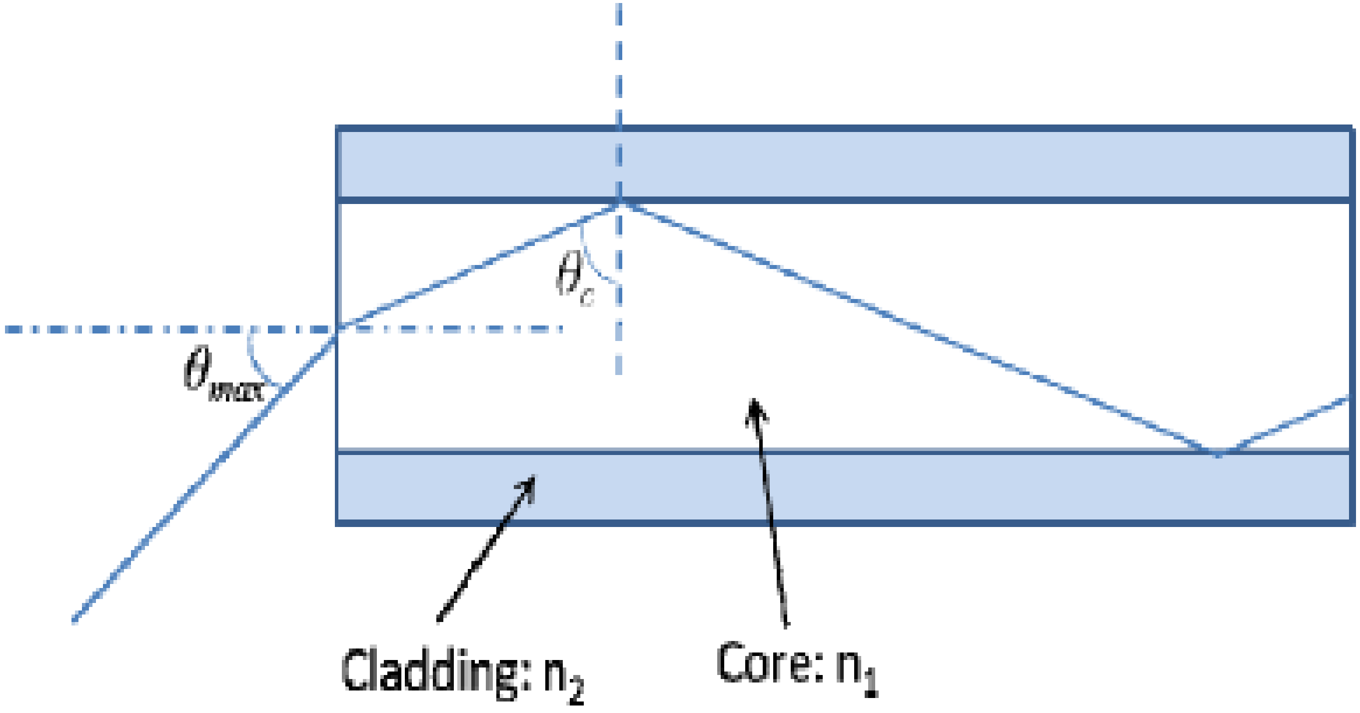


Light ray propagation along the core of an optical fiber. At the entrance to the fiber, a conical region is defined by the so-called acceptance angle, which is the region in space where light can be effectively collected and coupled into the fiber for guiding

Acceptance angle



Acceptance angle



Normalized frequency (V parameter) of fiber: It is a dimensionless parameter. It determines the number of the modes that can be supported by

Where d=2a is the diameter of the core, λ is the vacuum wavelength, a is the radius of the fiber core, and NA is the numerical aperture.

If V ≤ 2.405, then the fiber is single-mode fiber (SMF).

If V > 2.405, then the fiber is multi-mode fiber (MMF).

$$v = \frac{2\pi a}{\lambda} NA = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2}$$

$$V = \frac{\pi d}{\lambda} NA$$

Number of modes (M): the total number of modes that can travel in optical fiber is given by

$$M_{SI} = \frac{v^2}{2}$$

$$M_{GI} = \frac{\alpha}{\alpha + 2} M_{SI}$$

$$M_{GI} = \frac{\alpha}{\alpha+2} . a^2 . K^2 . n_1^2 . \Delta \qquad \text{Where } K = \frac{2\pi}{\lambda}$$

Ratio of the power wasted in cladding to the total power

$$\frac{P_{cladding}}{P_{Total}} = \frac{4}{3\sqrt{M}}$$

Summary of formula of O.F.

1. Numerical aperture (NA) $NA = \sqrt{n1^2 - n2^2}$
2. acceptance angle (θ max) $\theta max = \sin^{-1}(NA)$
3. V number (V) $V = \frac{2\pi a}{\lambda} NA$
4. no of modes (M|SI) $M|SI = \frac{V^2}{2}$
5. the fractional power ($\frac{Pc}{Pt}$) $\frac{Pc}{Pt} = \frac{4}{3\sqrt{M|SI}}$