Introduction to Telecommunications and Computer Engineering

Unit 6: Fibre Optic Communication

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Acknowledgements

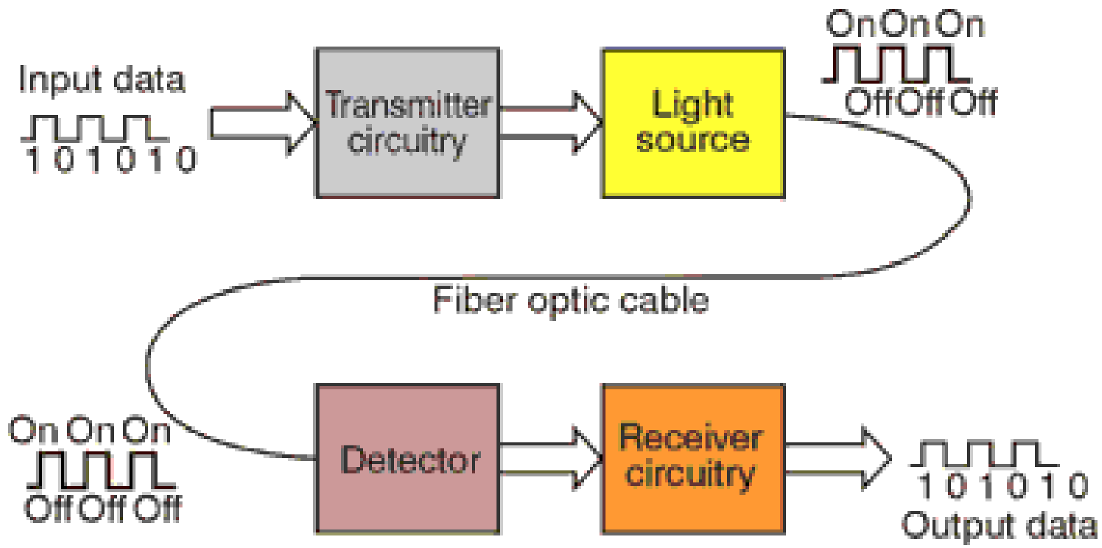
These notes contain material from the following source:

[1] *Fundamentals of Optic Fibre*, by T.Islam, CSE Department, North South University, 2005.

Introduction to Fiber Optics

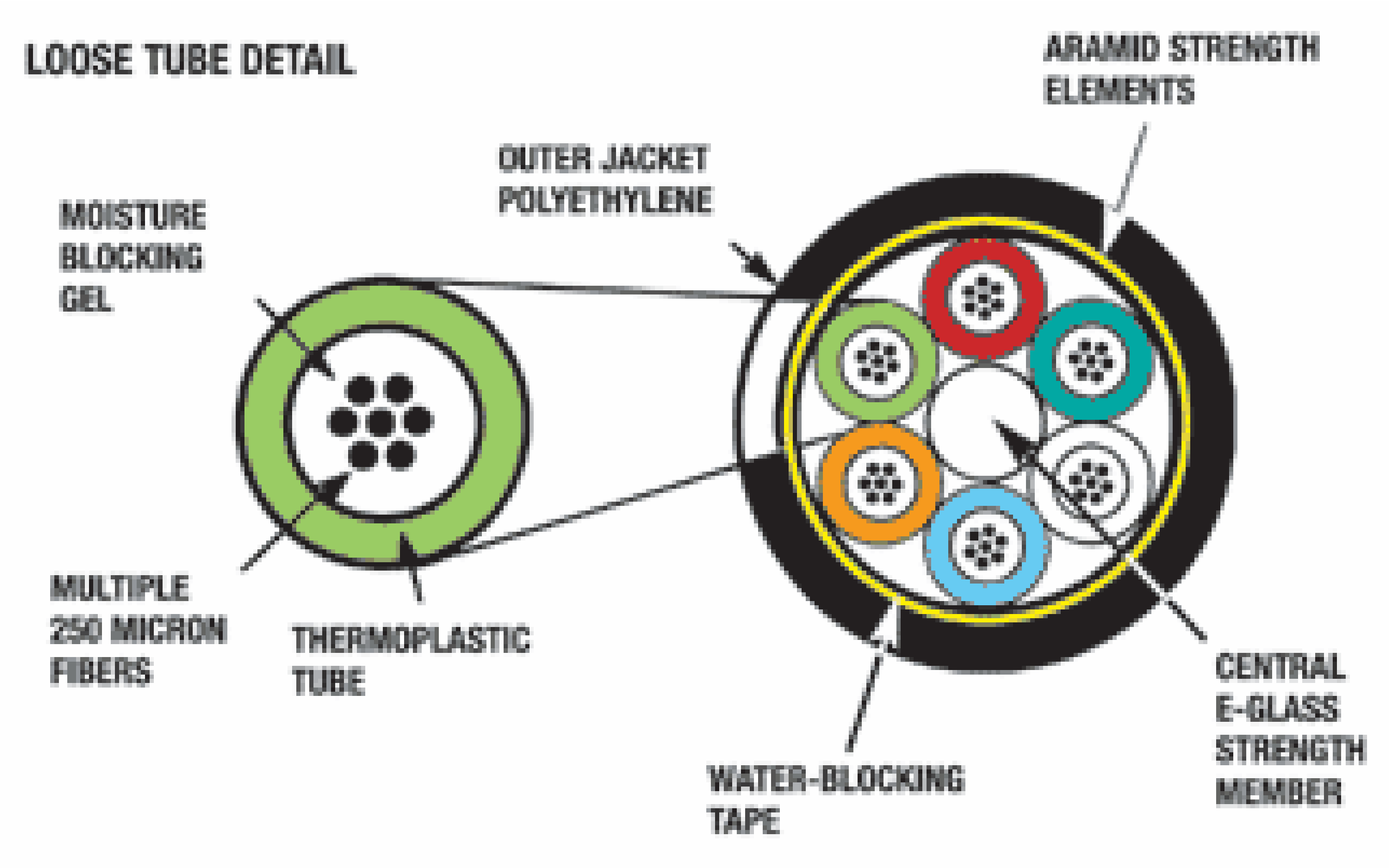
Fiber optics is a medium for carrying information from one point to another in the form of light. Unlike the copper form of transmission, fiber optics is not electrical in nature. A basic fiber optic system consists of a transmitting device that converts an electrical signal into a light signal, an optical fiber cable that carries the light, and a receiver that accepts the light signal and converts it back into an electrical signal.

Basic Fiber Optic Communication System



From [1]

Typical Fiber Optic Cable



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Advantages/Disadvantages of Fiber Optic

Advantages

- Enormous potential bandwidth
- Small size and weight
- Electrical Isolation.
- Signal security
- Low transmission loss
- Potential low cost

Disadvantages

- Higher initial cost in installation
- High cost of connector and interfacing
- Requires specialized and sophisticated tools for maintenance and repairing.

Refractive Index

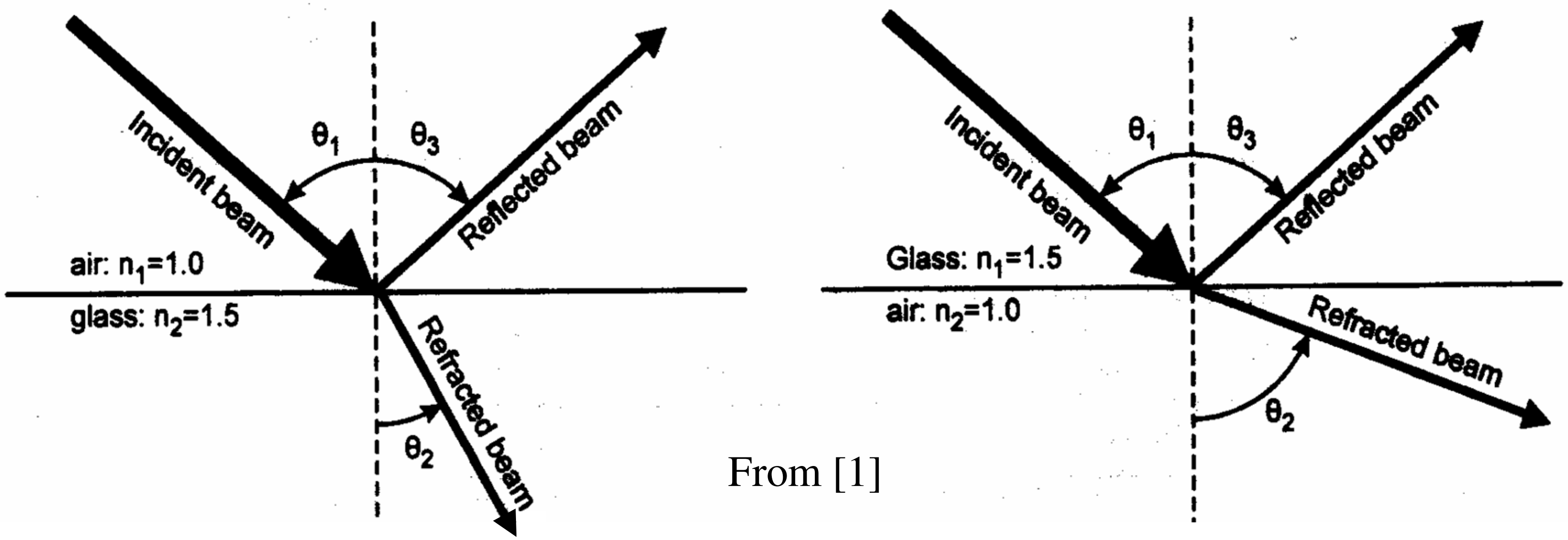
The guidance of the light beam which acts as a transmission channel for information (through the optical fiber) takes place because of the phenomenon of **total internal reflection** (TIR), which is dependent on the refractive index of the medium.

The **refractive index** (*n*) of a medium can be written as:

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

where c (≈ 3×10^8 m/s) is the speed of light in free space and v represents the velocity of light in that medium. For example, for light waves, $n = 1.5$ for glass and $n = 1.33$ for water.

A ray of light incident on a denser medium i.e. $n_1 < n_2$



From [1]

According to Snell's Law and the law of reflection we have

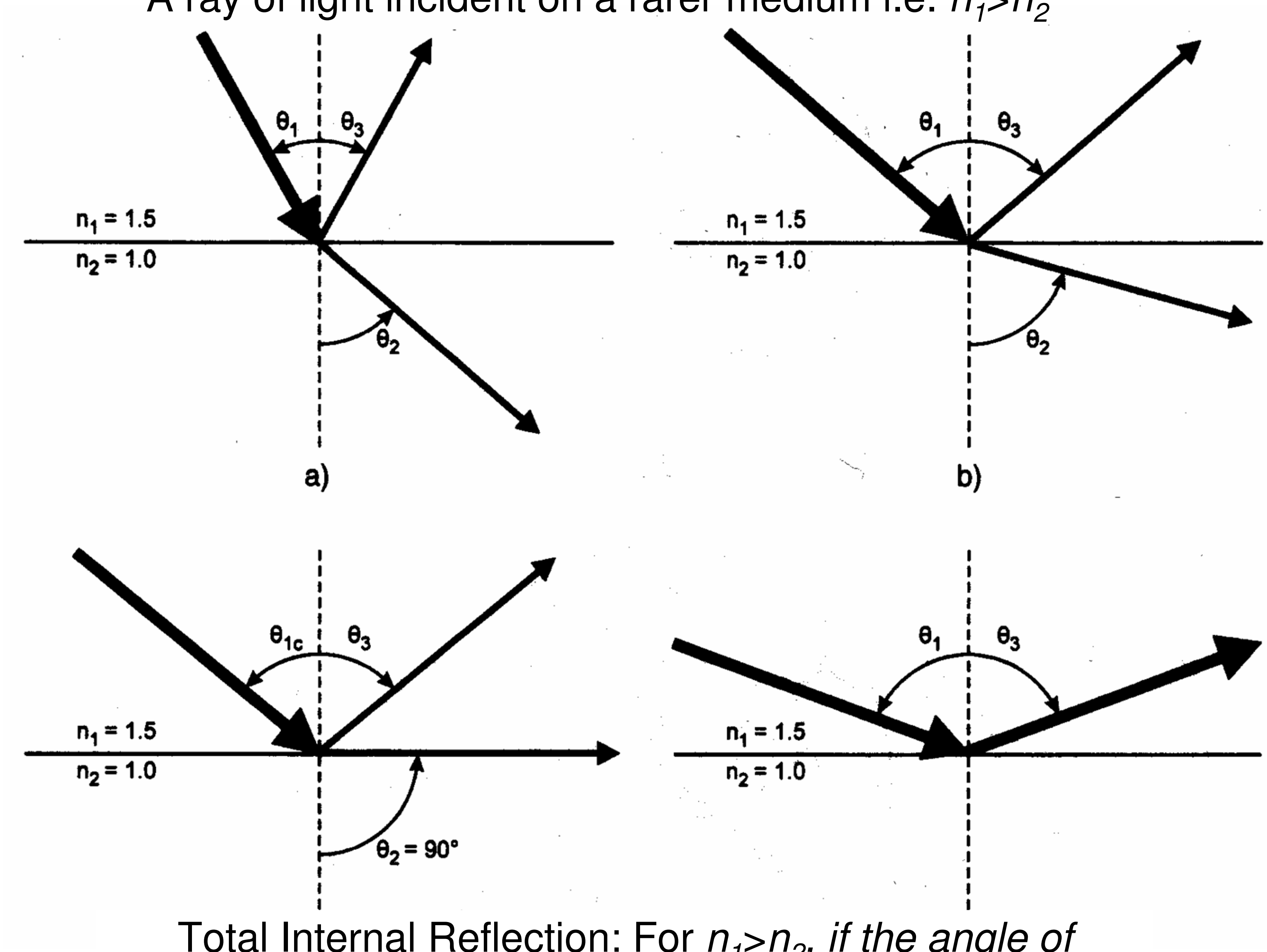
$$\boldsymbol{n_1 \sin \theta_1 = n_2 \sin \theta_2} \quad \textbf{and} \quad \boldsymbol{\theta_1 = \theta_3}$$

The angle of incidence, for which the angle of refraction is 90º, is known as the critical angle and is denoted by $\boldsymbol{\theta_c}$. Thus, when

$$\theta_1 = \theta_c = \sin^{-1}(\frac{n_2}{n_1})$$

$\boldsymbol{\theta_2} = 90$. When the angle of incidence exceeds the critical angle (i.e., when $\boldsymbol{\theta_1 > \theta_c}$.), there is no refracted ray and we have total internal reflection

A ray of light incident on a rarer medium i.e. $n_1>n_2$

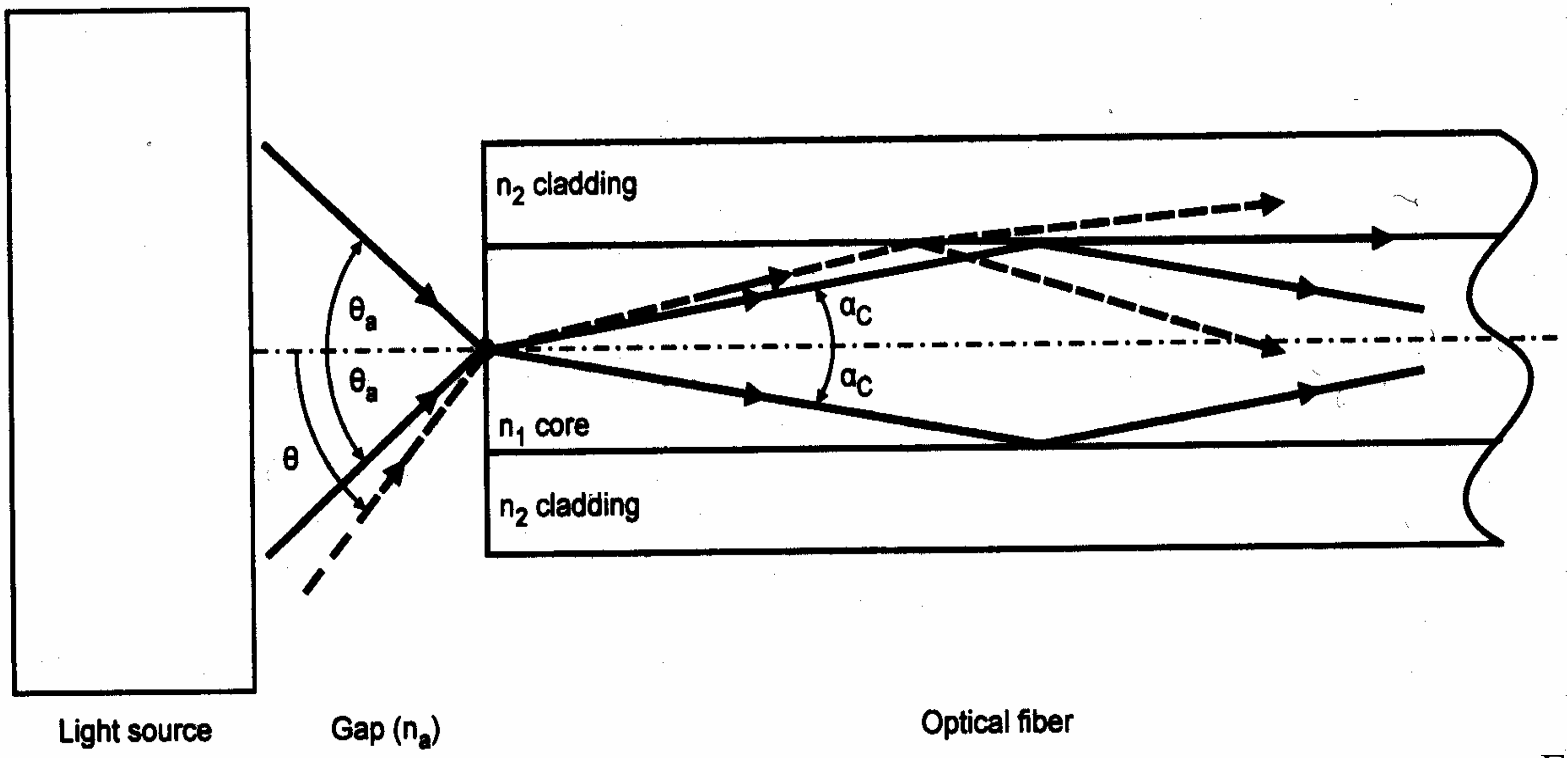


Total Internal Reflection: For $n_1>n_2$, *if the angle of incidence is greater that the critical angle*

From [1]

Acceptance Angle

Multimode optical fiber will only propagate light that enters the fiber within a certain cone, known as the acceptance cone of the fiber. The half-angle of this cone is called the ***acceptance angle***, $\boldsymbol{\theta}_{max}$.



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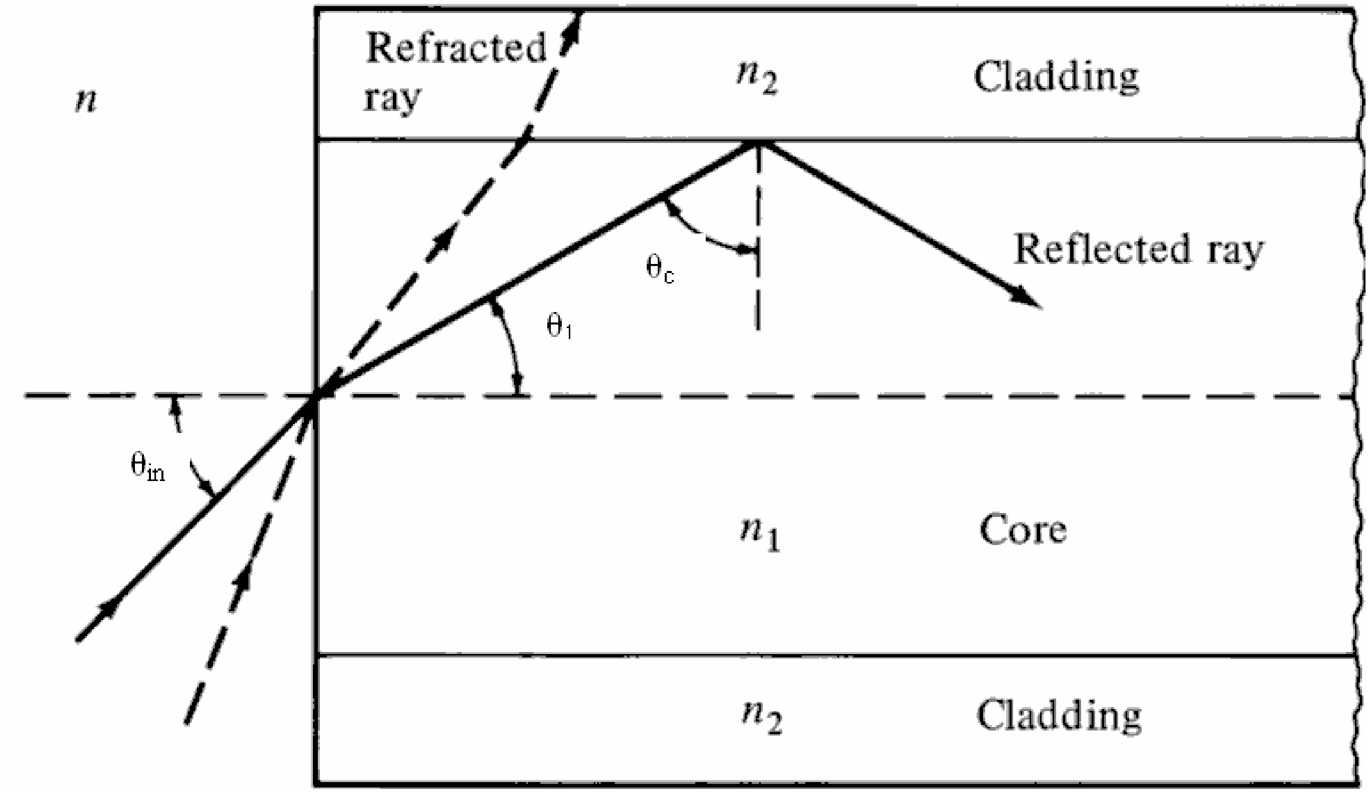

From [1]

To propagate the light beam down the optical fiber, the light beam at the core and cladding interface must taken an angle less than the critical angle $\boldsymbol{\theta_c}$. From Snells law, we can write,

$$n\sin\theta_{in} = n_1\sin\theta_1 = n_1\sin(90-\theta_c) = n_1\cos\theta_c$$

So, $$n\sin\theta_{in} = \frac{n_1\cos\theta_c}{n}$$

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

So,

$$\boxed{\sin\theta_{in} = \sqrt{n_1^{\,2}-n_2^{\,2}}}$$

$\boldsymbol{\theta_{in}}$ is thus known as ***acceptance angle*** or half angle of acceptance.

Numerical Aperture

Numerical Aperture is the measurement of the acceptance angle of an optical fiber, which is the maximum angle at which the core of the fiber will take in light that will be contained within the core. Taken from the fiber core axis (center of core), the measurement is the square root of the squared refractive index of the core minus the squared refractive index of the cladding.

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

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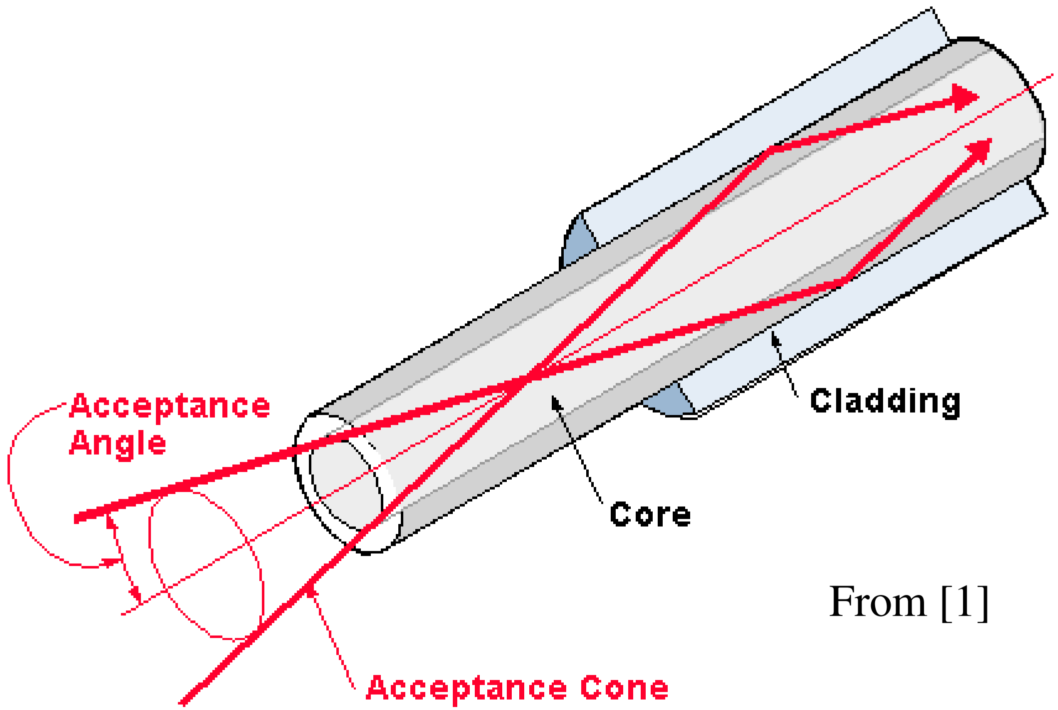


From [1]

Types of Optical Fiber

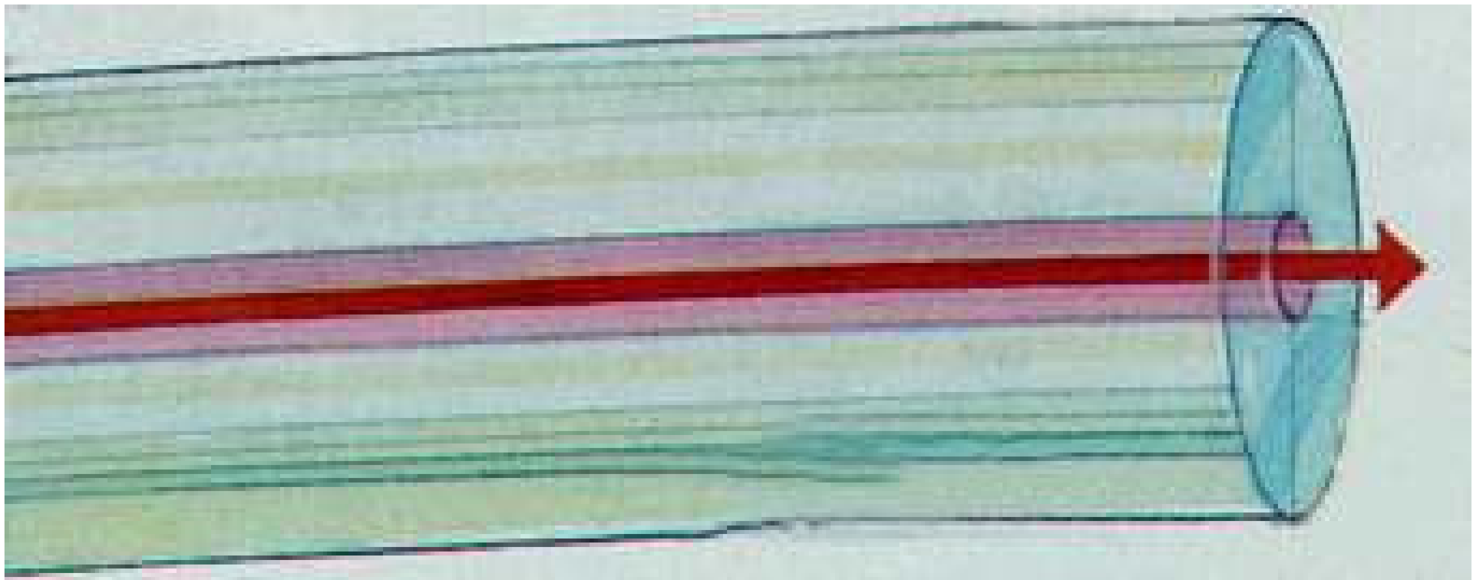
Optical fibers come in two main types:

A **single-mode** fiber has a small core that forces the light waves to stay in the same path, or mode. This keeps the light signals going further before they need to be beefed up, or amplified. Most long-distance, or long-haul, fiber optic telephone lines use single-mode fiber.

A **multimode fiber** has a much larger core than single-mode fiber. This gives light waves more room to bounce around inside as they travel down the path. The extra movement eventually causes the pulses to smear, and lose information. That means multimode fiber signals can't travel as far before they need to be cleaned up and re-amplified. Multimode fibers can carry only a third or less the information-carrying capacity—or bandwidth—than single-mode fiber. The technology for multimode fiber is less expensive and can only be used for short distances (such as in LANs)

Single-Mode Step-Index Fiber

These types of fibers have sharp boundaries between the core and cladding, with clearly defined indices of refraction. The entire core uses single index of refraction. Single mode fiber has a core diameter of 8 to 9 microns, which only allows one light path or *mode*.



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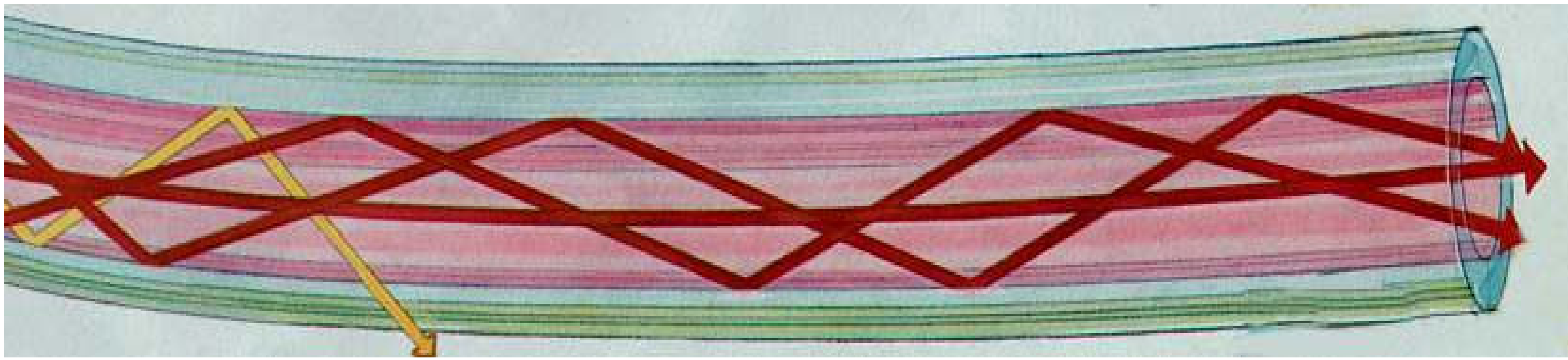
Multimode Step-Index Fiber

Multimode fiber has a core diameter of 50 or 62.5 microns (sometimes even larger). It allows several light paths or *modes*. This causes *modal dispersion* – some modes take longer to pass through the fiber than others because they travel a longer distance

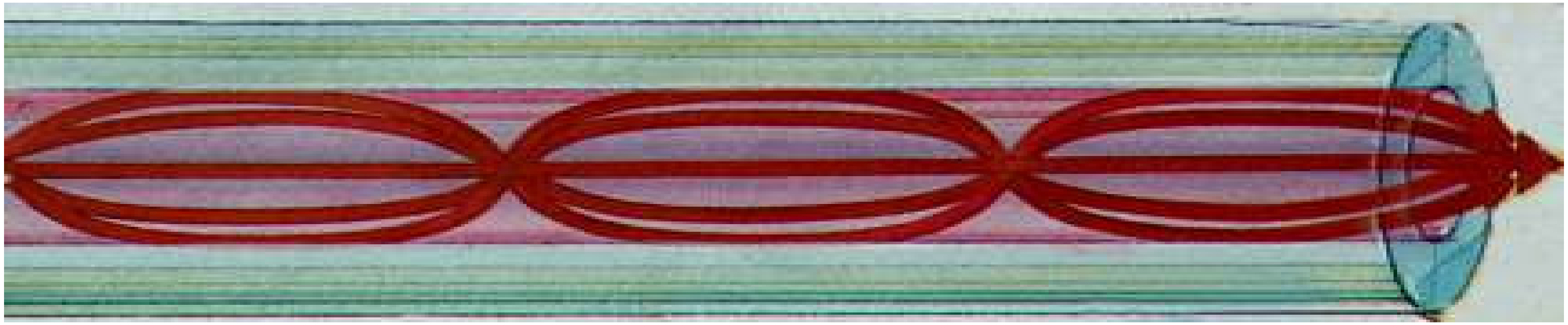


From [1]

Multimode Graded-Index Fiber

Graded-index refers to the fact that the refractive index of the core gradually decreases farther from the center of the core. The increased refraction in the center of the core slows the speed of some light rays, allowing all the light rays to reach the receiving end at approximately the same time, reducing dispersion.

From [1]



The light rays follow a serpentine path being gradually bent back toward the center by the continuously declining refractive index. This reduces the arrival time disparity because all modes arrive at about the same time. The modes traveling in a straight line are in a higher refractive index, so they travel slower than the serpentine modes. These travel farther but move faster in the lower refractive index of the outer core region.

Attenuation

The decrease in signal strength along a fiber optic waveguide caused by absorption and scattering is known as attenuation.

Attenuation is usually expressed in dB/km. Due to attenuation, the power output (P_{out}) at the end of 1km of optical fiber drops to some fraction (k) of the input power (P_{in}) i.e. $P_{out} = k.P_{in}$ (k less than 1). So, after 2km, $P_{out} = k^2.P_{in}$, and, after L km, $P_{out} = k^L.P_{in}$.

$$
\begin{aligned}
Power\ loss(dB) &= 10\log_{10}\frac{P_{out}}{P_{in}} \\
&= 10\log_{10}k^L \\
&= L.10\log_{10}k. \\
&= \alpha.L
\end{aligned}
$$

where α ($= 10\log_{10}k$) is the attenuation coefficient of the fiber in dB/km

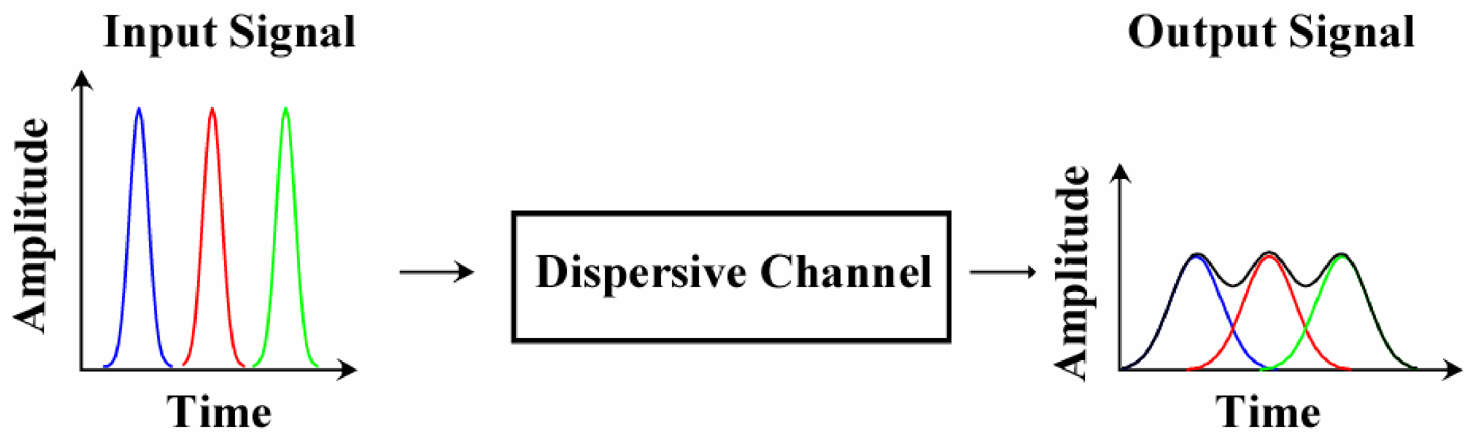
Since attenuation is the loss, therefore, it is always expressed as:

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

From [1]

Dispersion

Dispersion, expressed in terms of the symbol Δt, is defined as pulse spreading in an optical fiber. As a pulse of light propagates through a fiber, elements such as numerical aperture, core diameter, refractive index profile, wavelength, and laser line width cause the pulse to broaden. This poses a limitation on the overall bandwidth of the fiber



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