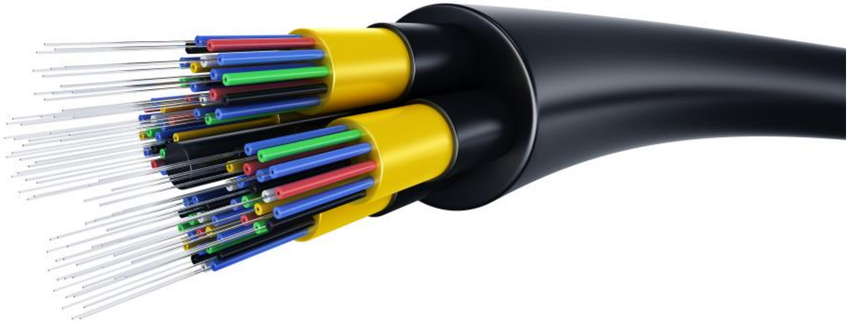
Optical Fibers



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- Introduction
- Basic components of Optical fiber
- Principle of operation
- Types of Optical fiber
- Wavelength, Attenuation and Bandwidth
- Applications

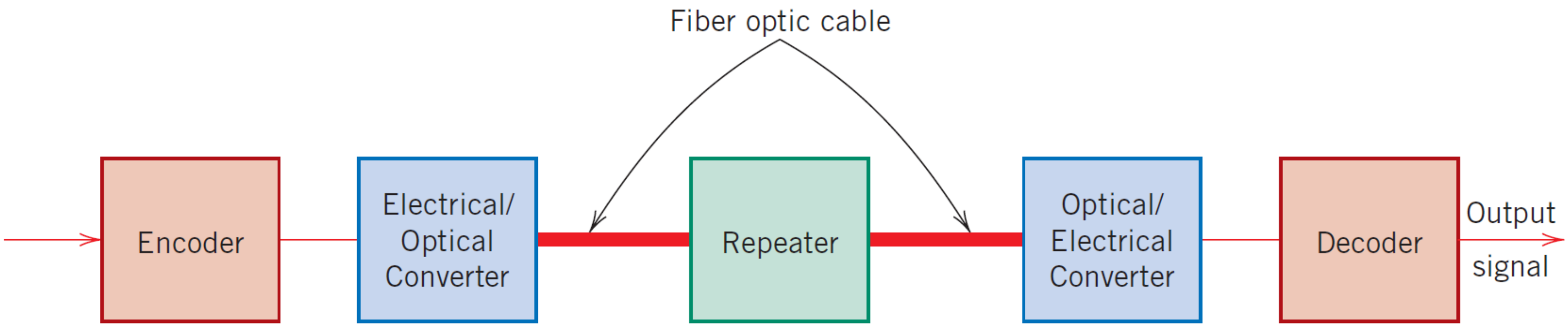
Optical Fibers

- Medium for **carrying information** from one point to another in the form of **light**.

- Fiber optics is **not electrical in nature** unlike copper form of transmission.

- It has been calculated that it would **require 30,000 kg of copper** to transmit the same amount of information as only **0.1 kg of optical fiber** material.

Optical Fiber Communications System



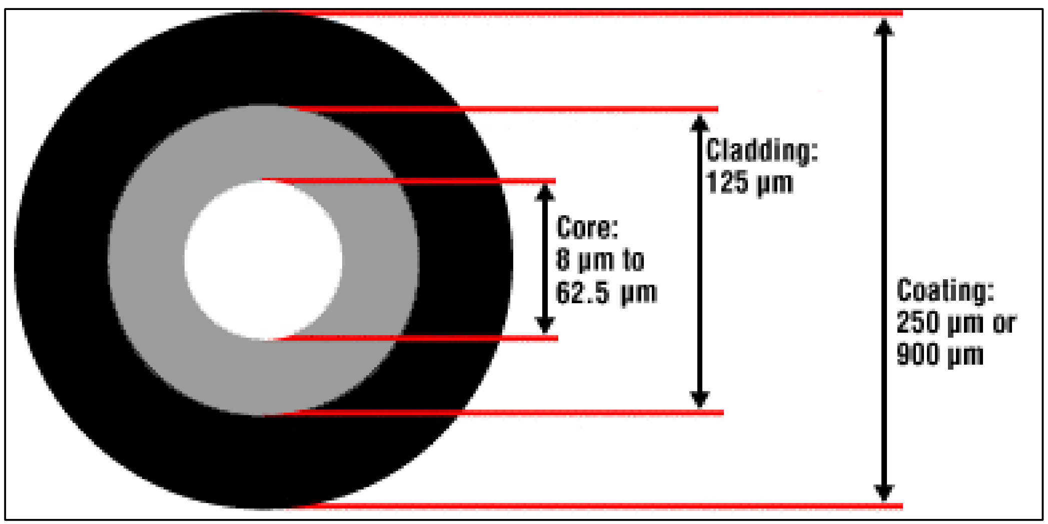
- The information (i.e., telephone conversation) in electronic form is first **digitized** into bits, that is, 1's and 0's; this is accomplished in the **encoder**.
- Then electrical signal is converted into an optical (photonic) one using the **electrical-to-optical converter** which is normally a **semiconductor laser**.
- Laser emits monochromatic and coherent light (infrared region, low absorption losses).
- The output converter is in the form of **pulses of light**; a binary "1" (high-power pulse), and a "0" (low-power pulse).
- Pulse signals are then fed into and carried through the fiber-optical cable.
- At receiving end reverse process takes place.

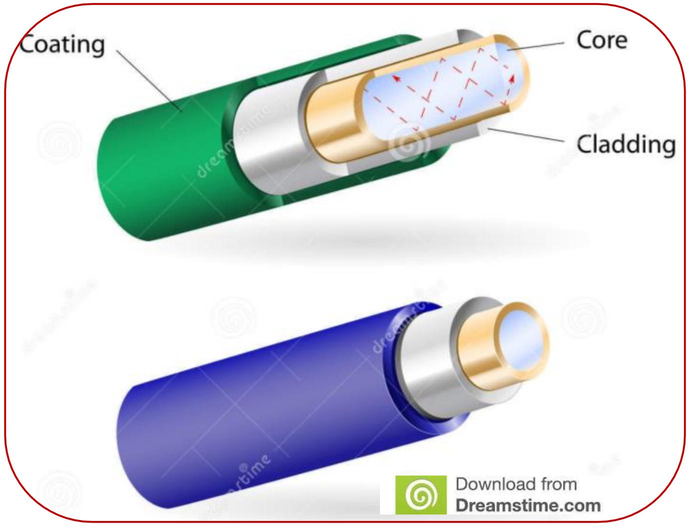
Reference: W.D Callister, 7 Ed.

Optical Fiber Components

It includes :-

- ❑ Core - Signal passes through the core.
- ❑ Cladding - Constrains the light rays to travel within the core.
- ❑ **Coating** - Protects core and cladding from damage.





Basics

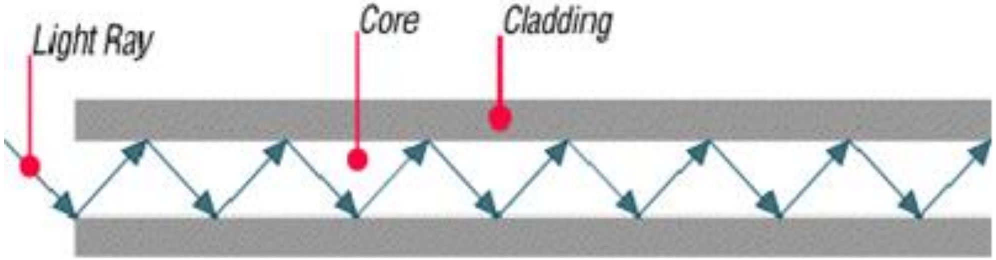
Refractive Index

$$\boxed{Refractive\ Index, n = \frac{Speed\ of\ light\ in\ a\ vacuum}{Speed\ of\ light\ in\ a\ Medium}}$$

- The $Refractive\ Index$ of a vacuum by definition has a value of 1.
- The **larger** the $\boldsymbol{refractive\ index}$, the more slowly light travels in that medium.

Total Internal Reflection

When a light ray traveling in one material hits a different material and **reflects back into the original material without any loss** of light, total internal reflection occurs.



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Principle – Total Internal Reflection (TIR)

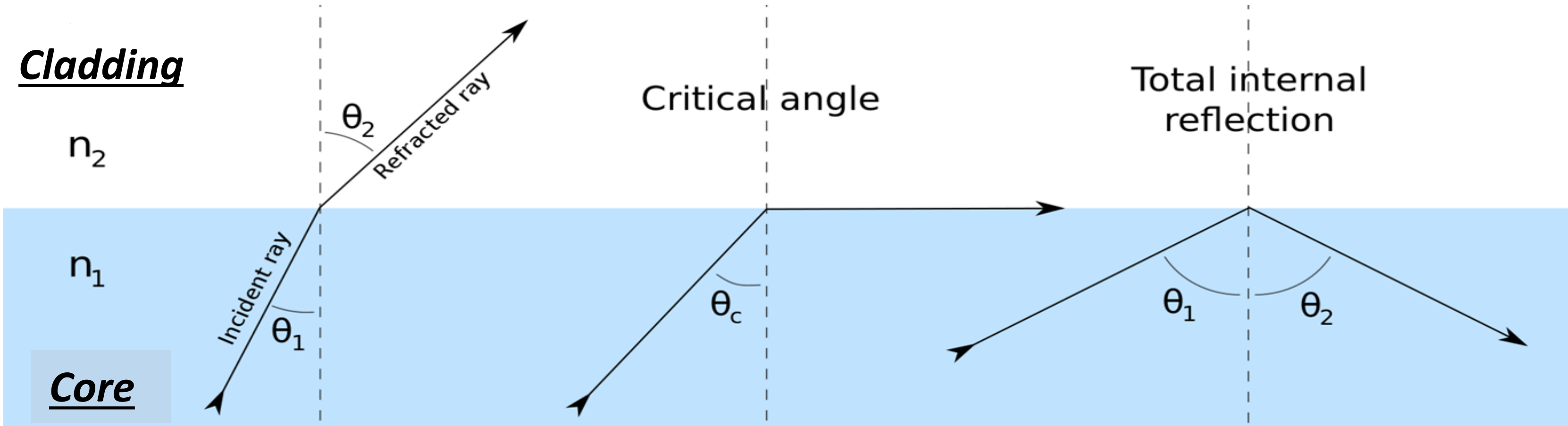


Image: Wikipedia

- The refractive index of Core (**n_1**) is **greater** than cladding (**n_2**) since core and cladding are constructed from **different compositions** of **silica glass**.

- Using **Snell's law**

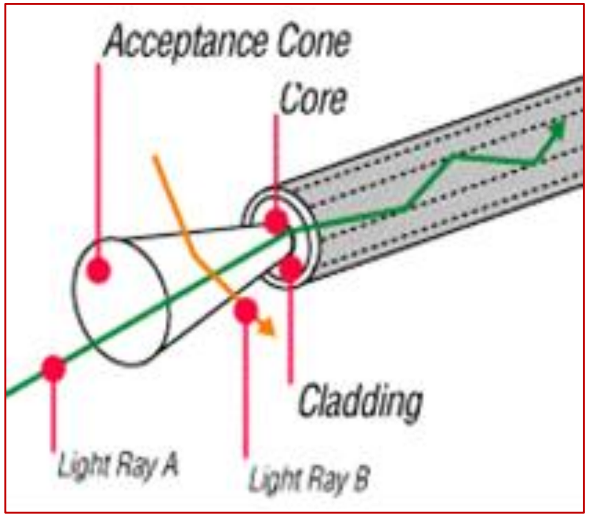
$$n_1 sin\theta_1 = n_2 sin\theta_2$$

For θ_1 = θ_c= Critical angle ,θ_2= 90^0,

- For **angle of incidence** greater than critical angle **total internal reflection** takes place.

Acceptance Cone

- Electrical signals are converted to light signals before they enter an optical fiber.
- To ensure that the signals reflect and travel correctly through the core, the **light must enter the core** through an imaginary **acceptance cone**.
- The size of this acceptance cone is a function of the refractive index difference between the core and the cladding.



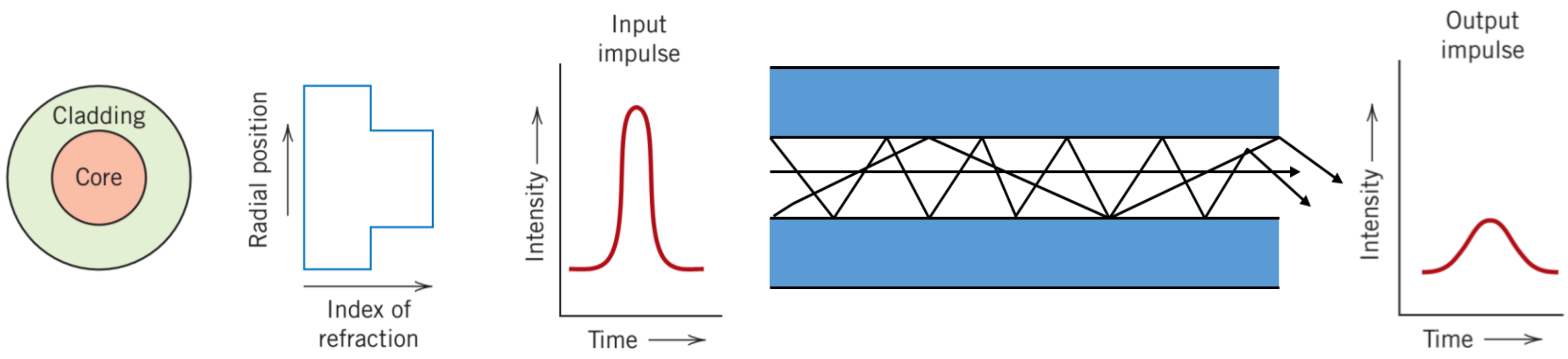
Light Ray A: Entered acceptance cone; transmitted through the core by TIR

Light Ray B: Did not enter acceptance core; signal lost

Optical Fiber Designs

Internal reflection is accomplished by **varying** the **index of refraction** of the **core and cladding glass materials**.

❖ ***Step-index Optical Fiber***

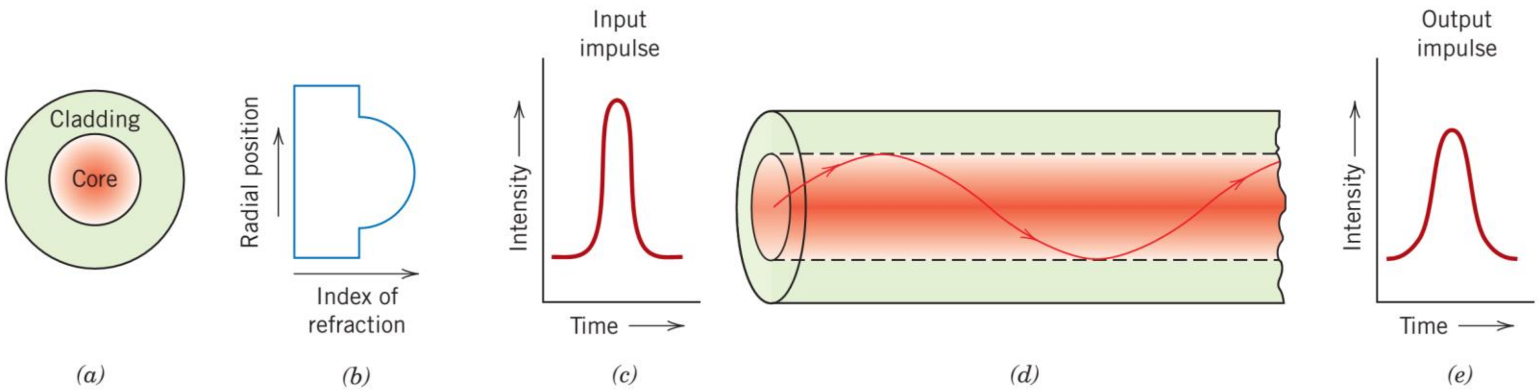


a) b) c) d) e)

- The index of refraction of the cladding (1.46) is slightly lower than that of the core (1.48).
- The main problem with this design is that different light rays follow slightly different trajectories and will therefore reach the **output at different times.**
- Hence, the **output pulse is broader than the input pulse** – Not desirable (*limits the data rate of digital communication*)

Reference: W.D Callister, 7 Ed.

❖ *Graded-index Optical Fiber*

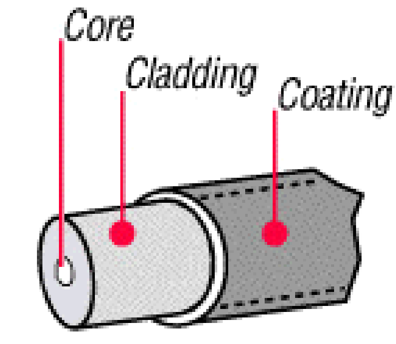


- Impurities such as boron oxide (B_2O_3) or germanium dioxide (GeO_2) are added to the silica glass such that the **index of refraction** is made to **vary parabolically** across the cross section.
- Now, **waves** which travel in the **outer regions**, do so in a lower refractive index material and their **velocity is higher** ($v = c/n$).
- Therefore, they travel both *further* and *faster* as a result, they arrive at the output at almost the same time as the waves with shorter trajectories

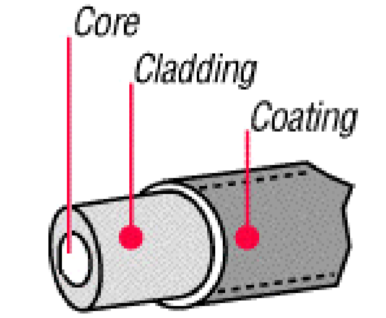
Reference: W.D Callister, 7 Ed.

Types of Fiber

- **Impossible** to **distinguish** between single-mode and multimode fiber with the **naked eye**.
- No difference in outward appearance, only in **core size.**



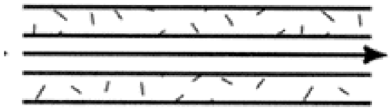
Single-Mode Fiber (SM)



Multimode Fiber (MM)

<u>Single-mode (SM) fiber</u>

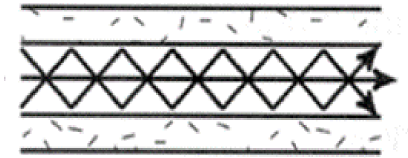
✓ Allows only one pathway, or mode, of light to travel within the fiber.



✓ The core size is typically 8.3 µm.

✓ Used in applications where low signal loss and high data rates are required.

<u>Multimode (MM) fiber</u>



✓ Allows more than one mode of light.

✓ Common Multimode core sizes are 50 µm and 62.5 µm.

✓ Better suited for shorter distance applications.

Wavelength

- Optical fiber transmission uses **wavelengths** which are **above the visible light** spectrum, and thus **undetectable** to the **unaided eye**.
- Typical optical transmission wavelengths are 850 nanometers (nm), 1310 nm, and 1550 nm.
- Both lasers and LEDs (light-emitting diodes) are used to transmit light through optical fiber.
- **Lasers** are usually used for **1310 or 1550 nanometer**, **single-mode applications**.
- **LEDs** are used for **850 or 1300 nanometer multimode applications**.

Attenuation

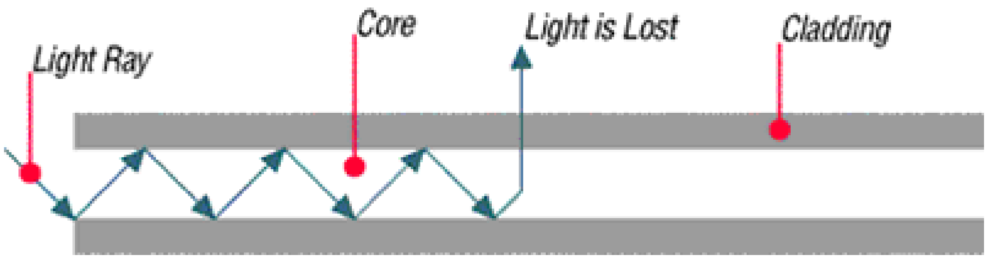
- ✓ Attenuation is the loss of optical power as light travels down a fiber.
- ✓ It is measured in decibels (dB/km).
- ✓ Over a set distance, a fiber with a lower attenuation will allow more power to reach its receiver than a fiber with higher attenuation.

Two types

- ❑ Intrinsic Attenuation
- ❑ Extrinsic Attenuation

Intrinsic Attenuation

- It is caused by impurities in the glass during the manufacturing process.
- Technological advances have caused attenuation to decrease dramatically since the first optical fiber in 1970.
- When a light signal hits an impurity in the fiber, one of two things will occur: it will **scatter** or it will be **absorbed**.



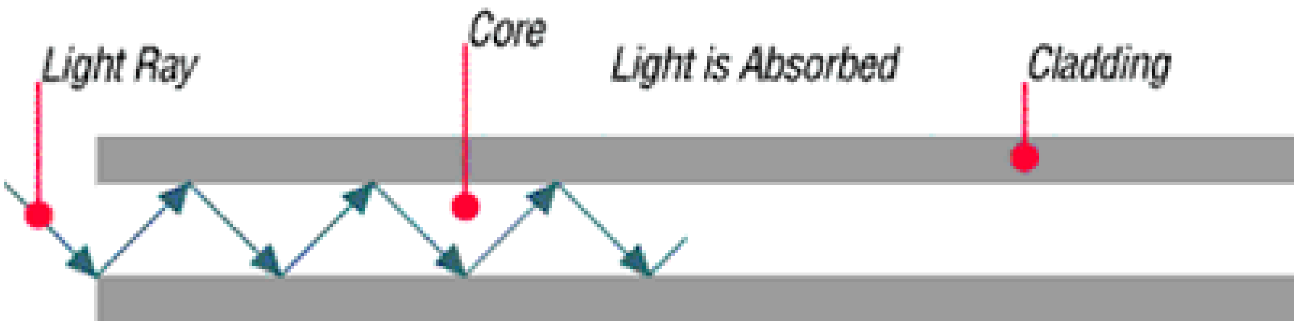
Rayleigh Scattering

a) Scattering

- Accounts for the majority (about 96%) of attenuation in optical fiber.
- The light waves elastically collide with the atoms, and light is scattered.
- If the light is scattered at an angle that does not support internal reflection, the light is diverted out of the core and attenuation occurs.

b) Absorption

- Second type of intrinsic attenuation.
- Absorption accounts for 3-5% of fiber attenuation.
- This phenomenon causes a light signal to be absorbed by natural impurities in the glass, and converted to vibrational energy or some other form of energy.
- Absorption can be limited by controlling the amount of impurities during the manufacturing process.

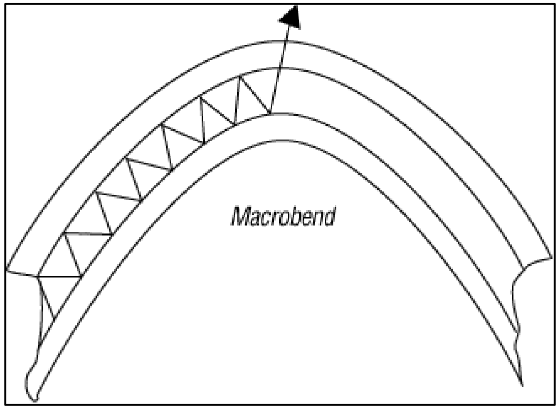


Extrinsic Attenuation

- Caused by two external mechanisms: **Macro-bending** and **Micro-bending**.
- Both causes a **reduction in optical power**.

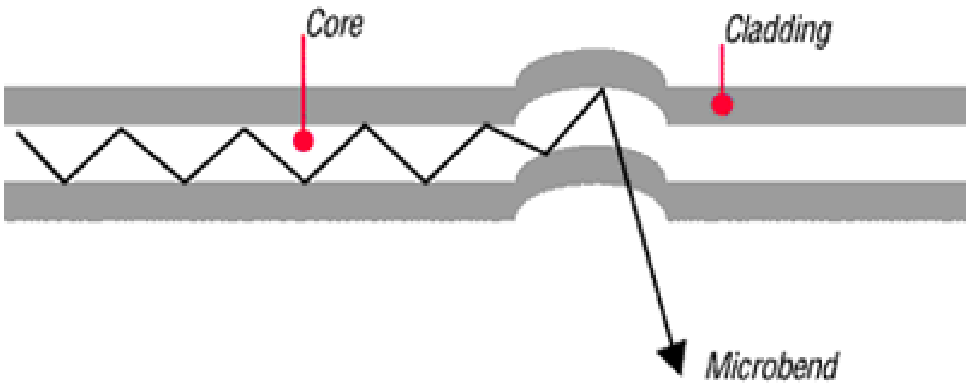
Macro-bending

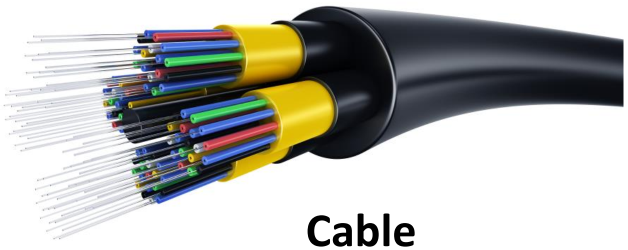
- **Large-scale bend** that is visible.
- For example, a fiber wrapped around a person's finger.
- This loss is generally reversible once bends are corrected.
- To prevent macrobends, all optical fiber (and optical fiber cable) has a minimum bend radius specification that should not be exceeded.



Micro-bending

- Micro-bending is very localized, and the bend may not be clearly visible upon inspection.
- May be related to temperature, tensile stress, or crushing force.
- With bare fiber, microbending may be reversible;
- But when many fibers are bundled in the form of cables, it may not be reversible.

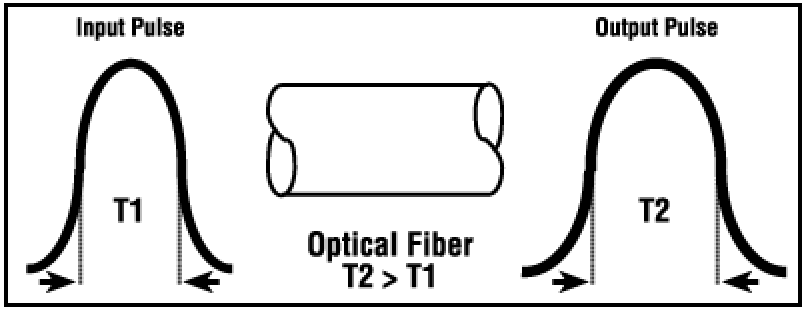




Cable

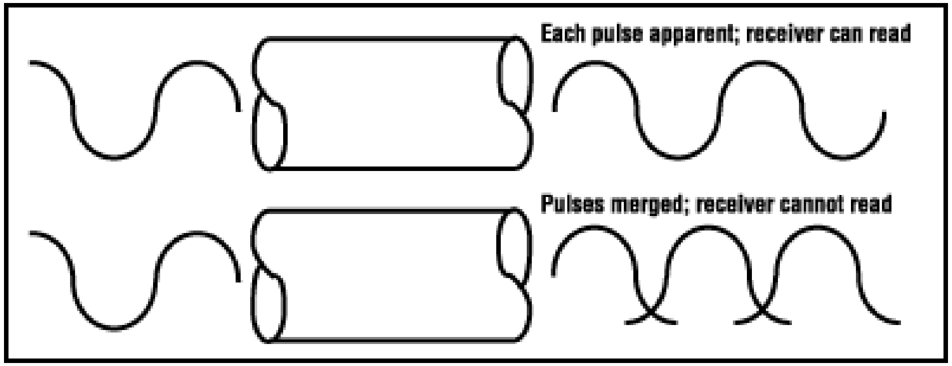
Dispersion

- “Spreading" of a light pulse as it travels down a fiber.
- As the pulses spread, or broaden, they tend to overlap, and are no longer distinguishable by the receiver as 0s and 1s.
- Light pulses launched close together (high data rates) that spread too much (high dispersion) result in errors and loss of information.
- Dispersion is significant in multimode applications, where the various modes of light traveling down the fiber arrive at the receiver at different times, causing a spreading effect.
- Dispersion limits how fast, or how much, information can be sent over an optical fiber.



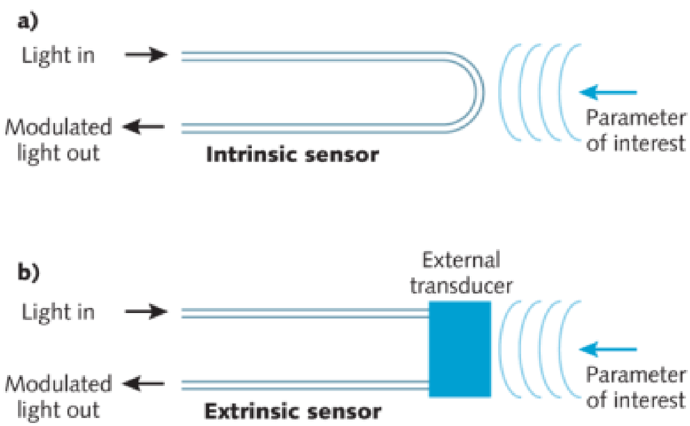
Bandwidth

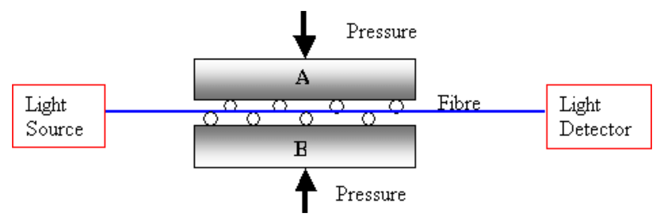
- Bandwidth is the amount of information a fiber can carry so that every pulse is distinguishable by the receiver at the end.
- The spreading of these light pulses causes them to merge together. At a certain distance and frequency, the pulses become unreadable by the receiver.
- The multiple pathways of a multimode fiber cause this overlap to be much greater than for single-mode fiber.
- These different paths have different lengths, which cause each mode of light to arrive at a different time.



Applications

- Optical fiber **experiences geometrical** (size, shape) and **optical** (refractive index, mode conversion) **changes** depending upon the nature and the magnitude of the **perturbation**.
- So the **optical fibre** serves as a **transducer** and **converts measurands** like temperature, stress, strain, rotation or electric and magnetic currents into a corresponding **change in the optical radiation**.
- Since light is characterized by intensity, phase, frequency and polarization, any one or more of these parameters may undergo a change.





Intrinsic Sensors: use the fiber itself as the transducer.

Extrinsic Sensors: Use fiber to supply light to a sensing device and return signal light to a detection system.

Reference: http://wikid.eu/index.php/Fiber_optic_sensing