PH 201

OPTICS & LASERS

Lecture_Lasers_16

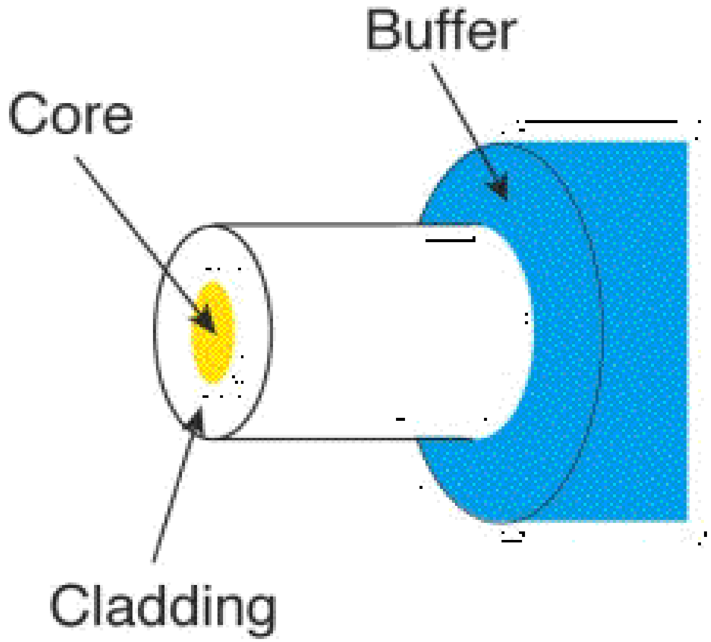
Ref.: K. Thyagarajan & A. K. Ghatak, *LASERS; Theory & Applications*, Macmillan India Ltd. (2008)

Fiber Optic Applications

Outside Plant Installations

Premises Installations

Fiber Technology



- Optical fiber is comprised of a light carrying core surrounded by a cladding which traps light in core by principle of TIR.

- Most optical fibers are made of glass, although some are made of plastic.

Fiber Technology

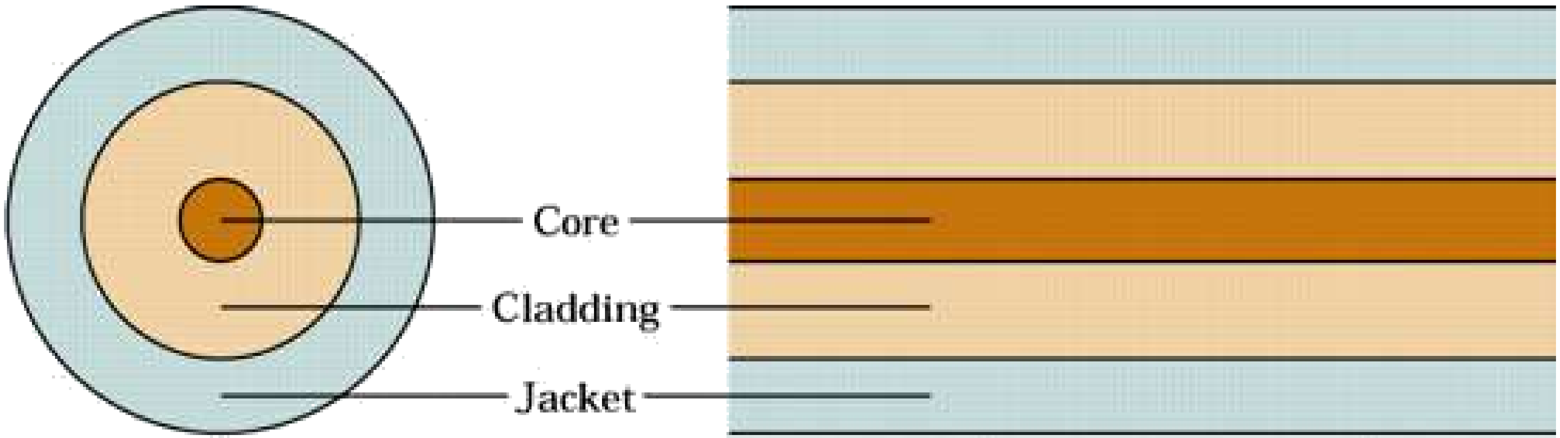
- Core & cladding are usually fused silica glass, covered by a plastic coating called buffer or primary buffer coating, which protects glass fiber from physical damage & moisture.

- Plastic fibers are used for specific applications. Glass fibers are most common type used in communications.

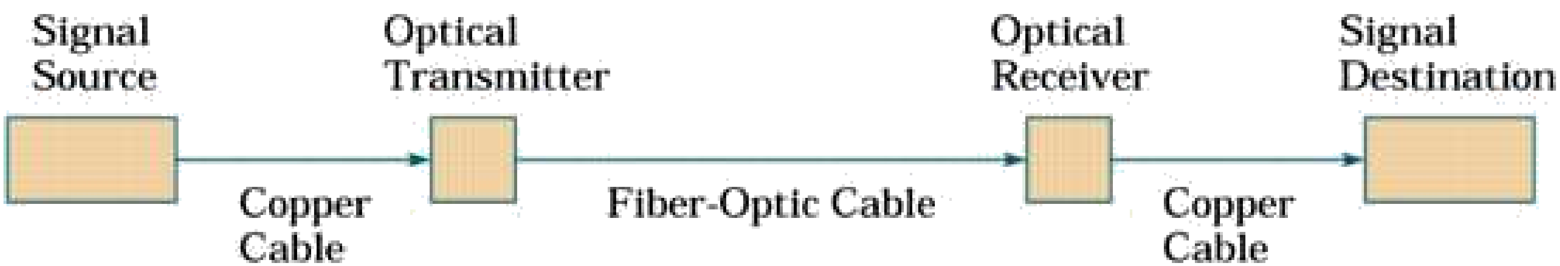
- Optical fiber has little mechanical strength, so it must be enclosed in a protective jacket.

- Often, two or more fibers are enclosed in same cable for increased bandwidth & redundancy in case one of the fiber breaks.

Fiber Technology



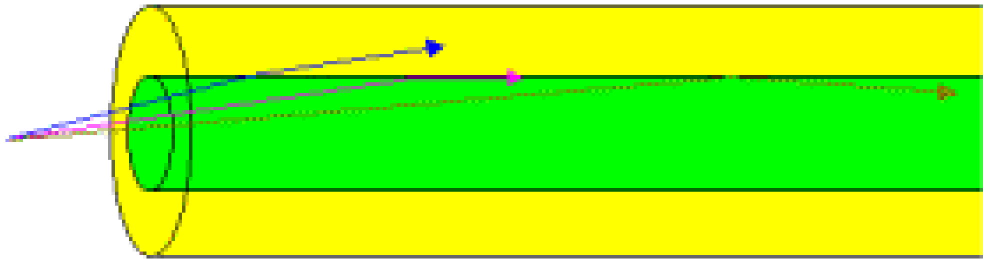
(a) Fiber cross section



(b) System

Fiber Technology

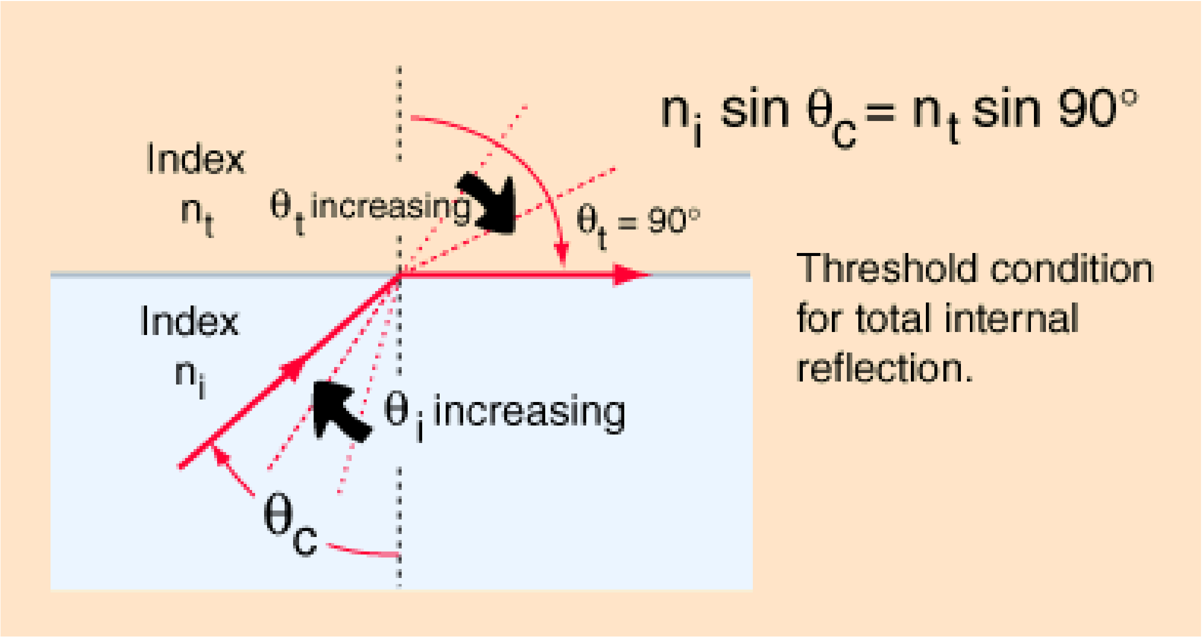
Total Internal Reflection



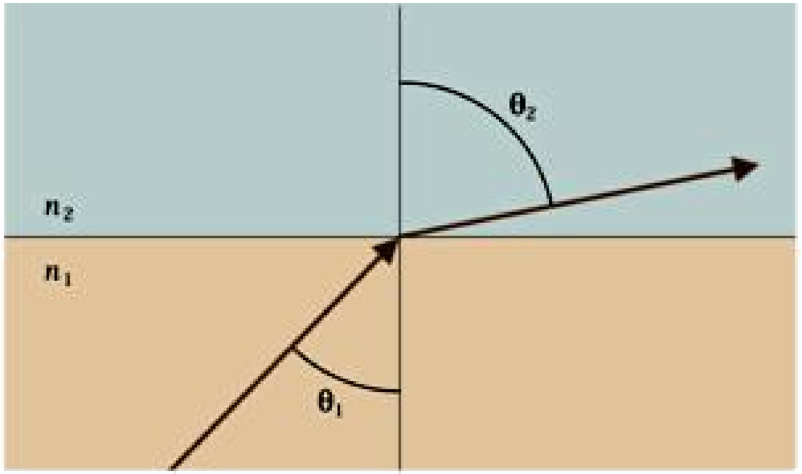
- ❖ By making core of fiber of a material with a higher refractive index, we can cause light in core to be totally reflected at the boundary of cladding for all light that strikes at greater than a critical angle determined by difference in composition of materials used in core & cladding.

Total Internal Reflection

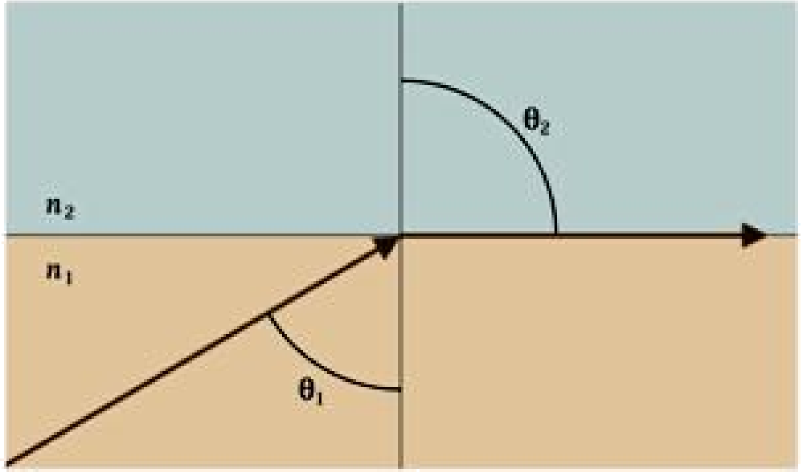
- TIR occurs when a ray of light strikes a medium boundary at an angle **larger than critical angle** with respect to normal to surface.
- If RI is lower on other side of boundary no light can pass through, so effectively all of light is reflected. Critical angle is angle of incidence above which TIR occurs.



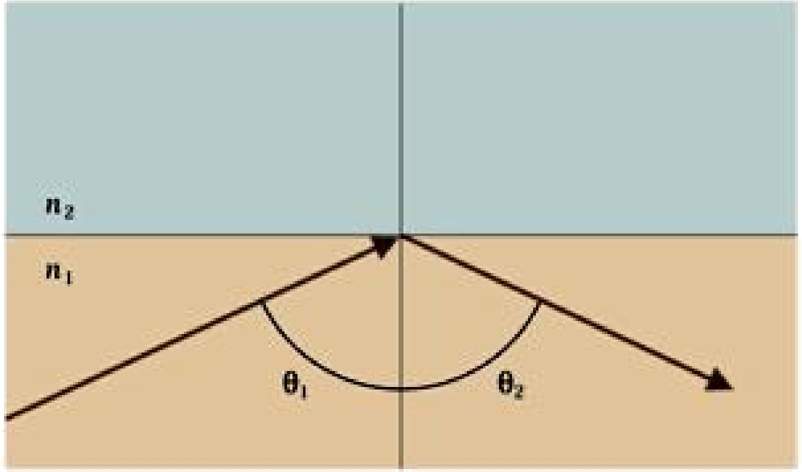
Total Internal Reflection



(a) Angle of incidence less than critical angle

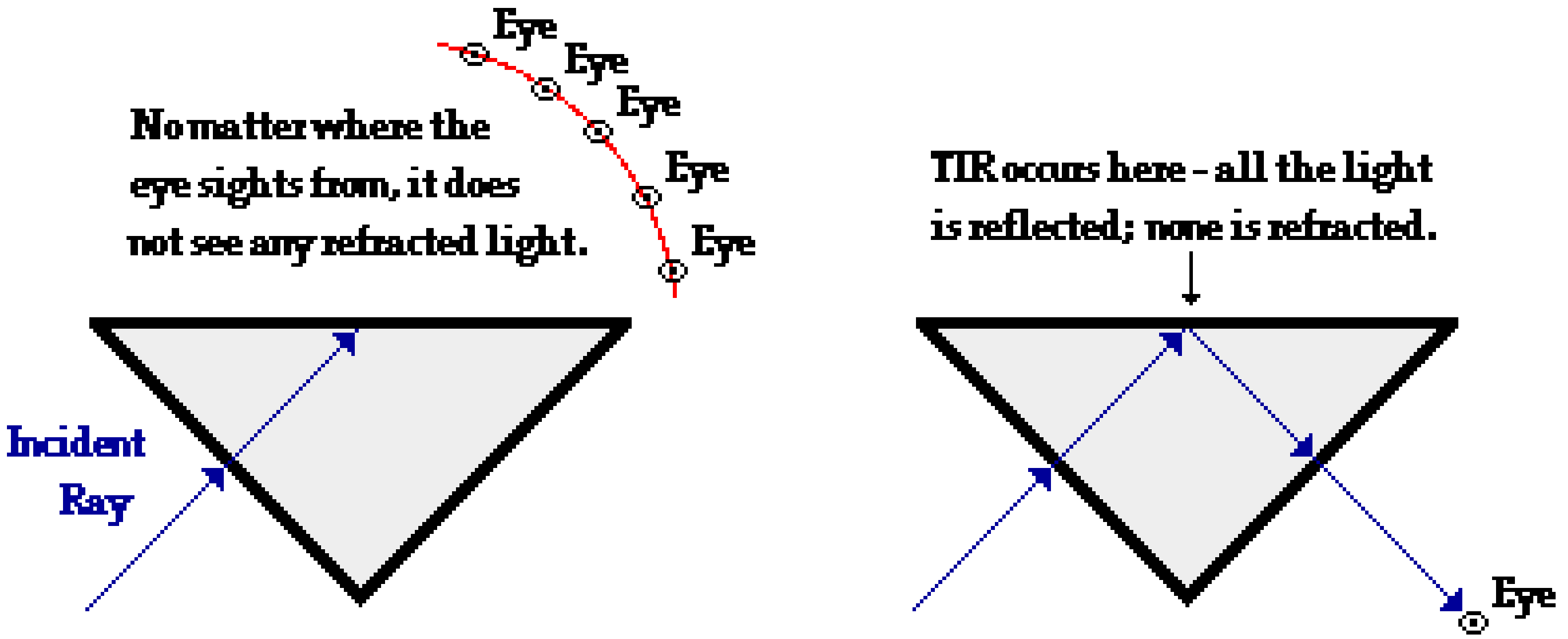


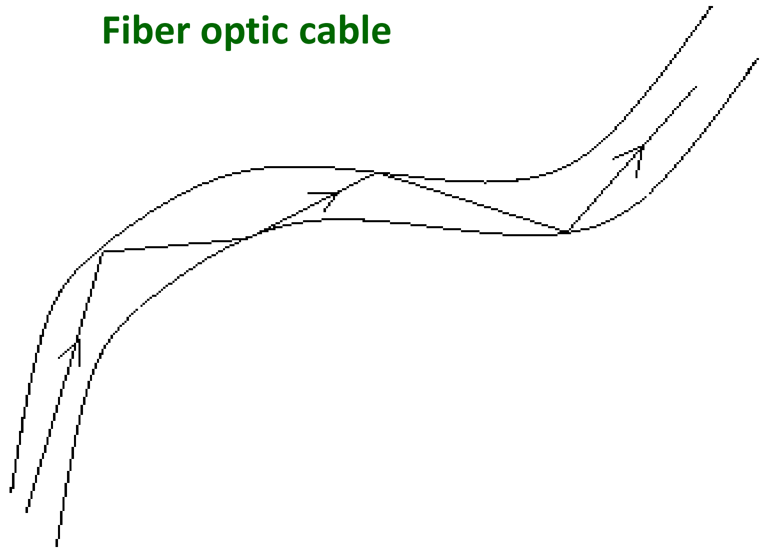
(b) Angle of incidence equal to critical angle

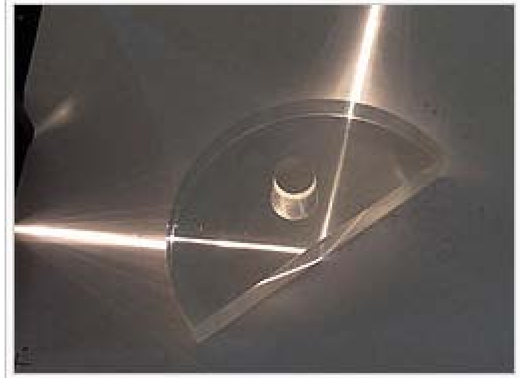


(c) Angle of incidence greater than critical angle

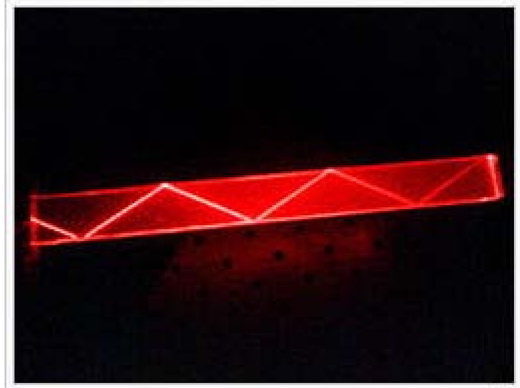
Total Internal Reflection







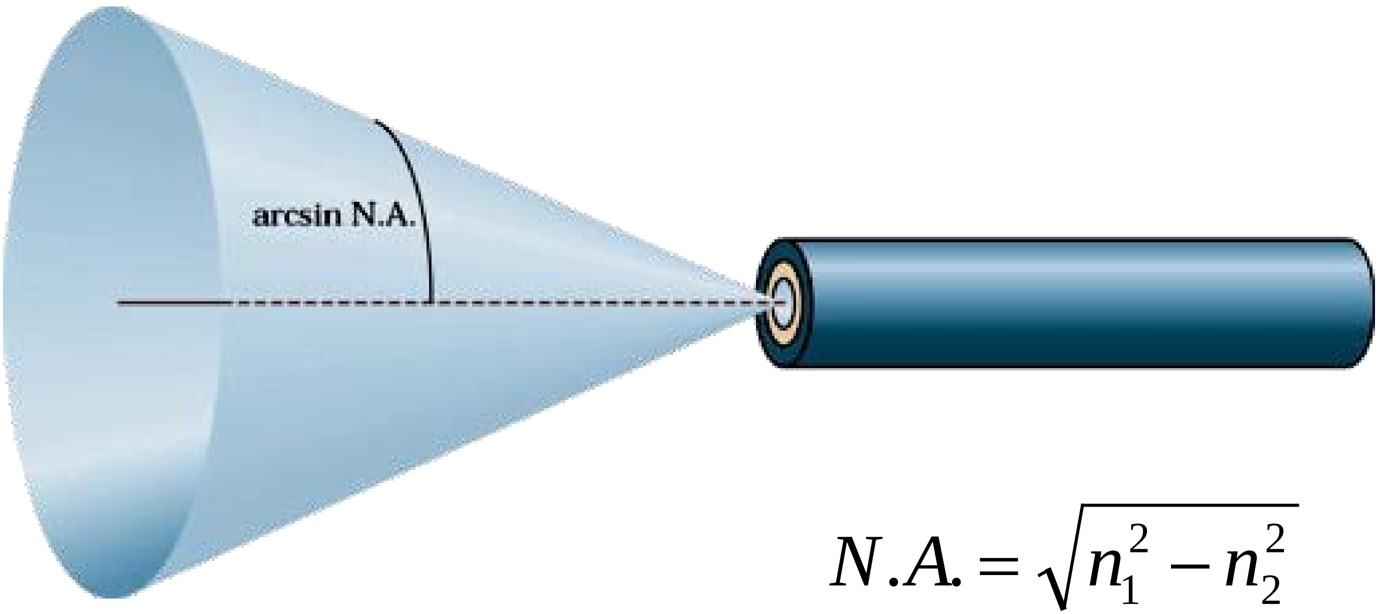
Total internal reflection



Total internal reflection in a block of PMMA

- ❖ **TIR is used in telephone & TV cables to carry signals. Light as an information carrier is much faster & more efficient than electrons in an electric current.**
- ❖ **Since light rays don't interact with each other (whereas electrons interact via their electric charge), it is possible to pack a large number of different light signals into same fiber optics cable without distortion.**

Numerical Aperture



$$N.A. = \sqrt{n_1^2 - n_2^2}$$

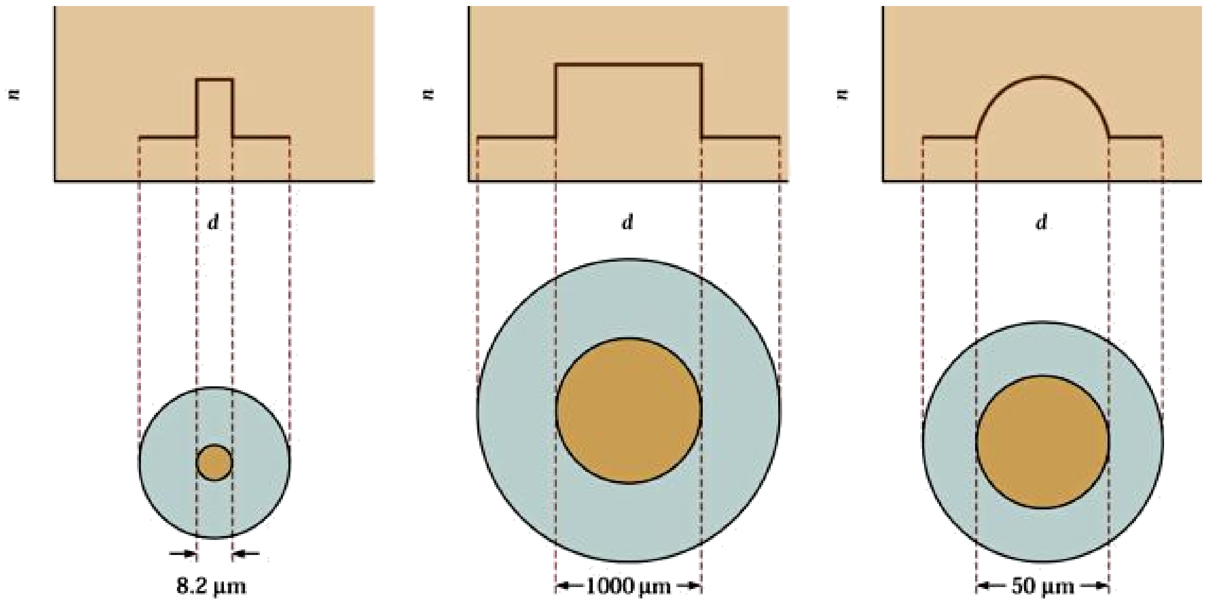
- **Numerical aperture of fiber is closely related to critical angle & is often used in the specification for optical fiber & components that work with it.**
- **Angle of acceptance is twice that given by NA.**

Modes & Materials

- Since optical fiber is a waveguide, light can propagate in a no. of modes.
- If a fiber is of large diameter, light entering at different angles will excite different modes while narrow fiber may only excite one mode.
- Multimode propagation will cause dispersion, which results in spreading of pulses & limits usable bandwidth.
- Single-mode fiber has much less dispersion but is more expensive to produce. Its small size, together with the fact that its NA is smaller than that of multimode fiber, makes it more difficult to couple to light sources.

Types of Fiber

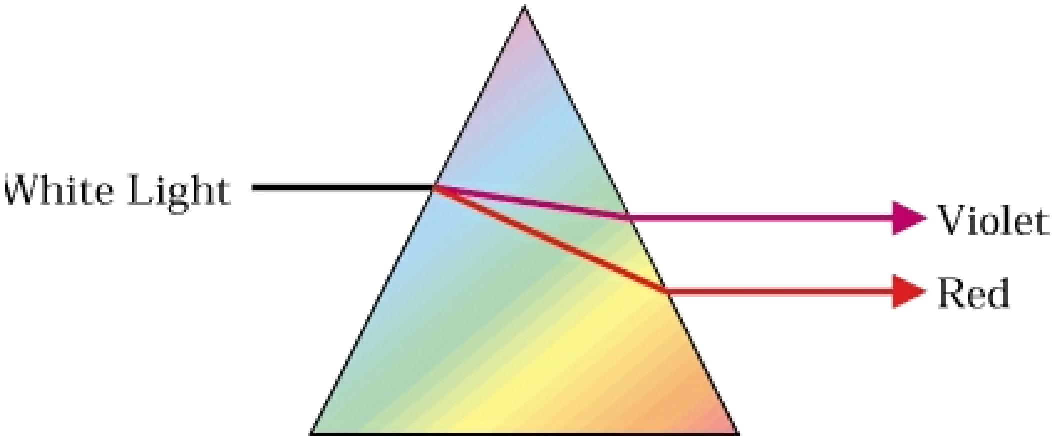
- Both types of fiber described earlier are known as step-index fibers because index of refraction changes radically between core & cladding.
- Graded-index (GRIN) fiber is a compromise multimode fiber, but index of refraction gradually decreases away from center of the core.
- GRIN fiber has less dispersion than a multimode step-index fiber.

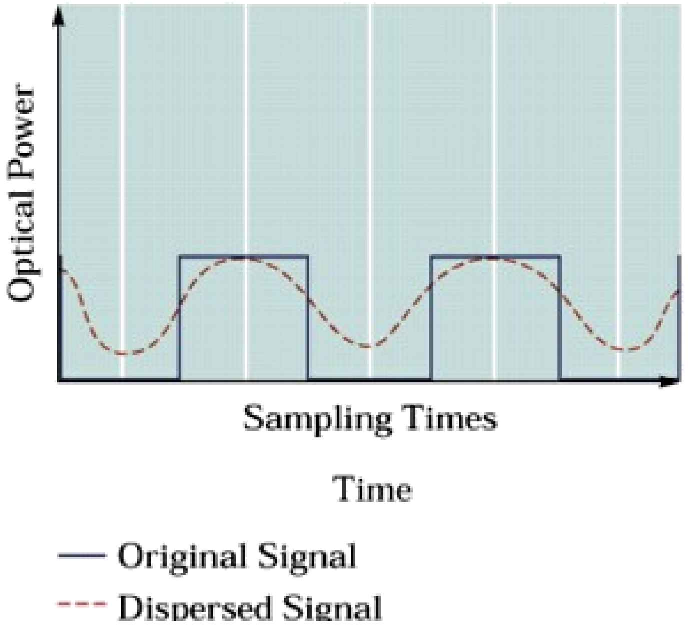


Dispersion

- Dispersion in fiber optics results from the fact that in multimode propagation, signal travels faster in some modes than it would in others.
- Single-mode fibers are relatively free from dispersion except for intramodal dispersion.
- Graded-index fibers reduce dispersion by taking advantage of higher-order modes.
- One form of intramodal dispersion is called material dispersion because it depends upon material of core.
- Another form of dispersion is called waveguide dispersion.
- Dispersion increases with bandwidth of light source.

Dispersion


White Light
Violet
Red


Optical Power
Sampling Times
Time
Original Signal
Dispersed Signal

Losses

- Losses in optical fiber result from attenuation in material itself & from scattering, which causes some light to strike cladding at less than critical angle.

- Bending optical fiber too sharply can also cause losses by causing some of the light to meet cladding at less than critical angle.

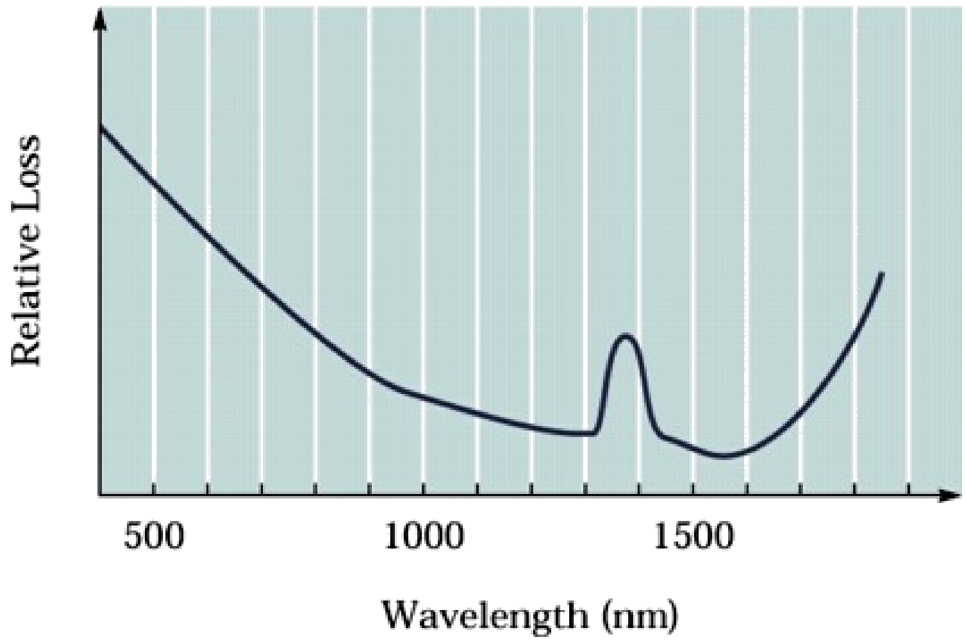
- Losses vary greatly depending upon the type of fiber.

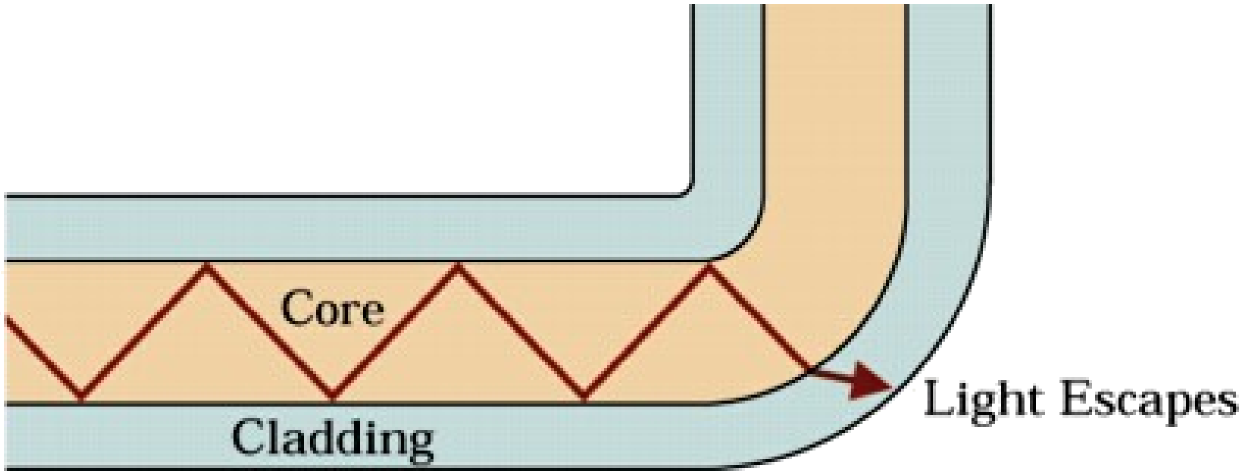
  - Plastic fiber may have losses of several hundred dB/km.

  - Graded-index multimode glass fiber has a loss of about 2-4 dB/km.

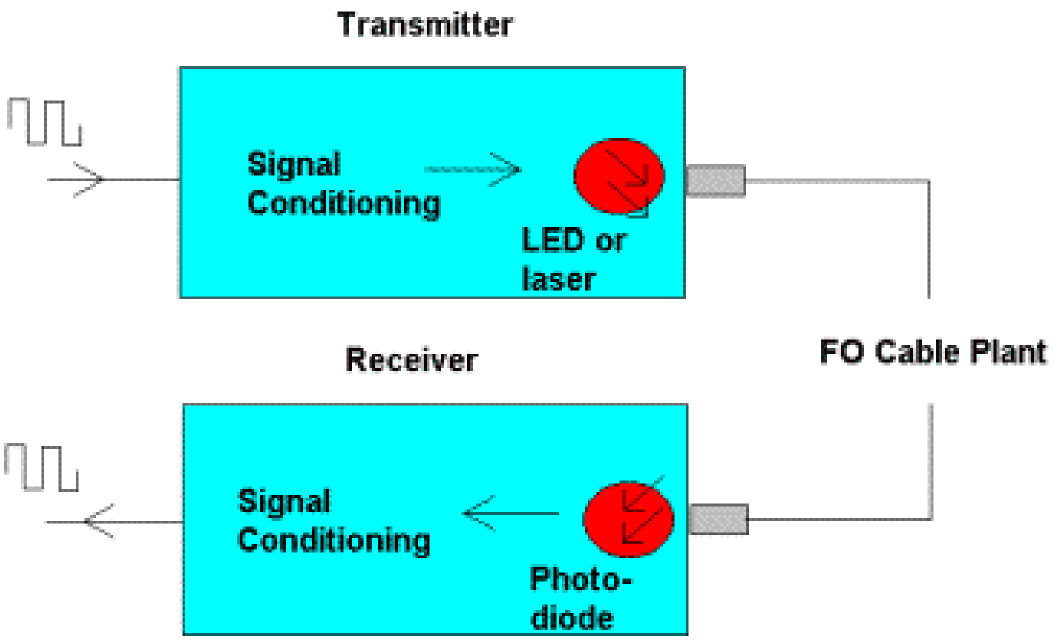
  - Single-mode fiber has a loss of 0.4 dB/km or less.

Losses


Relative Loss
500
1000
1500
Wavelength (nm)


Core
Cladding
Light Escapes

Fiber Optic Data Links



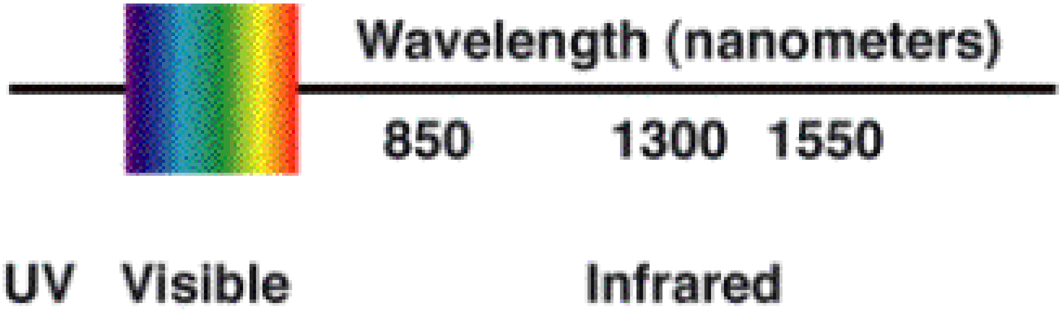
- Fiber optic transmission systems consist of a transmitter, which takes an electrical input & converts it to an optical output from a laser diode or LED.

- **Light from transmitter is coupled into fiber with a connector & is transmitted through fiber optic cable plant.**

- **Light is ultimately coupled to a receiver where a detector converts light into an electrical signal which is then conditioned properly for use by receiving equipment.**

- **Just as with copper wire or radio transmission, performance of fiber optic data link can be determined by how well the reconverted electrical signal out of receiver matches input to transmitter.**

Light Used in Fiber Optics



- **Fiber optic systems transmit information using infrared light, invisible to human eye, because it goes further in the optical fiber at those wavelengths.**

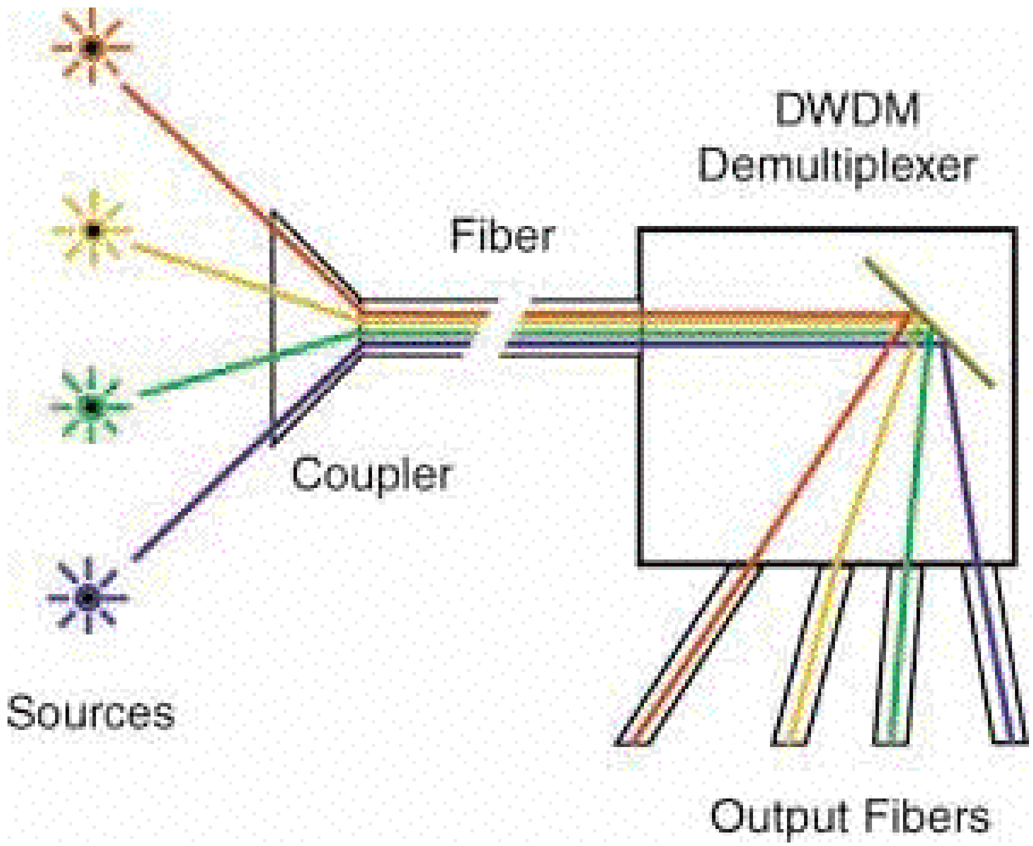
- **Ultra-pure glass used in making optical fiber has less attenuation (signal loss) at wavelengths in the infrared.**

- **Fiber is designed to have highest performance at these wavelengths.**

- **Particular wavelengths used, 850, 1300, & 1550 *nm*, correspond to wavelengths where optical light sources (lasers or LEDs) are easily manufactured.**

- **Some advanced fiber optic systems transmit light at several wavelengths at once through a single optical fiber to increase data throughput. This method is called wavelength division multiplexing.**

Wavelength Division Multiplexing



How does wavelength division multiplexing work?

- Consider the fact that one can see many different colors of light - red, green, yellow, blue, etc., all at once.
- The colors are transmitted through air together & may mix, but they can be easily separated using a simple device like a prism, just like we separate "white" light from sun into a spectrum of colors with prism.
- Input end of a WDM system is a simple coupler that combines or multiplexes all input signals into one output fiber.

How does wavelength division multiplexing work?

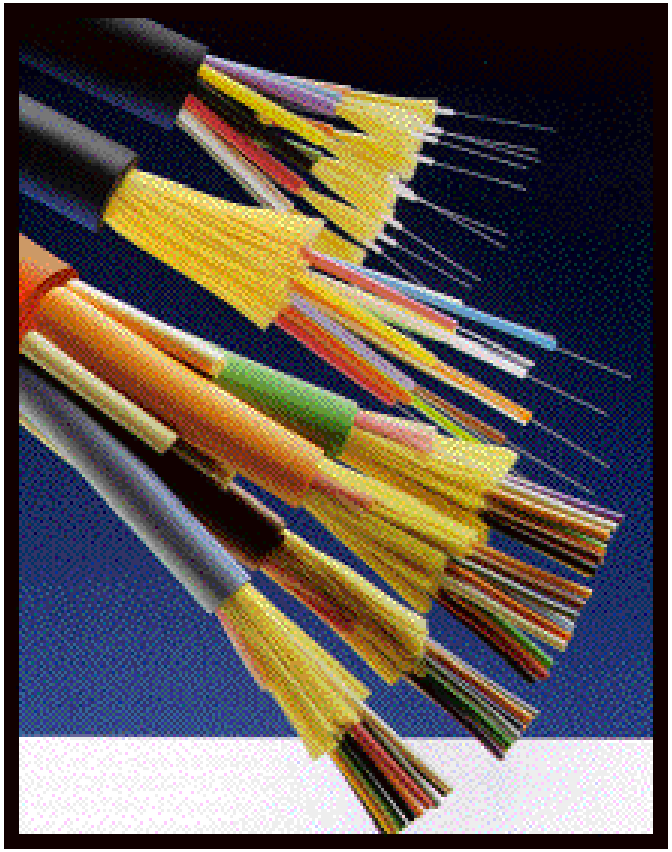
- Demultiplexer separates light at end of fiber. It shines light on a grating (a mirror like device that works like a prism & looks similar to data side of a CD), which separates light into different wavelengths by sending them off at different angles.

- Optics capture each wavelength & focuses it into another fiber, creating separate outputs for each wavelength of light.

- Current systems offer from 4 to 32 channels of wavelengths. Higher numbers of wavelengths has lead to the name Dense Wavelength Division Multiplexing.

Fiber Optic Cable

- ❖ Protects fiber wherever they are installed.
- ❖ May have 1 to over 1000 fibers.



Fiber Optic Cable

- Optical fibers are enclosed in cables for protection against the environment in which they are installed.
- Cables installed in trays in buildings require less protection than, for example, cables buried underground or placed under water.
- Cables will include strength members, typically a strong synthetic fiber called aramid fiber or Kevlar for its duPont trade name, which takes the stress of pulling the cable.
- Thin yellow fibers in the photo are the strength members.

Fiber Optic Cable

- Outside of the cable is called the jacket. It is the final protection for fibers & must withstand extremes of temperatures, moisture & stress of installation.

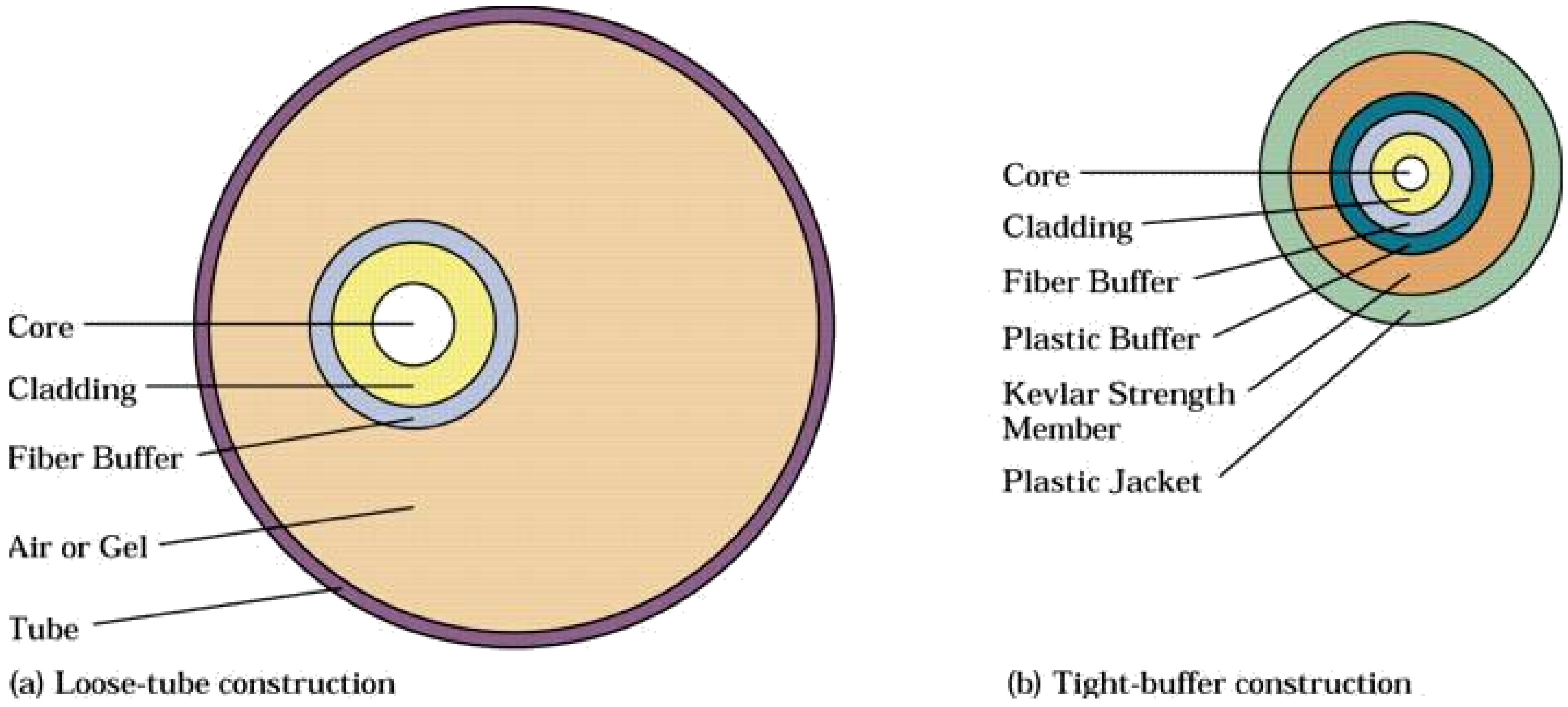
- Some cables even have a layer of thin metal under jacket to prevent rodents from chewing throughout the cable.

- Colors seen above are color-coding so one can identify individual fibers in the cable.

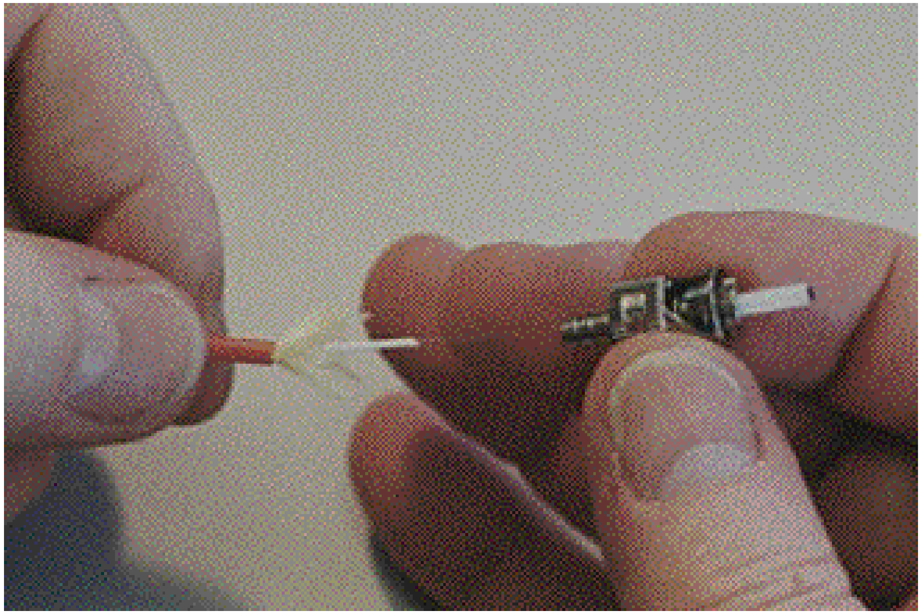
Fiber Optic Cables

- There are two basic types of fiber-optic cable: ***loose-tube*** & ***tight-buffer*** cables.
  - Difference is whether fiber is free to move inside a tube with a diameter much larger than the fiber or is inside a relatively tight-fitting jacket.
- Both methods of construction have advantages.
  - Loose-tube cables – all stress of cable pulling is taken up by cable’s strength members & fiber is free to expand & contract with temperature.
  - Tight-buffer cables are cheaper & generally easier to use.

Fiber Optic Cables



Fiber Optic Connectors



- Terminates the fibers.
- Connects to other fibers or transmission equipments.

Fiber Optic Connectors

- **When a fiber needs to be connected to another, it can be spliced permanently by welding it at high temperatures or with adhesives, or it can be terminated with a connector that makes it possible to handle the individual fiber without damage.**

- **Connectors align two fibers of size of a human hair such that little light is lost.**

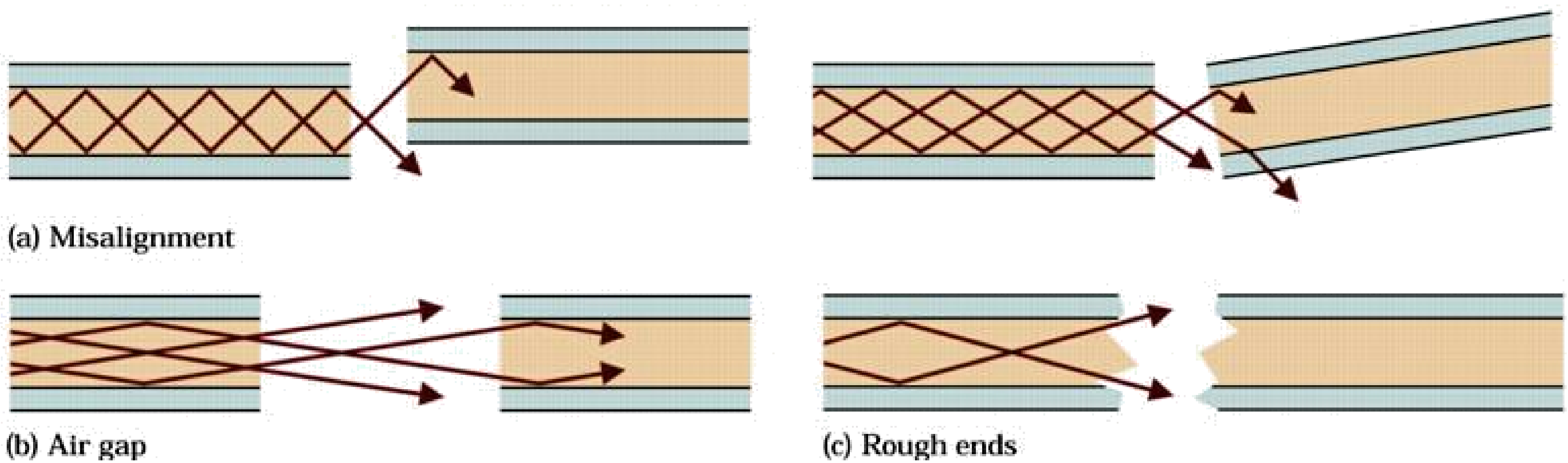
- **Most connectors use ceramic cylinders about 2.5 *mm* in diameter with precisely aligned holes in center that accept fiber.**

Fiber Optic Connectors

- Most connectors use adhesive to attach fiber & end is polished to a smooth finish.
- Putting connectors on end of fibers is a job that requires patience, skill, & good training.
- Fiber optic technicians are expected to be able to install connectors properly.

Splices & Connectors

- In fiber-optic systems, losses from splices & connections can be more than in cable itself.
- Losses result from:
  - Axial or angular misalignment
  - Air gaps between fibers
  - Rough surfaces at the ends of the fibers

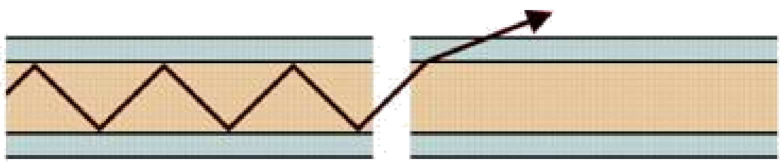


Splices & Connectors

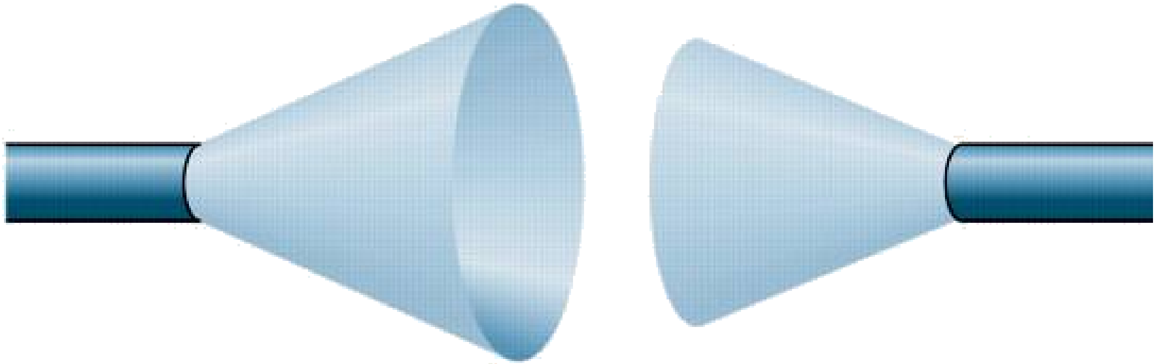
- Coupling fiber to sources & detectors creates losses as well, especially when it involves mismatches in NA or in size of optical fibers.

- Good connections are more critical with single-mode fiber, due to its smaller diameter & NA.

- A *splice* is a permanent connection & a *connector* is removable.



(a) Path of escaping ray



(b) Different cones of acceptance

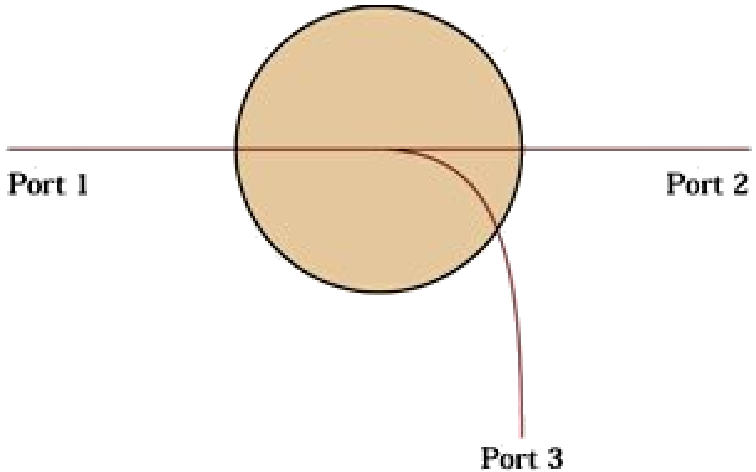
Optical Couplers & Switches

- As with coaxial cable & microwave waveguides, it is possible to build power splitters & directional couplers for fiber-optic systems.

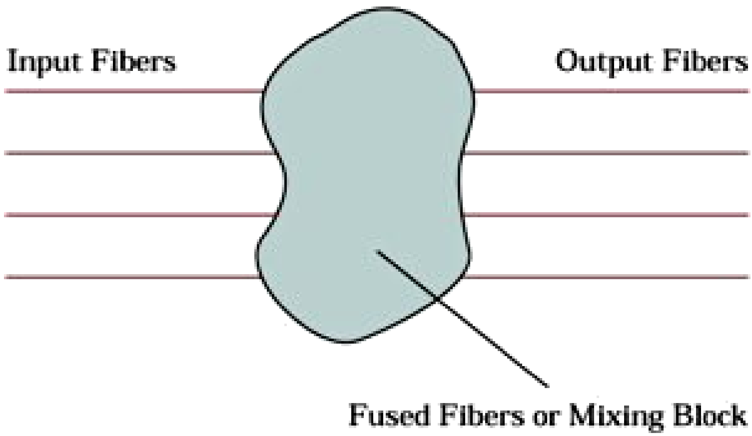
- It is more complex & expensive to do this with fiber than with copper wire.

- Optical couplers are categorized as either star couples with multiple inputs & outputs or as tees, which have one input & two outputs.

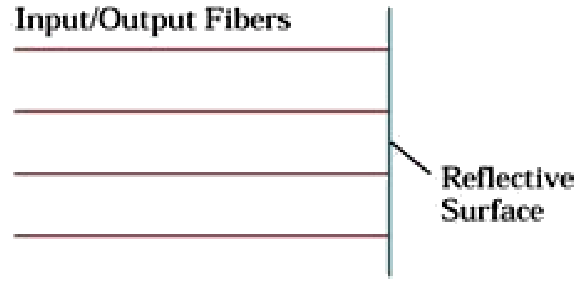
Optical Couplers & Switches



(a) Schematic representation of directional coupler



(b) Transmissive



(c) Reflective

Coupler Construction

- **Optical couplers can be made in many different ways:**
  - **A number of fibers can be fused together to make a transmissive coupler.**
  - **A reflective coupler allows a signal entering on any fiber to exit on all other fibers, so the coupler is bidirectional.**

Optical Switches & Relays

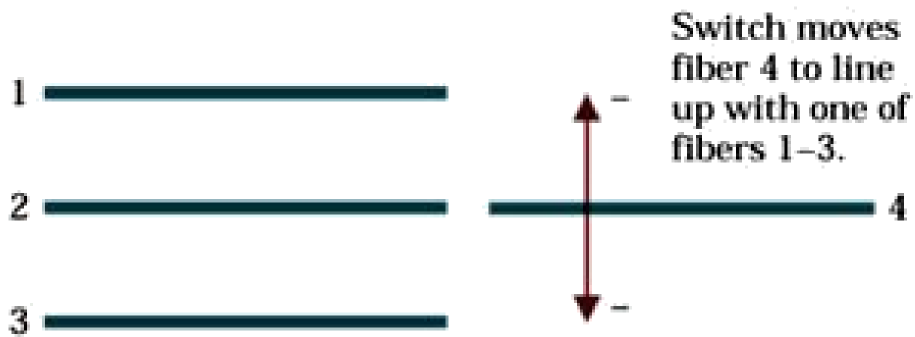
- Occasionally, it is necessary to switch optical signals from one fiber to another.

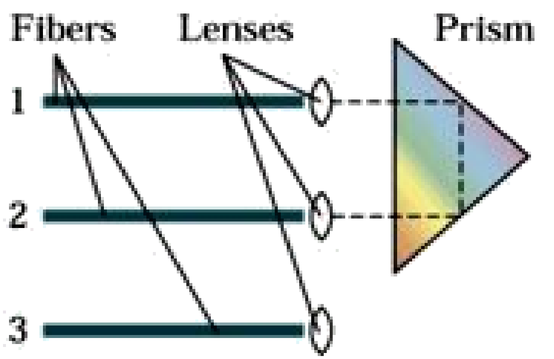
- Simplest type of optical switch moves fibers so that an input fiber can be positioned next to the appropriate output fiber.

- Another approach is to direct incoming light into a prism, which reflects it into outgoing fiber. By moving prism, light can be switched between different output fibers.

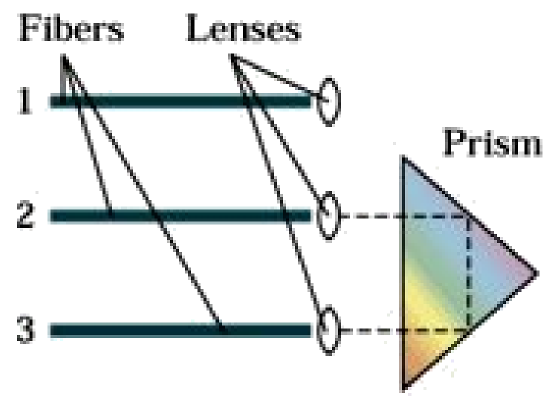
- Lenses are necessary with this approach to avoid excessive loss of light.

Optical Switches & Relays





Ports 1 and 2 connected together



Ports 2 and 3 connected together

Optical Emitters

- Optical emitters operate on the idea that electromagnetic energy can only appear in a discrete amount known as a quantum. These quanta are called photons when the energy is radiated.

- Energy in one photon varies directly with the frequency.

- Typical optical emitters include:
    - Light-Emitting Diodes
    - Laser Diodes

Jobs in Fiber Optics

- **Designing components**
- **Manufacturing fiber, lasers, etc.**
- **Designing systems**
- **Installation of cabling & networks**
- **Training & teaching**