ECE413B: WIRED COMMUNICATION

Fiber-Optics

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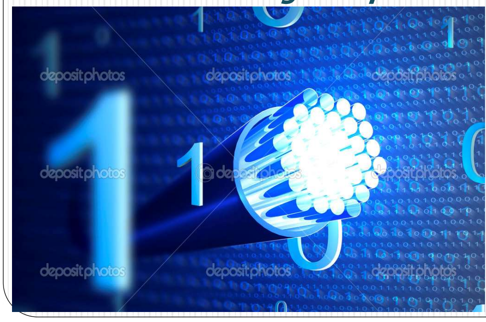

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OBJECTIVES

- Define **Optical Communication**
- Present an **overview of the history** of optical fibers and optical fiber communication
- Compare the **advantages and disadvantages** of optical fibers over metallic cables
- Define **electromagnetic frequency** and **wavelength spectrum**
- Define modes of propagation and index profile.
- Describe the three types of optical fiber configurations: single-mode step index, multimode step index and multimode graded index.

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Optical Communications

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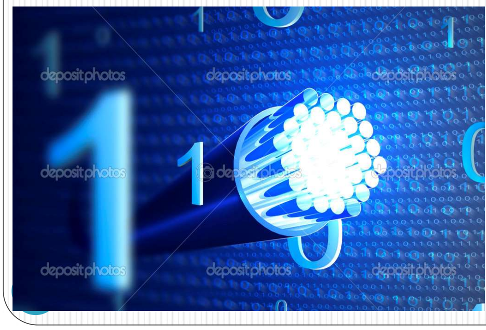

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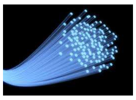
Optical Principles



- **Optical communication systems** use light to transmit information from one place to another.
- **Light** is a type of electromagnetic radiation like radio waves.
- Today**, infrared light** is being used increasingly as the carrier for information in communication systems.
- The transmission medium is either free space or a light-carrying cable called a **fiber-optic cable.**
- Because the frequency of light is extremely high, it can accommodate very high rates of data transmission with excellent reliability.

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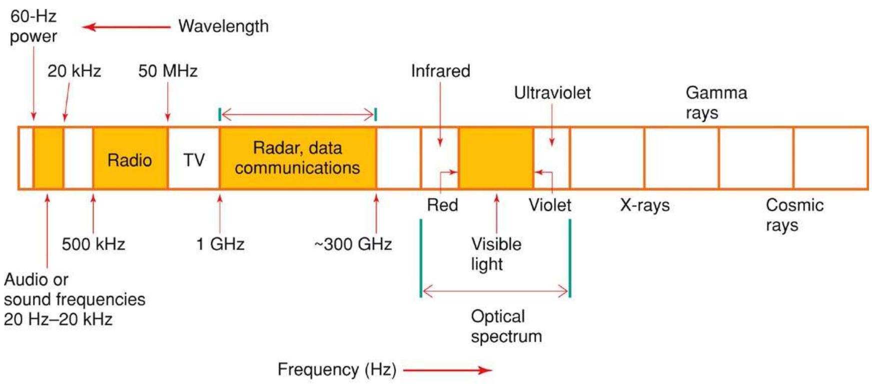
Optical Principles

Light

- Light, radio waves, and microwaves are all forms of electromagnetic radiation.
- Light frequencies fall between microwaves and x-rays.
- The **optical spectrum** is made up of infrared, visible, and ultraviolet light.

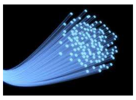
Optical Principles

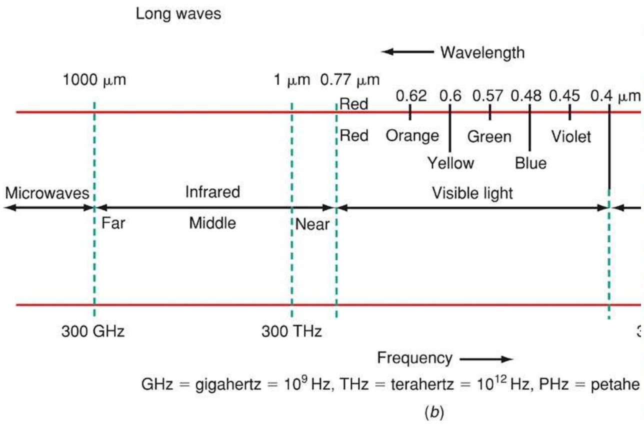


(*a*)

The optical spectrum. (a) Electromagnetic frequency spectrum showing the optical spectrum.

Optical Principles



Color	Frequency	Wavelength
violet	668–789 THz	380–450 nm
blue	606–668 THz	450–495 nm
green	526–606 THz	495–570 nm
yellow	508–526 THz	570–590 nm
orange	484–508 THz	590–620 nm
red	400–484 THz	620–750 nm

The optical spectrum. (*b*) Optical spectrum details.

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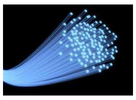
Optical Principles




Light

- Light waves are very short and are usually expressed in nanometers or micrometers.
- Visible light is in the 400- to 700-nm range.
- Another unit of measure for light wavelength is the **angstrom (Å).** One angstrom is equal to 10^{-10} m.

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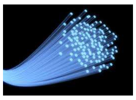
Optical Principles



Light: Speed of Light

- Light waves travel in a straight line as microwaves do.
- The **speed of light** is approximately 300,000,000 m/s, or about 186,000 mi/s, in free space (in air or a vacuum).
- The speed of light depends upon the medium through which the light passes.

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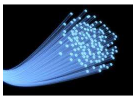
Optical Principles



Physical Optics

- **Physical optics** refers to the ways that light can be processed.
- Light can be processed or manipulated in many ways.
- Lenses are widely used to focus, enlarge, or decrease the size of light waves from some source.

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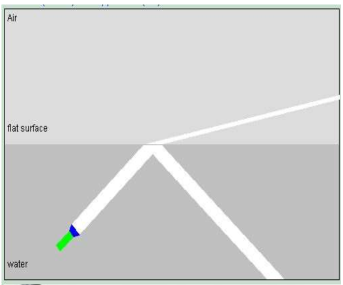
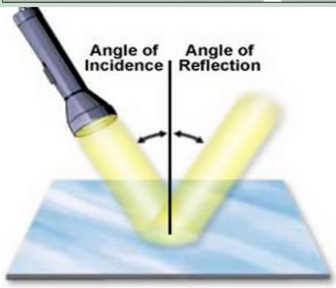
Optical Principles

Physical Optics: Reflection

- The simplest way of manipulating light is to reflect it.
- When light rays strike a reflective surface, the light waves are thrown back or reflected.
- By using mirrors, the direction of a light beam can be changed.

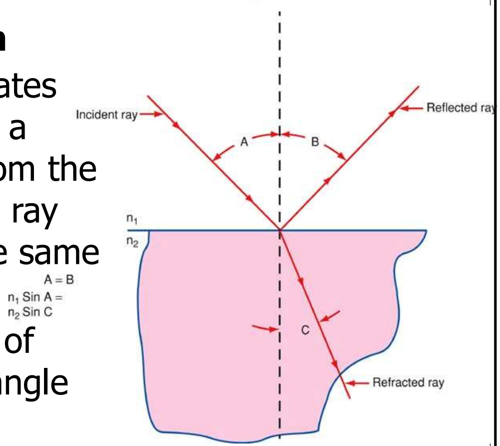




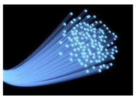
Optical Principles

Physical Optics: Reflection

- The **law of reflection** states that if the light ray strikes a mirror at some angle A from the normal, the reflected light ray will leave the mirror at the same angle B to the normal.
- In other words, the angle of incidence is equal to the angle of reflection.
- A light ray from the light source is called an **incident ray.**



Optical Principles



Physical Optics: Refraction

- The direction of the light ray can also be changed by **refraction,** which is the bending of a light ray that occurs when the light rays pass from one medium to another.
- Refraction occurs when light passes through transparent material such as air, water, and glass.
- Refraction takes place at the point where two different substances come together.
- Refraction occurs because light travels at different speeds in different materials.

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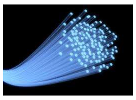
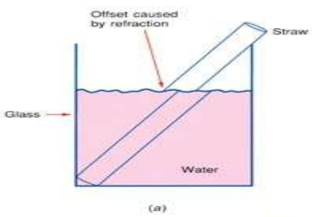
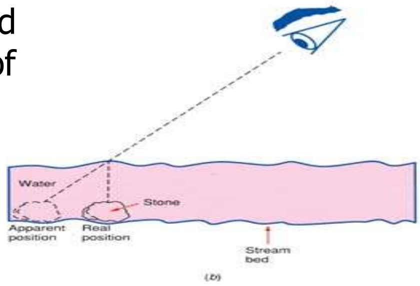
Optical Principles



Physical Optics: Refraction

- The amount of refraction of the light of a material is usually expressed in terms of the **index of refraction n.**
- This is the ratio of the speed of light in air to the speed of light in the substance.
- It is also a function of the light wavelength.





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Optical Communication System

- Optical communication systems use **light** as the carrier of the information to be transmitted.
- The medium may be free space as with radio waves or a special light "pipe" or waveguide known as fiber-optic cable.
- Using light as a transmission medium provides vastly increased bandwidths.

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Optical Communication System

Light Wave Communication in Free Space

- An optical communication system consists of:
  - A light source modulated by the signal to be transmitted.
  - A photodetector to pick up the light and convert it back into an electrical signal.
  - An amplifier.
  - A demodulator to recover the original information signal.

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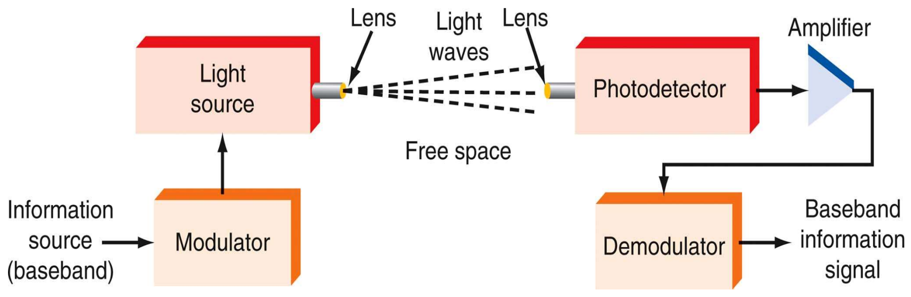
Optical Communication System



Free-space optical communication system.

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Optical Communication System

Light Wave Communication in Free Space: Light Sources

- A transmitter is a light source.
- Other common light sources are **light-emitting diodes (LEDs)** and lasers.
- These sources can follow electrical signal changes as fast as 10 GHz or more.
- Lasers generate **monochromatic,** or single-frequency, light that is fully **coherent;** that is, all the light waves are lined up in sync with one another and as a result produce a very narrow and intense light beam.

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Optical Communication System

Light Wave Communication in Free Space: Modulator

- A **modulator** is used to vary the intensity of the light beam in accordance with the modulating baseband signal.
- Amplitude modulation, also referred to as **intensity modulation,** is used where the information or intelligence signal controls the brightness of the light.
- A modulator for analog signals can be a power transistor in series with the light source and its dc power supply.

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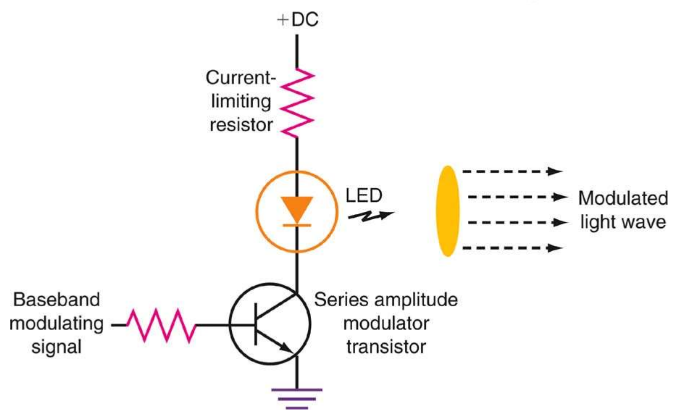
Optical Communication System



A simple light transmitter with series amplitude modulator. Analog signals: transistor varies its conduction and acts as a variable resistance. Pulse signals: Transistor acts as a saturated on/off switch.

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Optical Communication System

Light Wave Communication in Free Space: Receiver

- The modulated light wave is picked up by a **photodetector.**
- This usually a **photodiode or transistor** whose conduction is varied by the light.
- The small signal is amplified and then demodulated to recover the originally transmitted signal.
- Light beam communication has become far more practical with the invention of the laser.
- Lasers can penetrate through atmospheric obstacles, making light beam communication more reliable over long distances.

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Optical Communication System

Fiber-Optic Communication System

- Fiber-optic cables many miles long can be constructed and interconnected for the purpose of transmitting information.
- Fiber-optic cables have immense information-carrying capacity (wide bandwidth).
- Many thousands of signals can be carried on a light beam through a fiber-optic cable.

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Optical Communication System

Fiber-Optic Communication System

- At the receiving end, a light-sensitive device known as a **photocell,** or **light detector,** is used to detect the light pulses.
- The photocell converts the light pulses into an electrical signal.
- The electrical signals are amplified and reshaped back into digital form.
- They are fed to a decoder, such as a D/A converter, where the original voice or video is recovered.

Optical Communication System

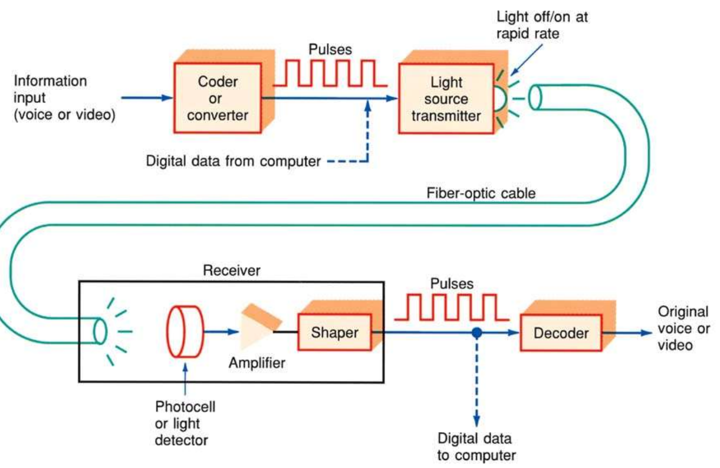

Figure 19-8: Basic elements of a fiber-optic communication system.

Optical Communication System

Applications of Fiber-Optics

- The primary use of fiber optics is in long-distance telephone systems and cable TV systems.
- Fiber-optic networks also form the core or backbone of the Internet.
- Fiber-optic communication systems are used to interconnect computers in networks within a large building, to carry control signals in airplanes and in ships, and in TV systems because of the wide bandwidth.

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Optical Communication System

Specific Applications of Fiber-Optics

- Local & long-distance telephone system
- TV studio-to-transmitter interconnection, eliminating microwave radio link.
- Closed-Circuit TV Systems used in buildings for security.
- Secure communication systems at military bases
- Computer networks, wide area and local area
- Shipboard communications
- Aircraft Communications & Controls
- Interconnection of measuring and monitoring instruments in plants and laboratories
- Data acquisition and control signal communications

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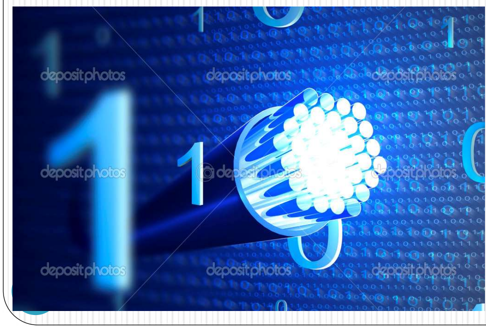
Fiber Optic Cables

OPTO-ELECTRONICS AND FIBEROPTICS



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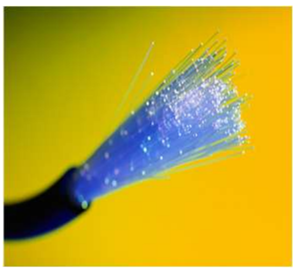
Fiber-Optic Cables

- Fiber Optics, also called optical fibers, are microscopic strands of very pure glass with about the same diameter of a human hair.
- A fiber-optic cable is thin glass or plastic cable that acts as a light "pipe."
- Fiber cables have a circular cross section with a diameter of only a fraction of an inch.
- A light source is placed at the end of the fiber, and light passes through it and exits at the other end of the cable.
- Light propagates through the fiber based upon the laws of optics.



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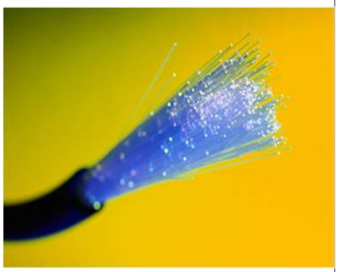
Fiber-Optic Cables

Fiber-Optic Cable Construction



- Fiber-optic cables come in a variety of sizes, shapes, and types.
- The portion of a fiber-optic cable that carries the light is made from either glass, sometimes called **silica**, or plastic.
- **Plastic fiber-optic cables** are less expensive and more flexible than glass, but the optical characteristics of glass are superior.
- The glass or plastic optical fiber is contained within an outer **cladding.**

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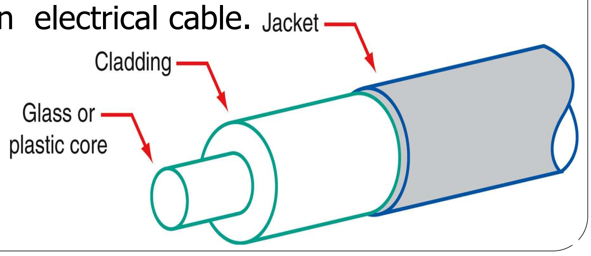
Fiber-Optic Cables

Fiber-Optic Cable Construction

- The fiber, which is called the **core,** is usually surrounded by a protective cladding.
- In addition to protecting the fiber core from nicks and scratches, the cladding gives strength.
- **Plastic-clad silica (PCS) cable** is a glass core with a plastic cladding.
- Over the cladding is usually a plastic jacket similar to the outer insulation on an electrical cable.



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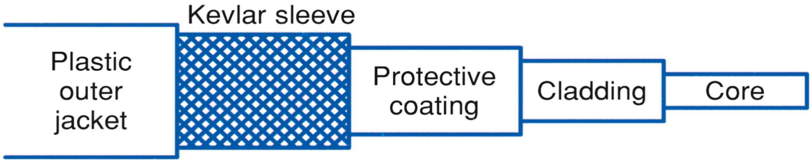

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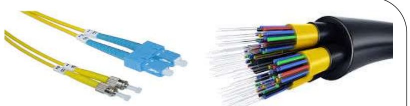
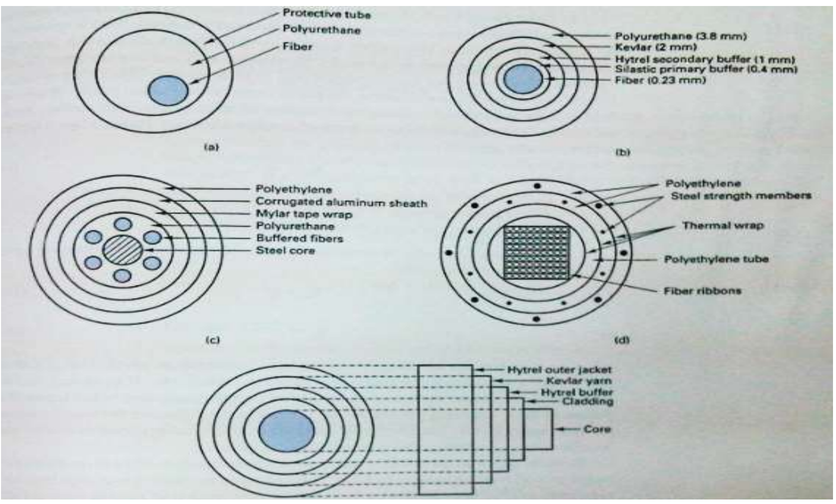
Fiber-Optic Cables





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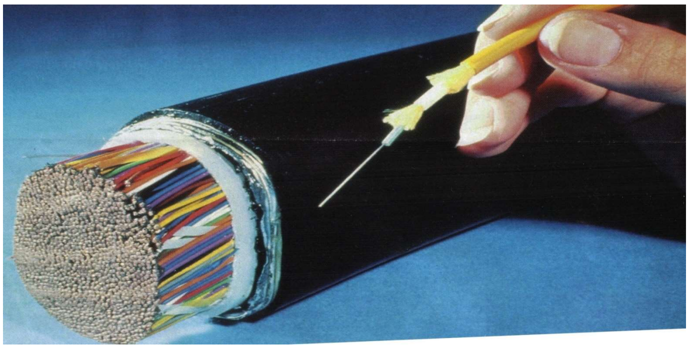
Fiber-Optic Cables

- What are the benefits of fiber-optic cables over the conventional electrical cables?
- What are the advantages and disadvantages?

Optical Fiber vs Copper



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Fiber-Optic Cables

Benefits of Fiber-Optic Cables Over Conventional Electrical Cables	
1. Wider BW	- Fiber Optic Cables have high information-carrying capability
2. Low Loss	- Fiber Optic Cables have less signal attenuation over a given distance than an equivalent length of coaxial cable
3. Lightweight	- Glass or plastic cables are much lighter than copper cables and offer benefits when low weight is critical.
4. Small Size	- Practical fiber-optic cables are much smaller in diameter than electrical cables and thus can be contained in a relatively small space.

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Fiber-Optic Cables

Benefits of Fiber-Optic Cables Over Conventional Electrical Cables	
5. Security	- Fiber Optic Cables cannot be easily "tapped" as electrical cables and they do not radiate signals that can be picked up for eavesdropping purposes.
6. Interference Immunity	- Fiber Optic Cables do not radiate signals and cause interference to other cables. They are immune to the picking up of interference from other sources.
7. Greater Safety	- Fiber Optic Cables do not carry electricity. Therefore, there is no shock hazard. - They are also insulators & thus not susceptible to lightning strikes - They can be used in corrosive and explosive environments w/o danger of sparks

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Fiber-Optic Cables

Advantages & Disadvantages of Fiber-optic Cables over Conventional Electrical Cables

ADVANTAGES	DISADVANTAGES
1. Wider BW & greater information capacity	1. Interfacing Cost
2. Immunity to crosstalk	2. Strength
3. Immunity to static interference	3. Remote Electrical Power
4. Environmental Immunity	4. More susceptible to losses introduced by bending the cable
5. Safety and Convenience	5. Specialized tools, equipment and training
6. Lower Transmission Loss	
7. Security	
8. Durability & Reliability	

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Origins of Fiber Optic Communication

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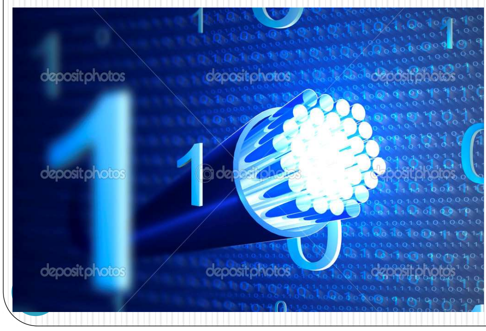

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HISTORY: Early Optical Communications

- The French used **semaphores** to transmit messages in the **1790s**
- Later systems also **sent optical signals through the air**
  - But clouds, rain, and other atmospheric disturbances can disrupt optical signals sent through the air
  - Electric signals through wires avoid that problem

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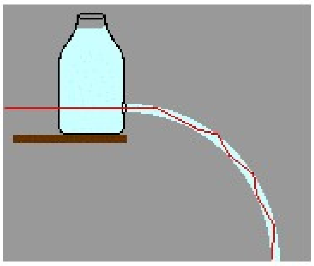
HISTORY: Guiding Light w/ Water

- Light in a stream of water stays inside the water and bends with it
- This was first demonstrated in the 1840s



The laser beam stays internal to the water, continuously reflecting at each boundary.

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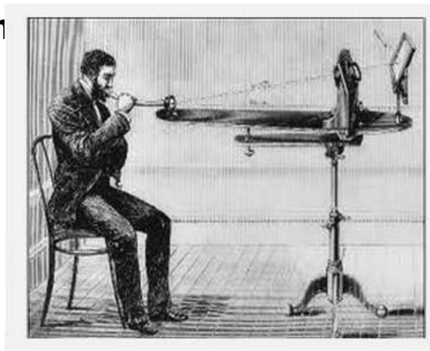
HISTORY: Photophone

- In 1880, **Alexander Graham Bell** with an apparatus called a **photophone.**
- The device was constructed from **mirrors and selenium detectors** that transmitted sound waves over a beam of light.
- Bell's unusual piece of equipment was the first attempt of using a beam of light for carrying information.



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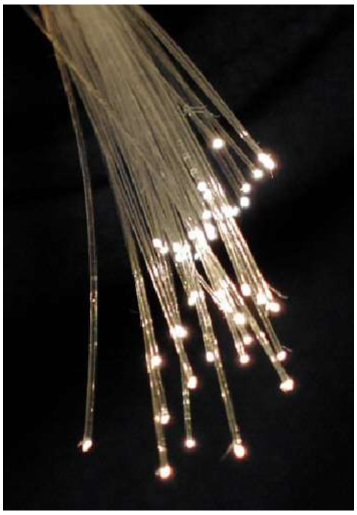
HISTORY: Bare Fiber

- During 1920-1950, **thin, flexible rods of glass** or **plastic** were used to guide light



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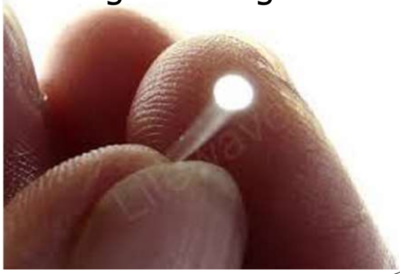
HISTORY: Bare Fiber

- In 1930, **J.L Baird**, an English Scientist and **C.W. Hansell**, a scientist from the United States, were granted patent for scanning and transmitting television images through uncoated fiber cables.

- A few years later, a German Scientist named **H. Lamm** successfully transmitted images through a single glass fiber.



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HISTORY: Fiber Optic

- In 1951, **van Heel** (of Holland)**, Hopkins & Kapany** (of England) experimented with light transmission through bundles of fibers.
- Their studies led to development of the **flexible fiberscope**, w/c is used extensively in the medical field.
- The term "**Fiber Optics**" in 1956 was coined by Kapany.

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HISTORY: LASER

- In 1958, **Charles H. Townes,** an American and **Arthur L. Schawlow**, a Canadian, wrote a paper describing how it was possible to use stimulated emission for amplifying light waves (laser) as well as microwaves (maser).
- Two years later, **Theodore H. Maiman**, a scientist with Hughes Aircraft Company, built the first optical maser.
- The laser **(Light Amplification by Stimulated Emission of Radiation)** was invented in 1960.

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HISTORY: Cladded Fibers

- By **1960**, **glass-clad fibers** were available for medical instruments, to look inside the body
- The glass was unable to transmit light far enough for communications, because of impurities
  - Attenuation (loss of light) was **1 decibel per meter**

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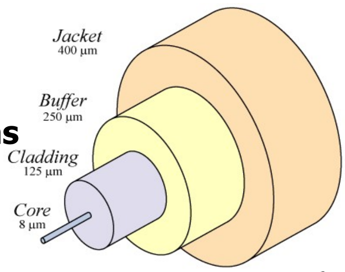
HISTORY: Optical Fiber (1967)

- **Charles Kao and Bockham** of the Standard Telecommunications Laboratory in England proposed a new communication medium using **cladded fiber cables.**
- They developed a fiber that could transmit **1 GHz** (One billion bits per second)
- But attenuation was **1000 dB/km**, so it could not transmit light far enough for practical communications.
- It has **limited optical transmissions** to short distance.



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HISTORY: Corning

- In 1970, **Kapron, Keck and Maure**r of Corning Glass Works in Corning, New York
- They developed an optical fiber w/losses less than **2dB/km**.
- Corning scientists developed **low-attenuation silica glass** fibers in 1970.
- That was the big breakthrough needed to permit **practical fiber optics communication systems.**
- Recently, Bell Laboratories successfully transmitted **1 billion bps through a fiber cable for 600 miles w/o regenerator**.

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HISTORY: Optical Fiber (1977)

- Telephone signals used **infrared light** with a wavelength of **850 nm to send data at 6.2 Mbps and 45 Mbps**
- Loss was **2 dB per km**
- Repeaters were required every few kilometers
  - The **repeaters were electro-optical** – converting the light to electricity and then back to light

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HISTORY:

- In the late **1970s and early 1980s**, the refinement of optical cables and the development of high-quality, affordable light sources & detectors opened the door to the development of **high-quality, high-capacity, efficient and affordable optical fiber communications systems.**

- In the **late 1980s**, losses in optical fibers were reduced to as low as **0.16 dB/km**

- In **1988**, NEC Corporation set a new long-haul transmission record by transmitting **10 Gigabytes per sec. over 80.1 km** of optical fiber.

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HISTORY: Transatlantic Cable

- In **1988** AT&T laid the first **fiber-optic transatlantic telephony cable**
- 3,148 miles long
- Connected North America to France
- Repeaters every 40 miles
- 565 Mbps bandwidth
- Used 1300 nm light
- Attenuation 0.4 dB/km

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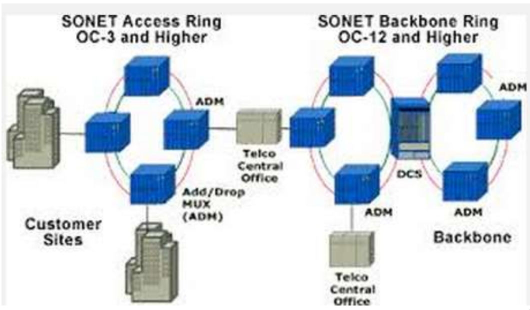
HISTORY:

- Also in 1988, **the American National Standards Institute (ANSI)** published the Synchronous Optical Network **(SONET)**
- By the **mid-1990s**, optical voice and data networks were common place throughout the US and much of the world.



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Types of Fiber Optic Cables

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Fiber-Optic Cables: Classification

- **Two Ways of Classifying Fiber-optic Cables.**

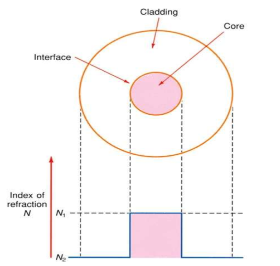
1. **Index of Refraction**
   - ➢ Varies across the cross section of the cable.

2. **Mode**
   - ➢ refers to the various paths the light rays can take in passing through the fiber.

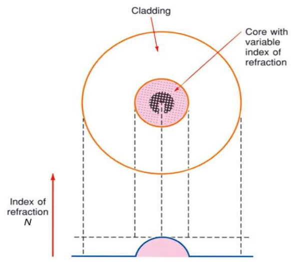
Fiber-Optic Cables: Classification

- **Two Ways to Define the Index of Refraction Variation Across a Cable**

1. **Step index**
   - ➢ refers to the fact that there is a sharply defined step in the index of refraction where the fiber core and cladding interface.



2. **Graded index cable**
   - ➢ the index of refraction of the core is not constant. It varies smoothly and continuously over the diameter of the core.



Fiber-Optic Cables: Mode

- **Mode**
  - refers to the number of paths for light rays in the cable.
- **Two Classifications:**

1. **Single Mode**
   - the light follows a single path through the core
2. **Multimode**
   - the light takes many paths

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Types of Fiber-Optic Cables

- **Types of Fiber-Optic Cables**
- In practice, there are **<u>three commonly used types</u>** of fiber-optic cable:

1. Multimode step index
2. Single-mode step index
3. Multimode graded index

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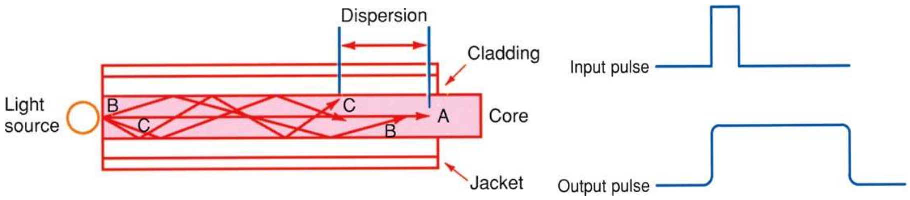
Types of Fiber-Optic Cables

1. Multimode Step Index Cable

- The multimode step index fiber cable is probably the **most common and widely used type**.
- It is the **easiest to make** and therefore the **least expensive.**



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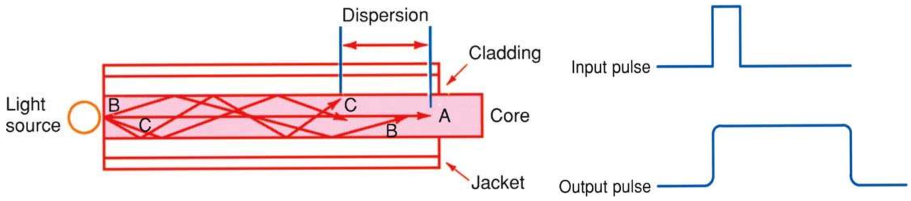
Types of Fiber-Optic Cables

1. Multimode Step Index Cable

- It is widely used for **short to medium distances** at relatively low pulse frequencies.
- The main advantage of a multimode stepped index fiber is its **large size.**
- Typical core diameters are in **50 to 1000μm** range



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Types of Fiber-Optic Cables

1. Multimode Step Index Cable

ADVANTAGES

- **Inexpensive** and **simple to manufacture.**
- **Easier to couple light** into and out of multimode step-index fibers because they have relatively large source-to-fiber aperture.

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Types of Fiber-Optic Cables

1. Multimode Step Index Cable

DISADVANTAGES

- Light rays take many different paths down the fiber, w/c results in large differences in propagation times.
- Light rays travelling this type of fiber is **spreading out** therefore, it is **distorted more** than with other types of fibers.
- **Bandwidth** and **information transfer rates** are **less** compared with other types of cables.

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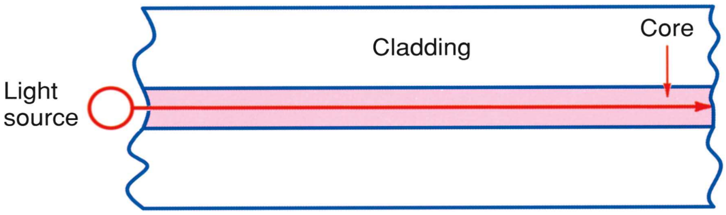
Types of Fiber-Optic Cables

2. Single Mode Step Index Cable

- A **single-mode or monomode step index fiber cable** eliminates modal dispersion by making the core so small that the total number of modes or paths through the core is minimized.
- Typical core sizes are **2 to 15 μm**.



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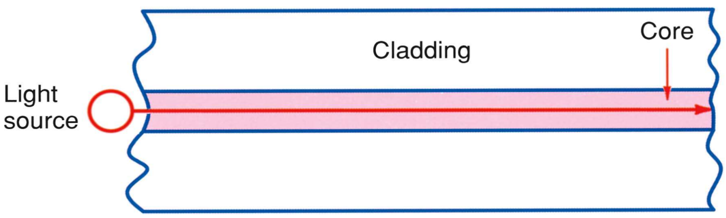
Types of Fiber-Optic Cables

2. Single Mode Step Index Cable

- The **pulse repetition rate can be high** and the **maximum amount of information** can be carried in this type cable.
- They are preferred for **long-distance transmission and maximum information content.**



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Types of Fiber-Optic Cables

2. Singlemode Step Index Cable

ADVANTAGES

- **Minimum dispersion:** light rays propagating down the fiber take the same path and approximately the same length of time. Pulse of light entering the cable can be reproduced at the receiving end very accurately.
- **Wider BW &higher information transmission rates** (bps) are possible compared with other types of fibers.

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Types of Fiber-Optic Cables

2. Singlemode Step Index Cable

DISADVANTAGES

- **Difficult to couple** light into and out of the cable due to the central core is very small.
- The source-to-fiber aperture is **the smallest** of all the fiber types
- An **expensive, super-intense and highly directive light** source (such as LASER) is required to couple light into the fiber.

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Types of Fiber-Optic Cables

2. Singlemode Step Index Cable

DISADVANTAGES
• **Expensive and difficult** to manufacture • It is also more **difficult to handle.** • Splicing and making interconnections are more difficult.

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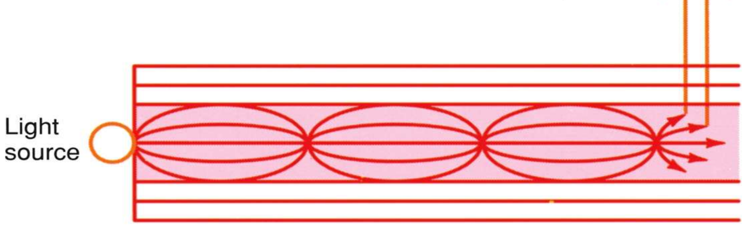
Types of Fiber-Optic Cables

3. Multimode Graded Index Cable

- Multimode graded index fiber cables have several modes, or paths, of transmission through the cable, but they are much **more orderly and predictable**.
- These cables can be used at **very high pulse rates** and a considerable amount of information can be carried.



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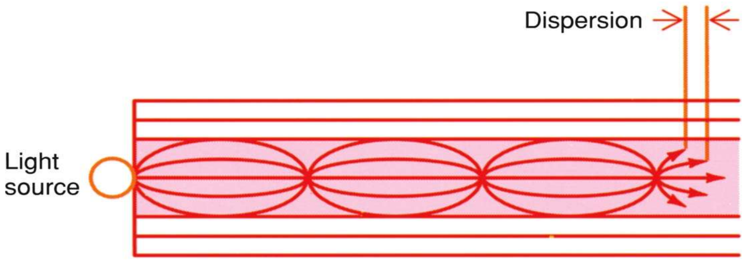
Types of Fiber-Optic Cables

3. Multimode Graded Index Cable

- This type of cable is much **wider in diameter**, with core sizes in the **50- to 100-µm range.**
- It is easier to splice and interconnect, and cheaper, less intense light sources can be used.



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Types of Fiber-Optic Cables

3. Multimode Graded Index Cable

ADVANTAGES/DISADVANTAGES
• There are **no outstanding** advantages or disadvantages of this type of fiber.
• They are easier to couple light into and out of the fiber than single mode step-index fibers but are more difficult than multimode step-index fibers.
• Distortion due to multiple propagation paths is greater than in single mode step-index fibers but less than in multimode step-index fibers.
• It is an intermediate fiber compared to other fiber types.

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Fiber-Optic Cable Specification

The most important **specifications of a fiber-optic cable** are:

- **Size**
- **Attenuation**
- **Bandwidth**

Fiber-Optic Cable Specification

CABLE SIZE

- Fiber-optic cable comes in a **variety of sizes and configurations.**
- Size is normally specified as the **diameter of the core,** and **cladding** is given in micrometers (μm).
- Cables come in two common varieties, **simplex and duplex.**
- Simplex cable is a **single-fiber core** cable.
- In a common duplex cable, **two cables** are combined within a single outer cladding.

Fiber-Optic Cable Specification

ATTENUATION

- Attenuation refers to the **loss of light energy** as the light pulse travels from one end of the cable to the other.
- Absorption refers to how light energy is **converted to heat** in the core material because of the **impurity** of the glass or plastic.
- Scattering refers to the **light lost due to light waves** entering at the wrong angle and being lost in the cladding because of refraction.
- Dispersion refers to the **pulse stretching** caused by many different paths through the cable.

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Fiber-Optic Cable Specification

BANDWIDTH

- The bandwidth of a fiber-optic cable determines the **maximum speed of the data pulses** the cable can handle.
- The bandwidth is normally stated in terms of **megahertz-kilometers** (MHz-km).
- A common 62.5/125-μm cable has a bandwidth in the 100- to 300-MHz·km range.
- As the length of the cable is increased, the bandwidth decreases in proportion.

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Fiber-Optic Cable Specification

FREQUENCY RANGE

- Most fiber-optic cable operates over a relatively wide light frequency range, although it is normally optimized for a narrow range of light frequencies.
- The most commonly used light frequencies are 850, 1310, and 1550 nm.

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Connectors and Splicing

- Fibers must be **joined** when you need more length than you can get on a single roll
- Connecting distribution cable to backbone
- Connecting to electronic source and transmitter
- Repairing a broken cable
- When long fiber-optic cables are needed, two or more cables can be spliced together.
- A variety of connectors are available that provide a convenient way to splice cables and attach them to transmitters, receivers, and repeaters.

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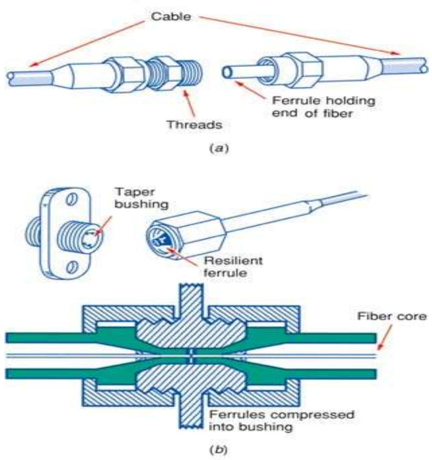
Connectors vs. Splicing

- A permanent join is a **splice**
- **Connectors** are used at patch panels, and can be disconnected

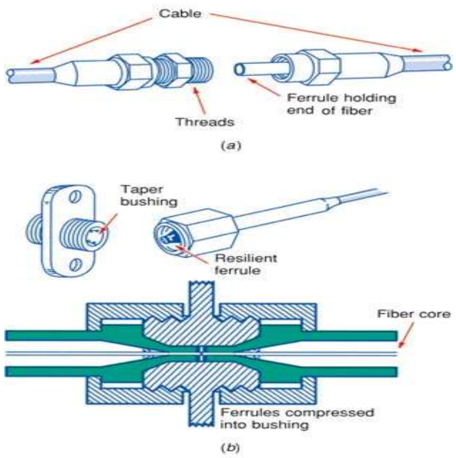
Connectors

- Connectors are special mechanical assemblies that allow fiber-optic cables to be connected to one another.
- Most fiber-optic connectors are either **snap or twist** together or **screw** together with threaded ends.
- Connectors ensure **precise alignment** of the cables to ensure maximum light transfer between cables.



Connectors

- Fiber optic connectors are unique.
- Fiber cables transmit pulses of light instead of electrical signals, so the terminations must be much more precise.
- Instead of merely allowing pins to make metal-to-metal contact, fiber optic connectors must align microscopic glass fibers perfectly in order to allow for communication.



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Connectors

- **Simplex vs. Duplex:**

- Simplex means 1 connector per end
- Duplex means 2 connectors per end.

- **Three Major Components of a Fiber Connector:**
  1. the ferrule,
  2. the connector body, and
  3. the coupling mechanism.

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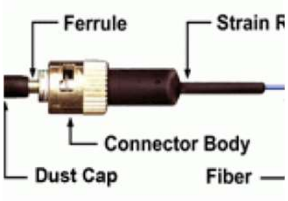
Connectors

- **Three Major Components**

1. **Ferrule**
   - this is a thin structure (often cylindrical) that actually holds the glass fiber.
   - It has a hollowed-out center that forms a tight grip on the fiber.
   - Ferrules are usually made from ceramic, metal, or high-quality plastic, and typically will hold one strand of fiber.



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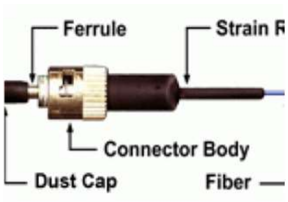
Connectors

- **Three Major Components**

2. **Connector body**
   - this is a plastic or metal structure that holds the ferrule and attaches to the jacket and strengthens members of the fiber cable itself.



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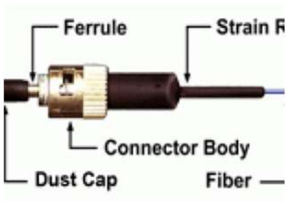
Connectors

- **Three Major Components**

3. **Coupling mechanism**
   - this is a part of the connector body that holds the connector in place when it gets attached to another device (a switch, bulkhead coupler, etc.).
   - It may be a latch clip, a bayonet-style nut, or similar device.



Connectors and Splicing

SPLICING

- Splicing fiber-optic cable **means permanently attaching** the end of one cable to another.
- This is usually done **without a connector**.
- The first step is to cut the cable, called **cleaving** the cable, so that it is perfectly square on the end.
- The two cables to be spliced are then permanently bonded together by heating them instantaneously to high temperatures so that they fuse or melt together.
- Special tools and machines must be used in cleaving and splicing to ensure clean cuts and perfect alignment.

Connectors and Splicing

SPLICES

- Splices are a permanent join of two fibers
- Lower attenuation and reflectance than connectors
- Stronger and cheaper than connectors
- Easier to perform than connectorization
- Mass splicing does 12 fibers at a time, for ribbon cables

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Connectors and Splicing

FUSION SPLICING

- Melts the fibers together to form a continuous fiber
- Expensive machine
- Strongest and best join for singlemode fiber
- May lower bandwidth of multimode fiber

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Connectors and Splicing

MECHANICAL SPLICING

- Mechanically aligns fibers
- Contains index-matching gel to transmit light
- Equipment cost is low
- Per-splice cost is high
- Quality of splice varies, but better than connectors
- Fiber alignment can be tuned using a Visual Fault Locator

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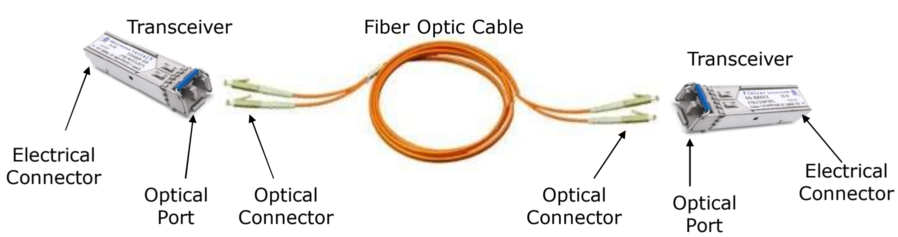
Connectors and Splicing

Newer technologies involving higher datarates, smaller form factors, higher port densities, pluggability, and parallel links are showing an increased need to focus on connectivity and interoperability issues



A failure anywhere along this link will cause the entire link to fail

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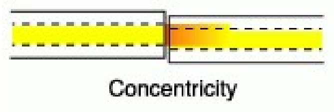
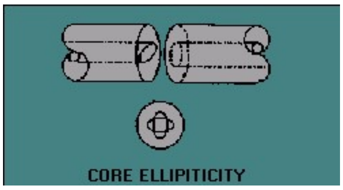
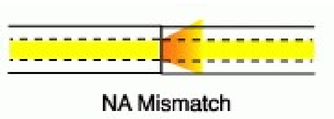
Optical Loss

- **Intrinsic Loss**
  - Problems the splicer cannot fix
    - Core diameter mismatch
    - Concentricity of fiber core or connector ferrules
    - Core ellipticity
    - Numerical Aperture mismatch







Optical Loss

- **Extrinsic Loss**
  - Problems the person doing the splicing can avoid
    - Misalignment
    - Bad cleaves
    - Air gaps
    - Contamination: Dirt, dust, oil, etc.
    - Reflectance