EC8751
OPTICAL COMMUNICATION

UNIT 1
INTRODUCTION TO OPTICAL FIBERS

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EC8751 OPTICAL COMMUNICATION

OBJECTIVES:

 To study about the various optical fiber modes, configuration and transmission characteristics of optical fibers

 To learn about the various optical sources, detectors and transmission techniques

 To explore various idea about optical fiber measurements and various coupling techniques

 To enrich the knowledge about optical communication systems and networks

UNIT I INTRODUCTION TO OPTICAL FIBERS

Introduction-general optical fiber communication system- basic optical laws and definitionsoptical modes and configurations -mode analysis for optical propagation through fibersmodes in planar wave guide-modes in cylindrical optical fiber-transverse electric and transverse magnetic modes- fiber materials-fiber fabrication techniques-fiber optic cablesclassification of optical fiber-single mode fiber-graded index fiber.

UNIT II TRANSMISSION CHARACTERISTIC OF OPTICAL FIBER

Attenuation-absorption –scattering losses-bending losses-core and cladding losses-signal dispersion –inter symbol interference and bandwidth-intra model dispersion-material dispersion- waveguide dispersion-polarization mode dispersion-intermodal dispersiondispersion optimization of single mode fiber-characteristics of single mode fiber-R-I Profilecutoff wave length-dispersion calculation-mode field diameter.

UNIT III OPTICAL SOURCES AND DETECTORS

Sources: Intrinsic and extrinsic material-direct and indirect band gaps-LED-LED structuressurface emitting LED-Edge emitting LED-quantum efficiency and LED power-light source materials-modulation of LED-LASER diodes-modes and threshold conditions-Rate equations-external quantum efficiency-resonant frequencies-structures and radiation patterns-single mode laser-external modulation-temperature effort.Detectors: PIN photo detector-Avalanche photo diodes-Photo detector noise-noise sources-SNR-detector response time-Avalanche multiplication noise-temperature effectscomparisons of photo detectors.

UNIT IV OPTICAL RECEIVER, MEASUREMENTS AND COUPLING

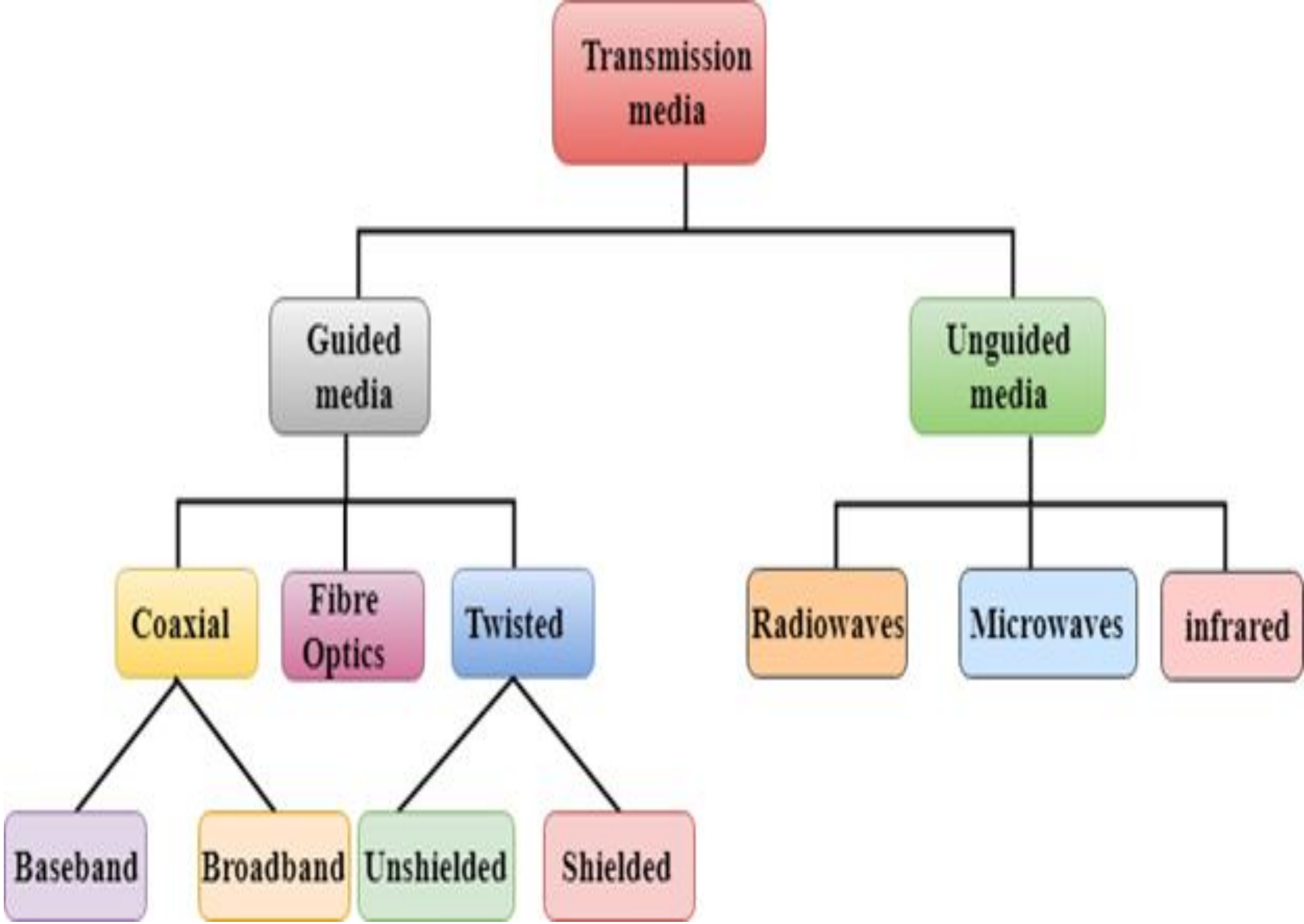
Fundamental receiver operation-preamplifiers-digital signal transmission-error sources-Front end amplifiers-digital receiver performance-probability of error-receiver sensitivity-quantum limit.Optical power measurement-attenuation measurement-dispersion measurement- Fiber Numerical Aperture Measurements- Fiber cut- off Wave length Measurements- Fiber diameter measurements-Source to Fiber Power Launching-Lensing Schemes for Coupling Management-Fiber to Fiber Joints-LED Coupling to Single Mode Fibers-Fiber Splicing□Optical Fiber connectors.

UNIT V OPTICAL COMMUNICATION SYSTEMS AND NETWORKS

System design consideration Point – to –Point link design –Link power budget –rise time budget, WDM –Passive DWDM Components-Elements of optical networks-SONET/SDH□Optical Interfaces-SONET/SDH Rings and Networks-High speed light wave Links-OADM configuration-Optical ETHERNET-Soliton.

Wired network

Wireless network

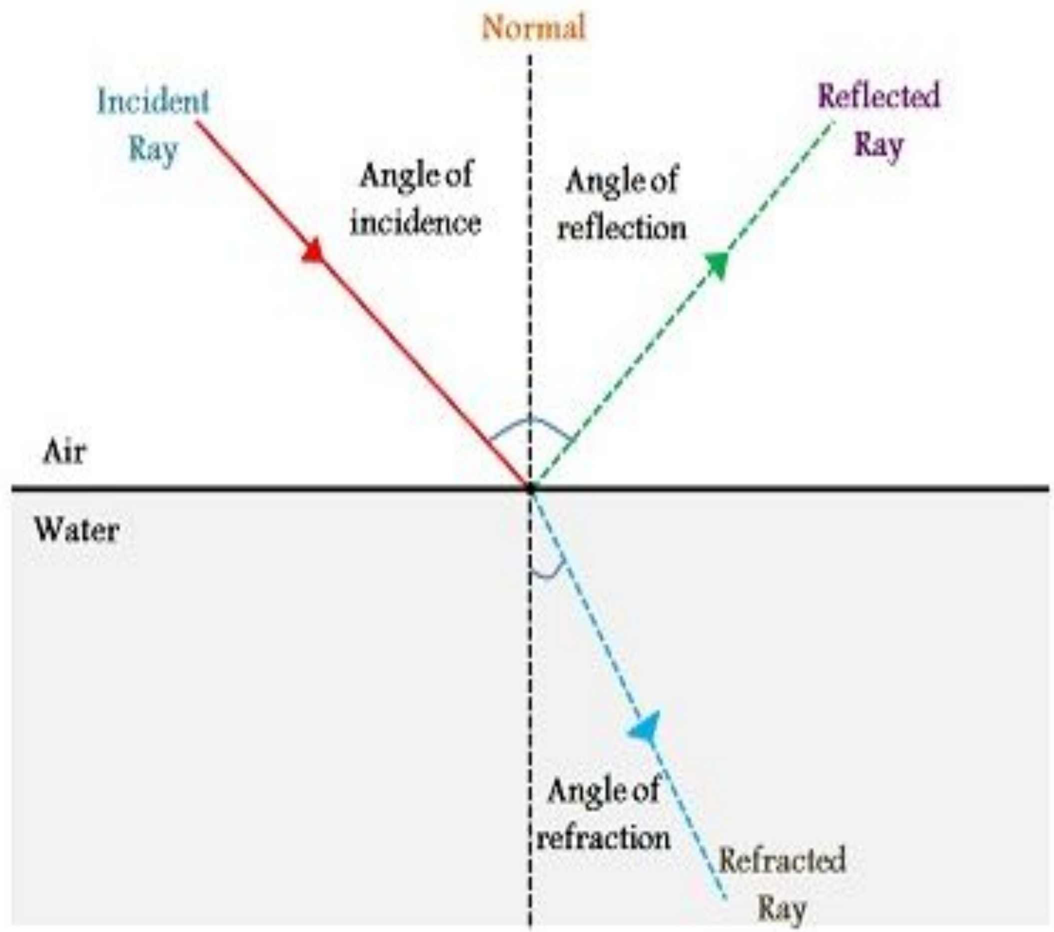

Transmission media
Guided media
Unguided media
Coaxial
Fibre Optics
Twisted
Radiowaves
Microwaves
infrared
Baseband
Broadband
Unshielded
Shielded

Types of Transmission media

- The computers and other electronic devices transmit the data from one to another device in the form of signals and using a transmission media. The transmission media can be fundamentally categorised into two types **guided** and **Unguided media**
- **Unguided media** is a wireless communication which carries electromagnetic waves by making use of air as a medium and also in the vacuum
- **Guided media** need a physical medium to transmit signals such as wires. Guided media is classified in three ways twisted pair cable, coaxial cable and fibre-optic cable. guided.

Optical Communication

- Optical Communication is transmitting information in form of light .
- The information is transmitted from one place to another by sending pulses of infrared light through an optical fiber
- The data to be transmitted which is in the form of 0’s and 1’s are converted to beams of light
- http://gccu.generalcable.com/AnatomyFOPT2web/anatomyfo_pt2_lms_general_cable_fiber_optics_anatomypt2__p004.htm



The two phenomena based on straight light propagation are reflection and refraction, wherein the reflection deals with the bouncing of light rays whereas the refraction talks about bending of light rays.

Refractive Index

- This is a measure of how much light slows down when it goes into a new medium.
- Symbol n
- n (vacuum) = 1

index of refraction

velocity of light in vacuum

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

velocity of light in the medium

$$n\ (\text{medium}) = \frac{c\ (\text{speed of light in vacuum})}{v\ (\text{speed of light in medium})}$$

Problems

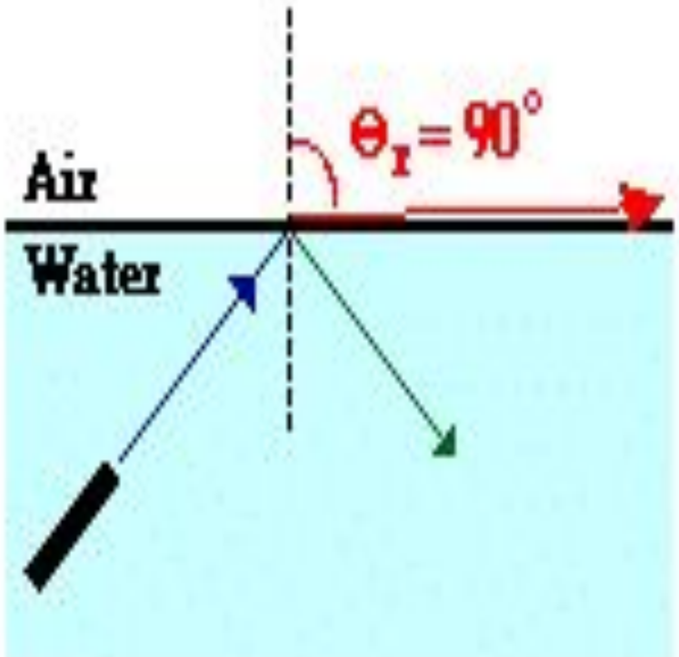
- What is the index of refraction in a medium where the speed of light is 1.5×10^8 m/s?
- What is the speed of light in water whose refractive index is 1.33?

Rarer and denser medium

- A medium in which speed of light is more is known as optically rarer medium
- A medium in which speed of light is less is said to be optically denser medium.
- For example in air and water, air is rarer and water is a denser medium.
- n=1.00 for air , n=1.33 for water,1.45 for silicaglass,2.45 for diamond.

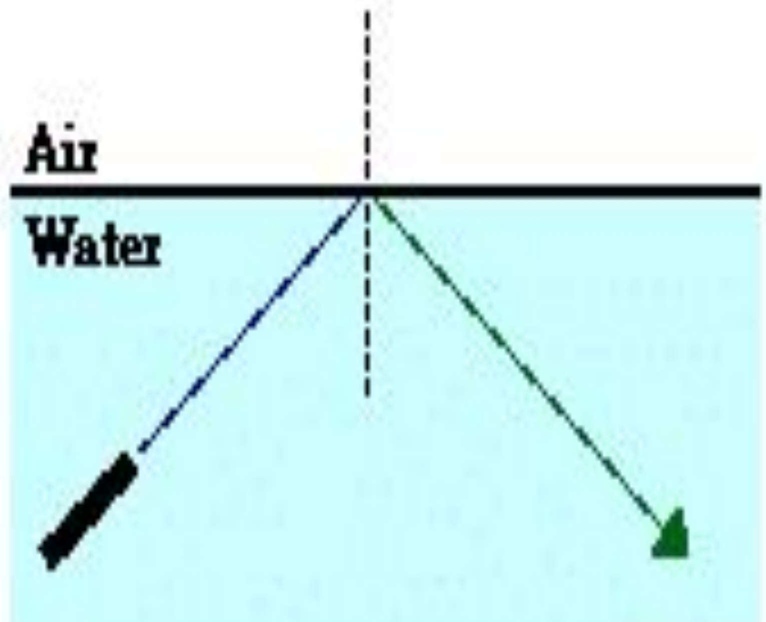
Critical Angle and TIR

Reflection and Refraction



When the angle of incidence equal the critical angle, the angle of refraction is 90-degrees.

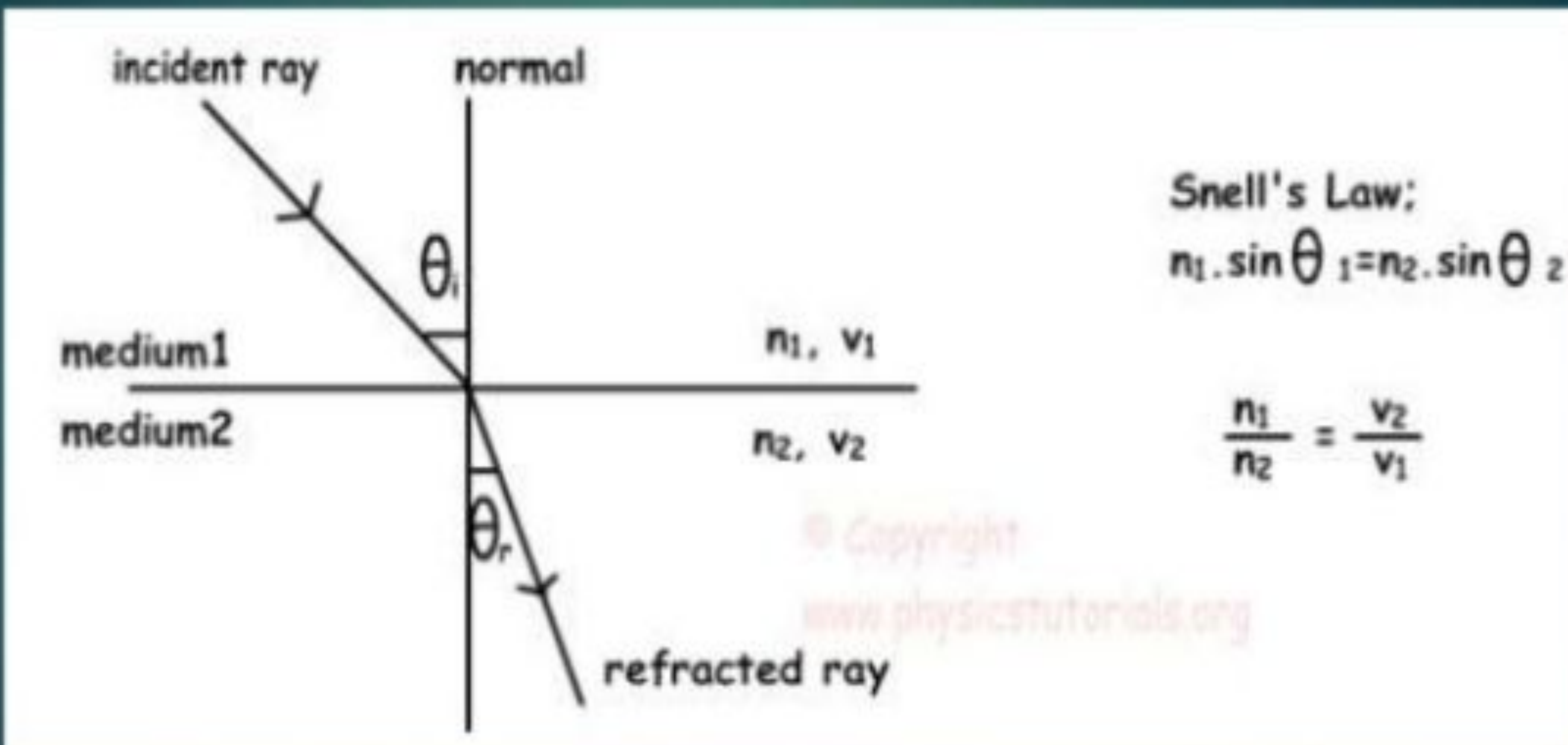
Total Internal Reflection



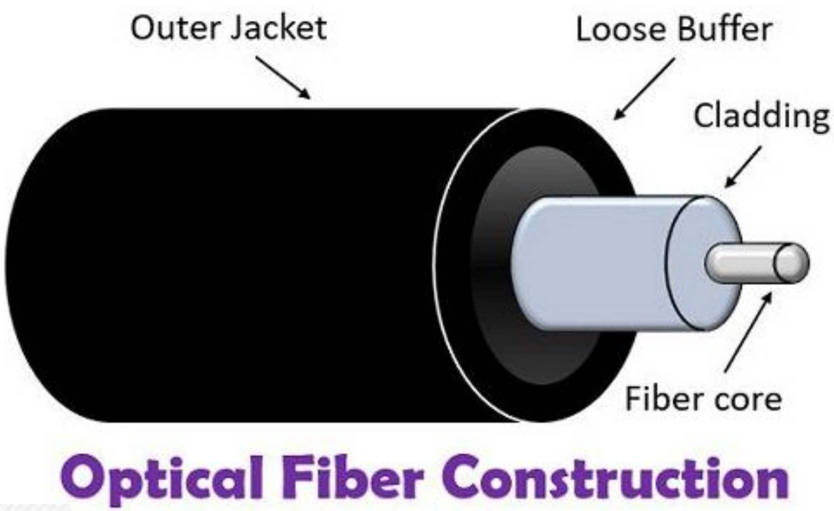
When the angle of incidence is greater than the critical angle, all the light undergoes reflection.

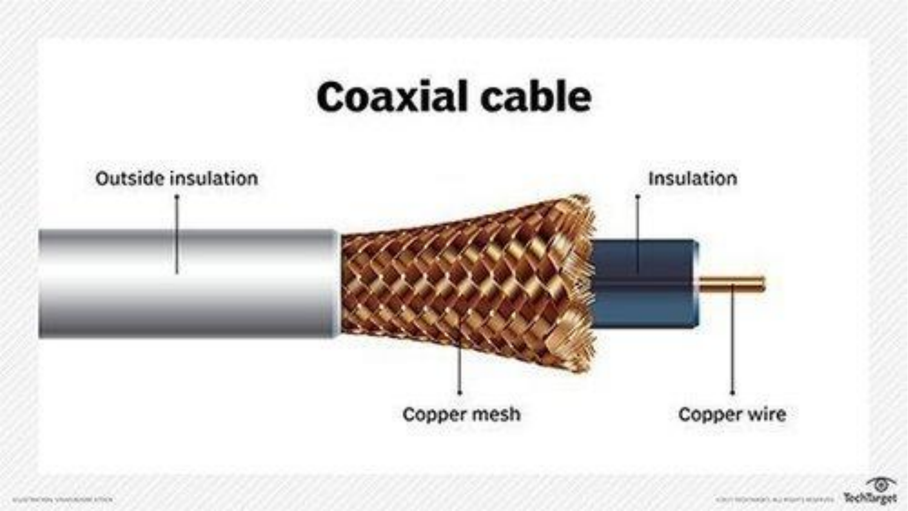
Snell's Law

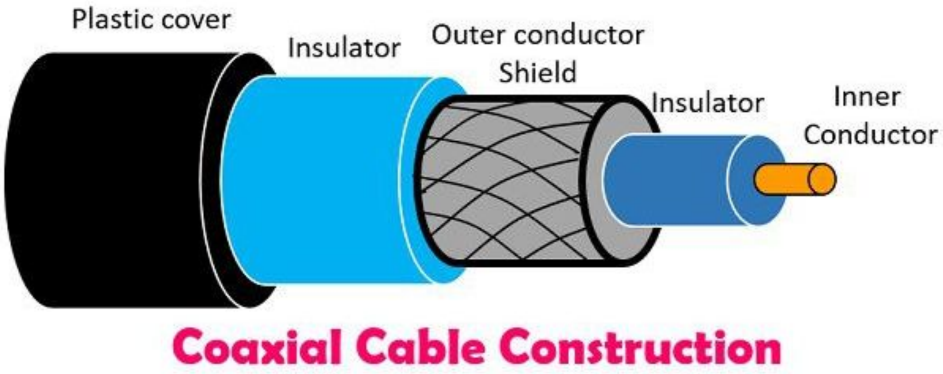
- When a light ray travels into a denser medium, it slows down and bends towards the normal. When it moves into a less dense medium, it speeds up and bends away from the normal.



Fiber optic Vs Coaxial cable







Following are the advantages of fibre optic cable over Co axial Cable

- **Greater Bandwidth:** The fibre optic cable provides more bandwidth as compared copper. Therefore, the fibre optic carries more data as compared to copper cable.
- **Faster speed:** Fibre optic cable carries the data in the form of light. This allows the fibre optic cable to carry the signals at a higher speed.
- **Longer distances:** The fibre optic cable carries the data at a longer distance as compared to copper cable.
- **Better reliability:** The fibre optic cable is more reliable than the copper cable as it is immune to any temperature changes while it can cause obstruct in the connectivity of copper cable.
- **Thinner and Sturdier:** Fibre optic cable is thinner and lighter in weight so it can withstand more pull pressure than copper cable.

Fiber-Optic Transmission Properties

- Fiber is not subject to EMI, RFI, or voltage surges.
- Cannot produce or transmit electric sparks.
- The non-conductive nature of fiber-optics makes it a great choice for areas of high lightning-strike incidence.

Increased Bandwidth of Fiber-Optics

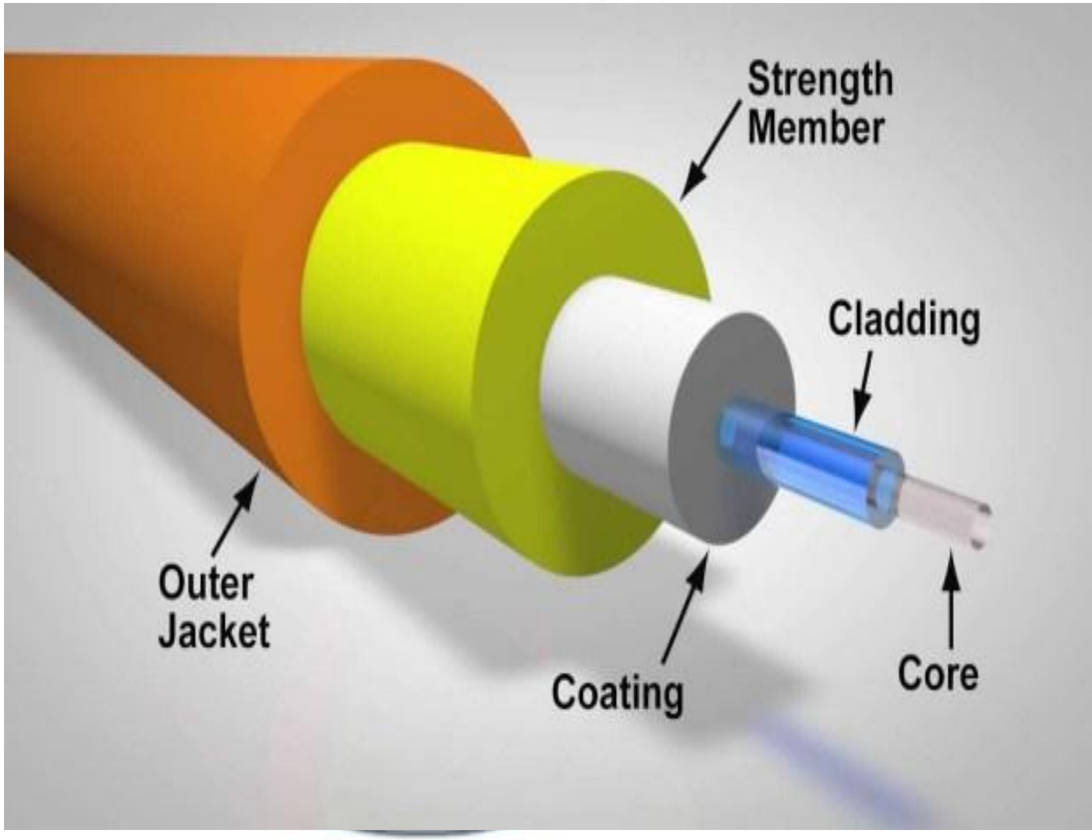
- Fiber circuits used in trunk connections between cities and countries carry information at up to 10 gigabits per second (Gbps).
- This is enough to carry 160,000 telephone circuits or 1000 television channels.
- Industry experts predict larger bandwidths than this as technology advances.

BASIS FOR COMPARISON	OPTICAL FIBRE	COAXIAL CABLE
Basic	Transmission of the signal is in optical form (light form).	Transmission of the signal is in electrical form.
Composition of the cable	Glass and plastics	Plastic, metal foil and metal wire (usually copper).
Losses in cable	Dispersion, bending, absorption and attenuation.	Resistive, radiated and dielectric loss.
Efficiency	High	Low
Cost	Highly expensive	Less expensive
Data transmission rate	2 Gbps	44.736 Mbps
Installation of the cable	Difficult	Easy
Bandwidth provided	Very high	Moderately high
External magnetic field	Doesn't affect the cable	Affects the cable
Noise immunity	High	Intermediate
Diameter of the cable	Smaller	Larger
Weight of the cable	Lighter	Heavier comparatively

Fiber-optic cable construction

Typically there are five elements that make up each fiber-optic cable:

- Core
- Cladding
- Buffer
- Strength material (Aramid Yarn)
- Outer jacket



Basic elements of Fibre optic cable:

- The core is the *innermost* part that is made out of glass or transparent plastic. It is extremely thin, flexible, and has a cylindrical shape.
- Its sole purpose is to keep all the light within itself. And also to guide the light in a direction parallel to its axis.
- Since it is the primary carrier and guide of the light waves, it can be called an optical waveguide.
- Its structure affects the transmission of the light. Hence, all the data that is being transferred will have its transmission parameters or properties based on the structure of this segment of the fiber optic.

The cladding of an optical fiber

- The cladding is the second layer on top of the core. It is *also* made of glass or transparent plastic. But with a different material, so the refractive index of the cladding is <u>lower</u> than that of the core.
- It helps to the light to be inside the core through Total Internal Reflection

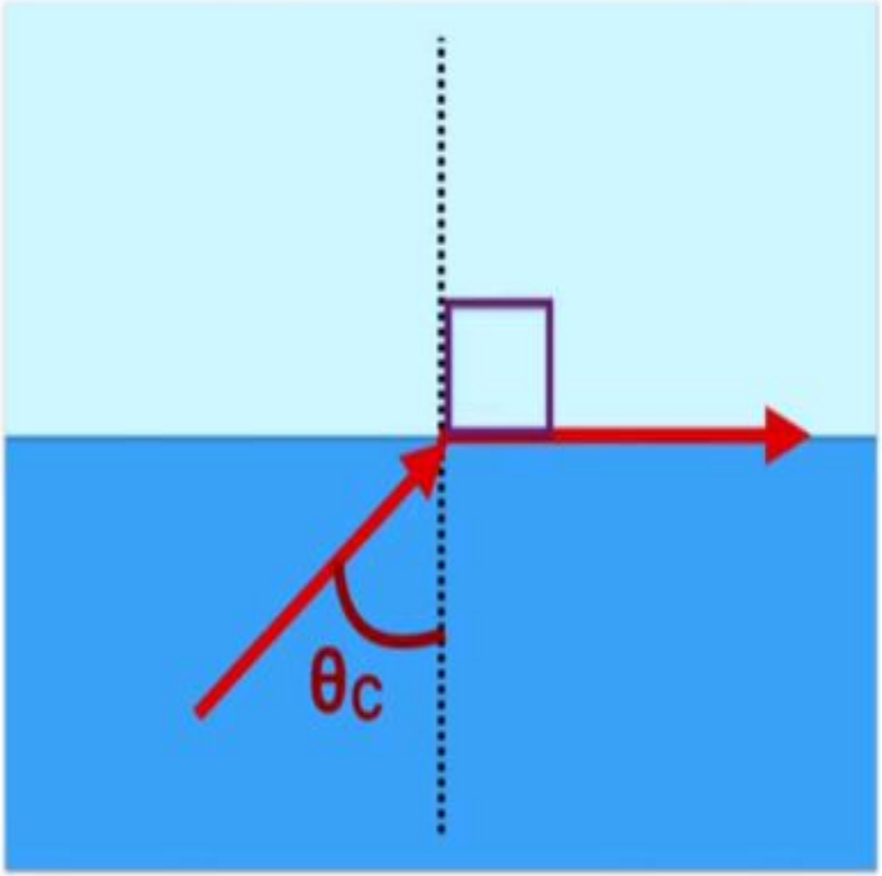
The jacket and buffer of an optical fiber

- The jacket exists purely for protecting the core and the cladding.
- It is made up of flexible and abrasion-resistant varieties of plastic.
- Usually, the jacket has another layer beneath it called a buffer.
- The buffer and the jacket together protect the optical fiber from environmental and physical damage.

Total Internal Reflection

Recall that Snell's Law says that when light moves from material with a higher index of refraction to a material with a lower index of refraction, it is bent away from the normal.

If we increase the angle of the incoming light to a certain point, we find that there is a certain angle of incoming light that causes the outgoing light to be exactly 90°. This is important, because this is the point where no light actually enters the new medium.



The critical angle θ_C is the angle of incidence that causes the angle of refraction to equal 90°.

Total internal reflection is when the angle of refraction is 90° or greater. The total light is reflected back into the original material and no light enters the new material.

Total Internal Reflection

Equation for the Critical Angle

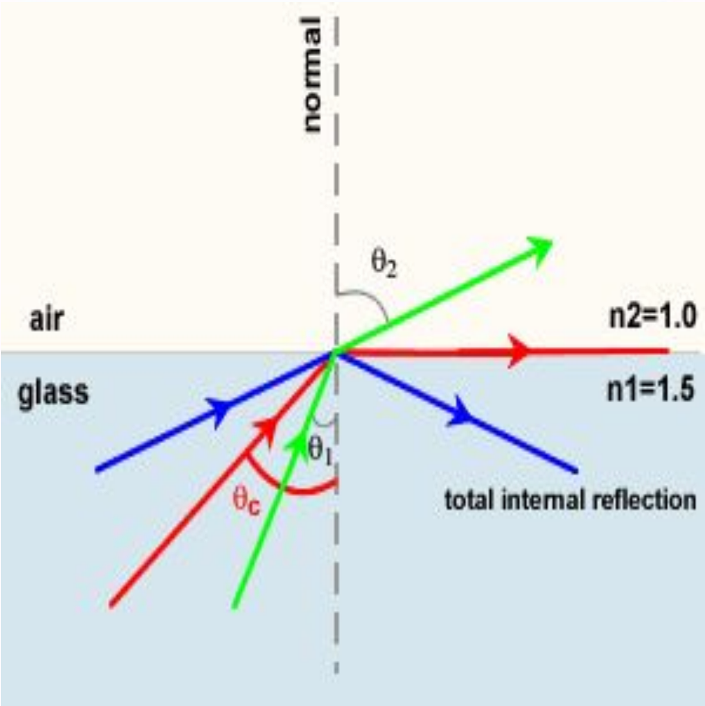
$$n_1 \mathrm{Sin}\theta_1 = n_2 \mathrm{Sin}\theta_2$$

$$n_1 \mathrm{Sin}\theta_C = n_2 \mathrm{Sin}90°$$

$$n_1 \mathrm{Sin}\theta_C = n_2$$

$$\mathrm{Sin}\theta_C = \frac{n_2}{n_1}$$

$$\theta_C = \mathrm{Sin}^{-1}\left(\frac{n_2}{n_1}\right)$$



Notice that the critical angle formula does not work when n_2 is greater than n_1, because the value of Sine cannot be greater than 1. This makes sense, because we know that total internal reflection only occurs when light moves from a higher to lower index of refraction.

Sample Problem 1:

Light travels from air into an optical fiber with an index of refraction of 1.44. (a) In which direction does the light bend? (b) If the angle of incidence on the end of the fiber is 22°, what is the angle of refraction inside the fiber? (c) Sketch the path of light as it changes media.

Solution:

(a) Since the light is traveling from a rarer region (lower n) to a denser region (higher n), it will bend toward the normal.

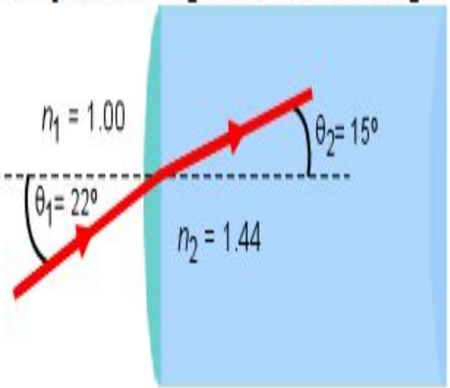
(b) We will identify air as medium 1 and the fiber as medium 2. Thus, $n_1 = 1.00$, $n_2 = 1.44$, and θ/font>$_1 = 22^o$. Snell's Law then becomes

$$(1.00)\sin 22^o = 1.44 \sin \theta_2.$$

$$\sin \theta_2 = (1.00/1.44)\sin 22^o = 0.260$$

$$\theta_2 = \sin^{-1}(0.260) = 15^o.$$

(c) The path of the light is shown in the figure below.



Sample Problem 2:

Light traveling through an optical fiber (n=1.44) reaches the end of the fiber and exits into air. (a) If the angle of incidence on the end of the fiber is 30°, what is the angle of refra
outside the fiber? (b) How would your answer be different if the angle of incidence were 50°?

Solution:

(a) Since the light is now traveling from the fiber into air, we will call the fiber material 1 and air material 2. Thus, $n_1 = 1.44$, $n_2 = 1.00$, and $\theta_1 = 30°$. Snell's Law then becomes

$$(1.44) \sin 30° = 1.00 \sin \theta_2.$$

$$\sin \theta_2 = (1.44/1.00) \sin 30° = 1.44\,(0.500) = 0.720$$

$$\theta_2 = \sin^{-1}(0.720) = 46°.$$

Notice that this time, the angle of refraction is larger than the angle of incidence. The light is bending away from the normal as it enters a rarer material.

(b) Replacing the angle of incidence with 50° gives

$$\sin \theta_2 = (1.44/1.00) \sin 50° = 1.44\,(0.766) = 1.103$$

This equality cannot be met, so light cannot exit the fiber under these conditions.

The situation in part (b) is an example of total internal reflection, discussed on the next content page.

OPTICAL FIBER FABRICATION

Materials and Construction

CHARACTERISTICS OF MATERIAL

In selecting material for Optical fiber

- Material from which long, thin and flexible fiber are to be made.
- Material should be highly transparent at optical wavelength in order to guide light efficiently.
- Two physical compatible material that has slightly different R.I for core and cladding must be available .

THE MATERIAL BASED CLASSIFICATION

Optical fibers are fabricated from glass or plastic which are transparent to optical frequencies. Step index fibers are produced in three forms:

1. A glass core with glass cladding
2. A silica glass core with plastics cladding
3. A plastic core with another plastic cladding.

ALL GLASS FIBERS

- The basic material of optical fibers is Fused silica (SiO_2). It has a refractive index of 1.458 at λ=850nm.
- The materials of different refractive index are obtained by doping silica material with various oxides.
- If the silica is doped with Germania (GeO_2) or phosphorous pentoxide (P_2O_5), the refractive index of the material increases.
- Such materials are used as core materials and pure silica is used as cladding material in these cases.

- When pure silica is doped with boria (B_2O_3) or fluorine, its refractive index decreases.
- These materials are used for cladding when pure silica is used as core material.
- The examples for fiber compositions are

1. SiO_2 core – $B_2O_3.SiO_2$ cladding
2. $GeO_2.SiO_2$ core – SiO_2 cladding
3. $P_2O_5 . SiO_2$ core - SiO_2 cladding

Glass fiber features:

- Advantages: low attenuation, cheap and abundant raw material (mostly sand)
- Disadvantages: high installation cost, complexity requires skilled technicians, inflexible, easy-to-break

ALL PLASTIC FIBERS

- The plastic made fibers are obtained from polymers of transparent to light, flexibility and interaction less to light etc,. For example poly-methyl-metha-acrylate (PMMA), polyethylene (PE), polystyrene (PS) are used as core materials.
- In these fibers, Perspex (PMMA) and polystyrene are used for core. Their refractive indices are 1.49 and 1.59 respectively.
- A fluorocarbon polymer or a silicone resin is used as a cladding material. A high refractive index difference is achieved between the core and the cladding materials.

- Therefore, plastic fibers have large NA of the order of 0.6 and large acceptance angles up to 77°.
- The main advantages of the plastic fibers are low cost and higher mechanical flexibility.
- The mechanical flexibility allows the plastic fibers to have large cores, of diameters ranging from 110 to 1400μm.
- They are temperature sensitive and exhibit very high loss.
- Therefore, they are used in low cost applications and at ordinary temperatures (below 80°C).

Examples of plastic fibers compositions are

1. Polystyrene core $n_1=1.60$ NA=0.60

   -Methyl methacrylate cladding $n_2=1.49$

2. Polymethyl methacrylate core $n_1=1.49$ NA=0.50

   -cladding made of its copolymer

- Advantages:
  - Simpler and less expensive components
  - Lighter weight
  - greater flexibility and ease in handling and connecting (POF diameters are 1 mm compared with 8-100 mm for glass)
  - Lower installation cost
- Disadvantages:
  - High attenuation
  - Limited production

PCS FIBERS

- The plastic clad silica (PCS) fibers are composed of silica cores surrounded by a low refractive index transparent polymer as cladding.
- The core is made from high purity quartz.
- The cladding is made of a silicone resin having a refractive index of 1.405 or perfluoronated ethylene propylene (Teflon) having a refractive index of 1.338.
- Plastic claddings are used for step-index fibers only.
- The PCS fibers are less expensive but have high losses. Therefore, they are mainly used in short distance applications.

Comparison between glass fiber, POF, copper wire

	PLASTIC	GLASS	COPPER
Component costs	Potentially low	More expensive	Low
Loss	High–medium (short distance)	Medium–low (long distance)	High
Connections	Easy to connect, requires little training or special tools	Takes longer, requires special tools and training	High
Handling	Easy	Requires training and care	Easy
Flexibility	Flexible	Brittle	Flexible
Wavelength operating range	Visible	Infrared	NA
Numerical aperture	High (0.4)	Low (0.1–0.2)	NA
Bandwidth	High (11 Gbps over 100 m)	Large (40 Gbps)	Limited to 100 m at 100 Mbps
Test equipment	Low cost	Expensive	High
System costs	Low overall	High	Medium

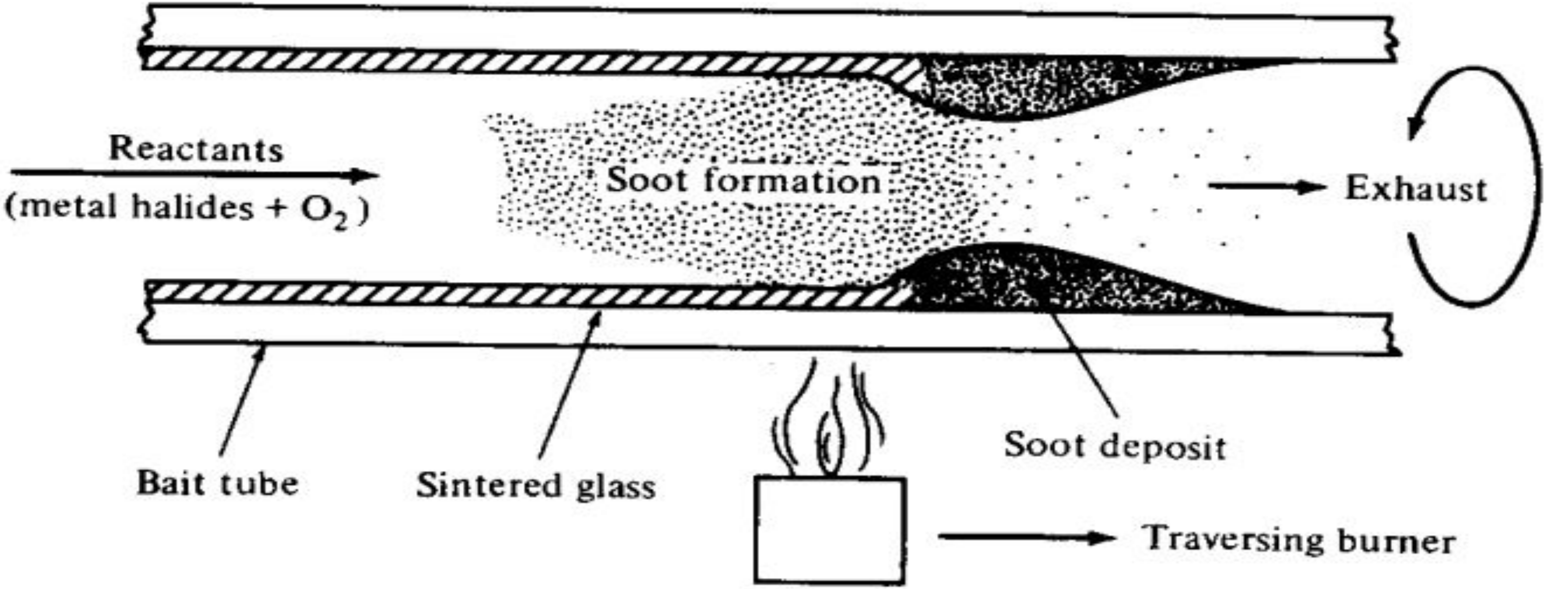
Requirements for fabricating useful optical fiber

- Materials must be extremely pure
  - Impurity < 1 part per billion for metals
  - Impurity < 1 part per 10 million for water
- About 1000 times more pure than traditional chemical purification techniques allow
- Dimensions must be controlled to extremely high degree
  - Core size, position, cladding size tolerances ~ 1 micron or less
  - Roughly 1 wavelength of light
  - Refractive indices must also be very precisely controlled
- Must be made in long lengths
- Must have tensile strength

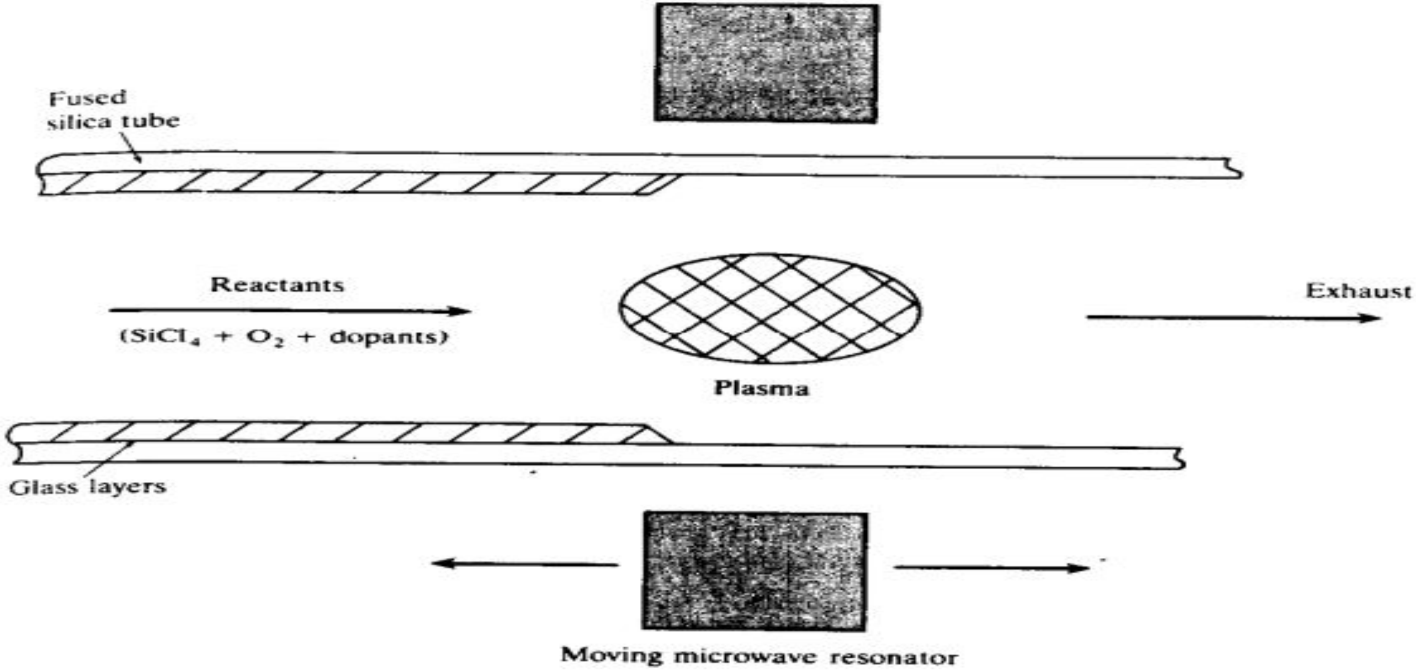
Other methods used to make fiber

- Vapor phase axial deposition (VAD)
  - Batch process
  - Preforms can be drawn up to 250 km
  - Flame hydrolysis
    - Soot formed and deposited by torches

Modified Chemical Vapor Deposition (MCVD)

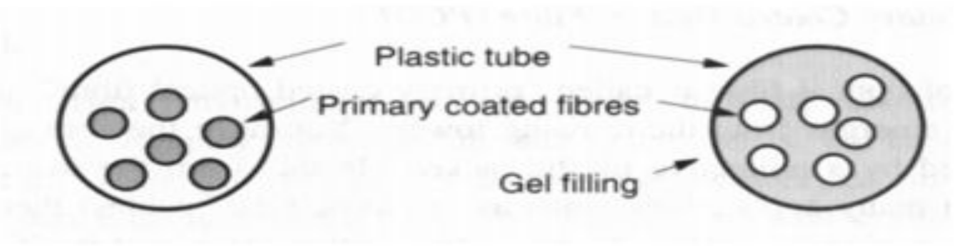


Plasma-Activated Chemical Vapor Deposition (PCVD)



Basic cable construction: types

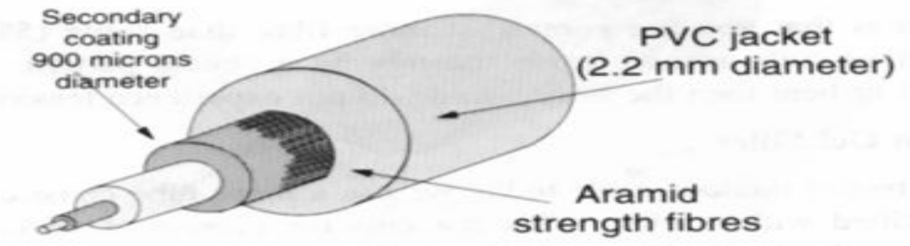
- Tight buffered
  - No room for fibers to move inside of cable
- Loose tube
  - Multiple fibers loose inside of outer plastic tube
  - Advantage is that with extra length of fiber inside tube due to curling, less likelihood of damage in sharp bends
- Loose tube with gel filler
  - Multiple fibers immersed in gel inside of plastic tube

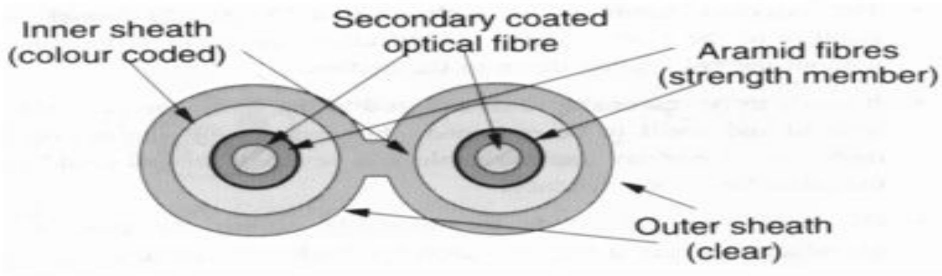


Source: Dutton

Typical indoor cable

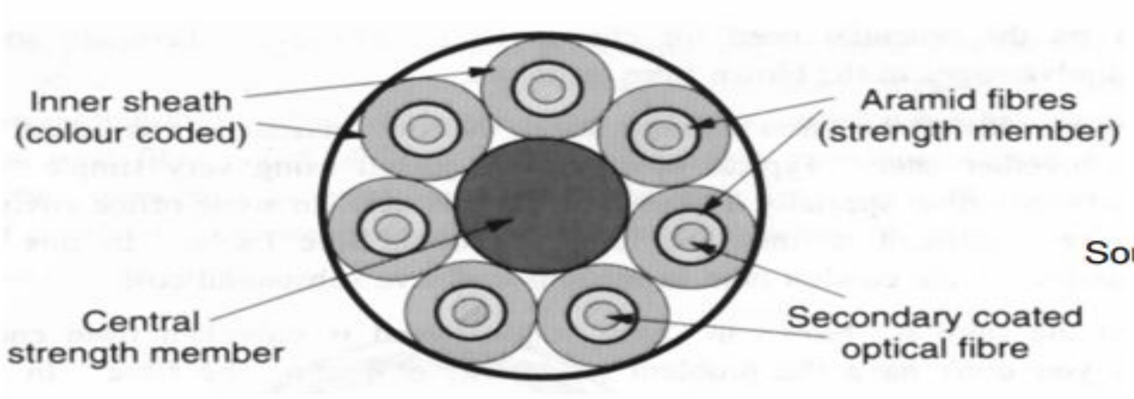
- Single core or double core
  - Utilize substrate for additional strength (aramid or fiberglass)





Tight buffered indoor cable

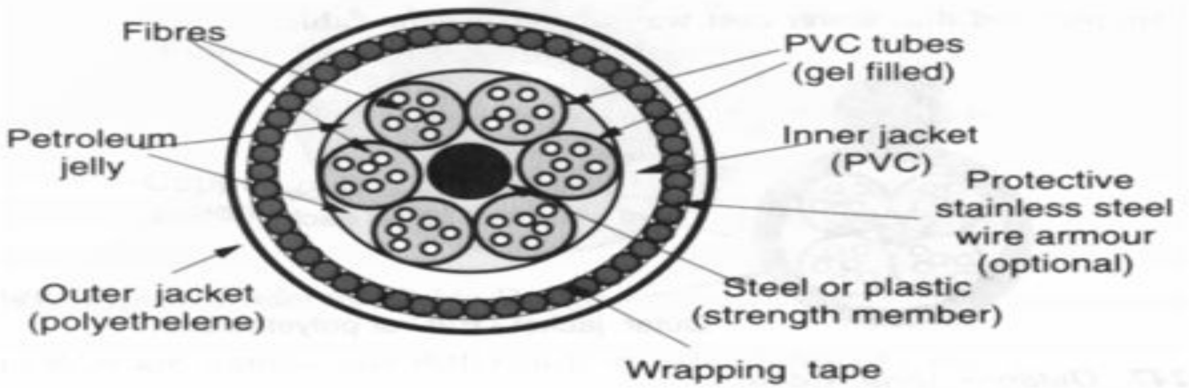
- Application: building risers
- 6 or 12 fibers typically
- Central strength member supports weight of cable
- Tight buffering means that fibers are not put under tension due to their own weight



Source: Dutton

Outdoor cable

- More rugged, larger number of fibers per cable
  - 6 fibers/tube, 6 tubes = 36 fibers
  - 8 fibers/tube, 12 tubes = 96 fibers
- Steel or plastic used for strength member
- Outer nylon layer in locations where termites are a problem



Submarine cable

- Smaller number of fibers because mechanical requirements much greater
  - 4 to 20 typically
- Must withstand high pressure, damage from anchors, trawlers, etc.
- Cables for shallow water are in greatest danger
  - Typically heavily armored