Unit-1

Overview of Optical Fiber Communications (OFC): Motivation, optical spectral bands, key elements of optical fiber systems.

Optical fibers: Basic optical laws and definitions, optical fiber modes and configurations, mode theory for circular waveguides, single mode fibers, graded-index fiber structure, fiber materials, photonic crystal fibers, fiber fabrication, fiber optic cables.

1.1 Motivation

Advantages of Optical Fibers

1) Long Distance Transmission-Optical Fibers have lower transmission losses compared to copper wires. Consequently data can be sent over long distances, thereby reducing the number of repeaters needed to boost and restore signals in long spans. This reduction in equipment and components decreases system cost and complexity.
2) Large Information Capacity-Optical fibers have wider bandwidth than copper wires, so that more information can be sent over a single physical line. This property decreases the number of physical lines needed for sending a given amount of information.
3) Small Size and Low Weight- Because of low weight and small size optical fibers are used in aircraft, satellites and ships where small light weight cables are advantageous, and in military applications where large amount of cable must be reeled and retrieved rapidly.
4) Immune to Electrical Interference-Optical fibers are made up of a dielectric material, which means it does not conduct electricity. This makes optical fibers immune to electromagnetic effects seen in copper wires, such as inductive pickup from other adjacent signal-carrying wires or coupling of electrical noise into the line from any type of nearby equipment.
5) Enhanced Safety-Optical fibers offer a high degree of operational safety, since they do not have the problems of ground loops, sparks, and potentially high voltages inherent in copper lines.
6) Increased Signal Safety-An optical fiber offers a degree of data security, since the optical signal is well-confined within the fiber and an opaque coating around the fiber absorbs any signal emissions. This feature is in contrast to copper wires where electrical signals potentially could be tapped off easily. Thus fibers are attractive in applications where information security is important, such as financial, legal, government, and military systems.

1.2 Optical Spectral bands

Optical fiber communication uses near infrared spectral band ranging from 770-1675nm.The 770-910nm band is used for shorter-wavelength multimode fiber systems, Thus this region designated as short wavelength Or multimode fiber band. The International Telecommunication Union (ITU) has designed six spectral bands for use in optical fiber communications within the 1260-1675nm region .These long –wavelength band designations arose from attenuation characteristics of optical fibers and the performance behavior of an erbium-doped fiber amplifier (EDFA).Table 1 defines these six spectral bands.

Table: 1 Six spectral bands of optical communication.

Name	Designation	Spectrum(nm)	Origin in name
Original Band	O-band	1260-1360	Original(first) region used for single-mode fiber links
Extended band	E-band	1360-1460	Link use can extend into this region for fibers with low water content
Short band	S-band	1460-1530	Wavelengths are shorter than C band but higher than E-band
Conventional Band	C-band	1530-1565	Wavelength region used by a conventional EDFA
Long band	L-band	1565-1625	Gain decrease steadily to 1
Ultra-long band	U-band	1625-1675	Region beyond the response capability of an EDFA

1.3 Key Elements of Optical Fiber Systems

Basic function of optical fiber link is to transport a signal from communication equipment (e.g. telephone) at one location to corresponding equipment at another location with a high degree of accuracy and reliability. The key sections are transmitter, a cable, and receiver. Additional components include active and passive components. Fig.1 shows the main constituents of optical fiber communication link.

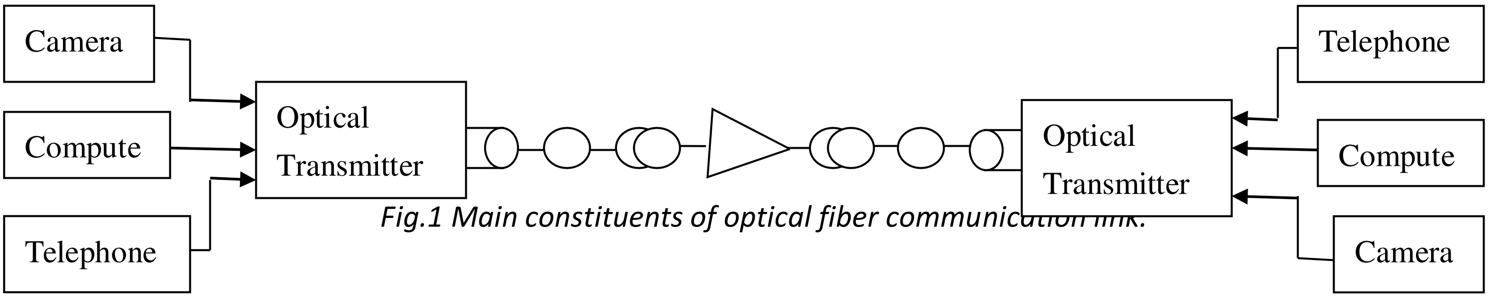


Fig.1 Main constituents of optical fiber communication link.

The Transmitter consist of a light source that is dimensionally compatible with a fiber core and a associated electronic control and modulation circuitry. In the 770-910nm light sources are generally alloys of GaAlAs. At longer , wavelengths 1260-1675nm InGaAsP alloy is the principle optical source material.

Inside the receiver is a photodiode that detects the weakened and distorted optical signal emerging from an end of optical fiber and coverts it to an electrical signal? The receiver also contains electronic amplification devices and circuitry to restore signal fidelity. Silicon photodiodes are used in the 770-910nm region. The primary material in the 1260-1675nm region is an InGaAs alloy.

Passive devices are optical components that require no electronic control for their operation. Among these are optical filters, optical splitters, optical multiplexers, couplers. Active optical components, which require an electronic control for their operation. These include light signal modulators, tunable optical filters, variable attenuators, and optical switches.

When setting up an optical link engineers formulate a power budget and add amplifiers or repeaters when path loss exceeds available margin. Furthermore, when a link is being installed and tested, operational parameters that should be measured include bit error rate, timing jitter, and signal to noise ratio as indicated by eye pattern.

- Windows and spectral bands

Early applications in the late 1970s made exclusive use of the 770-910nm wavelength band. Where there is a low loss window. Originally this region was referred to as a first window, since around 1000nm there was a large attenuation spike due to absorption by water molecules. As a result of this spike, early fibers exhibited a local minimum in attenuation curve around 850nm.

By reducing the concentration of hydroxyl ions and metallic impurities in the fiber material, in 1980s manufacturers could fabricate optical fibers with very low losses in the 1260-1675 nm region. Since the glass still contained some water molecules, a third order absorption spike remained around 1400nm. This spike defined two-loss windows, these being second window centered at 1310nm and third window centered at 1550nm.

1.4 Basic Optical Laws and Definitions

This includes snell's law, concepts of reflection and refraction.

When a light ray encounters a boundary separating two different media, part of the ray reflected back into the first medium and the remainder is bent (or refracted) as it enters second material. This is shown in Fig.2 $n_2 < n_1$. The relationship at the interface is known as Snell's law and is given by.

$n_1 \sin\varphi_1 = n_2 \sin\varphi_2$

φ_1 =Angle of Incidence between incident ray and normal to the surface.

According to the law of reflection angle θ_1 at which the incident ray strikes the interface is exactly equal to the angle that the reflected ray makes with the same interface. As the angle of incidence φ_1 in an optically denser material becomes larger, the refracted angle approaches $\frac{\pi}{2}$. Beyond this point refraction is possible and light rays becomes totally internally reflected. Or in other words if the angle of incidence φ_1 is greater than the critical angle, the condition for total internal reflection is satisfied; that is light totally reflected back into the glass no light escape from the glass surface .

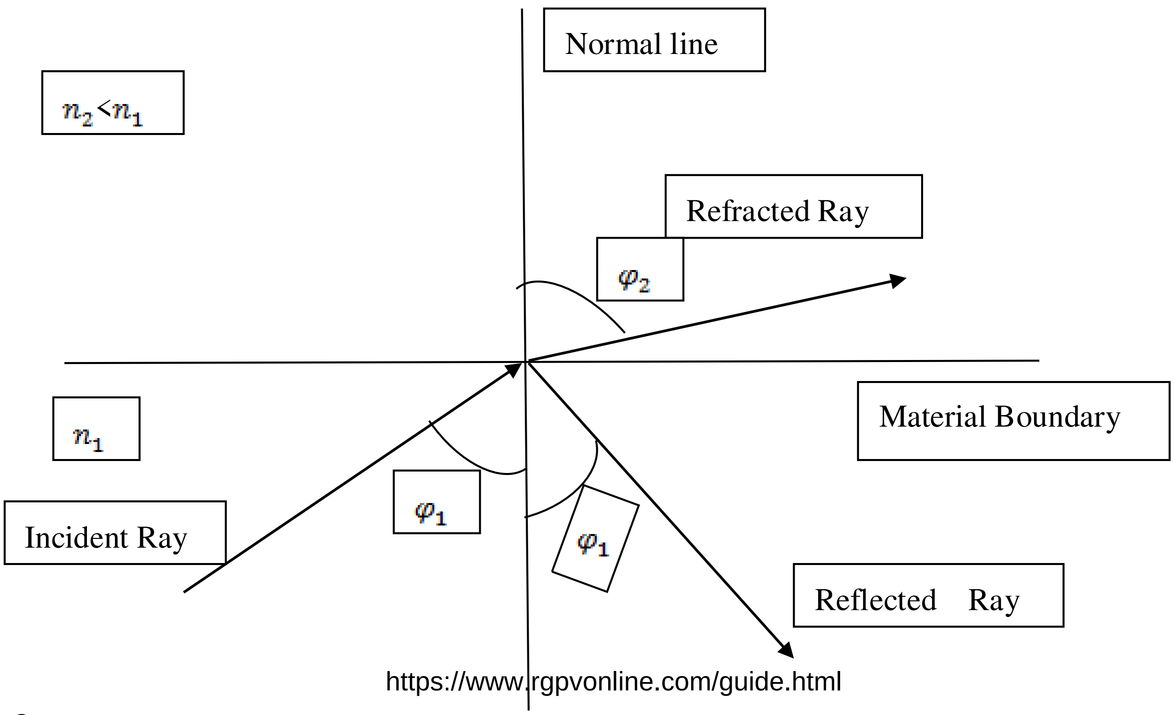


Fig.2 Refraction and reflection of a light ray at a material boundary

Polarization components of light:

An ordinary light consist of many transverse electromagnetic waves that vibrate in a variety of directions and is called un polarized light. Un polarized light can split into separate polarization components either by reflection off of a nonmetallic surface or by refraction when light passes from one material to another. The reflected beam is partially polarized at a specific angle (known as Brewster's angle) the reflected light is completely perpendicularly polarized. The parallel component of the refracted beam is transmitted entirely into the glass whereas perpendicular component is partially refracted.

Polarization characteristics of light are important when examining the behavior of components such as optical isolators and light filters. Three polarization sensitive materials are :Polarizer is a material or device that transmits only one polarization component and blocks the other. Faraday rotator is a device that rotates state of polarization of light passing through by a specific amount. Birefringent material or double refractive crystals splits the light signal entering it into two orthogonally polarized beams. One of the beams is called an ordinary ray or o-ray. The second beam is called the extraordinary ray or e-ray.

1.5 Optical Fiber Modes and Configurations, single mode fibers, graded-index fiber structure:

An optical fiber is a dielectric waveguide that operates at a optical frequencies guides light in a direction parallel to it. Structure of optical fiber as shown in Fig.3.

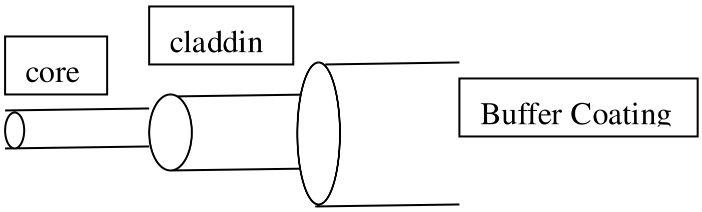


Fig.3 Structure of optical Fiber

Cladding surrounds the core adds mechanical strength to the fiber and protects core from absorbing surface contaminants. On the bases of variation in material composition optical fiber are of two types:

1) Step Index fiber- Refractive index of core is uniform throughout and under goes abrupt changes at the cladding boundary. On the bases of modes of propagation these are further classified as single mode step index and multimode step index fibers. single mode fibers sustains only one mode of propagation as shown in Fig.4. multimode fibers sustains many hundreds of modes of propagation as shown in Fig. 5.

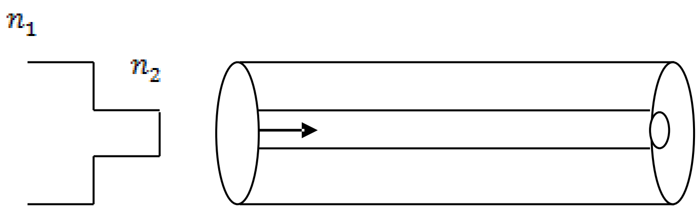


Fig.4 Mono mode step index fiber

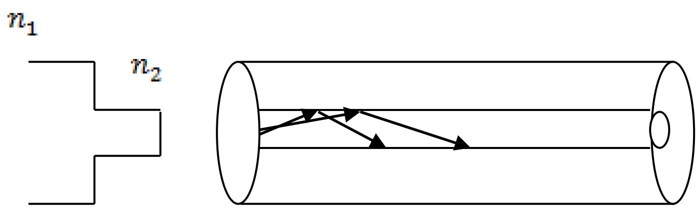


Fig.5 Multimode mode step index fiber

2) Graded Index fibers- Refractive Index is made to vary as function of the radial distance from center of the fiber. Further on the bases of modes of propagation these are classified as two types Mono mode graded index fiber and multimode graded index fiber as shown in Fig.6. Multimode fibers have large core radii due to which larger power can be launched. LED can also be used for launching power in multimode fibers. But multimode fiber suffers from intermodal dispersion.

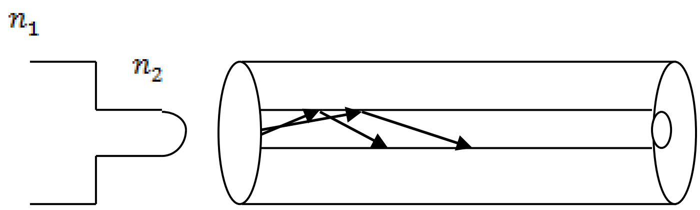


Fig.6 Multimode mode graded index fiber

Intermodal Dispersion: Optical Power in different modes travel with different velocity. Means mode arrive at different times, thus causing pulse to spread out. This can be reduced by graded index fiber. Information capacity of graded index fibers is greater as compared to the step index fibers (data rate transmission).

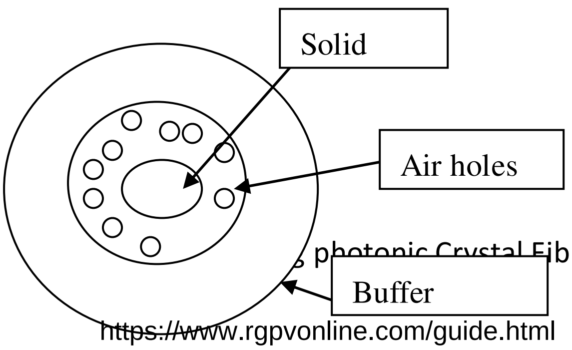
1.6 Fiber materials

Optical fibers are made from optically transparent glasses of these most common is silica Sio_2 which has refractive index 1.458 at 850nm. To produce two similar materials having slightly different indices of refraction for core and cladding, either fluorine or various oxides such as B_2O_3, Ge_2O_2, or P_2O_5 are added to the silica. P_2O_5 Increase the refractive index where the doping the silica with fluorine or B_2O_3 decreases it.

1.7 Photonic Fibers

Core or cladding contains air holes, which run along the entire length of fiber. They are insensitive to bending. They can deliver high power. These are of two types

1) Index guiding Fibers- Core is solid and cladding region contains air holes running along the length of the fiber as shown in Fig. 7. Core and cladding are made up of same material for example pure silica. Air holes in the cladding region lower the lower refractive index.



photonic Crystal Fiber

2) Photonic Band Gap Fiber (PBG)- Hollow core, surrounded by cladding region which contains air holes running along the fiber length as shown in Fig.8.

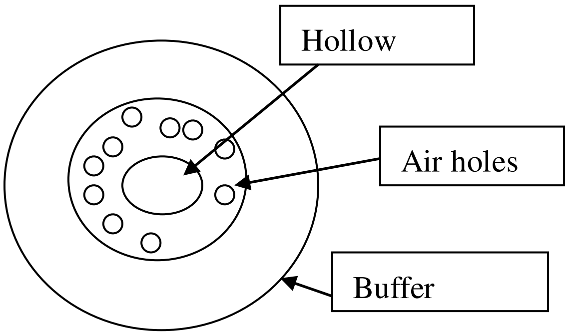


Fig. 8 Photonic Bandgap Fiber

1.8 Fiber Fabrication:

For fabrication two basic techniques are used : Vapor phase oxidation process and direct melt process. In vapor phase oxidation highly pure vapors and metal halides (e.g. $Sicl_4$ and $Gecl_4$) react with oxygen to form white powder of Sio_2 particles. The particles are then collected on the surface of a bulk glass by one of four different commonly used processes and sintered (transformed to a homogeneous glass mass by heating without melting) by one of variety of perform. Preform is a precision fed into a circular heater called the drawing furnace. Four different fiber fabrication process are as follows:

1)Outside Vapor Phase Oxidation(OVPO):Layer of Sio_2 particles called soot is deposited from a burner onto a rotating graphite or ceramic mandrel. The glass soot adheres to this bait rod, layer by layer, a cylindrical porous glass perform is built up. By properly controlling the constituents of metal halides vapor stream during deposition process , the glass composition and dimension desired for core and cladding can be incorporated into the perform.Bait rod rotates and moves back and forth under burner to produce uniform deposition of glass soot particles along the rod.The process is shown through Fig.9

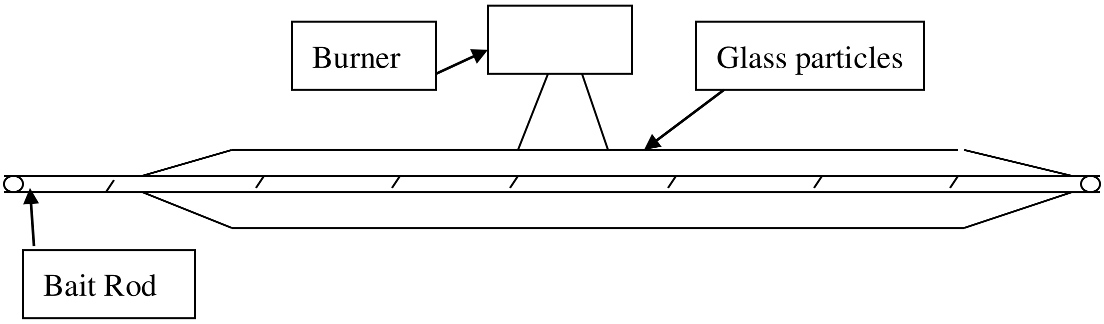


Fig. 9 Outside Vapor Phase Oxidation process of fiber fabrication

3.Modified Chemical Vapor Deposition(MCVD): The glass vapor particles arising from the reaction of the constituent metal halide gases and oxygen flow through inside of a revolving silica tube. As the Sio_2 particles are deposited, they are sintered to a glass layer by oxy hydrogen torch which travels back and forth along the tube as shown in Fig.10.When the desired thickness of glass is has been deposited, the vapor flow is shut off and the tube is heated strongly to cause it to collapse into a solid rod perform. The fiber that is subsequently drawn from this perform rod will have a core that consist of the vapor deposited-material and the cladding consisting of the original silica tube. This method produces low loss graded index fibers.

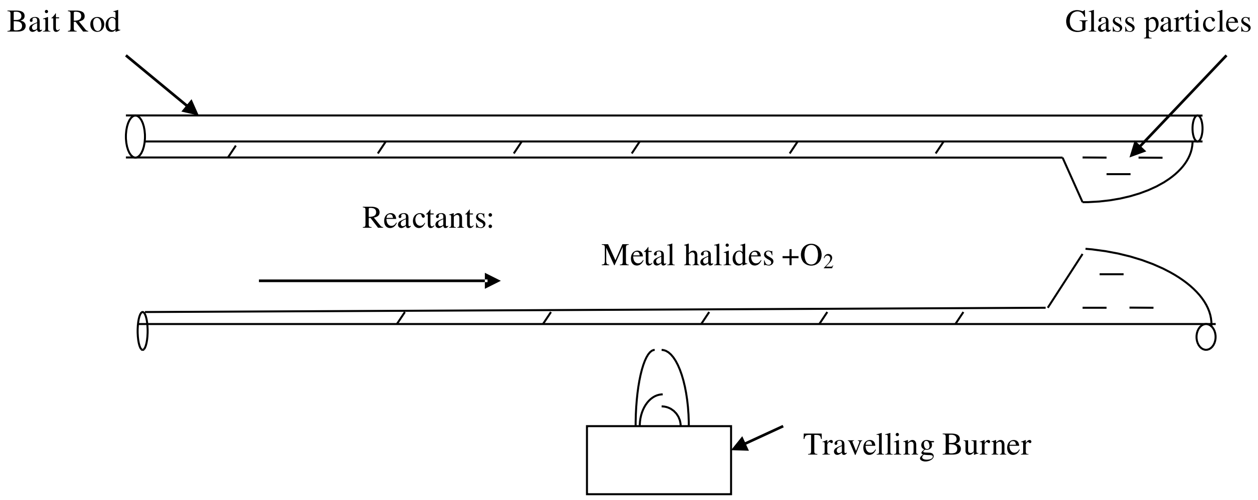


Fig. 10 Modified Chemical Vapor Deposition

3.Plasma Activated Chemical Vapor Deposition (PCVD)

In this method as shown in Fig.11. deposition occurs within the silica tube. However a non isothermal microwave plasma operating at low pressure initiates the reaction with the silica tube held at temperatures in the range of 1000-1200℃ to reduce mechanical stress in the growing glass films, a moving microwave resonator operating at 2.45Ghz generates a plasma inside the to activate chemical reaction. This process deposits clear glass material directly on the tube wall; there is no soot formation. Thus no sintering is required When one has deposited the desired glass thickness, the tube is collapsed into a perform.

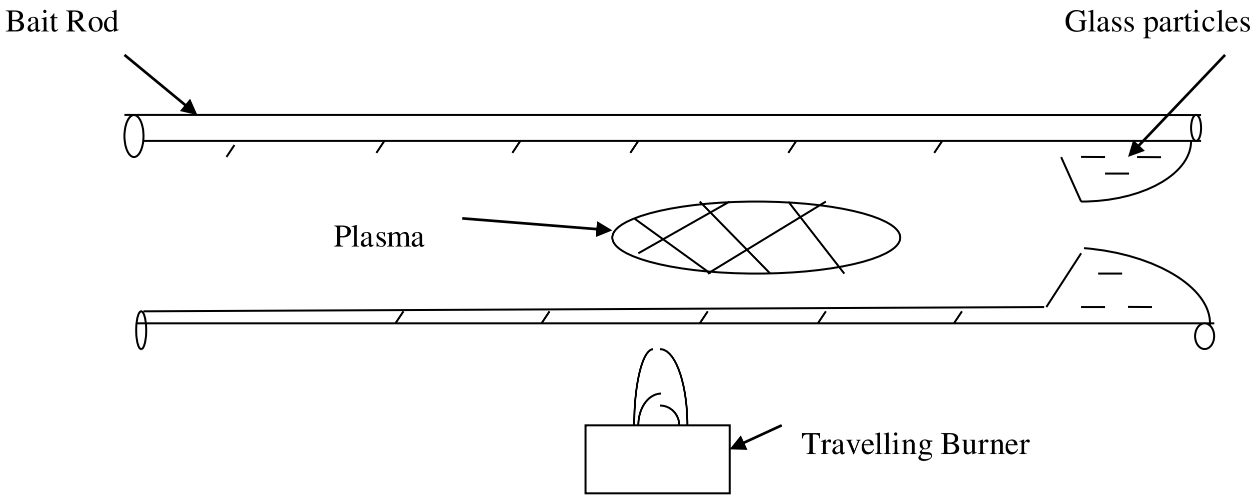


Fig. 11 plasma Activated Chemical Vapor Deposition process

3) Vapor Phase Axial deposition: A porous perform is grown in axial direction by moving rod upward. Fiber can be fabricated in continuous lengths which can affect process cost and product yields. The fact that deposition chamber and the zone melting ring heater are tightly connected to each other in the same encloser allows the achievement of a clean environment.

1.9 Fiber Optic Cables

An **optical fiber cable** is a cable containing one or more optical fibers that are used to carry light. The optical fiber elements are typically individually coated with plastic layers and contained in a protective tube suitable for the environment where the cable will be deployed. Different types of cable are used for different applications, for example long distance telecommunication, or providing a high-speed data connection between different parts of a building. Cables are fragile and are usually placed underground, which makes them difficult and expensive to install. Some fiber-optic cables are installed above ground, but if they break, they often need to be completely replaced, which is not cheap. Several layers of protective sheathing, depending on the application, are added to form the cable as shown in Fig.12. Plastic strength members and high tensile strength synthetic yarns are used to avoid electromagnetic

induction.

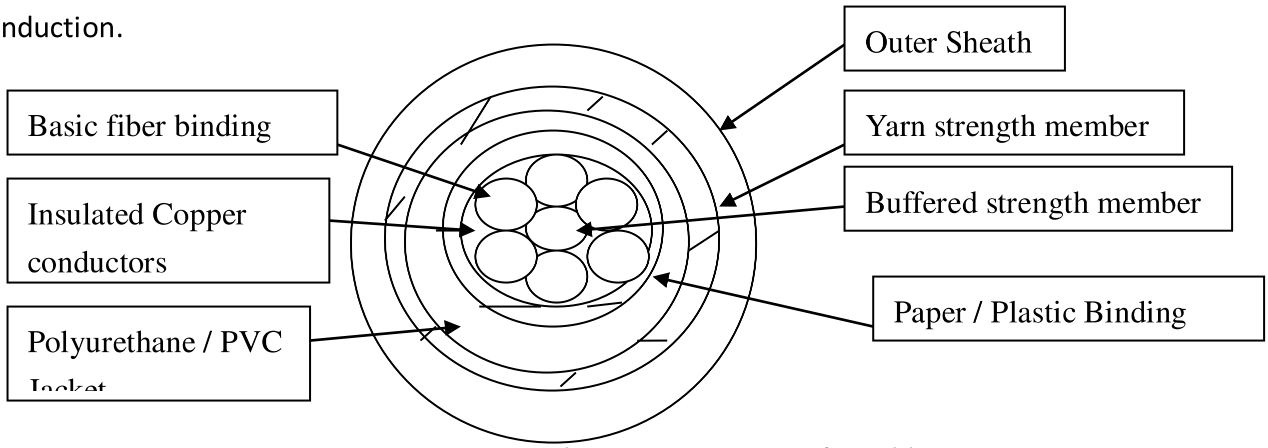


Fig.12 Schematic Structure of a Cable

Individual fibers or modules of bundled fiber groupings and optional copper wires for powering in line equipment are wound loosely around the central buffered strength member. A cable wrapping tape and other strength members such as Kevlar then encapsulate and bind these fibers grouping together. Surrounding these components is tough polymer jacket and provides crush resistance and handles any tensile stress applied to the cable so that the fibers inside are not damaged. Cables are categorized on the bases of their application.

1)Armored Or Underground Cable: For direct burial or underground duct applications has one or more layers of steel wire or steel sheath protective armoring below a layer of polyethylene jacketing. Strength protects from gnawing animals such as squirrels or burrowing rodents often cause damage to underground cables.

2) Underwater cables/Submarine Cables: Other layers are same as in normal cable but it has various water blocking layers, one or more protective inner polyethylene sheaths and heavy outer armor jacket. They are used in river, lakes and ocean environment.