

What are Optical Fibers? An Introduction:

Optical fibers are merely threads of glass, plastic, or a combination of both, yet they comprise a multi-billion dollar industry and govern our everyday livelihood. Optical fibers are a medium for communication. The first large-scale usage of optical fibers was in telephone links. Optical fibers allowed for increased bandwidth that decreased the load being placed on the global voice communication infrastructure.⁽¹⁾ Today optical fibers are everywhere in our lives; doctors use optical fiber tools for surgical applications, the military uses optical fiber for international communication, broadband internet is provided via optical fibers along with cable television. As companies like Lucent, Ciena, Redback, and Qwest continue to expand their networks, the optical fiber industry is expected to reach a value of 15 billion in North America by 2003.⁽²⁾ This paper will serve to provide the basic principles of optical fiber design and manufacturing, while providing examples of its use in our everyday lives.

Theoretical Background: Optical Fiber Design, Manufacturing, and Application

An optical fiber is a thin strand of silica glass thin as a human hair in diameter. The basic principle of operation is to send light through one end of the fiber and have it come out the opposite end with as little loss of data as possible.

Figure 1 shows that the optical fiber consists of three parts: a core, the cladding, and a buffer coating. The core is a narrow strand of glass and is the travel path for light. The cladding is an annular tubing which covers the core. The cladding serves as a barrier to signal loss as the data travels across the core. The interface where the cladding and core meet serves to provide total internal reflection so that light can travel even around

bends in the fiber. The buffer coating is a protective layer to protect the cladding and core from the atmosphere.

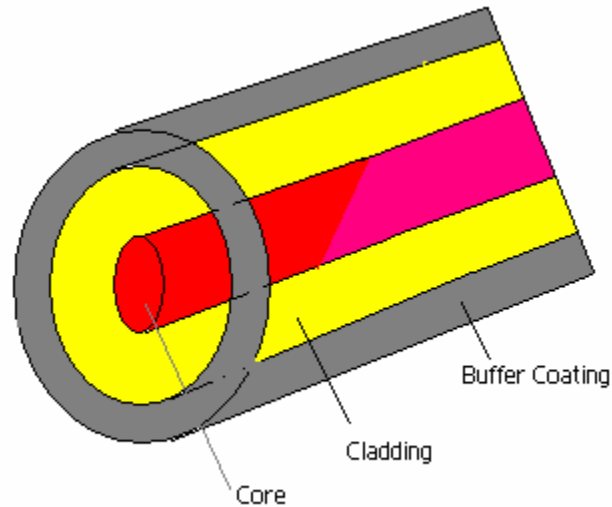


Figure 1: An Optical Fiber

Propagation of Light

The phenomenon of total internal reflection is what allows light to travel down the optical fiber and around bends. The light is able to bend around the corners because of the reflective core-cladding interface, which serves to confine the light within the core. The theory of total internal reflectance is based on Snell's Law. Snell's Law is stated in Equation 1.

$$N_1 \sin \theta_1 = N_2 \sin \theta_2 \quad \text{Eq. 1}$$

In Equation 1, N_i denotes the refractive index of a material and θ_i is the angle of refraction. In optical fibers, the cladding has a lower index of refraction relative to the core. As light passes from a material of higher refractive index (core) to a material of lower refractive index (cladding), the refracted angle increases. At the critical angle, the light from the higher refractive index material (core) passes to the lower refractive index material (cladding) and is refracted at a 90° angle. At all angles above the critical angle,

light is completely reflected, resulting in total internal reflectance. So as long as the light is incident on the higher refractive index material, which is the core, at an angle greater than the critical angle, the result will be total internal reflectance. This allows light to propagate along the optical fiber around bends and for great distances.

Signal Degradation Factors

As long as the angle of incidence on the core is greater than the critical angle, total internal reflectance will occur and the light will be able to travel a great distance. However, the signal will degrade over distance and time, since nothing is perfect. There are several factors that affect signal strength. The key factors are: attenuation, maximum power, polarization, and noise.

The signal strength of light attenuates primarily due to the glass used to make the core and cladding. There are impurities present in the glass because they are needed to alter the refractive indices of both the core and cladding in order to promote total internal reflectance can occur properly, however, these same impurities simultaneously degrade the signal strength by absorbing light and acting as scattering centers. Most light loss in an optical fiber is due to scattering.⁽³⁾ Additionally, defects such as scratches, digs, and dangling bonds on end surfaces which are the result of processing and handling, also cause scattering and back-reflection of light.⁽⁴⁾ Dispersion of light is also a strong factor in signal degradation. Based on the wavelength of light, the impurities serve to create dispersion so that a portion of the signal arrives earlier than the rest of the signal.

Optical Communication Systems

Figure 2 displays a basic optical fiber communication system. A basic optical communication system can be defined by three elements: a transmitter, the optical fiber, and a receiver.

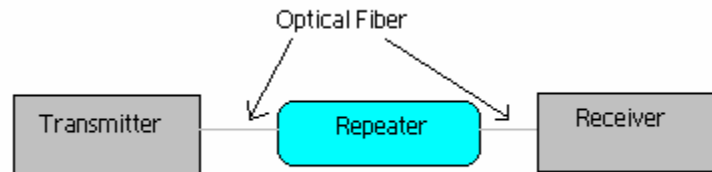


Figure 2: Optical Fiber Communication System

The transmitter collects a group of digital signals and organizes them via time division multiplexing (TDM) and transmits the data into the optical fiber as one stream. Time division multiplexing is simply a process in which the transmitter creates a data stream by send signals out over a period of time so that a bottleneck isn't formed. This data stream, now in the optical fiber is able to travel at speeds of up to 1.2 gigabits per second and the wavelength most often used for transmission is 1310nm. The receiver picks up the data stream and performs a de-multiplexing process so that the data stream is converted back to individual data segments. Figure 2 shows a repeater present in the system. Repeaters are always present in long-range communication systems. The repeater functions to maintain the integrity of the data. As discussed earlier, attenuation, dispersion, polarization, and other factors degrade the strength of the data stream over time and distance. The repeater serves as a “baby” transmitter. It decodes the data stream, re-synchronizes the time division multiplexing, and then re-transmits. Depending

on the length of the communication system multiple repeaters may be necessary. Usually a repeater is necessary every 30-50km.⁽⁵⁾ This is a fundamental optical system for point to point transmission and various industries use different combinations of devices and sources to create large-scale communication and data networking systems, however, on all levels we can break the system down to a transmitter, an optical fiber, and a receiver.

Optical Fiber Manufacturing Process

The key to producing optical fibers is purity and precision. The optical fiber has to have a great level of purity otherwise signals of light will not be able to travel great distances primarily due to degradation factors: attenuation and dispersion. For a good optical fiber, the maximum tolerable level of impurities is 1 part in 10^9 .⁽⁶⁾ Additionally, the size and positioning of the core and cladding with respect to each other and the refractive indices of the two have to be very precise in order to create total internal reflectance.

Optical fiber manufacturing can be broken down to a three-step process: 1) Making a Pre-form, 2) Drawing the fibers from the pre-form, and 3) Testing the fibers. There are several techniques, which can be used to manufacture the pre-form, including: Modified Chemical Vapor Deposition, Outside Vapor Deposition, and Vapor-Phase Axial Deposition. Modified Chemical Vapor Deposition (MCVD), is the process of choice for the majority of the optical fiber production. Silica is formed through a gaseous reaction inside another silica tube. Oxygen is initially bubbled through solutions of SiCl_4 and GeCl_4 . The vapors are driven inside a silica tube and oxy-hydrogen torches heat the entire system. Equations 2 and 3 show that silicon chloride and germanium chloride

react with oxygen to form silicon dioxide and germanium dioxide. The two dioxides then fuse to form glass with the proper refractive index for total internal reflection.



During this reaction, soot forms creating a small annular soot ring. The burners are used to sinter the soot and the result is a mirror-like interface between the core and cladding. MCVD is the most widely used manufacturing process because the refractive indices can be controlled accurately, it is a relatively fast process compared to the others mentioned above, and contamination risks are lower relative to the other processes mentioned above.⁽⁷⁾

Once the pre-form has been created, the next step is to draw out the fibers, similar to silicon ingots. Optical fiber can be drawn in two ways: drawing tower technique and the double-crucible method. The tower technique involves taking a rod from the pre-form and heating it to its melting point. The fiber is drawn from the end by the force of gravity with little mechanical assistance in order to control the rate of production. The fiber is cooled, coated, and set. The double-crucible method uses one platinum crucible inside another. Rods of pre-form are fed to the two crucibles while inside a furnace. The inner crucible forms the core and the outside crucible forms the cladding.

The final step is to test the properties and functionality of the fiber to ensure a quality product. All the factors mentioned before such as: attenuation, dispersion, refractive indices, total internal reflectance all come into play when testing for quality. In addition, tensile strength, operating temperature and humidity, and the capabilities to operate underwater are also examined for application purposes.

Application: Telecommunications, Networking, Military, Medical, and Automotive

Optical fibers are literally the thread of the world. Optical fibers are used all over in telecommunications across the globe. Optical fibers bring high speed Internet to millions of homes along with digital cable television. The military uses optical fibers for tactical command communications and companies around the world use optical fibers in their computer network infrastructure.

Optical fiber applications began development with telephone companies. In the 1960's telephone companies began to look at alleviating the load on their global and international networks. Copper wiring just didn't provide the necessary bandwidth and signal transmission capabilities to handle a growing population. Optical fibers came into play and were used to replace virtually all telephone links throughout the nation. Telephone links are comparable to transformers in power distribution. A link is designated to neighborhoods, communities, and cities off the main grid. Optical fibers were employed and since they're much thinner than copper wires, more optical fibers could be bundled in the same link, hence allowing more phone and cable lines to be distributed.

Since, cable television and Internet providers have taken full utilization of optical fiber's capabilities. A few years ago, cable television companies experienced the same problem as the telephone companies did. Cable television now is able to provide over 200 channels through their services. Up until a few years ago, this was only available via satellite television. The reason was because cable television didn't have the bandwidth in their network to propagate so many channels. This setback resulted in a loss of significant market share to satellite television providers. Now there's nothing but

digital cable, thanks to optical fiber implementation lines. Digital cable is able to send so many channels out through one line because of the bandwidth that optical fiber can provide. By taking a group of different signals from satellite (the channels are the signals), they are grouped and encoded into a data stream by a transmitter at the cable company, sent out via optical fiber, decoded by a receiver in your cable connection and provided to you for viewing entertainment!!

The military uses optical fiber in tactical communications operations. For instance in camps setup in the middle east, the military divisions lay out optical fiber for quick and efficient communication purposes, however, more so for data security and integrity. Traditional communication wiring systems can easily be spliced and tapped for information. This can lead to a very dangerous situation on a mission or loss of intelligence to the opposition. Optical fibers serve as its own security measure. Any splice or interference in the line will cause distortion in the signal due to disruption of total internal reflectance and thus lead to a loss of signal. In addition, optical fibers are free from electromagnetic interference, which is a big plus in high-voltage applications or in nuclear zones.

The medical world is also beginning to reap the benefits of optical fibers. Surgeons use optical fibers as endoscopes during complicated or invasive surgeries. One example is stomach surgery. An optical fiber can be employed rather than having to create a massive cut down the center of a person's body in order to examine and perform on a patient's stomach. The optical fiber can be sent in to the body via a small hole. Surgeons shine light through the optical fiber to get an image of the internal conditions without having to do massive operation. Dentists also employ optical fibers in many

tools such as drills and teeth cleaning tools. The biggest challenge for a dentist is to get light inside a patient's mouth in order to see a problem or to correct it. Dentist drills are now created with optical fibers built in so that an outside light source isn't needed.

The latest employment of optical fibers has come in the automotive industry. Today's automobiles are slowly becoming a home away from home. In most luxury and mid-size sports utility vehicles and luxury sedans items like navigation systems, telephone systems, and high-end audio systems are the norm and aftermarket add-ons like in-dash dvd-players and television screens are quickly on pace to becoming standard features. In addition, in today's vehicles, computer systems monitor and control everything from fuel capacity to tire pressure to oil life. The more equipment placed in cars, the greater the load placed on the car's network. Hence, optical fiber is coming into play because greater bandwidth is necessary in order to provide today's vehicle the capacity to function. Figure 3 provides a picture of a simple car audio network.

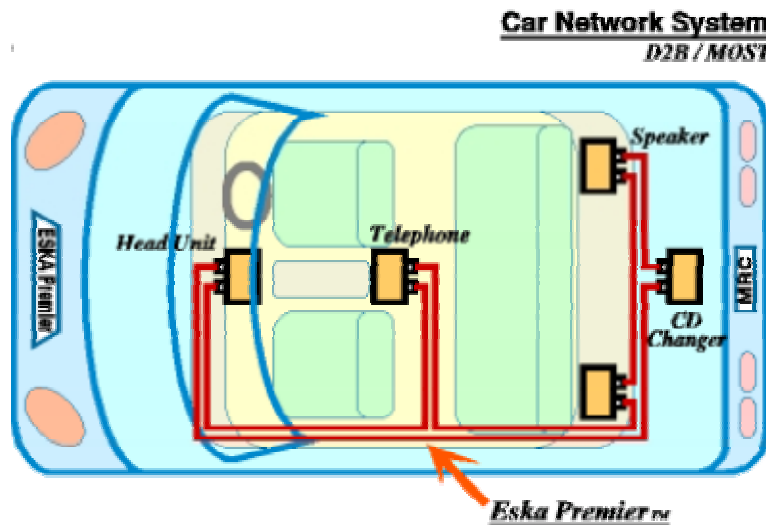


Figure 3: Car Audio Network⁽⁸⁾

Why an Optical Fiber World? A Summary:

The optical fiber world is growing and for very strong reasons. Optical fibers have proved to be more than capable in a diverse range of applications from medical procedures, automotive luxury, and military communications. Optical fibers are a part of our daily lives. Everyone who enjoys cable television, surfing the web, or making a phone call enjoys the benefits and capabilities of optical fibers. Optical fibers are cheaper, more compact, have greater bandwidth, and are less prone to damage and interference, non-flammable, lightweight, flexible, and suited for digital information transfer for long distances. Optical fibers bring a significant level of advantage over other competing materials and being the information age, the world wouldn't be able to progress in due fashion without them.

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