Student 1: Low Excellence

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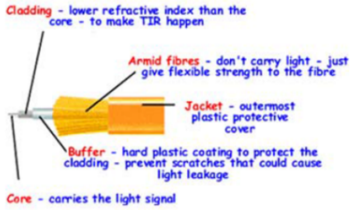
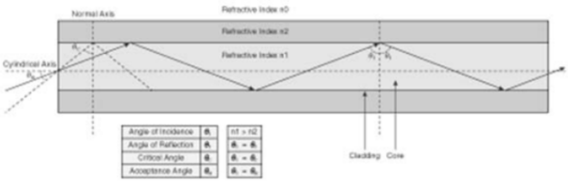
Fiber Optics

Fiber Optics is the study of the design and engineering of optical fiber cables. It is most likely that the last telephone conversation you had, the last TV programme you watched, or your last internet search was because of fiber optic cables. Fiber optics are an intensely physics controlled creation relying on the physics principal pf total internal reflection.

Fiber optics work because of how they are made. The fibers are made of very pure glass and range in diameter but are slightly thicker than a human hair. The fibers are first created by creating a preform blank (which will later be turned into fibers). The preform blank mixture is most important as the precise mixture controls the physical and optical properties of the fiber – including the refractive index. The fibers are tested for things such as refractive index, attenuation, bandwidth and chromatic dispersion. If the fibers pass the tests, the core of the cable is created, which can consist of one or more fibers. The core is then coated in the all-important cladding. Additional layers may be added to prevent light leakage through surface scratches etc. Buffer coating(s) are often added to protect the core and help absorb any shock. A strength member may also be added to protect against pulling/bending damage and environmental factors. All these layers help reduce the amount of attenuation and create a fiber optic cable.



The cables work through the principle of total internal reflection (TIR) which states a ray of light will be 100% reflected when it hits the boundary where a medium of a high refractive index meets a medium of lower refractive index ($n_1 > n_2$), and strikes the boundary at an angle larger than the critical angle ($\Theta_i > \Theta_c$).



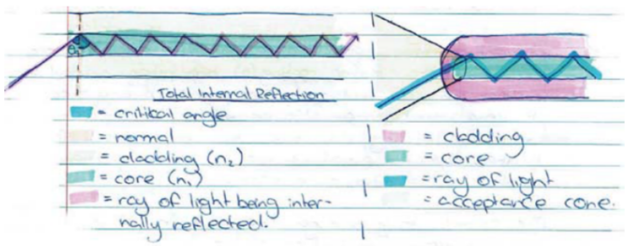
The refractive index is the mediums optical density or the ratio of the speed of light in a vacuum to the speed of light in the material. The core of a fiber optic cable usually has a refractive index of 1.48, therefore the cladding has a lower refractive index. The critical angle means that when the ray of light hits the boundary, it must hit at a certain angle to the normal, so it can travel along the boundary (90° to the normal). TIR occurs when the angle of incidence is larger than this angle. If the angle of incidence is less, some of the light will be refracted (pass through the boundary) and the light will eventually fade off resulting in signal loss.

The critical angle and refractive index (n) is calculated by Snell's law:

$$n_1 \sin\Theta_1 = n_2 \sin\Theta_2$$

For example, for a different fibre optic cable, if $n_1 = 1.557$ and $n_2 = 1.343$, the critical angle is 30.39 degrees. ①

The ray of light must also enter the core at an angle less than the acceptance angle. The acceptance angle is the angle at which if light enters, it will travel down the core. This can also be seen through an acceptance cone which is a core of which the maximum angle of incidence can be to travel down the core. The size of the acceptance cone is a function of the refractive index difference between the core and the cladding.

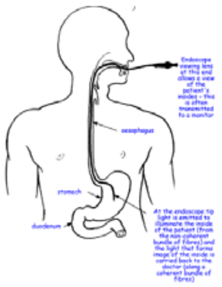


The construction of fiber optic cables will not always enter the core correctly – this results in energy loss of the ray of light or disruption to the light ray. Attenuation is the loss of energy/power in the light ray as it is transmitted down the cable. This can occur due to splices, connectors or faults in the cable. It most commonly occurs because when fiber optic cables are laid, bends in the cable occur. These bends mean the angle at which light hits the boundary is changing and could result in the light hitting the boundary at an angle less than the critical angle. Thus, some of the light refracts instead of 100% reflecting, and light escapes from the core therefore energy (or signal) is lost. However, this can counteracted by an optical regenerator (explained later in the report).

Dispersion is defined as the spreading of light pulse when they travel a fiber. This is due to the fact that speed of light depends on its wavelength and propagation mode. Dispersion does not weaken the signal, but it blurs the signal. For example, a pulse of 1 nanosecond at the transmitter will be spread out to 10 nanoseconds at the receiver. Hence, signals are not properly received and decoded. Modal dispersion means the light signal is spread over time due to different propagation of light rays in the fiber. Chromatic dispersion is the spreading of the light signal over time due to the different speeds of the different colours of light. Modal dispersion often occurs in multimodal cables. Multimodal have a large core, so the rays internally reflect, and the light signal is often produced by an LED. This light source isn't always the best as light enters the core at different angles, and travels in random lines down the core. The different angles of incidence mean some light rays experience TIR but others experience some refraction and thus signal loss occurs. Chromatic diffusion on the other hand occurs in single modal cables, which have a small core diameter this the light tends to travel in a straight line through the fiber (they can carry more information than multimodal cables). Lasers are usually the light source for single modal fibers, and therefore one wavelength of light travels down the fiber. This one ray of light experiences chromatic dispersion which in turn limits the length of the fiber because the light signal can arrive at the destination all jumbled because it has travelled at different times. (2)

For data to have travelled efficiently, with zero signal loss; the angle of incidence must have always been more than the critical angle, the amount of data sent must be less than the maximum transmission amount over a certain distance and the light must still have enough power to be converted into an electrical signal by an optical receiver (explained later).

The fiber optic cable cannot work by itself, other equipment must be used to transfer the signal. A transmitter is used to produce and encode the light signal by turning an LED/Laser on and off in the correct sequence to create a light signal. The transmitter is found at the start of the link (source) and may have a lens to focus the light into the core (reducing dispersion). Along the link, an optical regenerator may be found to boost the energy of the light ray. It does this as when the light ray comes into contact with a special coating (doping) on the regenerator that is pumped with energy from a laser, the molecules receive that energy and become lasers, thus emitting a stronger signal with the same characteristics as the incoming signal. This reduces the amount of attenuation a light ray may experience. An optical receiver is found at the end of the link (destination) and it receives and decodes the light signal into electrical signal. This occurs as a photocell or photodiode changes the incoming light rays into electrical signals to send to the destination.



Fiber optics has many uses, but an important use is fiber optic imaging. The fiber optic cables act as light pipes because TIR allows 100% of the light to be transferred. The fibers must be arranged in a coherent bundle (fiber placed in same spot in start as they are at the end of the cable) so a mosaic of light forms an image ray the opposite end. An example of this is the medical colonoscopy procedure where one bundle of fibers is used as a torch, and the others act as an elongated lens which sends an image to a video camera or the human eye.

Fiber optics are often preferred over copper wires as they are cheaper, thinner and more light weight. With fiber optics more information can be transmitted as more fibers fit into the same diameter thus more phone lines or TV cables can be wired. There is less signal loss with fiber optics as there is no energy loss due to heat through resistance like in copper cables. Therefore, less power is required. However, fiber optics are hard to join together in small spaces, which in this case copper wires are still preferred (e.g. kitchen appliances). Fiber optics are quicker and easier to repair, suffer minimal propagation delays and have a higher bandwidth so can carry more data. However, some of the light signal degrades within the fibre, mostly due to impurities in the glass. The extent that the signal degrades depends upon the purity of the glass and the wavelength of the transmitted light (for example, 850 nm = 60 to 75 percent/km; 1,300 nm = 50 to 60 percent/km; 1,550 nm is greater than 50 percent/km). Some premium optical fibers show much less signal degradation -- less than 10 percent/km at 1,550 nm.

Overall fiber optics are a brilliant piece of physical design and engineering thanks to the principle of total internal reflection. Even though fiber optics experience signal loss, it can be counteracted, and they are far more efficient than copper cables and sometimes satellite. Fiber optics are a technology that, thanks to Physics, continue to revolutionise data transfer in the world. (2)