Fiber Optics

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Introduction

One of the greatest advancements in the networking field in the last couple of decades has been the widespread adoption of fibre optic communication technologies. Without fibre optic cables we would not have the network speeds we see today. Likewise, we would not have a lot of the products and services that are available to us today.

Let's Begin

Fibre optics work by transmitting light signals instead of electrical signals like those found in traditional copper wire. Fibre optic cables do this by acting as a wave guide for light waves of a certain frequency. It can do this due to the scientific principle called refraction. Refraction is the change in direction of a wave (in this case a light wave) due to a change in speed. One example of this is a straw in a glass of water; it will appear that the straw is bent but in reality it is only the light waves which have been bent when they transition from air to water. Fibre optic cables work very much the same way except that the light wave's direction is changed more drastically in a way which keeps the light wave within the core of the fibre optic cable. This is called total internal reflection and is shown in Figure 1. As you can see, the beam of red light travels from side to side as it travels from one end to the other. This is how fibre optics can transmit data across long distances while not confined to being straight line of sight paths.

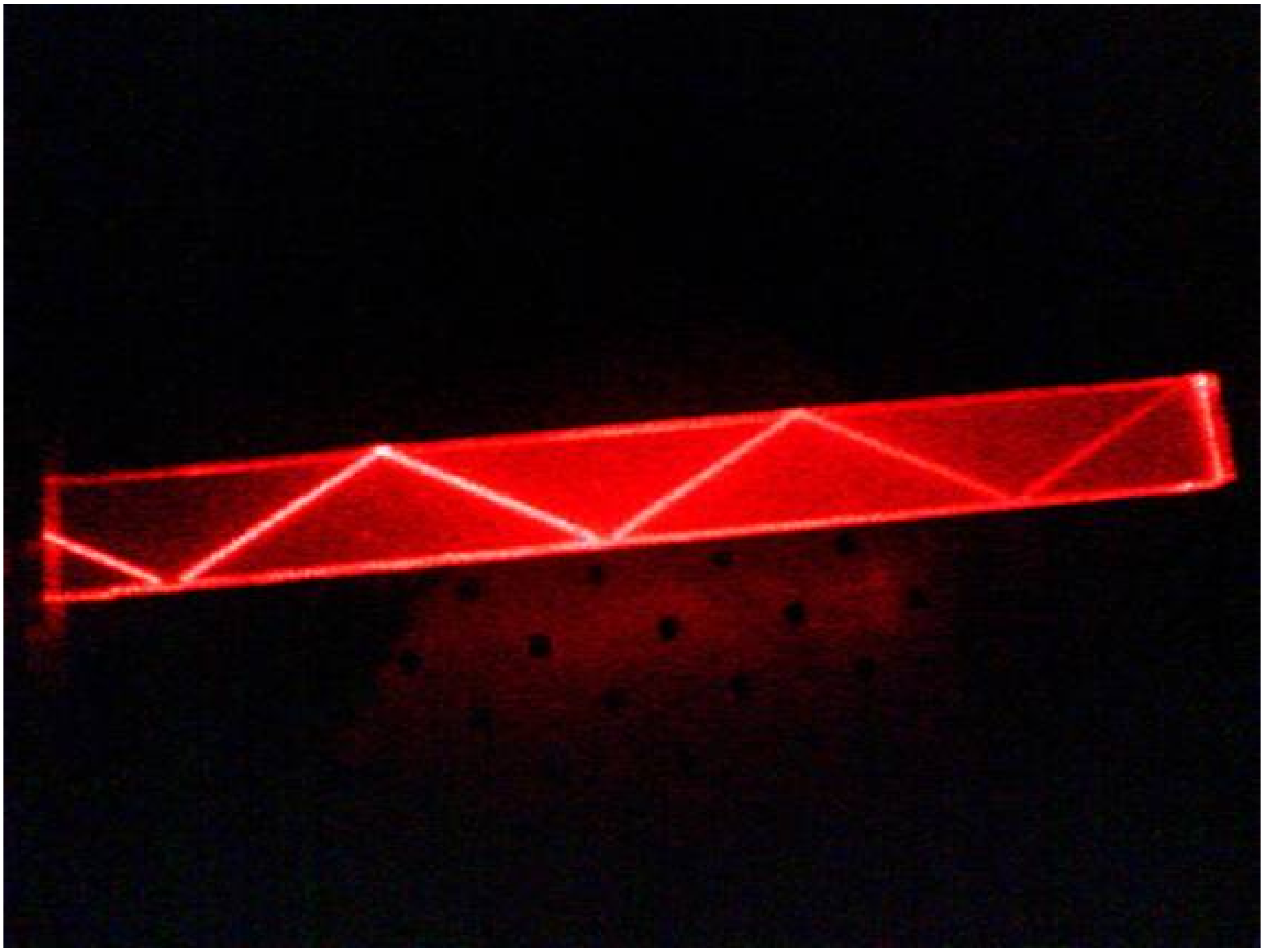

Figure 1: Total Internal Reflection

How do light waves change their speeds? They do this as they travel through different mediums. Light travels the fastest in a vacuum; this is considered the speed of light (about 300 million metres per second). In earth's atmosphere light travels slightly slower, and through water light travels even slower. In fact, different wave lengths of light (which is the same as saying different colours of light) will change their speed at different rates. This is how rainbows are created; light waves will be refracted as they contact water droplets, and different colours will be refracted different amounts and result in the splitting up of the colours.

The fact that different colours, or wavelengths, of light will refract differently is good if you want to make rainbows; but in fibre optic cables this is bad. Fibre optic cables are manufactured with a specific refractive index (a number which indicates the properties of refraction) and are designed to be used with one wavelength of light. These wavelengths are in the infra-red spectrum and the values used are 850 nanometres (nm), 1300nm (or 1310nm, more on that later), and 1550nm. However, due to imperfect transmitter manufacturing it is in fact a small spectrum of wavelengths around the desired wavelength. Even these very small differences in wavelengths will refract differently within the fibre cable. This is called dispersion, and there are many techniques available to counter this undesirable behaviour.

Of course, some applications may not be as sensitive to these dispersion effects. This is what multi-mode fibre is for. There are basically two types of fibres. Multi-mode fibre is the type of fibre one is likely to see within a building or between a few buildings, while single mode fibre is used for long-haul communications.

Multi-mode Fibre

Multi-mode fibre allows light-waves to travel along different paths within the core because it is manufactured with a larger core size. This is beneficial because it is easier to make the actual cable and it allows for more inexpensive transmitters, such as LEDs, which are not capable of the extreme precision required for single-more fibre optic cables. Transmitters for multi-mode fibre optic cables typically operate at either 850nm or 1300nm. Because of the larger core, which can collect more light easier, there is a high degree of dispersion which occurs in multi-mode fibre optic cables. This is why there is a limited range for which multi-mode fibres can be used. Multi-mode fibre optic cables are commonly seen within a building, or a small campus of buildings. If multi-mode fibre optic cable is used for longer ranges the dispersion will be seen as noise on the receiver and will significantly reduce performance.

Another, not as obvious, problem that is caused by this dispersion is the longer wait time required between pulses. Because different wavelengths refract differently, each wavelength will have a different total length traveled from transmitter to receiver. This means that a receiver will receive a pulse that is wider than the pulse originally sent by the transmitter. So, any transmitter will have to take into consideration what the pulse width will be at the receiver and leave an appropriate amount of space between pulses to compensate for this.

Another type of dispersion seen in multi-mode fibre optic cables is called modal dispersion. Basically, because light pulses can enter the core at different angles (because of the larger core) there can be a variety of paths which a pulse can take to travel to the receiver. Because of these different paths (called modes) the pulses traveling along these modes will not arrive at the receiver at the same time. This will be seen as noise by the receiver and must be compensated for. Modal dispersion is another reason why there must be a significant wait time between pulses which of course will limit the total achievable bandwidth.

Single Mode Fibre

Single mode fibers are typically used in long-haul communications. Single mode fibres have a smaller core and require a much more precise transmitter, which of course is considerably more expensive. Because of this smaller core a light pulse can only travel along one mode which eliminates the problem of modal dispersion. With that improvement over multi-mode fibre optic cables, single-mode fibre optic cables require less wait time between pulses and are capable of much higher transmission bandwidths.

Single-mode fibre optic cables typically operate with light wavelengths of 1310nm or 1550nm. Why 1310nm and not 1300nm like multi-mode fibre optic cables? Well this is only a convention, which I'm told, goes back to the days when AT&T was the king of fibre.

While single-mode fibre optic cables do not suffer from modal dispersion, they do suffer from the dispersion caused by different wavelengths refracting differently. Since single-mode fibre is used for long-haul communications this type of dispersion can be a significant problem. There are some very clever ways to overcome this dispersion, but they best left for another article.

Use of Fibre as Sensors

Most people, incorrectly, assume fibre optic cables are only used for telecommunication purposes; there are actually many other uses for fibre optic cables. While telecommunications is a very common, visible, use of fibre optics, it is also very common to use them as sensors.

Because of the various properties of light, all of which also occur within a fibre optic cable, fibre optics can be used to measure strain, temperature, or pressure. This can happen by designing a fibre optic cable to be sensitive to a specific element such as temperature, or strain. This will then affect the light pulse sent through the fibre optic cable, the change pulse received after passing through the fibre can then be analyzed to determine the amount of strain or the temperature, or whatever is being measured. This can be advantageous due to the fact that no electricity passes through the cable; in some sensitive environments this is a necessity.