fibre optics
the art of science

written and illustrated by
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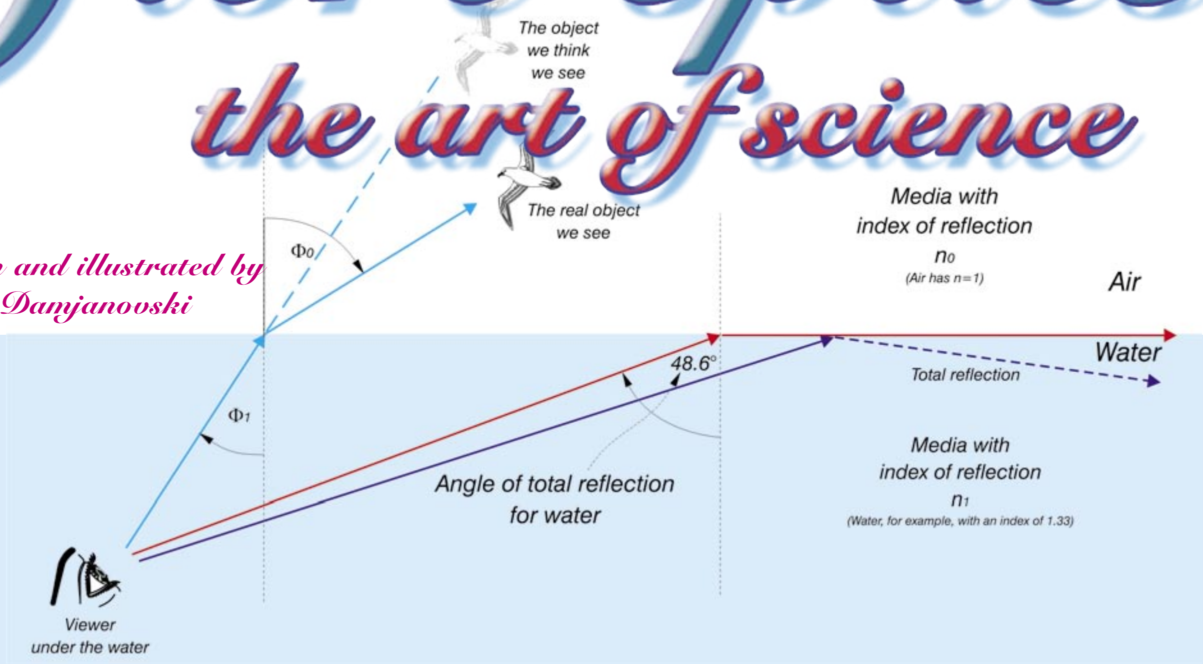


Fibre optics, if correctly installed and terminated, is the best quality and most secure transmission of all. Even though it has been used in long distance telecommunications, even across oceans, for over thirty years, it has been avoided or neglected in CCTV.

The main excuse installers have used was the fear of unknown technology, often labelled as "touchy and sensitive" and also considered "too expensive."

Fibre optics though, offers many important advantages over other media and although it used to be very expensive and complicated to terminate, it is now becoming cheaper and simpler to install.

Most important advantages of all are immunity to electromagnetic interference, more secure transmission, wider bandwidth and much longer distances without amplification. We feel that ***CCTV focus*** readers need and want to learn more about fibre.

Why fibre?

Fibre optics is a technology that uses light as a carrier of information, be it analog or digital. This light is usually infrared, and the transmission medium is fibre.

Fibre optic signal transmission offers many **advantages** over the existing metallic links. These are:

- **Very wide bandwidth.**
- **Very low attenuation**, in the order of 1.5 dB/km compared to over 30 dB/km for RG-59 coax (relative to 10-MHz signal).
- The fibre (which is dielectric) offers

electrical (galvanic) isolation between the transmitting and receiving end; therefore **no ground loops are possible**.

- Light used as a carrier of the signal travels entirely within the fibre. Therefore, it causes **no interference with the adjacent wires or other optical fibres.**

- The **fibre is immune to nearby signals and electro-magnetic interferences** (EMI); therefore, it is irrelevant whether the fibre optics passes next to a 110 V AC, 240 V AC or 10,000 V AC or whether it is close to a megawatt transmitter. Even more important, **lightning cannot induce any voltage** even if it hits a centimeter from the fibre cable.

- A fibre optics cable is very **small and light** in weight.

- It is **impossible to tap into the fibre optics cable without physically intercepting the signal**, in which case it would be detected at the receiving end. This is especially important for security systems.

- The cost of fibre is becoming cheaper every day. A basic fibre optics cable costs anywhere from $1 to $5 per metre, depending on the specific type and construction used.

There are also some not so attractive features of fibre optics, although they are being improved:

- Termination of fibre optics requires special tools and better precision of workmanship than with any other media. Lately though there is an increasing number of easy-to-terminate fibre optics kits.

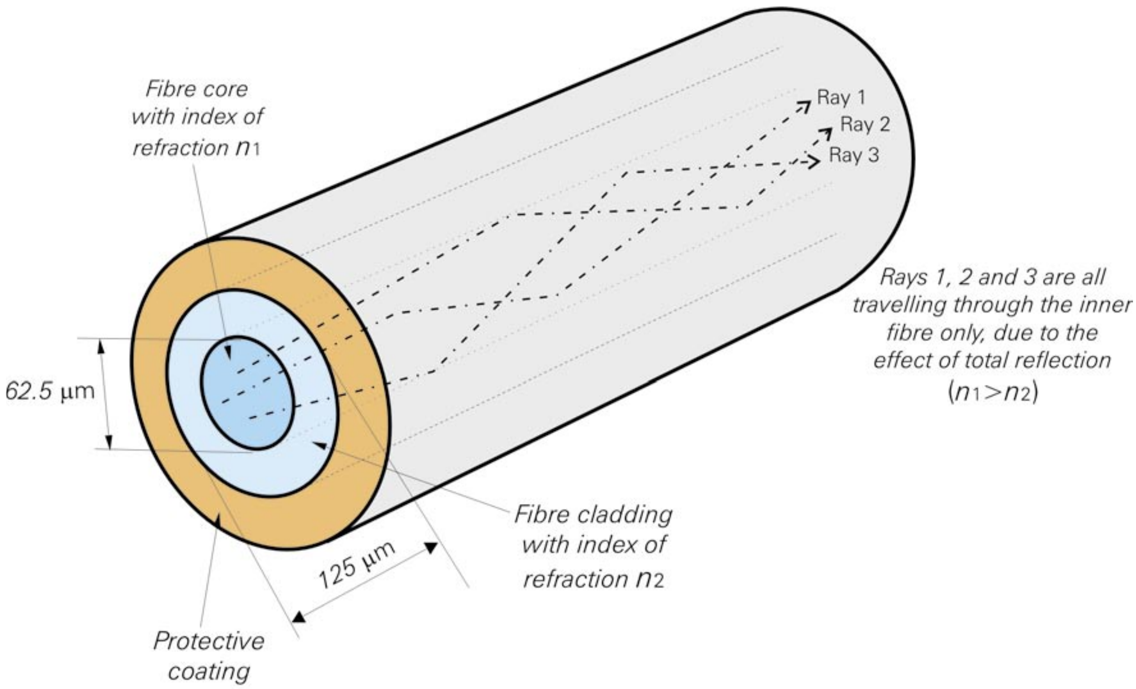
- Switching and routing of fibre optics signals difficult. Lately though, various fibre manufacturers have started introducing various digital switching and routing equipment.

So it is quite clear that fibre optics offers more advantages than the other types of cables (read copper).

These advantages are increasing daily.

It is only natural that as it becomes more affordable and better understood it will become more popular in CCTV and security in general.

From a technical point of view, there is no better or more secure cable transmission method.



Fibre optics usage is based on the effect of total reflection

The concept

The concept of fibre optics lies in the fundamentals of light refraction and reflection.

To some it may seem impossible that a perfectly clear fibre can constrain the light rays to stay within the fibre as they travel many kilometres, yet not have these rays exit through the walls along the trip. In order to understand this effect, we have to refresh our memory about the physical principle of total reflection.

Physicist Willebrord Snell laid down the principles of refraction and reflection in the early 17th century. When light enters a denser medium, not only does the speed reduce, but the direction of travel is also corrected in order for the light to preserve the wave nature of propagation. Basically, the manifestation of this is a light ray sharply bent when entering different media. We've all seen the broken straw effect in a glass of water. That is refraction.

A typical glass has an index of refraction (n) of approximately n=1.5. The higher the index, the slower the speed of light will be, thus the bigger the angle of refraction when the ray enters the surface.

The beauty behind a diamond is the rainbow of colours we see due to its high index of refraction (n=2.42). This is explained by the fact that a ray of light (natural light) has all the colours (wavelengths) a white light is composed of.

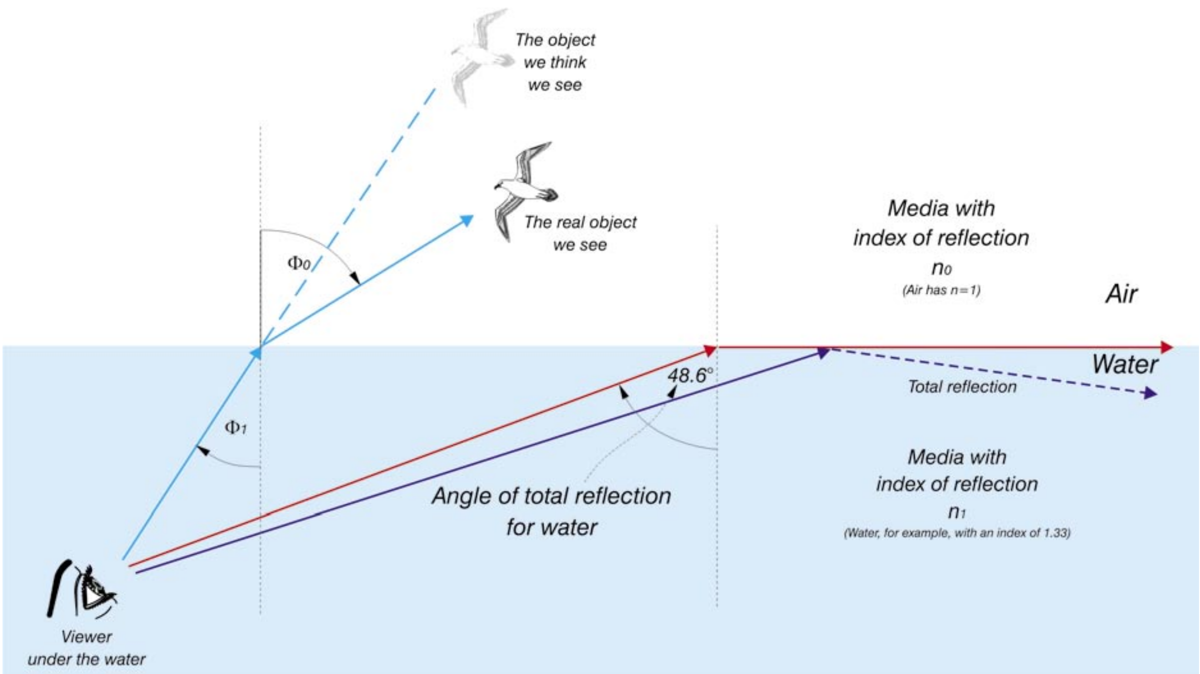
Fibre optics uses a special effect of refraction under a maximum incident angle; hence, it becomes a **total reflection**. This phenomenon occurs at a certain angle when a light ray **exits** from a dense medium to a sparser medium.

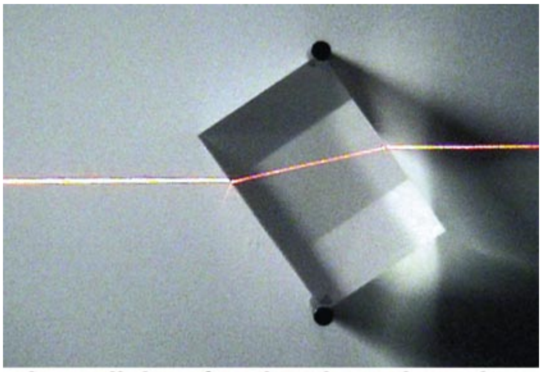
The drawing below shows the effect of a diver viewing the sky from under the water. There is an angle below which he can see no further above the water surface. This angle is called the **angle of total reflection**. Beyond that point he will actually see the objects inside the water further away from him and it will seem to him like looking through a mirror (assuming the water surface is perfectly still).

For the index of refraction of water (n=1.33), using Snell's Law, this angle can be calculated and it is 48.6°.

The concept of fibre optics transmission follows the very same principles.

The core of a fibre optics cable has an



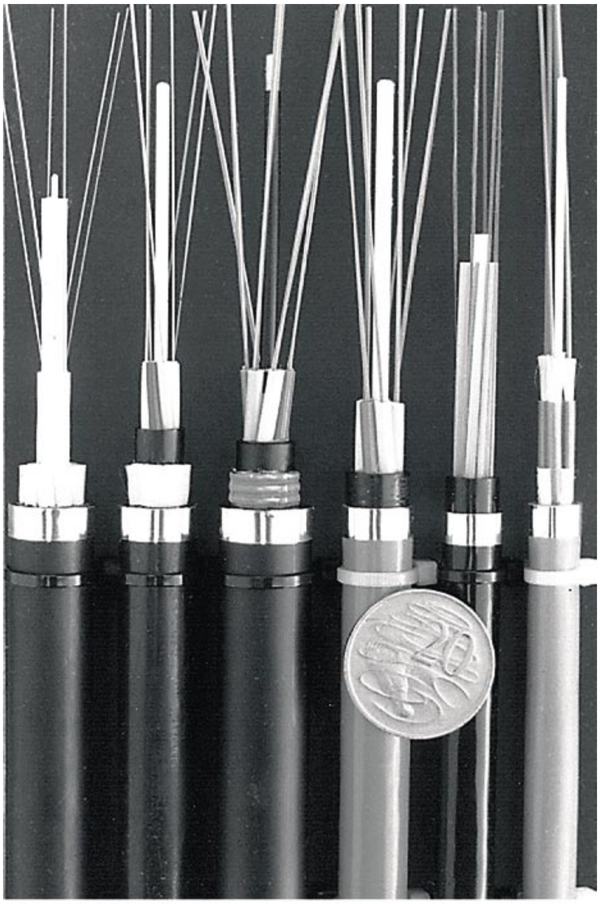


Laser light refraction through a prism

index of refraction higher than the index of the cladding. Thus, when a light ray travels inside the core it cannot escape it because of the total reflection.

So, what we have at the fibre optics transmitting end is an LED (light emitting diode) or LD (laser diode) that is modulated with the transmitted signal.

In the case of CCTV the signal will be video, but similar logic applies when the signal is digital, like a PTZ control or other security or network data.



Various types of multi-fibre cables

When transmitting the infrared diode is **intensity modulated** and pulsates with the signal variations. At the receiving end, we have basically a photo detector that receives the optical signal and converts it into electrical.

Fibre optics used to be very expensive and hard to terminate, but that is no longer the case, because the technology has improved substantially. Optical technology has long been known to have many potential capabilities, but major advancements are achieved when mass production of cheap fundamental devices like semiconductor light emitting diodes, lasers and optical fibres are made.

Nowadays, we are witnessing a conversion of most terrestrial hard-wired copper links to fibre.

Types of optical fibres

There are a few different types of fibre optics cables. This division is based on the path light waves take through the fibre.

As mentioned in the introduction, the basic idea is to use the total reflection effect that is a result of the different indices of refraction ($n_2 > n_1$, where n_2 is the index of the internal (**core**) fibre and n_1 is the index of the outer (**cladding**) fibre).

A typical representation of what we have just described is the **step index** fibre optics cable. The index profile is shown on the next page, as well as how light travels through such a cable. Note the input pulse deformation caused by the various path lengths of the light rays bounced from the cylindrical surface that divides the two different index fibres. This is called a **modal distortion**.

In order to equalise the path lengths of different rays and improve the pulse response, a **graded index** (or **multimode)** fibre optics cable was developed. Multimode fibre makes the rays travel more or less at an equal speed, causing the effect of **optical standing**

waves.

And finally, a **single mode** fibre cable is available with even better pulse response and almost eliminated modal distortion.

This latter one is the most expensive of all and offers the longest distances achievable **using the same or similar electronics**.

For typical CCTV applications, where camera to monitor distances are within a few kilometres, the multimode and step index are adequate. In larger systems, such as city and inter-city projects, where distances of up to 20~30km need to be achieved, the single-mode should be used.

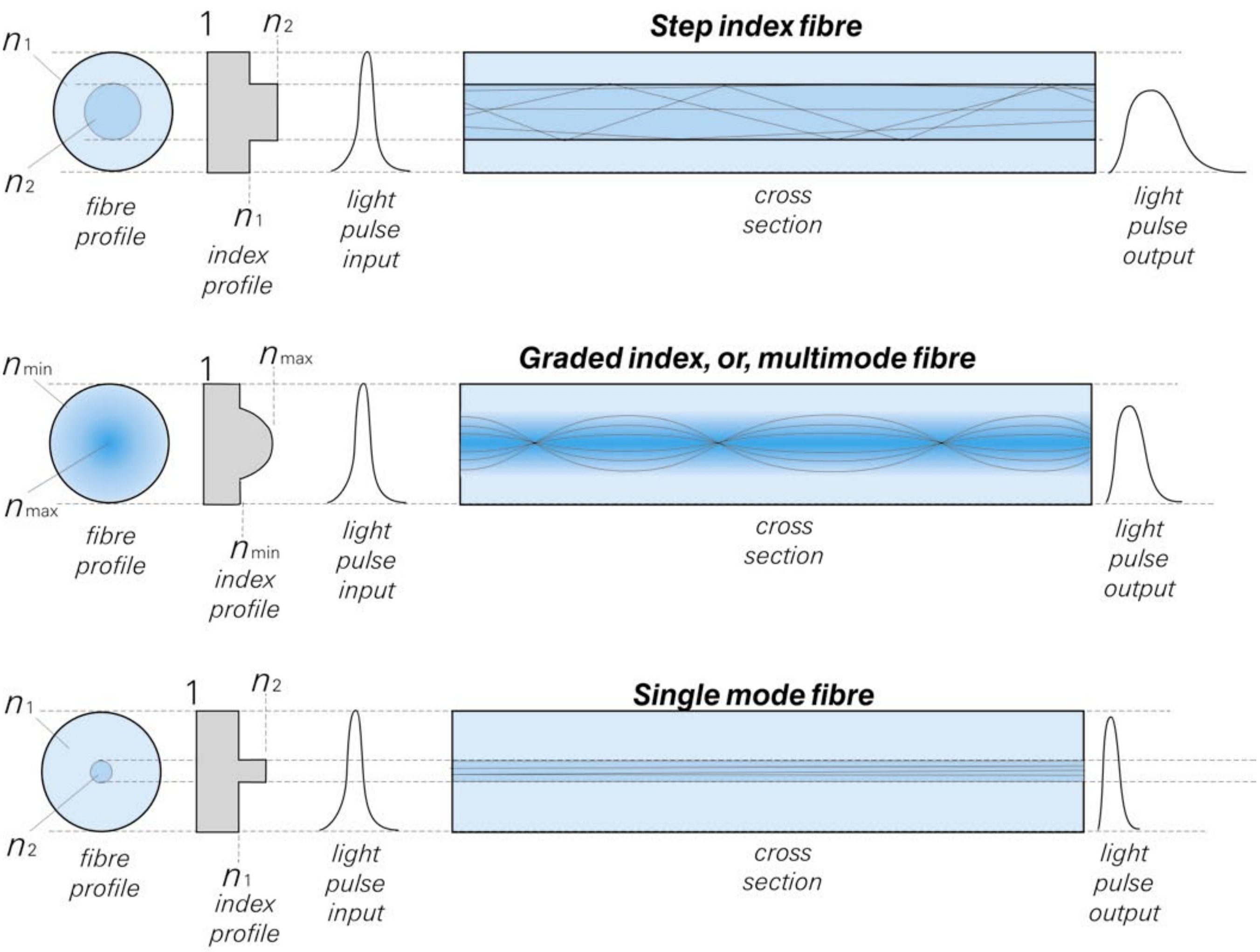
The index profiles of the three types are shown on the diagram below.

Numerical aperture

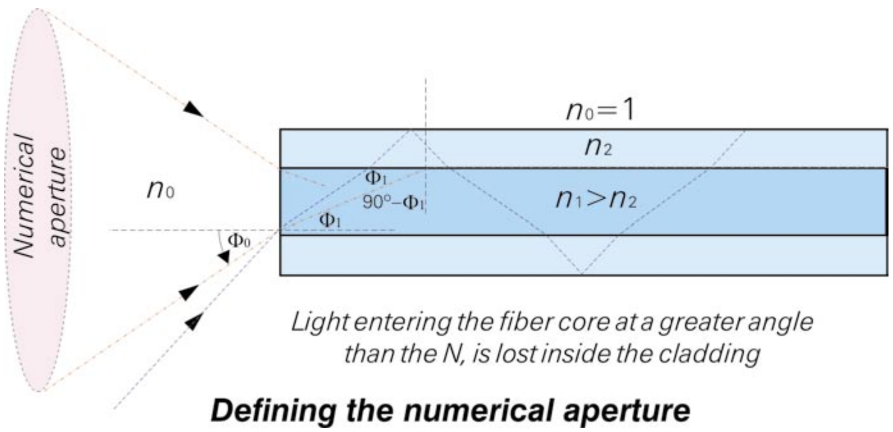
The light that is injected into the fibre cable may come from various angles.

Due to the different indices of the air and the fibre, applying the same Snell's refraction law, it can be concluded that there is a maximum entry angle for a light source entering the fibre cable. Above this angle, light that gets inside the fibre scatters outside the core and is **lost.**

So, when making a fibre cable contact or joint, it is important to understand that there are some limitation to how much light and at what angles it can get inside the fibre and still be used as a signal travelling through



Three different types of fibres



Defining the numerical aperture

the core.

This is a very important fibre cable property, called **numerical aperture** (**NA**).

So, in simple words, **NA represents the light-gathering ability of a fibre optics cable.**

In practice, NA helps us to understand how two terminated fibres can be put together and still make a signal contact.

The realistic value of a typical NA angle, for a step index fibre cable is shown on the drawing above.

Obviously, **the higher this number is, the wider the angle of light acceptance will be of the cable.**

A realistic example would be with $n1$=1.46 and $n2$=1.40 which will give us NA=0.41, i.e., $\phi 0$=24°.

For a graded index fibre this aperture is a variable and it is dependent on the radius of the index which we are measuring, but it is lower than the step index multimode fibre. A single mode 9/125-µm fibre has NA = 0.1.