

Optical Fibres.....Seeing the Light

Fibre optics is one of the most interesting and current fields of Physics today. It is the backbone and concept behind optical fibres which have important applications in many industries today.

Through this web page we hope to share the amazing knowledge we have gained about optics and optical fibres and show you how this has affected your life and will affect your life in the years to come. We hope that this page will be informative and interesting to all people regardless of age.

The Theory of Optical Fibres

These few pages will explain the concepts behind optical fibres and how they work. We have arranged them in order but feel free to navigate around as you like.

[1. Total Internal Reflection](#)

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The Physics of the Optical Fibre

1. Total Internal Reflection

When light traveling in a transparent material meets the surface of another transparent material two things happen

1. some of the light is reflected

2. some of the light is transmitted into the second transparent material

The light which is transmitted usually changes direction when it enters the second material. This bending of light is called refraction and it depends upon the fact **that light travels at one speed in one material and at a different speed in a different material**. As a result each material has its own **Refractive Index** which we use to help us calculate the amount of bending which takes place.

Refractive index is defined as:-

$$n = C/V$$

where

n is the refractive index

C is the speed of light in a vacuum

V is the speed of light in the material

Two possible cases exist.

These are:-

1. where light goes from a material with a low refractive index to one with a high refractive index

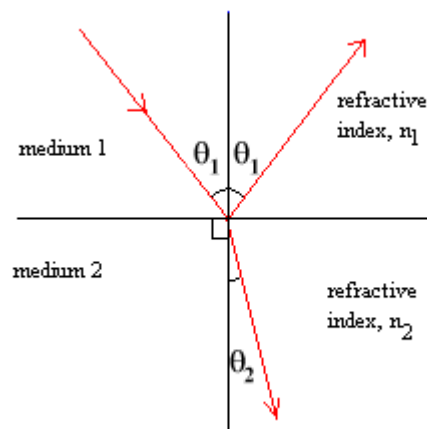


Figure 1 - $n_1 < n_2$

2. where light goes from a material with a high refractive index to one with a low refractive index.

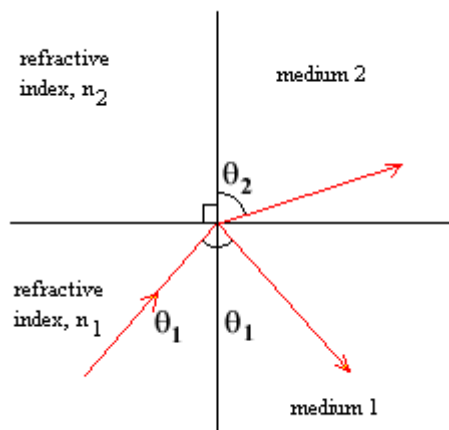


Figure 2 - $n_1 > n_2$

Total Internal Reflection

In the second case above, q_2 is always greater than q_1 (q_1 and q_2 refer to the angles) . So, as we increase q_1 , eventually q_2 will reach 90° before q_1 does. At this point where q_1 has reached a value called the **critical angle** (q_c).

The transmitted ray now tries to travel in both materials simultaneously. This is physically impossible so there is no transmitted ray and all the light energy is reflected. This is true for any value of q_1 , the angle of incidence, equal to or greater than q_c . This phenomenon is called Total Internal Reflection (TIR).

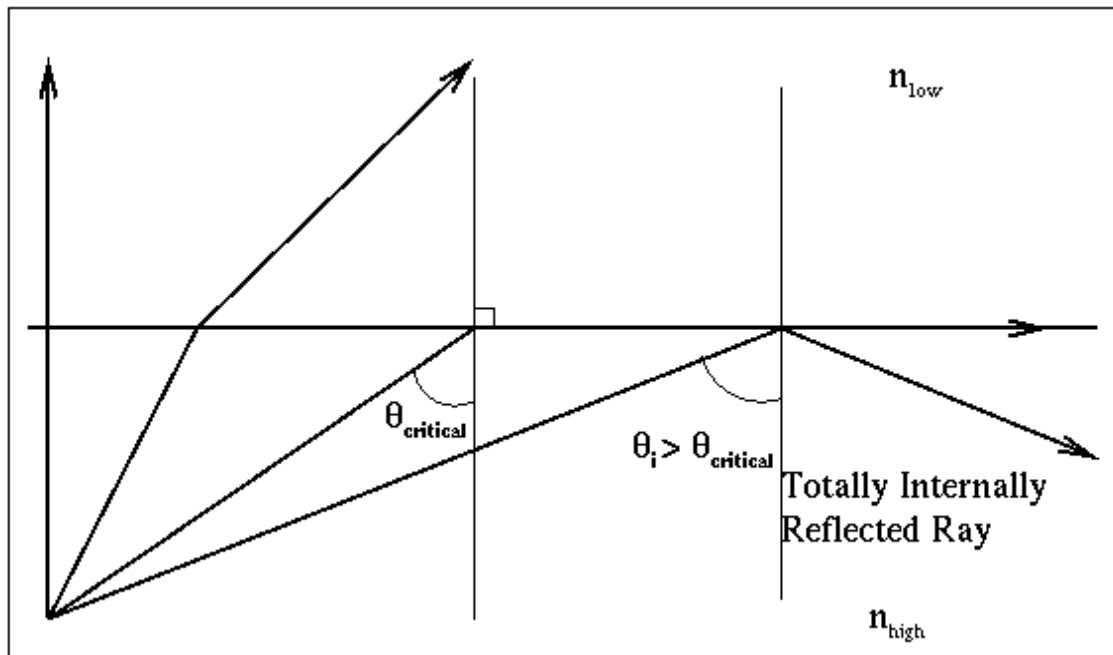


Figure 3- Total Internal Reflection

We can define the two conditions necessary for TIR to occur

- 1.The refractive index of the first medium is greater than the refractive index of the second one.
- 2.The angle of incidence, q_1 , is greater than or equal to the critical angle, q_c .

The phenomenon of TIR causes 100% reflection. In no situation in nature, where light is reflected, does 100% reflection occur. So TIR is unique and very useful and is used in optical fibre technology.

2. Structure of Optical Fibres

An optical fibre is basically made of 2 types of glass put together in a concentric arrangement so the middle is hollow.

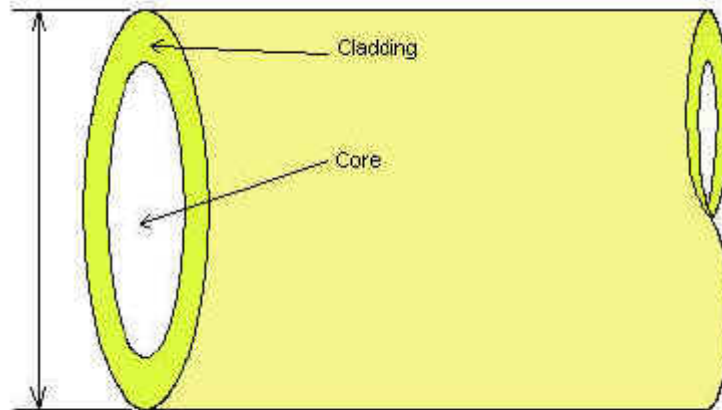


Figure 1 -Structure of an Optical Fibre

The inner circle of glass consists of a glass of higher refractive glass than the outside circle. The outer circle of glass, which is also known as the optical cladding, does not carry light but is essential to maintain the critical angle of the inner glass.

The main physics behind the optical fibre is a phenomenon known as [Total Internal Reflection](#).

Propagation of light in the fibre:

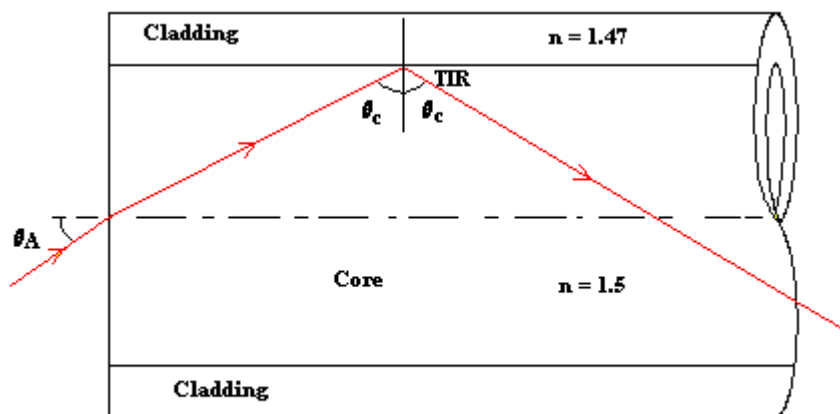


Figure 2 - The Propagation of Light in Optical Fibres

The angle q in the Figure is called the Acceptance Angle. Any light entering the fibre at less than this angle will meet the cladding at an angle greater than critical angle. If light meets the inner surface of the cladding (the core - cladding interface) at greater than or equal to critical angle then TIR occurs. So all the energy in the ray of light is reflected back into the core and none escapes into the cladding. The ray then crosses to the other side of the core and, because the fibre is more or less straight, the ray will meet the cladding on the other side at an angle which again causes TIR. The ray is then reflected back across the core again and the same thing happens. In this

way the light zig-zags its way along the fibre. This means that the light will be transmitted to the end of the fibre.

In reality the light which enters the fibre is a focused beam, consisting of many millions of "rays" behaving in a similar way. They all zig-zag along the core of the fibre, crossing over each other, and filling up the core with light. A pulse of light traveling along the core of the fibre is really a bundle of these rays.

Optical fibres act as a guide for light. Once light enters the fibre, it moves in the same direction as the fibre. As the fibre can be bent, light can thus be bent around corners by using optical fibres.

3.Types of Fibres

There are two main fibre types:

- 1) Step index (multimode, single mode)
- 2) Graded index (multimode)

1)Step Index Fibre

Step index fibre is so called because the refractive index of the fibre 'steps' up as we move from the cladding to the core of the fibre. Within the cladding the refractive index is constant, and within the core of the refractive index is constant.

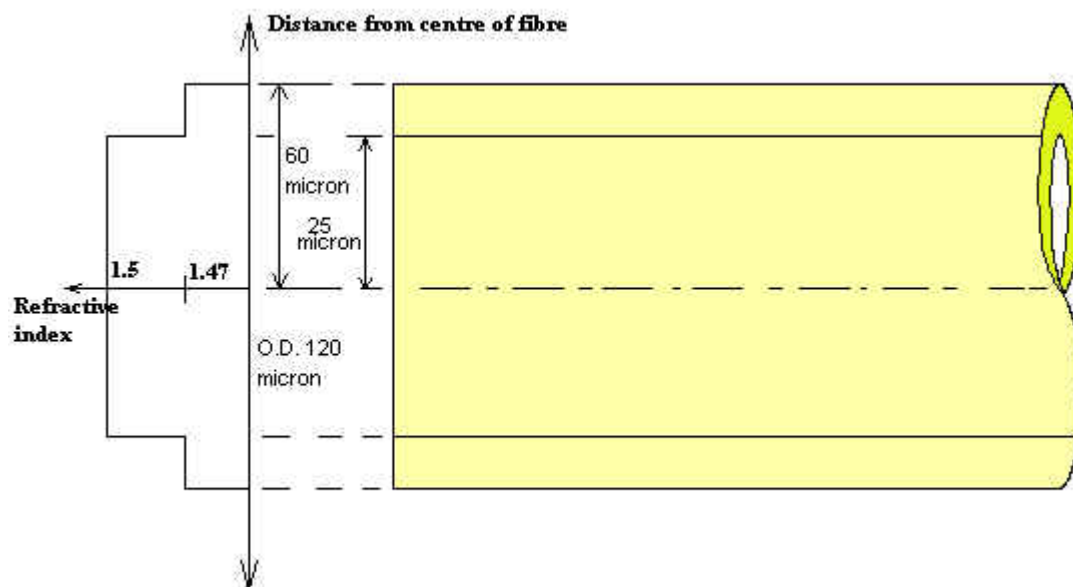


Figure 1 - Step Index Fibre

i) Single Mode Step Index Fibres

Because its core is so narrow, a Single Mode fibre can support only one mode. This is called the "Lowest Order Mode".

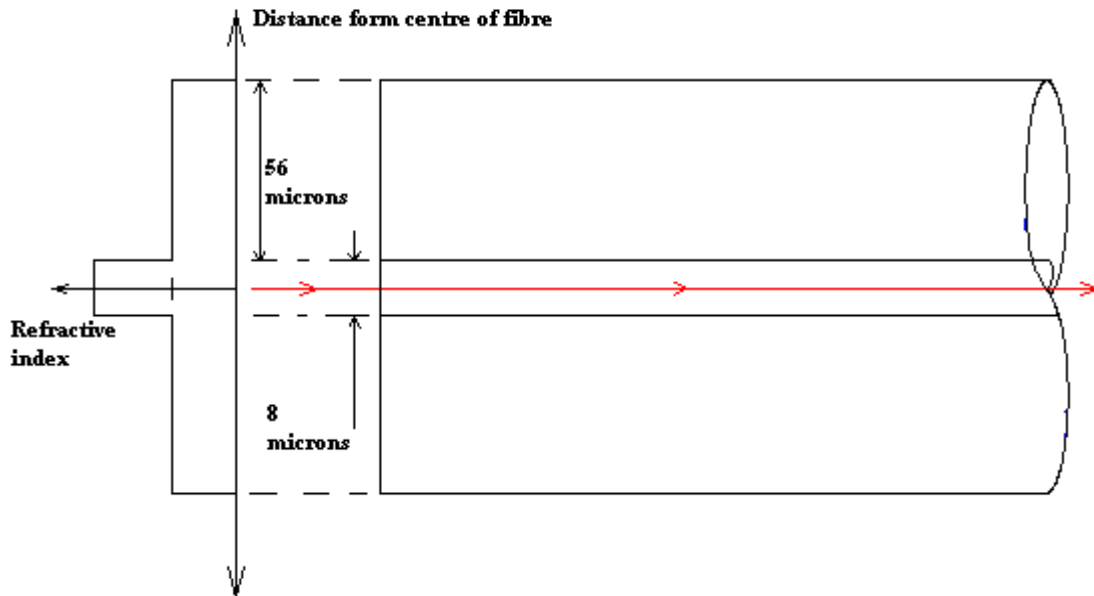


Figure 2-Single mode Step Index Fibre

ii) Multimode Step Index Fibres

Although it may seem from what we have said about [Total Internal Reflection](#) that any ray of light can travel down the fibre, because of the wave nature of light, only certain ray directions can actually travel down the fibre. These are called the "Fibre Mode". In a multimode fibre many different modes are supported by the fibre.

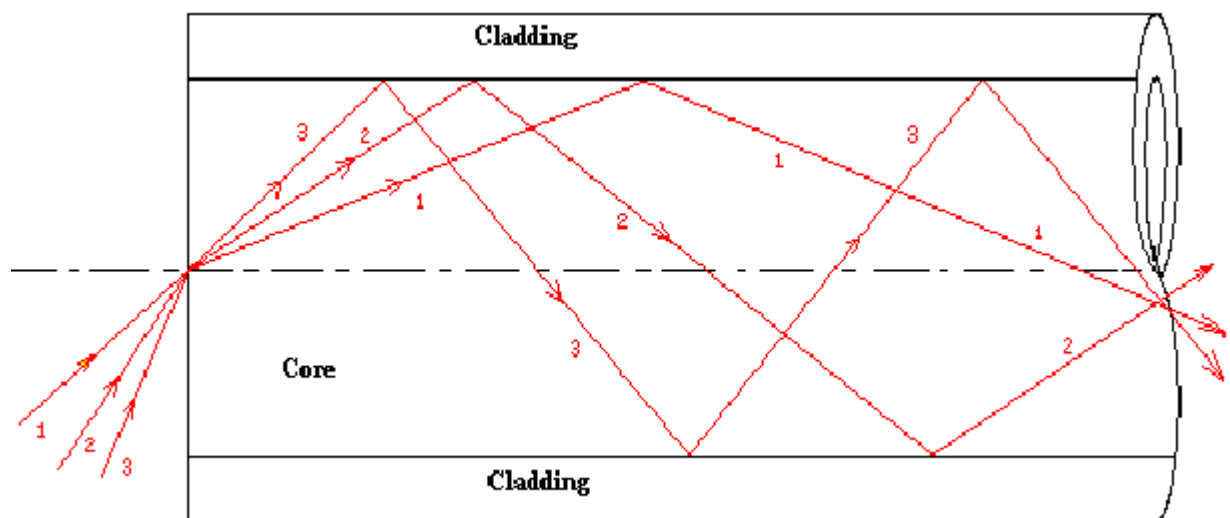


Figure 3- Multimode Step Index Fibre

2) Graded Index Fibre

Graded Index Fibre has a different core structure from single mode and multimode step index fibres. Whereas in a step-index fibre the refractive index of the core is constant throughout the core, in a graded index fibre the value of the refractive index changes from the centre of the core onwards. In fact it has a Quadratic Profile. This means that the refractive index of the core is proportional to the square of the distance from the centre of the fibre.

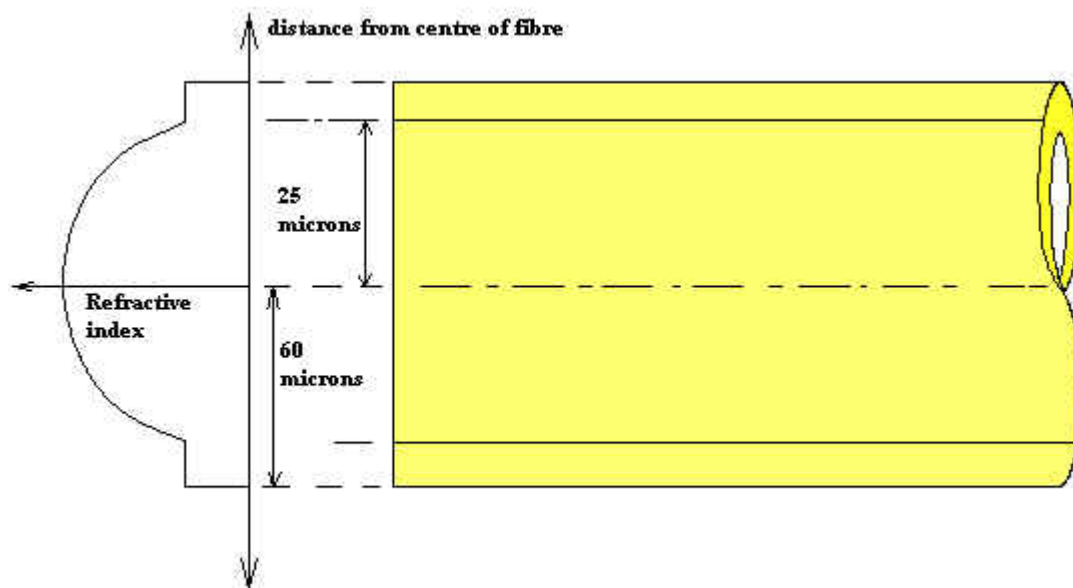


Figure 4- The Graded Index Fibre

4. Light Sources

There are two main light sources used in the field of fibre optics.-

Light Emitting diodes (LED's)

Laser Diodes (LD's)

Light Emitting Diodes

An LED is a p-n junction diode in a transparent capsule usually with a lens to let the light escape and to focus it. LED's can be manufactured to operate at 850 nm, 1300 nm, or 1500 nm. These wavelengths are all in the infrared region. LED's have a

typical response time of 8 nanoseconds, a linewidth of 40 nm, and an output power of tens of microwatts.

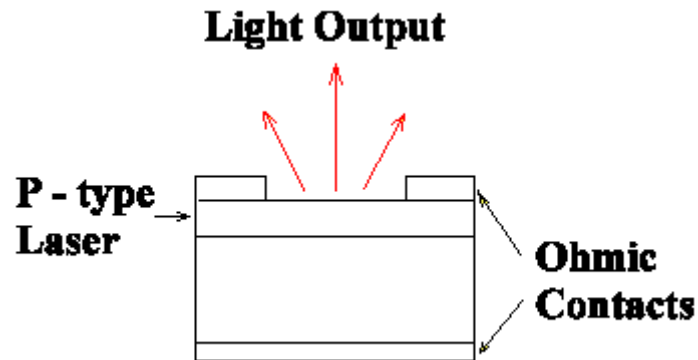


Figure 1- Planar LED

Laser Diodes

A laser diode is an LED with two important differences

- (1) The operating current is much higher in order to produce OPTICAL GAIN
- (2) Two of the ends of the LD are cleaved parallel to each other. These ends act as perfectly aligned mirrors which reflect the light back and forth through the "gain medium" in order to get as much amplification as possible

The typical response time of a laser diode is 0.5 ns. The linewidth is around 2 nm with a typical laser power of 10's of milliwatts. The wavelength of a laser diode can be 850 nm, 1300 nm, or 1500 nm.

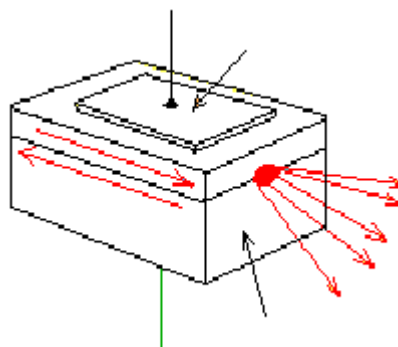


Figure 2- Laser Diode

5.Uses of Optical Fibres

In this section we will show you how optical fibres are used. As you will be able to see when you read further, optical fibres are revolutionising fields like communications and medicine.

Telecommunications Industry

Until the optical fibre network was developed, telephone calls were mainly sent as electrical signals along copper wire cables. As demand for the systems to carry more telephone calls increased, simple copper wires did not have the capacity, known as bandwidth, to carry the amount of information required.

Systems using coaxial cables like TV aerial leads were used but as the need for more bandwidth grew, these systems became more and more expensive especially over long distances when more signal regenerators were needed. As demand increases and higher frequency signals are carried, eventually the electronic circuits in the regenerators just cannot cope.

Optical fibres offer huge communication capacity. A single fibre can carry the conversations of every man, woman and child on the face of this planet, at the same time, twice over. The latest generations of optical transmission systems are beginning to exploit a significant part of this huge capacity, to satisfy the rapidly growing demand for data communications and the Internet.

The main advantages of using optical fibres in the communications industry are:

- A much greater amount of information can be carried on an optical fibre compared to a copper cable.
- In all cables some of the energy is lost as the signal goes along the cable. The signal then needs to be boosted using regenerators. For copper cable systems these are required every 2 to 3km but with optical fibre systems they are only needed every 50km.
- Unlike copper cables, optical fibres do not experience any electrical interference. Neither will they cause sparks so they can be used in explosive environments such as oil refineries or gas pumping stations.
- For equal capacity, optical fibres are cheaper and thinner than copper cables which makes them easier to install and maintain.

Case Study: British Telecom

In the UK at the moment there are three million kilometres of optical fibre cable in the BT network. Most of BT's trunk network now uses optical fibre cables. In a recent trial in Bishop's Stortford optical fibres were actually laid into homes. This allowed customers to receive cable TV and stereo radio as well as phone and information services.

Optical fibres could be put into all homes but currently the cost of the system including lasers and detectors would be too high for simple telephone calls. Some companies have

a direct optical fibre link if they need to send large quantities of information by phone, for example between computers at different business centres.

Optical fibre submarine links are in use all around the world. Because of the low loss and high bandwidth of optical fibre systems they are ideal for submarine systems where you want to minimise the amount of complex electronics in regenerators sitting on the sea bed. In fact, the link from the UK to the English Channel Islands is achieved directly without any submerged regenerators.

The world's first international optical fibre submarine cable was laid by BT in 1986 between the UK and Belgium. It is 112Km in length and has only 3 regenerators. BT was a major partner in the first transatlantic optical fibre cable system - TAT 8 (Transatlantic Telecommunications cable no 8) which was capable of carrying 40,000 telephone calls at once, or the equivalent in data, facsimile, or TV pictures.

The second transatlantic cable, TAT 9, which came into service in 1992, has twice that capacity and links five separate landing points in the UK the USA, Canada, France and Spain. The transatlantic optical fibre cable network, completed in 1996, spanned 14,000Km and linked the UK, France and the USA . It could handle up to 320,000 phone calls at one time.

Undersea cables consist of fibres with a copper coated steel conductor which are covered in protective layers of steel and polypropylene. In shallow waters, e.g. the continental shelf, a submersible remote-controlled plough is used to bury the cables one metre below the seabed, to protect them from damage by trawling and ships' anchors.

Medicine Industry

The advent of practicable optical fibres has seen the development of much medical technology. Optical fibres have paved the way for a whole new field of surgery, called laproscopic surgery (or more commonly, keyhole surgery), which is usually used for operations in the stomach area such as appendectomies. Keyhole surgery usually makes use of two or three bundles of optical fibres. A "bundle" can contain thousands of individual fibres". The surgeon makes a number of small incisions in the target area and the area can then be filled with air to provide more room.

One bundle of optical fibres can be used to illuminate the chosen area, and another bundle can be used to bring information back to the surgeon. Moreover, this can be coupled with laser surgery, by using an optical fibre to carry the laser beam to the relevant spot, which would then be able to be used to cut the tissue or affect it in some other way.

Other Uses

- Optical fibres can be used for the purposes of illumination, often carrying light from outside to rooms in the interiors of large buildings.

- Another important application of optical fibres is in sensors. If a fibre is stretched or squeezed, heated or cooled or subjected to some other change of environment, there is usually a small but measurable change in light transmission. Hence, a rather cheap sensor

can be made which can be put in a tank of acid, or near an explosion or in a mine and connected back, perhaps through kilometres of fibre, to a central point where the effects can be measured.

An advantage of fibre-optic sensors is that it is possible to measure the data at different points along the fibre and to know to what points the different measurements relate. These are the so-called distributed sensors.

- Fibre optics are also used to carry high power laser beams from fixed installations within factories to the point of use of the laser light for welding, cutting or drilling. The fibre provides a flexible and safe means of distributing high power laser radiation around a factory so that robots or machine tools can be provided with laser machining capability.

- Optical fibres can also be used as simple light guides. At least one fancy modern car has a single high intensity lamp under its bonnet, with optical fibres taking the light to a series of mini-headlamps on the front. Less high tech versions carry light from bulbs to the glove compartment etc.

- A research group at the Clarendon Laboratory, Oxford, is designing a laser installation at the William Hershel Telescope on La Palma to help astronomers make an 'artificial' star in the layer of atomic sodium which exists at a height of 100km above the Earth's surface.

The Earth's atmosphere is a big problem for astronomers. It is a gas that is constantly moving which makes the light traveling through it from distant stars flicker. If astronomers could use a reference 'star' whose brightness they knew, then they could allow for this twinkling.

The telescope will look at how the atmosphere is effecting the artificial star second by second and adjust the telescope's mirror to compensate. This should allow astronomers to capture pictures of astronomical objects of a quality previously only obtainable from the Hubble Space Telescope. The optical fibre in this case is used to pipe the laser power needed to create the artificial star from the lasers to the telescope itself.

- As light is not affected noticeably by electromagnetic fields. It also does not interfere with other instruments that do use electricity. For this reason, fibre-optics are also becoming very important for short-range communication and information transfer in applications situations like aircraft. This application is now being extended into motor cars, and plastic optical fibres will soon (say in 5-8 years time) be very common for transmitting information around the car.

So we can see that optical fibres are not just passive light pipes. Researchers are finding ways in which they can make the fibres become the active elements of the circuit, e.g. amplifiers or filters. This means that the information could remain in light form from one end of a link to the other, removing the limitations of the electronics in circuits and enabling more of the theoretical information carrying capacity to be used.

Engineers of the future can look forward to designing and using telecommunications systems that have no loss, infinite bandwidth and high reliability. New services for customers, such as 3D high definition TV and virtual reality information and entertainment systems, could be more easily provided as well as giving them the benefits of lower costs and greater flexibility - an exciting future.

Advantages and Disadvantages of Optical Fibres

Although there are many benefits to using optical fibres, there are also some disadvantages. Both are discussed below:

Advantages:

Capacity

Optical fibres carry signals with much less energy loss than copper cable and with a much higher bandwidth. This means that fibres can carry more channels of information over longer distances and with fewer repeaters required.

Size and Weight

Optical fibre cables are much lighter and thinner than copper cables with the same bandwidth. This means that much less space is required in underground cabling ducts. Also they are easier for installation engineers to handle.

Security

Optical fibres are much more difficult to tap information from undetected; a great advantage for banks and security installations. They are immune to Electromagnetic interference from radio signals, car ignition systems, lightning etc. They can be routed safely through explosive or flammable atmospheres, for example, in the petrochemical industries or munitions sites, without any risk of ignition.

Running Costs

The main consideration in choosing fibre when installing domestic cable TV networks is the electric bill. Although copper coaxial cable can handle the bandwidth requirement over the short distances of a housing scheme, a copper system consumes far more electrical power than fibre, simply to carry the signals.

Disadvantages:

Price

In spite of the fact that the raw material for making optical fibres, sand, is abundant and cheap, optical fibres are still more expensive per metre than copper. Having said this, one

fibre can carry many more signals than a single copper cable and the large transmission distances mean that fewer expensive repeaters are required.

Special Skills

Optical fibres cannot be joined together (spliced) as easily as copper cable and requires additional training of personnel and expensive precision splicing and measurement equipment.