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Wonder Pipes for Digital India

Optical Fibres

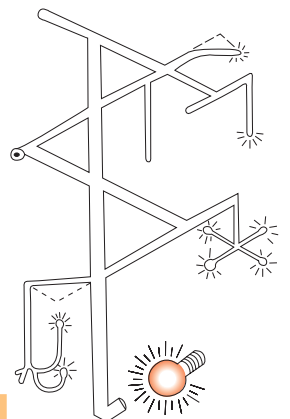
Fibre optics, along with lasers, finds place in the United States National Academy's list of the twenty most important engineering developments of the twentieth century.

AT the launching ceremony of the Digital India Week on 1st July 2015, the Prime Minister, Mr Narendra Modi observed (translated from Hindi), "Ages back, there was a time when people used to settle on the shores of rivers. Villages and cities used to develop on the shores of rivers or seas. Times changed. Later, cities started settling at places from where the highways passed. But now, mankind will settle at places from where optical fibres will pass."

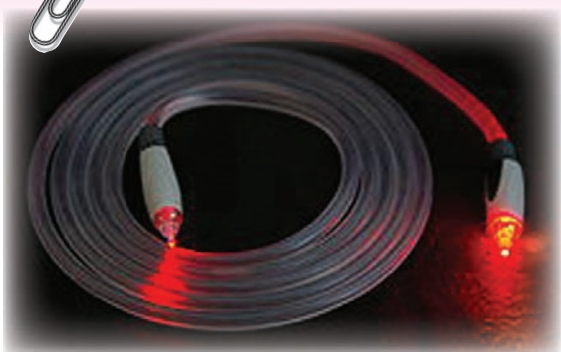
The technology that promises to fulfill the dream of a digital India is fibre optic technology and at the root of this technology is the tiny optical fibre – the wonder light pipe that enables communication.

Conventional forms of 'optical communication' suffered from the limitation that information could be carried only as far as humans can see and only when there was no obstruction in the path of light. But then, the idea that light could be transported from one place to another like electricity, water and domestic gas occurred to William Wheeler, a US engineer, still in his twenties. Wheeler suggested the use of pipes with reflective

linings for illuminating distant rooms, for which he received a patent. But Wheeler's suggestion didn't receive much attention because the use of electric wires and incandescent bulbs for illumination was far more practical than transporting light in this way.



Wheeler's idea



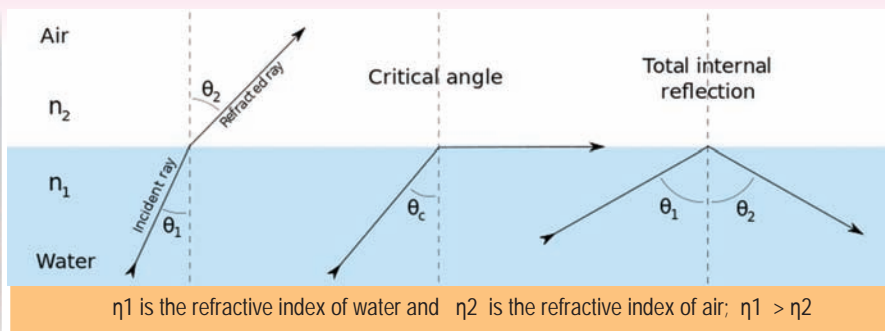
Fibre optics promises efficient solutions to the demands of digital India because of a much greater information carrying capacity.

The development of modern fibres can be traced to the motivation to overcome these limitations so as to enable light to carry signals from one place to any desired destination. Light propagates through an optical fibre by a phenomenon called total internal reflection (TIR) of light. But the translation of this simple concept into a powerful technology is a long story of struggle.

Total Internal Reflection

The phenomenon of TIR of light accounts for beautiful occurrences in nature like mirage and sparkling diamonds. It had been well understood on the basis of law of refraction proposed by Willebrord Snell, a Dutch mathematician, in 1621. This law governs refraction, i.e., bending of light ray when it passes from one medium to another. Though the experimental data of angles of incidence and those of refraction for light rays passing from air to water were reported by Claudius Ptolemy as early as 140 AD, the relation between the two angles could be understood theoretically only after about 15 centuries.

On the basis of Snell's law the phenomenon of TIR was understood as the one in which a light ray travelling from a denser medium to a rarer medium doesn't pass into the next medium but returns into the same medium for angles of incidence exceeding a certain angle called the critical angle. Thus, light rays can be confined to the same medium if two conditions are ensured, viz., light rays pass from a denser medium into a rarer medium and they incident at an angle greater than the critical angle.



Piping Light

In 1841, Jean-Daniel Colladon, a 38-year-old Swiss professor, observed such confinement of light accidentally in a lecture demonstration. He wanted to show the fluid flow through various holes of a tank. But as the light in the lecture was insufficient, Colladon used sunlight to show the water flow. What resulted was a spectacular illumination of the water jets squirting out through the holes of the tank. Instead of traveling in a straight line, the light followed the curvature of the water flow due to TIR.

Colladon described it as, "one of the most beautiful and most curious experiments that one can perform in a course on optics". He also coined the term "light guiding" for this phenomenon.

In 1854, John Tyndall demonstrated such confinement of light to a stream of water. These simple experiments marked the first research into the guided transmission of light.

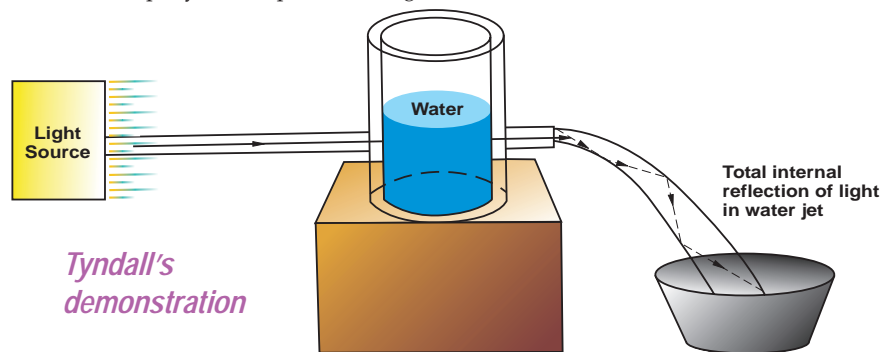
The early breakthroughs in using fibres as light pipes came in the field of dentistry when attempts were made to use them for dental illumination. In 1930, Heinrich Lamn, a medical student in Munich, reported for the first time transmission of the image of a light bulb through a bundle of optical fibres. In 1954, van Heel of the Technical University of Delft, Holland and Harold Hopkins and Narinder Kapany of Imperial College



Jean-Daniel (Left) Narinder Kapany (right)

in London separately reported imaging bundles in the prestigious British journal, 'Nature'. It was Kapany who coined the term 'fibre optics' in 1956.

As a schoolboy, Narinder disagreed with a teacher who told that light could only travel in a straight line. In his efforts to prove this he began experimenting with a series of prisms lined up to move the beams of light. But the light still traveled in a straight line between the prisms. This led him to think of using cylindrical geometry and the initial motivation for his work was to develop a flexible fibre scope as an instrument for doctors to look into the body. By 1960, glass-clad fibres suitable for medical imaging were developed but they were unsuitable for





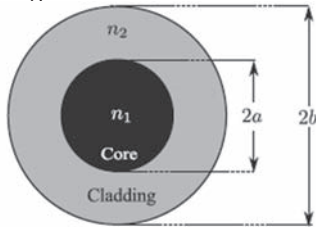
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communication purposes due to high attenuation.

Another major breakthrough came in 1960 when the American physicist, Theodore Maiman, developed Ruby laser – the first operational laser. It was followed by development of a semiconductor laser in 1962 and laser diode eight years later by researchers of various laboratories. Lasers provided the controlled, intense and directed light that enabled communication through glass fibres. This motivated development of fibres that could be suitable for optical communication over long distances. The aim of developing better fibres requires deeper insight into how light makes its journey in the fibre.

Journey of Light in a Fibre

Light propagation in a fibre through TIR is achieved by the flexible coaxial cylindrical structure of the modern optical fibre. The inner cylindrical core, which is made of a material of higher refractive index, n_1 , is encapsulated in the outer cylindrical cladding of a lower refractive index, n_2 .



For example, the core is made of doped silica glass that is optically denser than the pure silica glass of which the cladding is made.

Light launched into the core so that it is incident on the core-cladding interface at an angle greater than the critical angle is thus confined to the core and travels down the fibre in a zigzag path through successive TIRs.

The development of optical fibres is one of the most convincing examples of how the knowledge of natural phenomena has been exploited by mankind for development of newer and better technologies. Fibre optics, along with lasers, finds place in the United States National Academy's list of the twenty most important engineering developments of the twentieth century.

Fibre Protection

In a modern fibre cable about 99% of the cable space is used for protecting the delicate core-cladding structure and light remains confined to only about 1% space of the fibre. The layer of coating material provides insulation and a strengthening material provides support to the delicate structure inside. Finally a jacket separates the structure from other fibres.

In armoured cables the use of metallic jackets ensures additional protection against hazards such as construction work or rodents. To prevent contamination by water, solid barriers such as copper tubes and water-repellent jellies or water-absorbing powders are sometimes used to surround the fibre. Cables that are used under sea are more heavily armored to protect them from boat anchors, fishing gear and sea animals.

Light launched into the core so that it is incident on the core-cladding interface at an angle greater than the critical angle...

Fibre Optic Communication System

For better appreciation of the challenges fibre optic scientists and engineers encounter in development of the fibre optic communication systems, one needs to understand the significant role of a fibre cable in these systems.

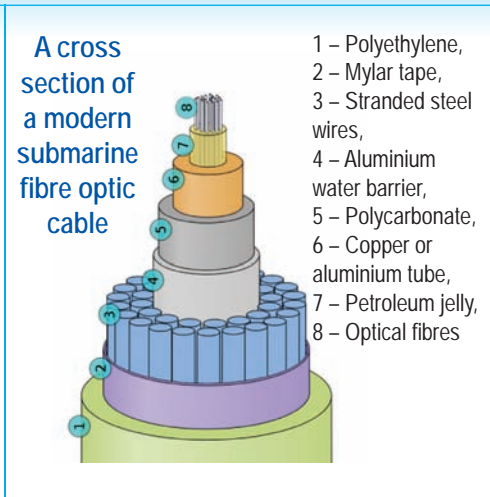
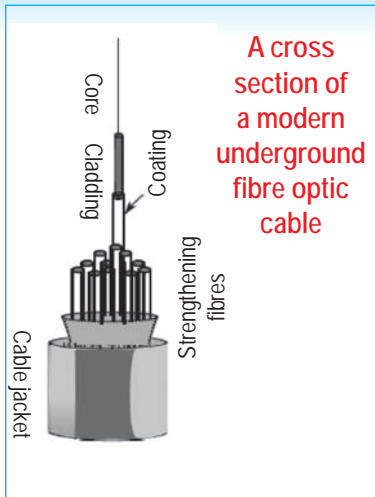
A fibre cable is at the heart of the fibre optic communication system. It links with the encoding (enciphering or modulating) section on its one end and with the decoding (deciphering or demodulating) section on its other end. The information (speech/picture, i.e., audio/video) to be communicated from the source is first converted into electrical signals by electrical transmitters. These signals are then converted into optical pulses using an optical source such as a light emitting diode or a laser diode, which illuminates the launching end of the fibre.

The output light is received at the other end of the fibre by an optical detector such as p-i-n photodiode or an avalanche photodiode, which converts the light signal back into the electrical signal. These electrical signals are then converted back into the original speech and picture signals by the electrical receiver and the information is finally retrieved at the destination end.

Fibre optic systems have several advantages over the traditional ones because fibre cables are small, lightweight, chemically passive and require less maintenance than conventional copper wires. They allow information to travel at great speed (at the speed of light in glass in case of a glass fibre) at greater distances without the need for strengthening the signal due to low transmission losses. They also do not suffer from crosstalk (undesired coupling from one channel to another) and so hundreds of fibres can be bundled together in a single cable. As optical fibres are made of glass or plastic, which are insulators, the fibre optic cables have a greater immunity to electromagnetic noise.

Thus, the optical signals traversing through these cables are immune to any radio frequency interference and electromagnetic interference giving a high degree of signal security. This makes installation possible in areas such as alongside utility lines, power lines, and railroad tracks where such interference is high and also makes unauthorised tapping difficult.





Fibre optic systems have been found to be suitable for long distance communication because of the easy availability of the starting raw material, i.e., silica, low costs of transportation and installation and future upgradability of the cables. These advantages have made optical fibres useful in several telecom applications such as telephony, Internet traffic, long high-speed local area networks, cable TV and also for shorter distances within buildings.

Improvements in Fibre Optic Systems

Thousands of fibre optic scientists and engineers contributed to the improvement of fibre optics systems over last few decades. The research pertained mainly to reduction of the attenuation and dispersion in fibres so as to prevent the loss and maintain the fidelity of the data.

In 1966, Charles Kao and George Hockham of the British company, Standard Telephones and Cables (STC), promoted the idea that the high attenuation of 1000 dB/km and more

existing in the optical fibres then was due to contaminants and not due to fundamental processes like scattering.

They proposed that the reduction of these impurities could decrease attenuation below 20 dB/km, a threshold value required for optical communication. They also proposed that fused silica (SiO₂) can be an ideal candidate for optical communication due to its high purity. Kao was known as 'Godfather of Broadband' and 'Father of fibre optic communications' and was awarded the Nobel Prize in Physics in 2009 for his groundbreaking achievements in optical communication.

The goal suggested by Kao was achieved four years later by Robert Maurer, Donald Keck and Peter Schultz of the Corning Glass Works who announced in September 1970 fibres made of fused silica with attenuation less than below 20 dB/km. This breakthrough opened the doors to fibre-optic communication. The attenuation in fibres further dropped dramatically in subsequent years due to sophistication in the fabrication methods. During the same period, fibre optic systems got another boost with the development of GaAs semiconductor lasers, which were suitable for transmitting light through fibres over long distances.

These advancements also resulted in an enormous increase in the bandwidth, i.e., the data transmission speed (data rate) of optical fibres. The data rate in a fibre is measured in units of bits per second or bps (1 kbps = 1000 bps, 1 Mbps = 1000 kbps, 1 Gbps = 1000 Mbps and 1 Tbps = 1000 Gbps). The higher the bps rate, the faster the download or upload

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time will be. The rise in data transmission speed in the last few decades has been faster than the rise in the storage capacity of electronic memory chips or in the rise in computation power of microprocessors.

Fibres Optics for Digital India

Internet access in India is about 20% of the population compared to the global penetration of about 42%. The initiative of Digital India aims to address these issues through its three core components: the creation of digital infrastructure, delivering services digitally and digital literacy. The initiative plans to connect rural areas with Internet networks and ensure government services to the people of India electronically.

India has the fastest growing telecom network in the world with its high population and development potential. The biggest optical fibre cable network in India is owned by Bharat Sanchar Nigam Limited (BSNL), which is India's oldest and largest communication service provider. It has more than 60% market share and had a customer base of 12 crores as of June 2015 [957.61 million telephone subscribers and 75.73 million Broadband subscribers (Sept. 2014)]. A recently introduced BSNL service called FTTH (Fibre To The Home) provides 100 percent fibre-optic connections to the subscriber's home.

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Charles Kao

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