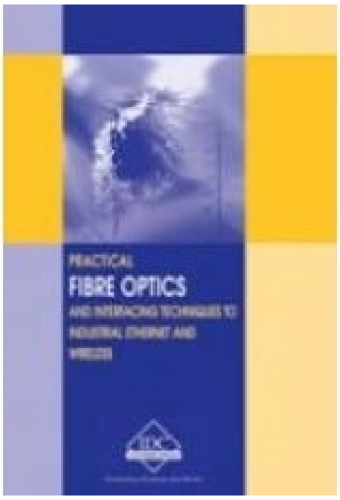
FX-E - Practical Fibre Optics and Interfacing Techniques to Industrial Ethernet and Wireless



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Short Description

This manual will provide you with the necessary background to understand the fundamentals of fibre optic systems and their individual components including fibres, cable construction, connectors, splices and optical sources and detectors. Various pitfalls associated with the implementation of fibre optic systems are discussed and workable solutions to these problems are provided. It will provide you with the knowledge to develop the required techniques for design, installation and maintenance of fibre optic systems.

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1 Introduction

The rapidly changing face of data communications and telecommunications has seen a continued growth in the need to transfer enormous amounts of information across large distances. The technologies that were used extensively in the past say 20 years, such as coaxial cable, satellite and microwave radio for transferring information were, very quickly running out of capacity. The demand for transmission capacity was far outstripping its availability.

There was a growing requirement to provide a communications medium that was more suitable to the noisy industrial environment where the need for data communications and networking of control systems was rapidly expanding. With the introduction of fibre optic communications systems, the solution to the problems of transmission capacity shortage and to noisy industrial environments has been successfully found.

An optical fibre is simply a very thin piece of glass which acts as a pipe, through which light can pass. The light that is passed down the glass fibre can be turned on and off to represent digital information or it can be gradually changed in amplitude, frequency, or phase to represent analog information.

Fibre optic transmission has become one of the most exciting and rapidly changing fields in telecommunications engineering. To most of us, who have not previously encountered this technology, it can look like a form of black magic and one that is best left to experts. However, in reality it is a relatively simple communications technology. Compared to copper cable transmission and particularly radio and microwave transmission (which really are black magic!), fibre optic transmission systems are far easier to design and understand.

Fibre optic transmission systems have many advantages over more conventional transmission systems. They are less affected by noise, do not conduct electricity and therefore provide electrical isolation, carry extremely high data transmission rates and carry data over very long distances. These and other advantages are discussed in detail throughout this book.

Fibre optic transmission systems are not perfect and there are difficulties involved in designing, implementing, and operating fibre optic communications systems. This book is designed to provide a thorough background to fibre optic communications systems and to illustrate the design and installation of these systems. The many pitfalls associated with the implementation of fibre optic systems are discussed and workable solutions to these problems are provided.

The objective of this book is to provide a thorough, detailed, and practical reference to the reader. It contains information that is of practical use and avoids the trap many texts on the subject fall into of getting involved in the maze of technical and mathematical irrelevance.

A brief overview of the basic concepts involved in fibre optic communications, historical background to fibre optics and a comparison of copper and optical fibre transmission mediums is provided in this chapter.

1.1 Historical background to fibre optics

Fibre optic technology did not advance enough to be a commercially viable proposition for communication purposes until the 1980s. However, there were evolving international telecommunications standards that were predicting very high data rate requirements. Although transmission capacity could be obtained from conventional cable, microwave and satellite technologies, there was a definite shortage of transmission capacity for the term data transfer requirements. Fibre optic transmission systems have provided the enormous capacity required overcoming the potentially disastrous short falls.

A brief chronological description of the main events in the technological history that have shaped the development of fibre optic communications is given here:

Prehistoric Early societies used signal fires to send digital messages to distant locations. Polybious, a Greek mathematician, developed a method of sending characters using fires by setting up a matrix of characters where one set of fires represented rows of the matrix and the other set represented the columns of the matrix.

1700 Isaac Newton discovered the diffraction of light and that light is constructed of a spectrum of many different colors.

1790 French engineer Claude Chappe developed the first optical telegraph system using semaphores. Messages were relayed from one hill to the next using moving semaphore arms.

1800 William Herschel discovered that a certain part of the spectrum of light contained infrared energy. French mathematician Augustine Fresnel developed the first mathematical model to explain the properties of light. His proposal was based on the premise that light is constructed of sinusoidal waves. Physicist James Maxwell laid the foundations for the development of the study of light transmission in the form of electromagnetic waves. Maxwell’s equations are still used to explain the behavior of radio and light waves in transmission systems.

1854 British physicist John Tyndall set up an experiment whereby he passed light down a beam of water, demonstrating the transmission of a signal by total internal reflection.

1880 The famous inventor Alexander Bell invented a device called Photophone, which contained a membrane made of reflective material. When sound caused photophone to vibrate, it would modulate a light beam that was shining on it and reflect this light to a distant location. The reflected light could then be demodulated using another photophone. Applying this method, Bell was able to communicate to a maximum distance of 213 meters. American engineer William Wheeler designed a lighting system for a building that was based on a series of pipes and ducting. Light was injected into one end and the internal reflection through pipes carried the light rays to a number of pipe ends that emanated in rooms where the light was to be diffused. Although the system would probably have never worked efficiently, the idea was sound and eventually led to the advent of fibre optic communications.

1907 A chemist named Round discovered that by forward biasing different types of silicon carbide crystals, they emitted yellow, green, orange, or blue light.

1910 Two physicists, Hondros and Deybe, published an important paper on the transmission of electromagnetic waves in dielectric solids.

1923 Lossew, a physicist, developed the light emitting diode (LED)

1927 Baird, an engineer, proposed the use of uncoated fibres to transmit images for television purposes.

1934 AT & T engineer Norman French first patented the idea of transmitting communications signals down a thin piece of glass. At that time, there were no transparent materials available with sufficiently low attenuation to make the technology feasible.

1955 An RCA engineer Braunstein developed a device made of gallium arsenate that emitted an infrared signal.

1956 NS Kapany, an American company, first used the term ‘fibre optics’. It has the credit of having invented the glass rod for the first time.

1960 Theodore Maiman, an engineer from Hughes Aircraft, developed the first operating gas laser. IBM, General Electric, and Massachusetts Institute of Technology all virtually simultaneously developed injection laser diodes.

1966 Two researchers at STL in Harlow developed a glass fibre that had an attenuation of approximately 1000 dB/km.

1970 The Corning Glass Works company developed a technique for manufacturing glass fibres that exhibited an attenuation of 20 dB/km. Bell laboratories, RCA, and scientists in the then Soviet Union developed continuous operation semiconductor injection lasers.

1972 Signal attenuation in optical fibres was reduced to 4 dB/km.

1976 Rediffusion installed the first commercial fibre optic system for transmission of analog television signals.

1980 Fibre optic communication systems became commercially available.

1.2 Comparison of fibre optic and copper cabling systems

Fibre optic technology will definitely be used in the future as the main medium for information transmission. It is one of the reasons for the massive increase in international telecommunications and arguably the perception of the apparent ‘shrinking planet’. This technology has been the backbone that has enabled the

Internet to become the incredible information medium it is today. However, contrary to popular belief, it is not everything to all people. There are still many limitations to fibre optic systems and many challenges yet to overcome.

Before discussing the theory of fibre optic transmission, this section will compare copper cables to fibre cables and weigh the advantages and disadvantages of using each.

1.2.1 Bandwidth

Fibre

Fibre optic cables have enormous bandwidth with transmission speeds up to 40 Gbps operating today and over 100 Gbps is expected in the near future. The factors presently limiting an increase in data speeds are: firstly, the time responses of the source and detectors are slow compared to the pulse periods for high data rates; secondly, the wavelength of light is close enough to the pulse period to cause differentiation problems at the detectors. Methods of multiplexing several wavelengths onto one fibre (referred to as wave division multiplexing (WDM)) increase combined transmission speeds over a single fibre to over several Tbps.

To provide a feel for what this represents in terms of information transfer, a fibre optic link operating at approximately 1 Gbps per second can carry over 30 000 compressed audio telephone calls simultaneously. A link operating at 30 Gbps can carry up to 1 million telephone calls simultaneously on a single glass fibre!

Copper

Coaxial cables with diameters of up to 8 cm can carry speeds reaching 1 Gbps over distances of 10 km. The limiting factor is the very high cost of copper.

Significant research is presently going on into increasing transmission speeds on twisted pair cables. Speeds of 100 Mbps are now quite common in many local area networks. Commercial systems are also available that operate up to 1 Gbps. Laboratory tests have successfully been carried out at 10 Gbps and products are nearing commercial release. The reason for such active development in this area is to make use of the over abundance of twisted pair cable infrastructure already installed and hence provide significant cost savings associated with trenching, ducting and laying of new fibre optic cables. For this reason, twisted pair cable technology is presently very competitive compared to fibre optic technology as both have many common applications.

1.2.2 Interference

Fibre

Fibre optic cables are completely unaffected by electromagnetic interference (EMI), radio frequency interference (RFI), lightning and high voltage switching. They do not suffer from capacitive or inductive coupling problems. If designed correctly, fibre optic cables should be unaffected by nuclear magnetic pulses from nuclear explosions, and they should be unaffected by background nuclear radiation. (The greater majority of the population will be comforted by this knowledge after a nuclear war!)

As an adjunct to this fact, fibre optic cables do not emit any electromagnetic interference or radio frequency interference. This characteristic is very important in the areas of computing, video, and audio, where low noise environments are increasingly more vital for increased performance and production quality.

Copper

Copper cables are affected by external interference. Depending on the type of cable and the amount of shielding around the cable, they are affected to varying degrees by EMI and RFI through inductive, capacitive, and resistive coupling. Copper cable-based communications systems are permanently destroyed by nuclear magnetic pulses.

Copper cables also emit electromagnetic radiation, which can cause interference to other copper cable-based communications systems. The amount of radiation they emit depends on the magnitude of the signal they are carrying and the quality of the shielding.

1.2.3 Electrical isolation

Fibre

Fibre optic cables provide complete galvanic isolation between both ends of the cable. The characteristic of non-conductivity of fibres makes the cables immune to voltage surges. This eliminates interference that may be caused from ground loops, common mode voltages, as well as shifts and shorts in ground potential. The fibre optic cable acts like a long opto-isolator. A further advantage is that because optical fibres do not emit radiation and are not affected by interference, there is no cross talk between cables (that is, emission of radiation from one communications cable interfering with another cable, which is running next to it).

Copper

Copper cables, simply working in their designed purpose, provide an electrical connection between both their ends. Therefore, they are susceptible to ground loops, common mode voltages, and ground potential variations. They will also suffer from potential cross talk problems.

1.2.4 Transmission distances

Fibre

As for cheap simple fibre optic systems, distances up to 5 km between repeaters are possible. For high-grade commercial systems, distances up to 300 km between repeaters are now readily available. Systems have been installed between two end points (where repeaters were not required) for distances upto 400 km. Distances close to 1000 km have been achieved in the laboratory but have not made it into the commercial world as yet. A European company has claimed that it is presently developing a fibre cable that could be laid completely around the larger diameter of the earth, and without any repeaters, and can carry a signal from one end to the other! How is this possible? Using a slightly radioactive cladding, the incoming low energy light photons excite electrons in the cladding, which in turn release higher energy light photons. Thus, a form of self-amplification occurs. The chapters that follow will help the reader to understand these terms.

Copper

Distances upto 2.4 km between repeaters at data speeds of 4 Mbps are commercially available as for twisted cables. Distances upto 25 km between repeaters at speeds of less than 1 Mbps are possible in case of coaxial cables.

1.2.5 Size and weight

Fibre

Compared to all other data transmission cables, fibre optic cables are extremely lightweight and very small in diameter. A four-core fibre optic cable will weigh approximately 240 kg/km and a 36-core fibre optic cable will weigh only about 3 kg more. Because of their small size compared to copper cables of the same transmission capacity, they are generally easier to install in existing conduits, and installation time and cost are generally reduced since they are light in weight and easier to handle.

Copper

Copper cable might weigh from 800 kg/km for a 36 twisted pair sheathed cable to 5 tons for a kilometer of high quality large diameter coaxial cable.

1.2.6 Use in hazardous gas areas

Fibre

Multimode fibres operating with LED light sources are suitable for use in hazardous gas areas. Until recently, it was thought that all fibres were suitable for use in hazardous areas; research has however, shown that certain fibre links with powerful light sources (lasers) can raise the temperature of a metal surface they are shining on to the point of gas ignition or, they may cause sparks under certain conditions.

Copper

Unless copper cable transmission systems are very stringently designed and adhere to strict intrinsic safety standards, they are not suitable for use in hazardous gas areas. Copper cables that are carrying even small currents can form sparks or arc between cables, unless current limiting controls are applied to the transmission circuits.

1.2.7 Security

Fibre

It is almost impossible to hook across a fibre optic cable and ‘bug’ the data transmission. The fibres have to be physically tapped to extract the data, which will decrease signal levels and increase error rates, both of which are easily detected. With presently available technology, fibre optic systems are considered highly secure systems. It is anticipated that this will change in the near future, as methods of multidropping of fibres improve.

Copper

Tapping into a copper cable transmission system is simply a matter of hooking across the cable with an equivalent high impedance cable. Copper cables are not considered highly secure systems.

1.2.8 Multidropping for LANs

Fibre

At present, there are a few methods of multidropping from a fibre optic transmission system, but they are not very effective. They are difficult to implement, and are very costly. Significant research is presently being undertaken into this area but cost effective systems are probably still some years away.

Optical fibre cables are also difficult to install, delicate and must be kept clear of possible physical stress that may damage them.

Copper

Multidrop copper-based systems are commonplace, simple to install and are very cost effective. Twisted pair cables, in particular, are cheap, easy to install and terminate, reliable and robust.

1.2.9 Jointing and connectors

Fibre

Jointing of optical fibres is relatively difficult and requires specialized training and tools. These days, most short distance cables are bought pre-terminated, where machines in factories apply the terminations. The costs of connectors and tools are relatively high.

Copper

Jointing of twisted pair cables is comparatively easy and relatively cheap. Coaxial cables can be difficult to terminate and components are relatively expensive but not to the extent of fibre optic systems.

1.2.10 Terminal equipment

Fibre

The biggest single factor limiting the mass distribution of fibre optic systems is the very high costs of the terminal transmission and receiving equipment. For high-speed systems, the costs can be between four and ten times those of equivalent copper-based systems. Slower speed systems are gradually reducing in cost but are still generally slightly more expensive than their equivalent copper-based systems.

Copper

The electronics of the terminal equipment for copper-based systems is significantly easier to design and manufacture than fibre optic terminal equipment and is therefore, significantly cheaper.

1.2.11 Test equipment and testing (fibre and copper)

Both fibre optic and copper system test equipment is complicated and generally very cumbersome and expensive. The only exception is in copper systems that have low speed transmission links.