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AN INTRODUCTION TO FIBRE OPTIC SYSTEMS - Part I

This series of articles on Fibre Optics, plans to introduce the reader to CATV Fibre Optics. Part -1 of this series introduces the reader to the basic technology, components and functioning of a Fibre Optic System. Academic Details and the Physics are kept to a minimum, with greater emphasis on the practical aspects, relevant to CATV Systems. Practical details and approximate prices are provided where-ever possible, to provide a better appreciation of this esoteric subject.

AN INTRODUCTION

Fibre Optics is often perceived as a futuristic technology within the Indian Cable TV industry. As is the case with most futuristic technologies, factual technical details are hard to come by. The CATV operator then usually assumes either, that Fibre Optics is a panacea for all his problems or that Fibre Optics is too expensive for him to implement. Often the CATV operator assumes both the above. As is frequently the case, the truth is somewhere in-between.

To fully understand and appreciate the capabilities and limitations of a fibre optic system, lets take a close look at the basics. A copper (coaxial conductor) based CATV system utilises a RF carrier which is Amplitude Modulated (AM) by the program signal. This modulated carrier is then carried on a cable for distribution. The signal is fed to different points using Tap-offs and Splitters which divide the signal as required. The signal is then fed into a TV set which provides the final picture.

The basic Fibre Optic system is quite similar to a copper based system, but for a few important differences. Before we get down to details, it is relevant to note that not all Fibre Optic (F.O.) systems use amplitude modulation. Fibre Optic systems used in Communications such as Telephony, utilise digital transmission and are quite different from the CATV Fibre Optic transmission systems. Contrary to the popular perception, it is not possible to use the digital F.O. systems employed for telephony, for CATV signals. The range of equipment and signal processing are totally different. These series of articles will be restricted only to A.M. Fibre Optic systems used for CATV signal distribution.

THE SIGNAL SOURCE

In a CATV F.O. system, the carrier not a R.F. signal, but a light beam. Just like an RF signal, light is also part of the electromagnetic spectrum, only of a much higher frequency. Since the frequency is so much higher, (Typically 200,000 GHz.) a single carrier can be used to modulate 80 or more television signals simultaneously ! This is one of the main advantages of a Fibre Optic System.... a very large bandwidth. The light beam, needs to be of a single frequency (or colour), i.e. “ Monochromatic “ and all the light should be in-phase, i.e. “ Coherent ". These requirements are easily met by a LASER. Hence, just as an Oscillator is used as a source of a carrier in a copper system, a laser is used as the source for the light beam.

The brightness (amplitude or intensity) of the Laser beam is varied by the incoming signal simply by changing the current fed to the laser. This produces an Amplitude Modulated light beam, which is Coherent and monochromatic. This single carrier usually carries 70 to 80 channels of TV programs.

In the early days of Fibre Optics, a LASER used to typically be a large unwieldy piece of equipment, that required an entire room to house it. This image of the laser, was further reinforced by science fiction stories of mad scientists in the labs, toiling over giant Lasers capable of vaporising air planes in mid-air ! While there do exist today, Lasers that are capable of burning a hole through a thick slab of steel, most commercial lasers are mundane pieces of equipment, called Laser Diodes. Every CD player (Video, Audio or computer) uses a laser diode to read the information from the disc. This laser diode is the size of a regular LED and is also fabricated using similar production facilities. These laser diodes cost approximately US $ 100 (Rs. 4,200) each. Of course, a range of products are available, with different intensities and wavelengths. CATV F.O. systems utilise lasers emitting light at 1310 or 1550 nanometers. This wavelength is in the near infra red region, not visible to the human eye.

The light from the laser is quite powerful, particularly since it is focused into a narrow beam. This beam, though invisible, can injure the retina if the light is directed, even accidentally, to the eye. For safety reasons, most Laser equipment carry statutory warning near active lasers. Several CATV transmitters even have a provision to automatically reduce the laser intensity if the output port is left open, or a fault develops in the distribution system. A Fibre Optic Transmitter typically costs approximately Rs. 4 to 5 Lakhs each. One of the most important factors that influences price of the transmitter, is the output power of the laser. A more powerful laser permits longer runs of cable from the F.O. Transmitter to the Receiver. The lasers initially developed had a life of about 10,000 hours. The more powerful lasers had an even shorter life. The technology has now advanced significantly, and now Scientific Atlanta claim a M.T.B.F. (Mean Time Before Failure) of 100,000 hours, fortheir Fibre Optic transmitters. This is equivalent to over 10 years of continuous use.

THE TRANSMISSION MEDIUM

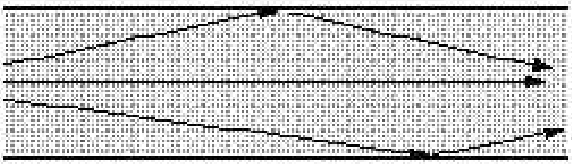
The next step in the process is to transmit this light beam to where ever it is required. Just as in an electrical system, copper is used to carry the signals, the laser light is carried in a transparent medium such as a cable made of glass. Though glass is a hard and brittle substance, it was observed that thin (thinner than the human hair) strands or fibres of glass, can be very flexible. If light is injected into these fibres, the light will continue to travel inside the fibre; due to total internal reflection of the light in the fibre; even if the fibre is bent. The light will travel in the centre of the core, when the fibre is straight, and will be reflected off the walls at bends.

A FIBRE OPTIC CABLE

For the light to be injected into the fibre efficiently, it must enter the fibre at an angle greater than the "Critical Angle ". While it is not necessary to dwell deep into the Physics of the process, it is important to bear in mind that a Fibre Optic system need to confirm to some very tightly controlled, critical parameters, both during installation and operation. The connectors in a F.O. system therefore play a very critical role, and need to be fitted with the utmost care. We will take a look at that a little later.

The Fibre Optic Cable Basically consists of an optically transparent core. This core can be made of either Glass or plastic. The plastic core has a much higher loss and is not used in large, high bandwidth systems, such as those required for CATV applications.

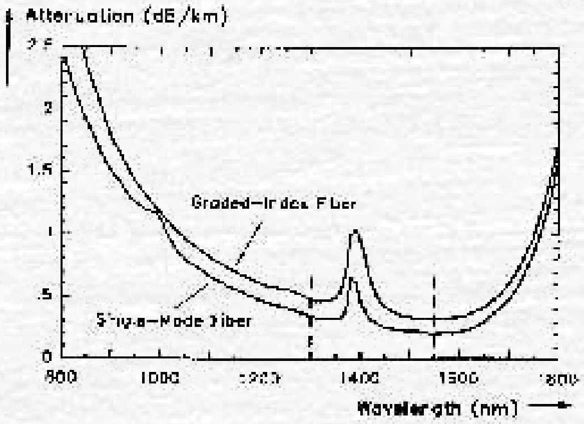
CATV Fibre Optic cable consists of a Silica (Glass) core of a very fine diameter - about 125 microns (1000 microns = 1 millimetre). Physically this means that each core is about the thickness of a human hair. Each glass core is then covered with a protective sheath or " Cladding ". Several such cladded cores can be packed into a small sized cable. Manufactures, such as Commscope usually provide a minimum of 4 cores and 100 or even more cores per cable. These cores are the enclosed in a mechanically robust jacket. The actual construction is shown in the picture of a Fibre Optic Cable.



Fibre Optic cables are also classified as Single Mode & Multi Mode. A detailed discussion of this is beyond the scope of this article, but it will suffice to know that CATV F.O. systems utilise only Single Mode, glass fibre.

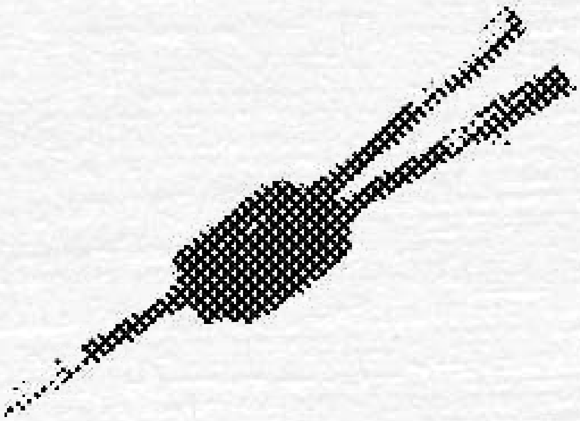
TRANSMISSION CHARACTERISTICS

Over the years, extensive research has been done for the glass used to manufacture the glass fibre. During research, it was observed, that though there was a reasonably high transmission loss for light travelling in glass, if the glass was doped with certain elements, the glass transmitted particular wavelengths of light with almost no loss at all. Today, practical F.O. systems offer transmission loss of only 0.5dB per Km ! Of this, the glass fibre contributes about 0.2 dB and other losses such as joints and connectors, and other stay losses account for the balance.



In coaxial CATV systems, the carriers are referred to by their frequencies. However in Optical systems the frequencies are very large, and it is more convenient to refer to these by their wavelengths, usually in nano meters. (1 nano meter is 1 millionth of a millimeter.) As an example, the frequencies used for F.O. transmissions are approx. 200,000 GHz . It is simpler to refer to it as 1300nm. The particular wavelengths at which there is a minimal loss, are referred to as " Transmission Windows ". Fig 1 shows that the loss/ attenuation falls to a very low value, around 2 wavelengths: 1310 nm and 1550nm. CATV fibre optic systems all operate only at these wavelengths to minimise transmission losses.

ATTENUATION MECHANISM



Attenuation in a glass fibre is caused by three effects. Raleigh scattering, absorption and ending. The attenuation of the modulation amplitude at high modulation frequencies can be considered as part of the bandwidth characteristics of the fibre. This effect is not very significant for fibre trunks of upto 20 Kms length, and will be ignored in this article.

Raleigh scattering is caused by the microscopic non-uniformity of the refractive index of glass. A ray of light is partially scattered into many directions, thus some light energy is lost. An important precondition for this phenomenon is that the structure of the glass is not much finer than the wavelengths of interest. Therefore, the attenuation decreases as the wavelength increases. Raleigh scattering represents by far the strongest attenuation mechanism in modern glass (silica) fibres; it may be responsible for upto 90% of the total attenuation.

Absorption is caused on unwanted material in the fibre. Chemically, glass is not a solid but a " Super cooled liquid " Water (OH-ions) in the glass crystal are the dominant absorber in most fibres, causing the peaks in optical loss at 1250nm and 1390nm. Above 1700nm, glass starts absorbing light energy due to the molecular resonance of SiO_2. Modern manufacturing methods are capable of reducing these effects to almost zero. The attenuation curve in Fig. 1 clearly shows why Optical CATV system designers prefer the 1300nm and 1550nm wavelengths.

The third effect is bending. Two types can be distinguished: MICROBENDING is due to microscopic imperfections in the geometry of the fibre (rotational asymmetry, changes of the core diameter, "rough boundaries between core and cladding) caused by either the manufacturing process or by mechanical stress, such as pressure, tension and twist.

Fibre curvatures with diameters on the order of centimeters are called MACROBENDING. In this case, the loss of optical power is due to less-than-total internal reflection at the core-to-cladding boundary. Bending loss is usually unnoticeable if the diameter of the bend is larger than 10 cm. An interesting application of the fibres sensitivity to bending is a (non-reflecting) termination of the fibre. Just as in coaxial cable systems, it is necessary to properly terminate the end of a fibre. If this is not done, the light in the fibre will reflect back into the fibre, and destructively interfere with the incoming signal, causing severe distortion. An optical termination can be constructed with one or two knots of 1cm diameter, this will reduce the reflections to less than -40dB.

THE DISTRIBUTION SYSTEM

OPTICAL SPLITTERS: The optical signal, travelling down a fibre optic cable has to be distributed to various nodes. A coaxial cable based system utilises directional couplers (Tap-Offs) and splitters. A similar method is employed for fibre optic systems. F.O. systems employ only optical splitters. These are available in a range of splitting ratios viz.: 50:50 (i.e. split in 2 equal parts), 60:40, 70:30, 80:20 and 90:10. Obviously, the unequal splits perform the same function as conventional directional couplers, with different Tap-Off losses. An optical splitter typically costs approximately US $ 500 each.

OPTICAL AMPLIFIERS.

A conventional coaxial cable based CATV system employs amplifiers at regular intervals to amplify the signal and compensate for cable and distribution losses. Contrary to popular belief, there are no optical amplifiers for Amplitude Modulated signal, used in CATV F.O. systems.

There are optical amplifiers available for amplifying digital, optical pulses, that are employed in digital telecommunication systems, but these cannot be deployed for analog signals. This means that once the optical signal becomes weak, there is no alternative, but to convert the signal back to an electrical (R.F.) signal, using a fibre optic receiver. The R.F. signal can be amplified if necessary, and then fed to another F.O. Transmitter, for retransmission.

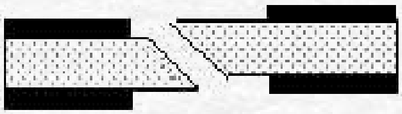
Clearly, such conversions of the signal from an optical form to R.F. and then back to an optical signal is economically extravagant, and the conversions will add noise and distortion to the original signal. Hence, every effort is made to minimise all losses in the optical path. Where necessary (or possible) a more powerful laser transmitter can be employed. However, enhanced laser power comes attached with a significant price tag, and usually a shorter operational life.

BI-DIRECTIONAL TRANSMISSIONS.

Most advanced CATV Systems require Bi Directional transmission capabilities. Separate frequencies (wavelengths) are to be employed for this purpose. Such CATV systems utilise a 1310nm carrier for the forward path (Head End to distribution nodes) and 1550nm for reverse path transmissions (from Nodes back to the Head End), on the same fibre core. Alternately, separate fibre cores can be used for the forward & reverse paths, both at 1310nm. Details of the practical implementation will be given in the Part II of this series.

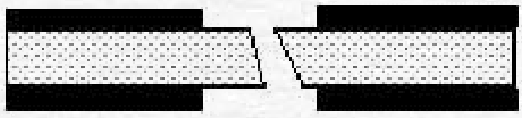
JOINTS & CONNECTORS

Fibre Optic Cable typically has a very low transmission loss... only 0.2 dB per Km. If the low loss is to be fully exploited, it is necessary to ensure that joints and connections do not significantly add to the loss. This makes cable jointing and connecting is a critical and demanding task. Losses at joints or connectors could be either due to misalignment of the fibres as shown above, or due to a mis-match of the 2 ends, as shown in the figure below. To fully appreciate the practical difficulties, it is important to keep in mind that the fibre core is approx. 125 microns in diameter, so a misalignment of even 10 microns is quite significant.



A Misaligned Joint

Connecting optical fibres, usually requires an optical microscope to view and centre the fibre in the connector. The fibre is the potted in a transparent epoxy compound, which is rapidly set (in a few minutes) by exposing the epoxy to Ultra violet light. Yes, all this needs to be done in the field. To ensure a perfect joint, and avoid the situation shown in the fig above, it is necessary to carefully grind ends of both the fibres, to produce a smooth uniform surface at the same angular cut. This cut is usually 45 or 90 degrees, and is specific to the type of connector being used.



Surface Mismatch at the Joint

A few years ago, RADIALL of France developed a fibre optic connector, which does not require precise external aligning or accurate surface polishing. This connector utilises a ball bearing, through which a tiny hole is drilled. Both fibres are inserted from opposite ends of the ball bearing, where the are automatically aligned. The point where the two fibres meet, contains a soft material, with approximately the same refractive index as the figure. Hence, light travelling from one fibre to the other does not encounter any change in the refractive index at the joint.

Inspite of all the precautions taken, a good Fibre connector will have a loss of atleast 0.2dB. (i.e. a loss equivalent to 1Km of uncut cable!) While connectors are inevitable for use with optical splitters, clearly, a more efficient connection would be welcome. With copper wire, an excellent joint can be produced by melting metal and forming the joint as in soldering or welding. Similarly, an almost perfect joint can be made on an optical fibre by FUSION WELDING. The process trains a powerful burst of Laser light at the joint, which fuses the glass fibre. The ends are joined by the as the molten glass solidifies. Laser fusion equipment is expensive, a typical, fully automatic field set up would cost approximately Rs. 8 Lakhs As a cynic commented, “ The common razor blade is a very potent weapon to sabotage a Fibre Optic Distribution system. “

THE F.O. RECEIVER

CATV signals are ultimately meant to be fed to television receivers. It is therefore necessary to convert the optical signal into an R.F. electrical signal before it can be fed to a TV set. The Fibre Optic Receiver performs this task. The incoming optical signal from the F.O. cable is directed onto a PIN photodiode. The photodiode is normally connected to a reverse voltage (reverse biased). Under these conditions, no electric current passes through the photodiode. The light from the optical fibre, when incident on the PIN photodiode, causes the photodiode to conduct current in proportion to the amount of light on it. This current is sensed and amplified, to produce a final R.F. signal of 550 MHz or 860 MHz bandwidth, offering upto 80 channels at over 80dBU. Thus, a fibre optic receiver accepts an Optical input, and directly produces a 80 dB R.F. output for upto 80 channels. This is equivalent to having duplicated the entire output of a master Head end at the receiver, without the distortion of any intermediate amplifiers. A typical Fibre Optic receiver costs approximately US $ 1,200.

CONCLUSION

Does Fibre Optic Transmission offer the perfect, - distortionless, noiseless medium ? Again, contrary to popular belief, the answer is “ NO ".

DISTORTION:

The amplification and conversion of the R.F. signal, does introduce distortion. However, in a typical F.O. system, the worst case distortion is fairly low, and is not a major concern. This is mainly because the F.O. system does not employ multiple amplifiers to boost the signal for transmission. Distortion can only take place at the time of conversion of the R.F. signal to an optical signal, and then again when converting the optical signal back to an electrical signal.

NOISE

The F.O. receiver has the difficult task of accepting a weak beam of light and converting it to a large (80dB +) R.F. signal. The PIN photodiode produces only a very tiny current fluctuation in response to the incident light. Further, the situation is compounded when a larger number of channels are employed. These changes are to be amplified by several orders of magnitude, to obtain the required output. This large signal amplification results in a fairly large noise, ultimately yielding a poor C/N (Carrier-to-Noise) ratio. Other more sensitive photodetectors could be used, but these do not exhibit the excellent linearity (Low Distortion) of the PIN Photodiode.

As a result of the above, the F.O. system noise increases significantly, if a larger number of channels are used, particularly where the incident optical power to the receiver is low. A Fibre Optic CATV system, would typically provide much lower distortion, but the same, or more noise, than a conventional R.F. distribution system offering 70 channel operation over the same distance.