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AN INTRODUCTION TO FIBER OPTICS SYSTEMS - PART II

BASIC SYSTEM DESIGN

This series of articles on Fiber Optics plan to introduce the reader to the use of Fiber Optics in CATV Networks. Part 1 of the article covered basic system building blocks such as Fiber Optic Transmitters, Receivers, Cables, etc.

This article provides an overview of Basic Fiber Optic System Design, and provides details in a simple form, on a topic often thought to be esoteric & beyond the comprehension of a CATV technician.

THE BASIC SYSTEM

As detailed in Part 1 of this article, a basic Fiber Optics System consists of 3 main elements viz.: The Transmitter, Fiber Optic Cable and the Fiber Optic Receiver. Most Fiber Optic systems the world over are installed transmission of te1ephone conversations and data. Actually for carrying telephone signals over long distances, the signal is first converted into a digital format and then this digital signal is transmitted by Fiber Optics. Hence most Fiber Optics system employed today are for digital transmission of data.

Before we start examining the CATV Fiber Optic system, it is essential to know that unlike most other Fiber Optic systems, for CATV transmission, Analog Modulation of the light source is used. This makes CATV Fiber Optics a unique technology.

TRANSMISSION WAVE LENGTH

As we have seen in Part I, Fiber Optics operates at a very high frequency - of several ,thousand GHz. Actually the Fiber Optic light is in the near infra red region and not visible to the human eye. At these very high frequencies, it is more convenient to refer to the wavelength of the light in nano meters (nm), rather than the frequency. (as an example,1300 nm is equivalent to 231000 GHz.

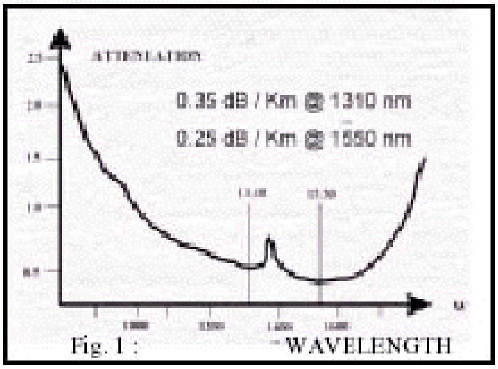


Fig. 1 :

As shown in Fig. 1, the attenuation or loss of the signal in the Fiber is not linear, unlike coaxial cable. The loss is relatively very high around 800 nm and falls rapidly until it reaches a minimum at 1310 nm. For further increase in wave length the loss again starts rising and peaks. It then falls once again to its lowest point at approximately 1550 nm.

Therefore Fiber Optic Cable provides 2 "Windows" - at 1310 nm and 1550 nm. At these two wave lengths the loss is extremely low.

Typical good quality single mode Fiber that is employed for CATV applications will exhibit a loss of 0.35 dB per Kilometer (yes, per 1000 meters!) at1310 nm. At1550 nm the Fiber transmission loss is even lower at 0.25 dB per Kilometer. From this it is apparent that Fiber Optic CATV Systems are designed to operate at either 1310 nm or 1550 nm. CATV Fiber Optics system installed over the past 5 to 10 years had been designed for operation at 1310 nm. These systems now provide proven technology at fairly economical prices.

THE FO TRANSMITTER

The light output of a transmitter is specified either in milliwatts (mW) or as is more prevalent for RF CATV systems, in dB. For Fiber Optics the units are dBm. This refers to a comparison of the signal with 1mW as the reference. Hence double the power i.e. 2 mW would be 3 dBm. Table 1 below provides a ready reference of various optical output power levels both in mW and dBm.

Most optical transmitters available today, operate at 1310 nm and provide an optical (light) output ranging from 6 dBm (4 mW) to 12 dBm (16 mW). The cost of the optical transmitter sharply increases as its light output capability increases. As an example, a 6 dBm optical transmitter operating at1310 nm would cost approximately Rs.3 lakhs (all prices indicated in this article are approximate and include prevailing customs duty and freight). In comparison a 12 dBm optical transmitter operating at the same wave length would cost approximately Rs.7 lakhs.

Optical Transmitters are also available that operate at 1550 nm. This is a relatively new technology that aims to operate with the absolute minimum loss possible on the cable. However, like all new technologies it is very expensive. A 1550 nm Optical Transmitter with an output of 6 dBm would cost almost Rs.30 to 40 lakhs. From the above it is apparent that Optical output is very very expensive and the Fiber Optic System designer must buy a transmitter that exactly meet his need without too much of extra optical power output (technically referred to as Optical Margin), or else it would almost double his cost of equipment ! All along, in the design of Fiber Optics systems, extreme care and precautions are taken to minimise the optical loss.

THE FO RECEIVER

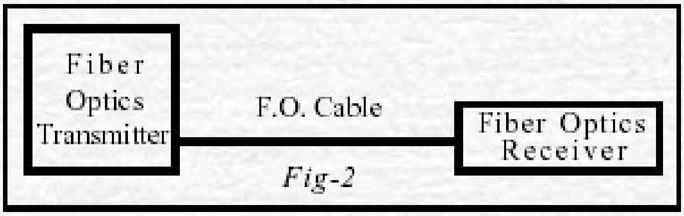


Fig-2

The Fiber Optic Receiver accepts an optical input and provides an RF output. Typically a Fiber Optic Receiver requires an optical input ranging from -3 dBm to +3 dBm. In most cases an input of O dBm would be ideal. If the light received is weaker than -3 dBm. The conversion of this signal to RF would be noisy as a result of which the Carrier to Noise Ratio (C/N) would be badly affected.

The Fiber Optic Receiver provides an RF output of approximately 80 dBU for all channels i.e. without any slope! This means that at the Fiber Optic Receiver, a flat response for all channels is obtained. The highest and lowest frequency channels are reproduced at exactly the same relative signal levels, that they were transmitted from the Headend (Fiber Optic Transmitter).

THE FIBER OPTIC CABLE

As shown in Fig. 1, the Fiber Optic Cable loss is 0.35 dB per Km @ 1310 nm. The basic system is shown in Fig. 2. Light from the Fiber Optic Transmitter passes through the glass cable and is received by the Receiver. Let us assume that the Transmitter has an output of 6 dBm. We have also said that the Receiver requires a minimum input of approximately O dBm.

Hence a loss of 6 dB can be accommodated along the Fiber Optic Cable. Since the Cable has a loss of 0.35 dB per kilometer, a transmission loss of 6dB can be accommodated. This is referred to as 6dB "Optical Budget" indicating that the system designer can "spend" or utilise upto 6 dB of optical power in the distribution network.

Cable length in Kms = 6 dB/0.35dB = 17.14 Kms!

In practice, other losses are also part of the distribution network. These include losses due to Optical Splitters inserted in the path and loss due to joints or Splicing (as it is referred to in Fiber Optics).

OPTICAL BUDGET

The "Optical Budget" can be put down as a simple formula.
Transmitter Power = Loss in Cable + Splice loss + Splitter loss + Power required at Receiver.

Going back to our previous example, the Transmitter power was 6 dBm. The power at the Receiver was O dBm. Therefore 6 dBm = Loss in Cable + Splice loss + Splitter loss + O dBm

Most system designers will add another 0.5 dB loss as a "Safety Loss". This "Safety Loss" is to accommodate any unpredicted losses during installation of the system.

OPTICAL SPLITTERS

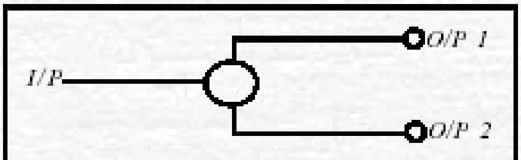


Fig. 3 : An Optical Splitter

As indicated in Part I of the article, a Fiber Optic system also utilises distribution by Splitters and Tapoffs. In RF systems, a Splitter provides equal outputs i.e. a 2 Way Splitter would divide the incoming signal into 2 equal parts of 50% each.

In a Tapoff, the input is divided unequally with most of the signal transmitted from the input to the output and a small fraction fed to the branch. In Fiber Optic Systems, Optical Splitters are available in different split ratios. These split ratios vary from 50:50 upto 95:5. This is shown in Table 2.

SPLICE LOSSES

Table 2

Optical Splitter	Ratios Available
Output 1	Output 2
50 %	50%
45 %	55%
40 %	60%
35 %	65%
30 %	70%
25 %	75%
20 %	80%
15 %	85%
10 %	90%
5%	95%

As detailed in Part I, " Jointing " of two pieces of Fiber is an extremely demanding task. The two ends of the Fiber surface must match perfectly and also be aligned perfectly. Even in practice this is a very difficult task. Two methods of Fiber Cable Jointing are prevalent viz.: Mechanical Splicing and Fusion Splicing.

MECHANICAL SPLICING

Mechanical Splicing joints the two ends mechanically. It yields a high amount of loss. The typical loss for good Mechanical Splicing is 0.15 dB. If the Splicing is not done perfectly, the loss could increase significantly above this value.

While a loss of 0.15 dB may not seem significant by RF standards, this is a very large loss for Fiber Optics, and is equivalent to the loss of almost 500 meters of cable!

FUSION SPLICING

Another method of splicing is referred to as Fusion Splicing. In this method, two pieces of cable are cleaned, surfaces matched and aligned. An electrical are (spark) then melts both ends of the Fiber and welds it together. This method is very similar to metal welding.
Fusion Splicing is often done by computer controlled automated equipment. A fully automatic Fusion Splicer is priced at approximately Rs.7 lakhs to Rs.20 lakhs. The more expensive equipment is capable of Fusion Splicing upto 4 Fiber strands simultaneously. Fusion Splicing

yields a very low loss. A perfect Fusion Splice would provide a loss as low as 0.05 dB.

When designing -the Fiber Optic System, one must keep in mind the splice loss when joining a broken cable or a splice when a new drum of cable is employed. However, one must also keep in mind the splice loss when fitting an Optical Splitter. Each Splitter will add two splice losses on the trunk and an additional splice loss on the branch.

THE FIBER OPTIC CABLE

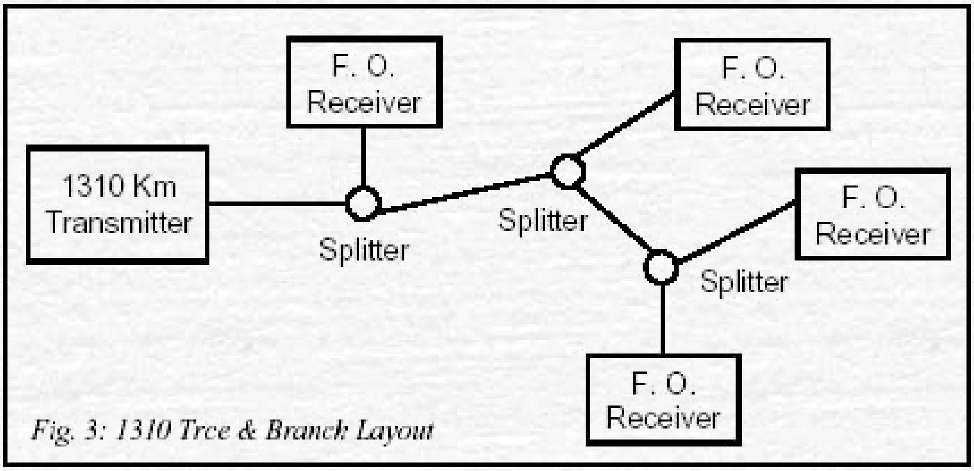


Fig. 3: 1310 Tree & Branch Layout

The Fiber Optic Cable is a thin strand of glass no thicker than a human hair. Approximately 10 Fibers laid side by side would span just one millimeter. The cable is drawn from an extremely pure ingot of glass. The drawing process is critical where the speed of drawing and the temperature at which the glass Fiber is drawn has to be carefully controlled. Drawing of the glass Fiber from the ingot (cylinder shaped lump of glass) is roughly similar to drawing a cotton thread from a piece of cotton wool.

Since CATV systems utilise the optical transmission Windows of 1310 nm and 1550 nm, during the drawing process the Fiber is carefully drawn to have its best characteristic (lowest loss) at the wave length of operation, usually 1310 nm.

There are several manufacturers of glass Fiber in India. These manufacturers typically import the glass ingot and draw or extrude the Fiber at their factory.

The Department of Telecommunications (DoT) is today the only major buyer for Fiber Cable in the country. These cables are used for Telecommunications, not Cable TV. However Indian manufacturers also offer CATV grade Optical Fiber Cables.
An 8 core Optic Fiber Cable is typically available, from local manufacturers at approximately Rs.48 per meter (Rs.48,000 per Kilometer). This is a very low cost and is in fact cheaper than 500 series Trunk Cable. 8 core Fiber Optic Cable is cheaper than 500 series Trunk Cable.

SYSTEM RELIABILITY

The basic Fiber Optic System has been indicated in Fig. 1. Distribution of the Fiber Optic signal is done by the cable, optical Splitters and connectors. This implies that the entire Fiber Optic System is passive. The only active components in a Fiber Optic CATV Network are the transmitter and Receiver. No power is required by distribution of the signal.

Further since no active distribution electronics such as amplifier is employed, there is nothing to fail electronically. This provides the system a very high degree of reliability. The key element in the Optical Transmitter is the laser diode which emits the 1310 nm or 1550 nm light. Over a period of time the (light) power output of the laser diode fades down. For this reason, Fiber Optic System designers will often build in an additional 1/2 or 1dB of optical margin to accommodate for reduction in light output from the transmitter over a period of time.

Having said this, Fiber Optic transmitters have evolved to a very high degree of reliability.

Scientific Atlanta, B leading manufacturer of Fiber Optic components quotes an MTBF (Mean Time Before Failure) of approximately 100,000 hours i.e. 10 years of continuous operation. Special switching equipment is also available at the Headend, which will automatically switch in a stand by transmitter in case of any failure of the transmitter in use.

AMPLIFICATION

1310 NM SYSTEMS

After the optical signal travels through the length of cable and distribution Splitters its intensity is reduced due to system losses. For 1310 nm systems, it is not possible to directly re-amplify these signals. Once the output reaches a level of O dBm, it is reconverted back to an electrical signal, using a Fiber Optic Receiver. This RF signal is then amplified by a special high output pre Amplifier + Amplifier combination which provides an output of upto 120 dBU. This high output RF signal is then fed into a Fiber Optic Transmitter for retransmission. Clearly this process is tedious and undesirable. Hence, as far as possible, the Fiber Optic System designer will prefer to utilise a higher output transmitter at the Headend, even though it may be substantially more expensive.

1550 NM SYSTEMS -

Current state-of-the-art systems utilise 1550 nm signals. These signals have a slightly lower loss on the cable. Contrary to what was stated in Part I of this article (which was actually written and published almost 3 years ago in this magazine), Direct Optical Amplifiers are available for 1550 nm systems. These Amplifiers accept an optical input and provide an optical output without going through an intermediate RF conversion. These Optical Amplifiers utilise Erbium technology and are popularly referred to as ED-FA Amplifiers.

SYSTEM LAYOUT

ED-FA Amplifiers accept an input of approximately 6 dBm and provide a total optical output of approximately 22 dBm. This very high optical output of 25 dBm is often split and distributed over 4 outputs each of approximately 16 dBm. Due to the much higher optical output power from EDFA Amplifiers, a 1550 nm Fiber Optic System typically utilises a STAR based distribution topology or layout. Compared to this, the 1310 nm Fiber Optic System typically utilise a tree and branch distribution structure. These are indicated in Figures 3 & 4 below.

HYBRID SYSTEMS

One must keep in mind that all RF inputs for distribution over a CATV network are electrical signals. Hence the Headend always puts out an electrical signal. Further the customers TV set also requires an electrical signal. This clearly indicates that both the input and output must ultimately be electrical signals. The electrical signals need copper coaxial cable for their distribution. Therefore all Fiber Optic CATV Networks must also deploy copper coax for distribution to the customers TV set, that is they must be a mix of both Fiber and Copper. These are termed as Hybrid (Mixed) Systems.

Due to the advantages of Fiber Optics it is desirable to carry the signal optically as far as possible. The optical Receiver cost approximately Rs.75,000 (as indicated in Part I). It is hence desirable to have one optical receiver feeding a fairly large number of subscribers so that the cost of the optical receiver is amortised over a large number of subscribers. Often the Fiber is brought upto a local area (or basti - in India) and then distributed over coaxial cable. In the US each local area typically covers 600 homes. In Europe it is more common for each Fiber node to serve an area of approximately 2000 homes. Such a layout is called Fiber to the Serving Area (FSA) layout. This is indicated in Fig. 5.

REVERSE PATH

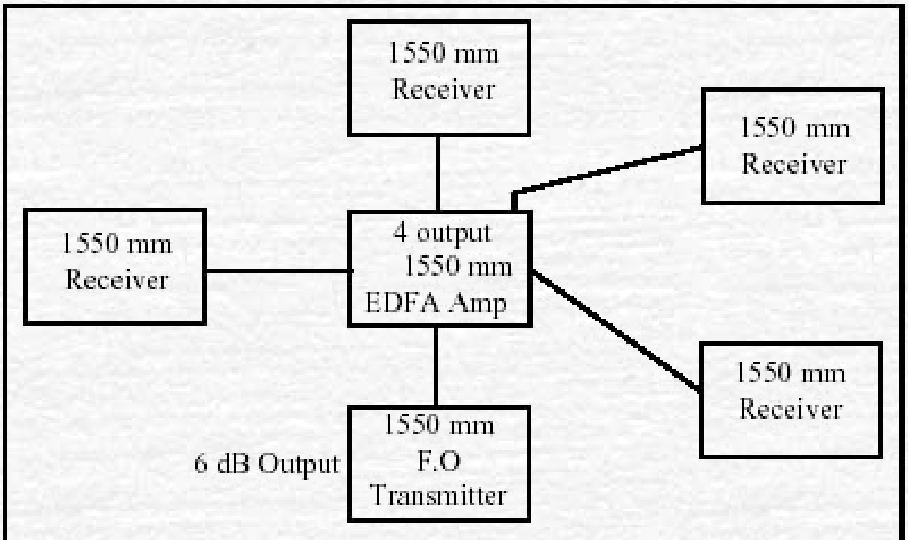


Fig. 4 : 1550 mm ED-FA star Distribution

Most Cable Networks today are upgrading for Reverse Path capability all the way from the customer to the Headend. A full Reverse Path capability is necessary for providing lucrative value added services such as Internet Delivery, Data Transfer, RF Pay per View, etc. Installing a Reverse Path is not that difficult for a coax system since the same coaxial cable carries signals in both the Forward and Reverse Path. The Forward and Reverse signals are separated by using different frequency bands.

For a Fiber Optic System, each Fiber strand carries signals of a specific wave length e.g. 1310 nm. There are no other frequencies or wave lengths that are employed. Hence, each Fiber core is essentially unidirectional and will not carry signals in the reverse direction. Technically, systems have explored the possibility of carrying a reverse signal on the same Fiber at another wave length e.g.: a system utilising 1550 nm in the Forward Path, could in principle utilise 1310 nm transmission of signals in the same Fiber, on the Reverse Path.

A key factor to remember is that a Fiber Transmitter costs between 5 to 10 times more than a Fiber Receiver. To send signals in the reverse direction, each of the reverse nodes must include a Fiber Optic Transmitter. Let us take the example of a typical Fiber System transmitting from a central Headend to 50 serving areas throughout the city. Such a system would require 1 Transmitter (approximately Rs.4 lakhs) + 50 Receivers at approximately Rs.75,000 each yielding a total cost of Transmitters and Receivers at Rs.41,500,000 (keep in mind that a system of 50 Receivers is fairly large by any standard and could cover a large city such as Calcutta or Bombay).

Now if each of these 50 nodes was also to be equipped with a Fiber Optic Transmitter for full Reverse Path capability, it would imply an additional cost of Rs.2crores, i. e. almost 4 times the initial cost of Transmitters and Receivers.

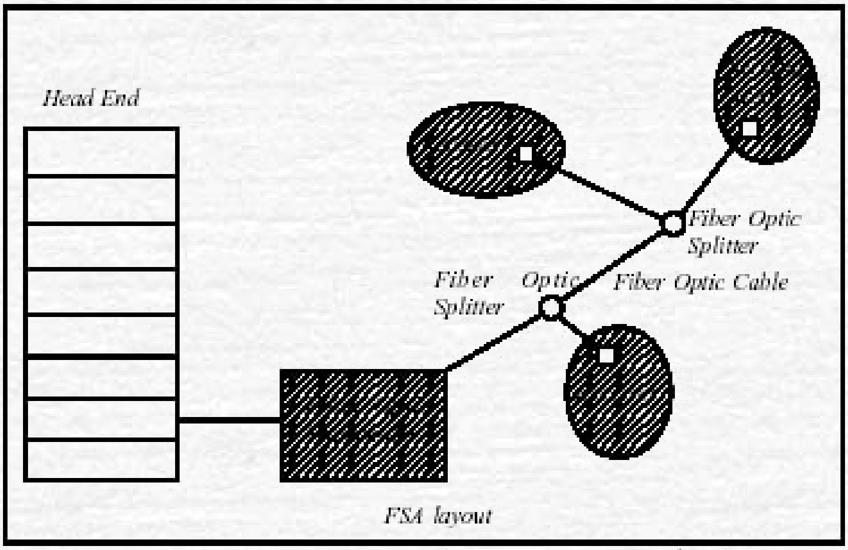
In certain applications, it may be adequate to provide only digital data in the Reverse Path. Relatively low cost (Rs.80,000) Fiber Optic Digital Transmitters are available for such applications which could serve the need for providing Internet delivery & Data exchange, over a Fiber Optic based CATV network. Another concern for Reverse Path capability is that separate, dedicated Fibers are necessary from each reverse node back to the Headend.

Full Reverse Path On A Fiber Optic System Multiplies The Project Cost Very Significantly. Hence, a network with 50 receiving nodes would require a Fiber Cable with atleast 51 cores, 1 core for the Forward Path and 50 additional cores, one from each node back to the Headend! Clearly, establishing a full Reverse Path on a Fiber Optic System multiplies the project cost very significantly.

INDIAN CONDITIONS

In India most of the cabling is done overhead, primarily due to lack of government and municipal sanctions for underground cabling or the use of electricity poles.

OVERHEAD CABLING



It is interesting to note that there is a general feeling within the CATV industry in the country, that Fiber Optics cannot be laid overhead as suspended cable spans. This is not true. Double jacketed Fiber Optic Cable with Kelvar strands fitted in between the 2 jackets is used for overhead, suspended Fiber Optic Cable runs. This is a well established practice the world over. The Kelvar strands in between the double jacketing is the equivalent of a messenger used on coaxial cables. The Kelvar takes the load, leaving the optic Fiber stress free.

Infact, in Northern India, extended runs of Fiber Optic Cable have been laid along high voltage electric transmission lines. The Fiber is totally immune to electric noise or radiated pick up. Kelvar is a non- metallic nylon. The cable strands are made of glass and the jacketing of HDPE. Hence the entire assembly is metal free and provides a highly insulated electrically safe conductor that can be laid close to high voltage lines without any risk.

UNDERWATER CABLES

Special Fiber Cable, filled with petroleum jelly is also available for under water laying. It may also be viable to lay under water Fiber Optic cables in certain locations such as Bombay. Under water cable will have the added advantage of high security since it is not easy to access and therefore sabotage. Cable cutting has been a common retort by the competition, in India. This can prove particularly troublesome in the long run since each splice, even if Fusion Splicing is used, adds a permanent loss to the system.

COST COMPARISONS

Most Cable Network Owners instinctively assume that a Fiber Optic based distribution system is more expensive than copper. Let us factually examine the details.

CABLE COST

Low cost Trunk Cable is priced between Rs.50 to Rs.60 per meter. Let us assume that this is about the same price as an 8 core Fiber Cable which is available at Rs. 48 per meter. Hence cable costs are similar (of course utilising better cable such as 750 series would prove much more expensive.

AMPLIFIER COST

Assuming a loss of approximately 6 dB per 100 meters for 500 series coaxial cable, approximately 3 Amplifiers would be required every Kilometer. Assuming that a high quality Trunk Amplifier station, capable of delivering signal quality similar to a Fiber system would cost approximately Rs.25,000 each, the cost of Amplifiers is Rs.75,000 per Kilometer. A 5 Kilometer stretch would imply a cost of Rs.3,75,000. This is about the price of a competitively priced Fiber Optic Transmitter (Rs.3 lakhs) + 1 Fiber Optic Receiver (Rs.75,000).

From the above rough estimate, the indication is that a 5 Kilometer long Fiber Optic Trunk costs about the same as a coax based RF distribution system. For Trunk lengths of more than 5 kilometers, a Fiber Optic distribution system may actually be cheaper. One must keep in mind that the Fiber System provides a much higher degree of reliability since there are no Amplifiers to fail along the trunk.

DISTORTION AND NOISE

Since the Fiber Distribution System utilises electronics only at the sending and receiving end, distortion can only be generated either by the Transmitter or the Receiver. Fiber Optic Distribution Does Substantially Lower The Distortion Between the Headend and any customer, there would be only 1 Fiber Optic Transmitter and Receiver, the distortion would essentially be from these 2 devices only for the Fiber System. The final coaxial distribution would of course add its own distortion but that too would be low since typically not more than 2 to 3 Amplifiers would be in the path between the Fiber Optic Receiver and the customer. Thus, Fiber Optic distribution does substantially lower the distortion.

The noise contribution from a cable Amplifier increases by just 3 dB for doubling the number of Amplifiers. Hence only 3 dB more noise is generated by a cascade of 64 Amplifiers compared to a cascade of 32 Amplifiers. In contrast, the noise at the Fiber Optic Receiver increases rapidly if the optical signal falls appreciably below O dBm. Every effort should be made to ensure that the light received at the optical receiver is approximately O dBm. If this does not happen due to various factors such as poor quality connector, poor quality of repair splice or degradation of the laser over a period of time, the noise from the Fiber Optic based system may actually exceed that of a copper system.

CONCLUSION

It has been the intention of this article to provide the readers a quick overview of key considerations in Fiber Optic System design as well as to provide a simple, basic working knowledge of how a Fiber Optic CATV Distribution Network is designed. Both Fiber Optic and Coax systems have similar loss calculations. Only, in the case a Fiber Optic System, there is a total " Loss Budget" or " Optical Budget" that needs to be calculated. This " Excess " optical power can be distributed as a loss over the cable, splicing, Optical Splitters, etc. Further, it is not possible to regenerate or amplify the signal in a Fiber Optic Amplifier System (except with Esoteric Optical Amplifiers which cost Rs.30 to 40 lakhs !). It is hoped that this article would help remove readers fears that comprehending a Fiber Optic system is beyond their reach. We welcome any queries that readers may have on the subject. This article is a re-print of an article carried in our magazine, a couple of years ago.