# FIBER BY DESIGN

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*Abstract*

*The evolution of CATV systems employing fiber optics has been both rapid and dramatic. Fiber optic CATV use has made the transition from following and adapting technology developed for telephony to driving fiber optic development. Couple this with the continual and fast changes in fiber optic technology and it is not surprising to have conflicting information when designing a CATV system. This paper presents a review of the major fiber optic technologies and gives some guidelines that can be used in determining the optimal design.*

## INTRODUCTION

The rapid development of CATV fiber optics has led to some confusion and contradictory information in system implementation. This paper reviews the technology and offers some guidelines in system design. To review and compare technologies for fiber optic CATV it is apparent that system aspects that are discriminators be brought out. Rather than listing the advantages and disadvantages of competing approaches this paper will present the desired system goals and see how alternative approaches rate within that category. However, these options easily fall into two classes. The first is the forward (headend to node) system including the Optical Transition Node (OTN) method of remotting headends and/or reducing fiber counts. The other is the return (node to headend) system, and this separation will be used for the following discussion.

## FORWARD SYSTEM

Today the CATV forward system mainly carries video channels. However the system is expected to carry video, telephony, personal communications and data. The main technologies, in practical use, for the forward system are 1310nm DFB transmitters, 1310nm Externally modulated transmitters, and 1550nm Externally modulated transmitters. Each of these offers unique advantages and could be considered for a CATV forward system. This paper assumes that receivers do not make a critical difference in the system tradeoffs. This assumption is justified, in that the receiver semiconductor, InGaAsP, is capable of receiving both the 1310nm and 1550nm wavelength. Also, once most system parameters are determined the receiver choice would likely be the same for all the potential transmitters. In the next few paragraphs system considerations are presented and the impact by differing technology choices is considered. One issue at a time will be considered without regard to others. These issues will then be tied together at the end of this section.

### Cost

No system design can be considered without the overriding concern being cost. It is imperative that the completed system be profitable to operate. The system cost is not just the price of equipment and installation fees but involves maintenance as well as reliability. The last two could conceivably be the cost drivers over the expected system life.

Certainly, in cost, it can be seen that the 1310nm DFB transmitters have the advantage. The 1310 DFB transmitter is the most commonly used transmitter in the CATV plant. This has translated into volume related discounts that are passed on to the customer. Also it has a proven reliability record that comes with the maturity of the device and product offering.

The 1310nm External modulator is the next choice. This product offering is relatively young and the volumes are not on the same order of magnitude as the 1310 DFB transmitter. It does, however, take advantage of proven techniques and components, to a large extent, indicating the potential for highly reliable operation.

In cost the last choice is the 1550 External modulator. This offering is in its infancy and while interest is growing it is still a low volume product. From the point of view of maturity there are major components that are relatively new and this is a potential risk.

Link Length and Performance

The transmission length in fiber optics is specified in dBs of loss. This is made up of two components. The first is passive loss (couplers, splitters, wavelength division multiplexers) that will be considered equal for both wavelengths. The second is fiber loss and is specified as dB/Km at a particular wavelength. For wavelengths near 1310 this is approximately 0.35 dB/Km while for 1550 this is 0.22 dB/Km. Based on fiber loss alone there is a significant advantage to 1550 operation. However, since real systems always have a component of passive loss the actual length of fiber is always less than would be predicted by fiber loss alone. The real advantage in link length for 1550 lies in the opportunity to repeater the signal with an inline optical amplifier. The optical amplifier also offers the advantage of transparency. Essentially this allows system upgrades at the transmission and reception points without needing to change intermediate repeaters. Currently, the 1550 fiber amplifier has no competition in the 1310nm operating window. While 1550nm External modulators have a distinct length advantage (when optical amplifiers are considered), the second choice is the 1310 external modulator. Since the source can be a solid state laser, high power operation is limited only by the modulator physics. It must be noted that this operational limit has yet to be met in a practical application. The third choice in link length is the directly modulated 1310nm DFB laser. However, the range of this choice is easily sufficient for 90% of applications and is also being improved on a yearly basis.

In link length, the issue of Stimulated Brillion Scattering (SBS) often arises. This is a nonlinear interaction of acoustic waves in fiber. The limit for a purely coherent source is on the order of 10mW or 10dBm at both wavelengths (the limit is wavelength dependent and is lower at 1550nm). However the SBS threshold is affected by the dynamic linewidth of the source. For directly modulated DFB lasers the limit is an order of magnitude larger than 10dBm and is therefore not an issue in CATV systems. For externally modulated transmitters the SBS limit can be a problem, however by "dithering" the source (via phase modulation) the limit can be raised to the needed level eliminating any concern.

You cannot separate reach from distortion performance as an issue in system design. If you were to separate them the comparisons of differing technologies would be meaningless. So in the preceding paragraphs a standard 77 NTSC channel lineup with 200 MHz of digital loading has been assumed. In this a C/N of 51, CSO of 62, and CTB of 65 for the video has been used. However this is not the whole story. While both the direct modulation and external modulation techniques use complex linearization schemes the external modulator is theoretically easier to linearize and therefore some specifications have shown an improved CSO to 65 dBc. This is important for repeatered applications and an example of this is remotting headends via the OTN approach. For systems (with or without transition nodes) that are approaching the "passive coax" model, by having less than 6 rf amplifiers in cascade, this is a non issue. Indeed these systems are normally C/N and/or CTB limited and CSOs of 58-62 dBc are acceptable.

## Narrowcasting

For this paper narrowcasting will be defined as the need to provide a single transmitter per receiver allowing different channel lineups and data to smaller groups of customers while increasing system reliability. It has its basis in the desire to run telephony over cable. Traditionally a transmitter output is split providing the same signal to 4 optical nodes. Therefore narrowcasting has a direct impact on cost because there are now approximately four times the transmitters per system. For this definition the 1310 DFB transmitter is the desired choice, it is the most cost effective solution with a proven reliability track record. The external modulator choices of both wavelengths have their advantage in serving multiple receivers, and this is particularly true for the 1310 External modulator.

## Choice

As can be seen in the preceding paragraphs the best choice depends on the specific system needs. The three extreme examples that follow help define the boundaries of this decision.

The first system is the typical CATV system. This system is in a suburban area with customers within a 20 km fiber radius of the headend. It is important to be able to provide standard CATV service today with the option to upgrade to Narrowcasting to compete with the local telephone company. In the preceding paragraphs we see that the needs today are low cost, short fiber length and CATV reliability, while the needs tomorrow are low cost/node, signal diversity, short lengths and telephone reliability. The difference between the "reliability" considerations results from telephony being considered a lifeline service. When we compare these needs to the above discriminators we see that the 1310 DFB transmitter is the obvious choice.

The second system serves a highly dense urban area with extremely short fiber lengths but many splits from a single headend. This system is looking for as few components as possible, with low cost/node, but due to density it will be sending the same signal lineup to many nodes. This is a bit trickier than the previous system in that it seems the DFB transmitter might be the preferred option. However the intent is to show that even though the fiber lengths are very short the loss due to extensive splitting makes the overall loss budget large. With this in mind the preferred choice is the 1310 External modulator. Even though this unit cost more than a DFB, it is ideally suited for this multiple splitting application.

The last system is in a very rural area where fiber lengths are long and headends are remoted from the customers for ease of maintenance. The system has been determined to be profitable with any technology, but the overriding concern is reach. In this scenario the best alternative is the 1550 external modulator coupled with fiber amplifiers as needed.

In these three polarized systems the choice is obvious. In reality any moderately large system may include all of the above scenarios. Therefore a system may need more than one technology or may make tradeoffs in technology use to accomplish its goals. All the technologies have their place for the foreseeable future and the choice on which is best is system dependent.

## Future Intangibles

The rapid advancement of fiber optic technology is making our industry change even faster than the personal computer industry! Therefore advances that could change the product and technology mix are inevitable. The most interesting change that could happen is the development of a 1310 optical amplifier. The transparency at 1310nm coupled with the overwhelming use of this wavelength in CATV fiber optics would easily shift the decision lines.

## RETURN SYSTEM

The return fiber optic system is identical to the forward system in that cost, reliability, maintainability, link length and performance, and narrowcasting are the key system concerns. Unlike the forward system, the return system topology is not well established, and this leads to additional confusion. This portion of the paper takes the same style as the preceding section to help in the design considerations of return systems.

The CATV return system carries mainly FSK converter data as well as the odd video channel today. It is expected to grow completing the bi-directional path for video data and telephony. Each return band is capable of transmitting 6 video channels with bandwidth in the 5-42 MHz region or many data carriers, dependent on modulation type and bit rate. This capability is augmented at the fiber node by taking advantage of the unlimited fiber bandwidth. Typically four of these return bands will be combined on the return fiber link. The infancy of this application has brought a multitude of potential solutions from 1310 and 1550 nm FP lasers, to 1310 and 1550 nm DFB lasers. Each brings its unique advantages to the fold, but once again we shall look at the system needs and compare the choices.

## Cost

Certainly the application of the return system dictates the cost of the return transmitter and whether the system can generate revenue. Therefore the following information must be held until further system needs are considered. The 1310 FP laser is the lowest cost device, followed by the 1550 FP laser, the 1310 DFB, and the 1550 DFB. However these costs differences may not be as extreme as first thought. Since the return system need not be as complicated as the forward (80 Video vs. 2-12 Video) and the number of return transmitters needed today is roughly 4 times as many as are needed in the forward system (due to outbound splitting) the variations in cost can be lower that expected. In terms of maturity the order presented above needs modification in that the 1310 DFB and the 1550 FP trade places. This opinion is due to the fact that there are few applications for 1550 FP lasers outside instrumentation.

Link Length and Performance

This is generally where confusion in the return system arises. A typical system returns fiber to the headend at a much shorter optical length than is transmitted from the headend. The reason for this is the forward transmitter is normally split to multiple receivers. This splitting loss is not actual distance and is not encountered in the return path which will have one transmitter per node. In any case, the loss of fiber at 1550 nm is still markedly lower than at 1310 and this is always an advantage.

For lower level data applications (like FSK converter data) all the technologies mentioned can readily be used; however, the FP lasers are the devices of choice due to cost. Using a 1550 nm FP results in a high noise environment due to the interaction of the laser mode partitioning and the fiber dispersion. Data application may still be valid though, and this device cannot be ruled out. It would seem most appropriate to use this device when length is at a premium.

For low numbers of video (2 channels typically) the 1550 FP is ruled out due to the noise, as mentioned above, and the others can still be considered. Here length again plays an important role in determining the choice. The FP is good for short lengths while the 1310 DFB can be used for longer lengths and the 1550 DFB for extremely long lengths.

For large numbers of video channels the FP lasers is completely ruled out and only the DFBs remain. Their use is predicated upon length and channel line up. The 1550 DFB is possible here and more information will be gained by a paper presented in this session, "Return Path Lasers for High Capacity Hybrid Fiber Coax Networks."

For hybrid applications of multiple video and data channels, as would be used in a telephony application, the choice would seem to favor the DFBs again with emphasis on the 1310 DFB.

It should be mentioned that the use of a DFB is not without certain costs. They include a large power consumption for the thermal electric cooler and the high packaging costs. The application needs to justify this cost, and surely the revenue from telephony could do so.

Narrowcasting

Narrowcasting does not directly effect the choice for the return system as it does in the forward system. The reasoning here is the return system is not split and therefore does not see an impact. Hidden in this, however, is that narrowcasting drives the DFB volume higher and this can only foster lower prices for all grades of DFB. Therefore narrowcasting can help make the DFB return transmitter a profitable solution.

## Choice

Again, the choice is application dependent. Since applications are too diverse in the return system only two extreme examples will be given.

In the first example the system operator wishes to return FSK converter data over short link lengths. In this application a 1310 FP would be the best possible choice. The cost is the lowest with high reliability. Distances of 7-10 dB are easily handled.

In the second example. The system operator is in head to head competition for telephony. The franchise agreement also requires local video origination. The link lengths again are short. In this application the 1310 DFB is the device of choice. With good linearity and low transmitter noise it will be able to handle the job admirably. The higher cost is expected to be offset by telephony revenues.

## Future Intangibles

There are two main areas that can change these concepts. The first is the development of a DFB without the need for an expensive Thermal Electric Cooler. Work in this area progresses, and this could lower the cost of the DFB laser. In addition the main reason that FP lasers are noisy is mode partitioning. Simply stated the FP lasers have many optical carriers all competing in a random fashion for photons. If a FP laser could be developed with a single mode, then this mode partitioning noise would be eliminated. This is being researched, for other applications, as a surface emitting laser. Of the two the wide temperature range DFB is closer to being productized. Fiber optics is changing rapidly, monitoring these changes will allow you to make application improvements as they become available.

## CONCLUSION

This paper has looked at the system design of a fiber optic CATV application and compared various approaches based on system needs. The conclusion that the correct choice is system dependent has been shown. Indeed, a complete system most likely benefits from a combination of all technology choices. The other major conclusion is that fiber optics is a rapidly changing field and these comparisons are only valid as of the writing of this document (March 1995). The continual changes need to be monitored to keep confusion at a minimum and benefit at a maximum.

## REFERENCES

Darcie, Thomas E., "Subcarrier Multiplexing for Lightwave Networks and Video Distribution Systems," IEEE Selected Areas in Communications, Vol. 8, No. 7, September 1990.

Wolfe, Douglas E., "Impact on Fiber: Stimulated Brillouin Scattering, Laser Sources," Communications Technology, March 1994.

LaViolette, K. D., et. al., "System and Design Considerations for the Cable Return System," Proceedings of the NCTA Conference, New Orleans, May 1994.

Dykarr, D. R., et. al., "2.5 Gb/s Raman Amplifier at 1.3 um in Germanosilicate Fibers," The Optical Fiber Conference, San Diego, February 1995.

Woodward, S. L., et. al., "Error-Free Digital Transmission on Subcarriers using Uncooled Fabry-Perot Lasers," The Optical Fiber Conference, San Diego, February 1995.

Shimizu, M., et. al., "High Power and Low Noise Praseodymium Doped Fiber Amplifiers," The Optical Fiber Conference, San Diego, February 1995.