Cost Effective Point to Point AM Fiber Links Using High Power Optical Receivers

H. Blauvelt, J. Paslaski, and J. Lipson
Ortel Corporation

Abstract

Fiber optic links for transmitting AM video have typically operated with received optical power levels of about 1 mW. In the past, the most common practice was to split the laser output to serve multiple optical nodes. The higher the output power of the laser, the more optical splitting that could be done, but the received optical power was always approximately 1 mW.

Recently there has been much interest in point to point links without any optical splitting. These links commonly have optical loss budgets in the 2-6 dB range. With conventional 10 mW DFB lasers, the received optical power greatly exceeds 1 mW. To avoid overdriving the receiver, low power DFB lasers are used for these point to point links. Although point to point transmitters have lower output power requirements, the linearity demands on the laser are approximately the same as for high power DFB lasers.

An alternative approach to point to point links is to use medium power (6-10 mW) lasers and higher received power. If the modulation depth is kept the same, this results in significantly higher link C/N. Alternatively, the modulation depth can be reduced to provide the same C/N, with substantially relaxed linearity requirements for the laser. In this paper, the factors influencing receiver linearity and designs capable of operating up to 5 mW received power will be described. The impact of high optical power receivers on laser linearity requirements and on the channel capacity of AM fiber links will also be discussed.

Introduction

Most of the optical transmitters deployed for AM fiber optic links have used 1310 nm DFB lasers. The most common use of 1310 nm DFB technology has been to use 10-15 mW DFB lasers with the output optically split to serve multiple nodes. As the cost of 1310 nm DFB transmitters has dropped, it has become economically viable to use DFB transmitters that are dedicated to a single node. By doing so, the interactive bandwidth available to each node can be greatly increased. The loss budgets for these links are greatly reduced when there is no optical splitting. For this reason, the lasers used for point to point links have had much lower output power levels than lasers used with splitting. In this paper, several of the more important cost and yield issues related to the production of point to point lasers will be discussed. In particular, the impact of higher power optical receivers on point to point link design will be examined. High optical power receivers also can play an important role in increasing the channel capacity of AM fiber optic links.

Point to Point AM Fiber Links

Most point to point AM fiber links have optical loss budgets of 2-6 dB. If optical receivers are constrained to a maximum received optical power of 0 dBm, then the maximum laser power is 2-6 dBm (1.6-4 mW). In most cases, the linearity requirements for point to point lasers are identical to those of lasers used with optical splitting. There has been an expectation within the CATV industry that the cost to produce low power lasers would be significantly less than the 10-15 mW lasers used with optical splitting. This would be true if the yield for a 4 mW laser was much higher than that of a 10 mW laser. However, for standard butterfly modules, almost all 1310 nm DFB lasers are now capable of at least 8 mW. The distribution of optical power for a randomly selected population of 1310 nm DFB modules is shown in Figure 1. Recent advances are pushing this distribution to even higher power. The power shown is the power at which the laser module linearity is optimum. As can be seen, none of the modules had an optimum power less than 8 mW. The standard method for producing a low power laser module is to take one of these higher power modules and add an optical attenuator to bring the power down to the required range. Clearly, this does not result in cost savings. It is possible to achieve some module cost savings by using lower performance optical components, but the savings are generally not large. A much more attractive solution would be to use the power capabilities of the DFB lasers to improve the performance capabilities of the AM links or to relax the linearity requirements of the lasers. This requires high optical power receivers.

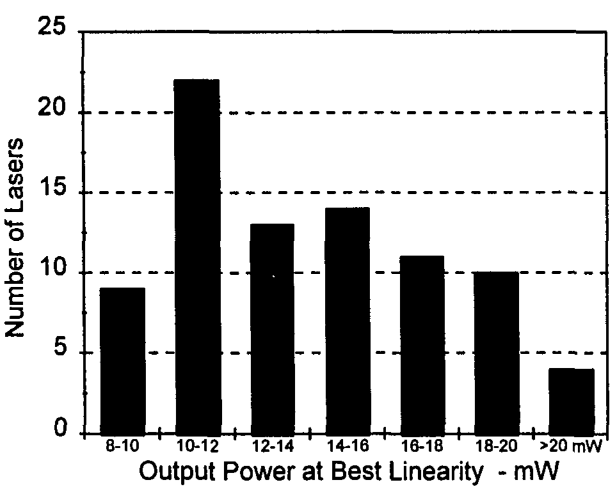

Figure 1. Distribution of optical power for cooled butterfly modules biased for optimum linearity.

If the received optical power of an AM fiber link is increased, then the link C/N increases. The C/N vs received optical power for several link lengths is shown in Figure 2. These calculations are for 80 channels with an optical modulation index (OMI) of 3.5%/ch. The chirp was assumed to be 100 MHZ/mA and the receiver noise was the value appropriate for each received power level (see Figure 5).

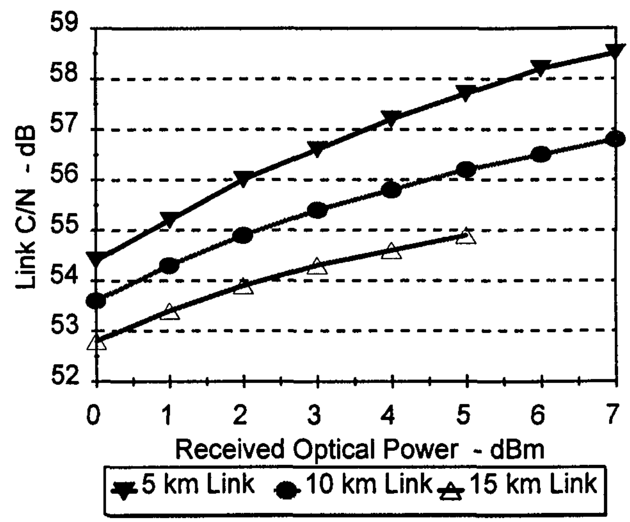

Figure 2. Link C/N vs received optical power for various link lengths.

Figure 2 shows that significant improvements in C/N are obtained when the links are operated at high received power. No results are shown above +5 dBm for the 15 km link because this would require laser output power levels that are sufficiently high that the yield for optical power would become important. The C/N improves as received power increases because the output signal level increases faster than the output noise level. In the range of 0 dBm, the dominant noise source for AM fiber links is photodiode shot noise. The output signal level increases 2 dB for every 1 dB increase in received optical power while the output noise level due to shot noise only increases 1 dB. Most of the benefit of higher C/N is achieved by increasing the received power to the 5 dBm range. At higher received power levels, most of the noise in the link comes from laser RIN or interferometric noise, which increase at the same rate as the signal. Above the power level where these noise sources become dominant there is no significant improvement in link C/N. Figure 2 also shows that although there may not be a direct cost benefit from using lower power lasers, there is a definite benefit from shorter link lengths. The shorter the fiber length, the less degradation there is to the C/N from interferometric noise due to double backscattering within the fiber.

There are many potential benefits from operation at high received power. One benefit is to simply make use of the higher C/N. Another option is to decrease the optical modulation index (OMI) needed to achieve a desired link C/N. The OMI needed to achieve a C/N of 52 dB is shown in Figure 3 for several link lengths. The link assumptions for these calculations are the same as in Figure 2. When the OMI of a laser is reduced, the linearity improves or the channel capacity can be increased. Linearity, and in particular, CSO, is the most important yield and cost factor for 1310 nm DFB lasers. High received power can therefore be used to relax the linearity requirements of the lasers, which substantially reduces the manufacturing costs for AM lasers.

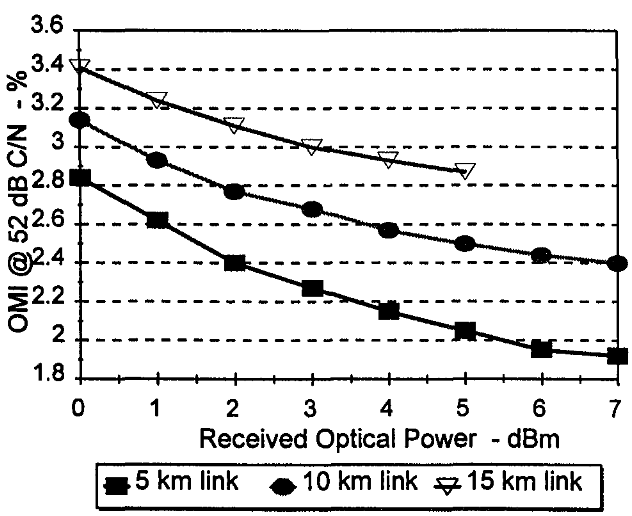

Figure 3. Optical modulation index required to achieve 52 dB C/N vs. received optical power.

For a given OMI per channel, the channel capacity of AM fiber links is limited by laser clipping. If the RF signal modulating the laser is too large then the laser will occasionally be driven down to zero power by large negative peaks in the multichannel signal. Such clipping events cause picture impairments in the AM channels and errors in digital channels being transmitted. By lowering the OMI per channel, the number of channels that can be transmitted before reaching clipping is increased. Figure 4 shows the limit to the channel capacity determined by laser clipping vs received optical power, for a link C/N of 52 dB. In this figure, the RMS modulation depth of the laser, due to the AM channels, is restricted to 23% to allow for the addition of digital channels and still avoid laser clipping. The link assumptions for these calculations are the same as in Figures 2 and 3 except the number of channels is varied. Higher capacity can be achieved using lasers with higher chirp, but the CSO can be degraded due to fiber dispersion[1].

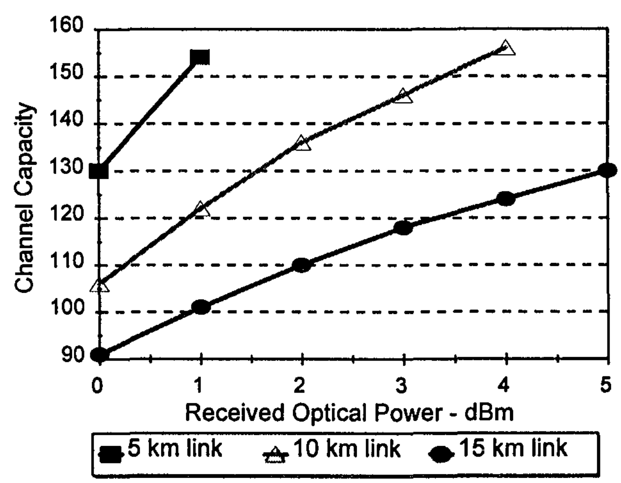

Figure 4. Channel capacity of AM fiber links vs. received optical power.

High Power Receiver Design

The preceding sections clearly demonstrated the benefits of high received optical power to AM fiber links. The only disadvantages are that the linearity, and possibly the reliability, of the receiver are degraded when operated at high power. Until recently, most optical receivers have had rated power levels for linearity of about 0 dBm and conservative absolute maximum ratings of 3 dBm. Recent improvements in the power handling capabilities of linear photodiodes has increased the maximum reliable received power by approximately 5 dB with excellent reliability being demonstrated for power levels in excess of 10 dBm[2].

The second challenge with high power receivers is maintaining linearity. Distortion is produced in optical receivers by both the photodiode and the amplifier following the photodiode. Photodiodes produce primarily second order distortion. With proper design, highly linear photodiodes can operate at received optical power levels up to at least +7 dBm. The second distortion source is the amplifier. In general, the amplifier distortion can be made arbitrarily low by using high power amplifiers or by reducing the gain and therefore the output level of the amplifier. However, both of these degrade receiver noise performance. The fundamental trade-off in high power receivers is therefore between the rated optical power of the receiver and the noise performance of the receiver. We have recently built and tested a family of optical receivers optimized for power levels between 0 and +5 dBm. For this discussion, rated optical power is defined to be the maximum power for which the CSO and CTB of the receiver exceed 75 dB for 80 channel operation at 3.5% OMI. The receivers for 0-2 dBm optical power use low noise integrated amplifiers and have an RF output level of 18 dBmV/ch for 80 channel operation. The receivers for operation at greater than 2 dBm received power use higher power amplifiers and have an output level of 22 dBmV/ch for 80 channel operation. The typical receiver noise versus rated optical power for receiver designs within this family is shown in Figure 5. The dashed portion of the curve represents projected performance for rated power levels up to +7 dBm. In this figure, both the noise of the amplifier integrated with the photodiode and the noise of the following gain stage are included. Although the receiver noise current increases for the high power receivers, the output signal levels and other noise sources, such as interferometric noise, increase much more rapidly at high received power. The fraction of the overall link noise due to the receiver is totally negligible for high power receivers.

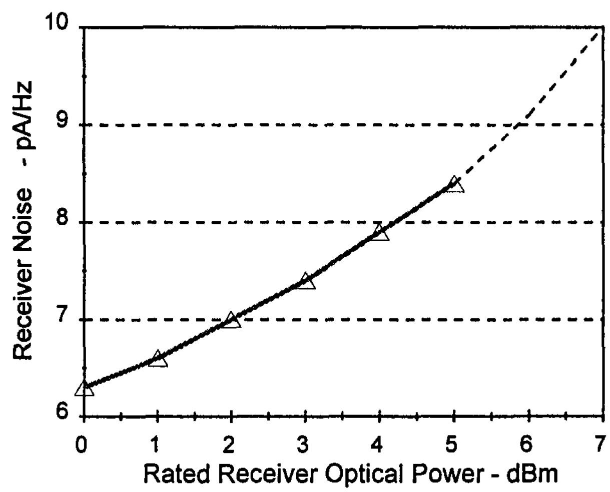

Figure 5. Trade-off between rated optical power and measured receiver noise for optical receivers with integrated amplifiers.

Conclusions

Until recently, most 1310 nm lasers were used with optical splitting to serve multiple nodes. If these lasers are used without splitting using existing optical receivers, the receivers will be overdriven resulting in poor receiver linearity. The current solution to this problem is to use low power lasers. However, low power lasers are almost always simply high power lasers to which an optical attenuator has been added or which are intentionally decoupled. In this paper, an alternate approach that uses the full power capabilities of 1310 nm DFB lasers was discussed. This requires the use of receivers that can operate linearly at high received optical power. Operation at high received power increases the link C/N. If higher C/N is not required, then the use of high power receivers can allow for a relaxation in the linearity requirements for the laser, which can substantially reduce the laser cost. Alternatively, high received power can be used to increase the channel capacity of the AM links. Most of the benefit of high received power is obtained by operating in the range of 5 dBm, but receivers for up to at least 7 dBm appear to be practical.

References

[1] H. Blauvelt, "Laser Chirp in Linear Fiber Optic Links" CED, Sept. 1995, pp. 72-76.

[2] J. Paslaski, et.al. "High Power Microwave Photodiodes for High Performance RF Link Applications" ARPA Symposium on Photonic Systems for Antenna Applications, Jan. 1995, p.628.