Trends in Output Power and Bandwidth of 1310 nm DFB Lasers for AM Video

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Abstract

DFB lasers have been used for AM video transmission for less than 5 years. In that time there have been spectacular improvements in the performance characteristics of 1310 nm DFB lasers. The output power of production lasers has increased from 3-4 mW to well beyond 10 mW. Output powers as high as 25 mW have been demonstrated. The channel capacity has increased from 40 channels for initial systems to 80 or more channels today. In this paper, the factors which limit the output power and bandwidth of DFB lasers will be examined. The performance capabilities that are expected in the near future and the potential impact on CATV architectures will be discussed.

I. Output Power Capabilities of 1310 nm DFB Lasers

The output power of a DFB laser module is determined by three factors; the efficiency of the laser chip, the efficiency of the coupling of the laser light to a single mode fiber, and the operating current of the laser above the threshold current.

Laser Chip Efficiency

The maximum possible efficiency for a semiconductor laser corresponds to an output of one photon for every electron injected into the laser. For 1310 nm DFB lasers, this maximum possible efficiency corresponds to 0.94 mW/mA. In practice, the laser efficiency is lower since not all injected carriers result in the generation of light and not all of the light generated is emitted from the front facet of the laser. Typical efficiencies have improved over the past several years from about 0.3 mW/mA to 0.40 mW/mA. The best results demonstrated to date for 1310 nm lasers are in the range of 0.6 mW/mA. Although there may still be unforeseen break-throughs in laser efficiency, it appears that the efficiency of production lasers will saturate at a level slightly higher than that which is achieved today, probably at around 0.5 mW/mA.

Fiber Coupling Efficiency

There are several factors which prevent coupling all of the light from a DFB laser into the fiber. The main losses are due to optical aberrations in focusing the highly divergent output beam from the laser onto the single mode fiber. Some losses also result from coupling the elliptical beam from the laser into a circular fiber. Finally, there is some loss from the internal optical isolator. Typical coupling efficiencies which can be obtained from production devices have improve from about 40% to 55% over the past several years. This has primarily been due to improvements in coupling optics. This trend towards improved optical design is continuing. Recent R&D results indicate coupling efficiencies of 75-80% are possible for improved optical designs. The expectation is that production efficiencies will continue to move up over the next few years with a probable saturation at about 70%.

Operating Current

Most of the improvements in output power from DFB lasers has been obtained by increasing the module efficiency. The impact of effiency improvements is to essentially increase system loss budgets with no other changes in operating characteristics such as linearity or RF drive levels. Output power can also be increased by simply operating the lasers at higher DC currents. However, this does have an effect on other operating characteristics.

One of the most challenging aspects of AM laser design is minimizing second order distortion in DFB lasers. The three dominant mechanisms responsible for CSO in DFB lasers are nonlinear leakage currents, axial hole burning effects[1], and laser resonance effects[2]. The last two effects decrease in importance at higher bias currents, but nonlinear leakage currents tend to increase at high bias currents. Leakage currents generally limit the maximum linear operating current of DFB lasers. Over the past several years, the typical maximum operating current above threshold for which AM CSO performance are maintained has increased from 40 mA to 50-60 mA. It is possible to significantly increase the maximum operating current, for example with longer laser chip lengths. Operating currents as high as 100 mA above threshold have been demonstrated, even for standard chip lengths, while maintaining levels of CSO required for AM systems. However, high operating currents can have some negative impact on system performance which must be considered.

One negative consequence of higher DC operating currents is that higher RF modulation currents are also required. Laser modules are commonly designed for 25 Ω and matched to 75 Ω with a 3:1 transformer. In this case, a module biased 60 mA above threshold and operating with 80 channels at 4% modulation depth per channel requires an RF power of 37.3 dBmV/ch for a lossless transformer. This can easily be supplied by either feed forward or power doubled amplifiers. If the bias current is increased to 100 mA above threshold the RF power requirement increases by 4.4 dB. At this power level, the distortion due to a power doubled amplifier is no longer negligible.

A second consideration for high operating current lasers is chirp and dispersion. 1310 nm DFB lasers biased 40-50 mA above threshold have chirp values which provide a nearly optimum trade off of dispersion induced distortion and interferometric noise[3]. To minimize CSO due to chirp and dispersion, low chirp is desired. To minimize interferometric noise from double Rayleigh scattering, high chirp is desired. The dispersion induced CSO depends on the amount of chirp per channel of RF modulation. This in turn is linearly proportional to the modulation current. Increasing the bias current and modulating current therefore increases the chirp level per channel and reduces the maximum amount of fiber dispersion that can be tolerated. For this reason, increasing operating currents is best suited to applications where higher power is required due to optical splitting losses. It is possible to increase transmission distances, but only if precautions are taken to minimize potential CSO problems from chirp and dispersion. This might include selection of lasers with operating wavelengths close to the fiber zero dispersion wavelength or selection of low chirp lasers.

High Power Potential of 1310 nm DFB Lasers

The trend in output power of DFB modules produced by Ortel is shown in Figure 1. Since the beginning of 1991 the power for both "champion" laboratory results and production devices has been increasing by 2 dB per year. Output powers as high as 25 mW have been demonstrated. This allows for AM links with very high optical loss budgets. The C/N versus optical loss for the 25 mW laser is shown in Figure 2. This was for 62 channel loading at 5.25%/ch. This is the near the clipping limit for modulation depth. If the modulation depth is restricted to 4%/ch to allow margin for adding digital channels, then the C/N is 2.4 dB lower.

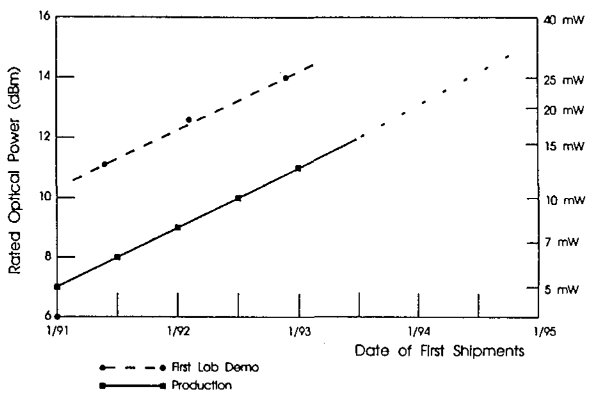

Figure 1. Trends in output power of 1310 nm DFB lasers.

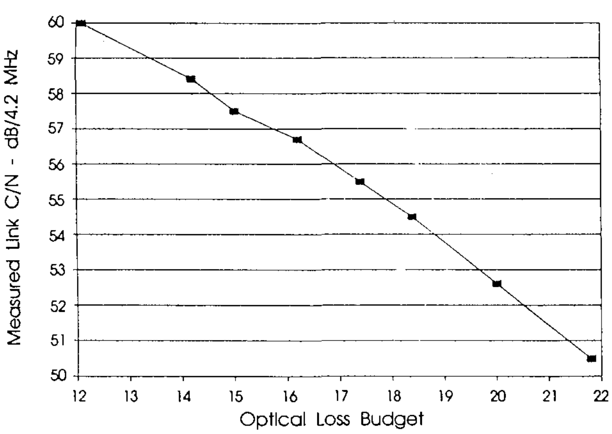

Figure 2. C/N vs. optical loss for a 25 mW 1310 nm DFB laser.

If laser operating currents are limited to 60 mA above threshold, for which there are minimal problems with RF drive levels and chirp, then the output power of production modules will most likely saturate in 1994 near 20 mW. If this constraint on operating current is not imposed, then output power can continue to increase up to the 30-50 mW range. For high current devices, it is desirable to reduce the chirp value from that which is typically obtained today.

II. Bandwidth Potential of DFB Lasers

The operating bandwidth of any electronic or optoelectronic device can either be limited by the frequency response of the device or by the dynamic range of the device. The frequency response of a high speed DFB laser is shown in Figure 3[4]. The operating bandwidth as measured by the -3 dB point is in excess of 16 GHz. For low dynamic range optical links, such as either baseband or subcarrier multiplexed digital links, the maximum transmission bit rate is primarily determined by the frequency response of the laser. The C/N and distortion levels are generally easy to achieve, particularly for the relatively low loss links used in CATV networks.

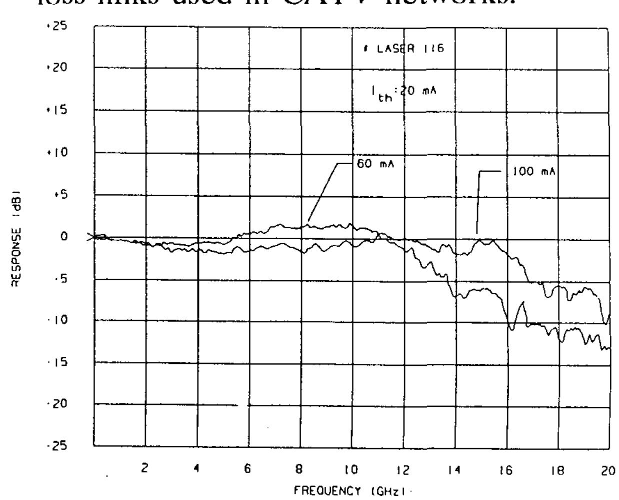

Figure 3. Frequency response of a high speed 1310 nm DFB laser.

For AM video, or other high dynamic range applications, the bandwidth is determined by the dynamic range of the laser and not the frequency response. To meet C/N requirements requires relatively high modulation depths per channel. The number of channels is in turn restricted by the requirement that the total RF modulation is below the laser clipping threshold. This clipping limit has been discussed in many technical articles[5,6]. Although there is still some controversy over the clipping limit, the limit to the parameter μ is in the range of 0.25-0.3, where μ is given by:

$$\mu^2 = m^2 N/2$$

where m is the modulation depth per channel and N is the number of channels.

Our own tests based on observable degradation to actual video signals corresponds to a limit of $\mu = 0.25$. For typical laser and receiver noise levels and 1 mW of received power, the AM channel capacity is about 150 at 52 dB C/N. At higher received power levels the channel capacity can be increased somewhat, but in all cases the bandwidth of an AM laser is far less than the inherent frequency response of the DFB laser.

For mixed formats where both AM video as well as lower dynamic range signals are sent, then the bandwidth is again limited by clipping assuming most of the capacity is allocated to transmitting AM channels. For example, in the case of AM video plus compressed digital video, the AM channels may require 52 dB C/N and the digital channels may require 35 dB C/N. The overall limit to capacity can be expressed as:

$$\mu^2_{TOT} = \mu^2_{AM} + \mu^2_{DIG} = 0.0625$$

where

$$\mu^2_{AM} = m^2_{AM} N_{AM}/2$$

and

$$\mu^2_{DIG} = m^2_{DIG} N_{DIG}/2$$

For the case of 80 channels at 3.5% modulation depth per channel, $\mu^2_{AM} = 0.049$. The remaining allocation for the digital channels is $\mu^2_{DIG} = 0.0135$. Because of the lower C/N requirement, the digital channels only require a modulation depth of 0.5% per channel. The total capacity for such digital channels is then $N_{DIG} = 1080$. Each of these 6 MHz wide digital channels could transmit up to 10 video channels. This would occupy the bandwidth of the DFB laser out to 7 GHz. In practice, the noise performance of the laser and of such a wideband receiver would result in a requirement for somewhat higher modulation depths for the digital channels. This will reduce the digital capacity, but the DFB lasers have the capacity to transmit many more digital channels than are being projected for any near term network architectures in addition to AM channels. The same general design rules can be used for other types of signals that might conceivably be transported on the network.

III. Impact of Laser Technology Improvements on System Architectures

The history of AM video has been that system architecture needs have determined the direction of technology development. To a large extent this continues to be the case. Recently, there has been significant interest in combining AM signals with digital signals. This application does not require any significant improvements in basic DFB device characteristics. It is desirable to operate at somewhat lower total modulation levels to avoid bit errors due to laser clipping. The only other requirement is that the electronics, such as RF amplifiers, can handle the mixed AM plus digital signal load. For systems up to 1 GHz, there are no new technical advancements required to implement such transmitters.

The role of high power DFB lasers in future CATV networks is highly dependent on the penetration of fiber into the CATV network. Most future architectures include a dedicated transmitter for blocks of 500-2000 homes. If this block of homes is served by a single optical receiver followed by a coaxial tree and branch network, then current DFB power levels are sufficient and what is desired are lower cost versions of current transmitters. However, if deeper fiber penetration is desired, for example fiber to the last amp (FTLA), a single laser would ideally serve many optical receivers. This requires higher loss budgets and correspondingly higher optical output levels. The application of high power DFB lasers to FTLA is shown in Figure 4.

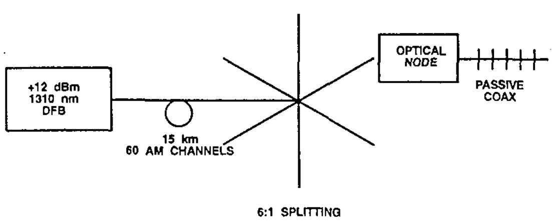

Figure 4. Fiber to the last amp architecture using high power 1310 nm DFB lasers.

The amount of optical splitting possible depends on several factors including laser power, the number of AM channels, the AM C/N, and the fiber link lengths. One feature of FTLA is that the C/N is completely determined by the fiber link and therefore lower values for fiber C/N are generally acceptable. Table I lists the launch power per optical node that is required for various combinations of parameters. In all cases a C/N of 50 dB, fiber losses of 0.4 dB/km and 1 dB loss margins are assumed. A receiver noise of 7 pA/Hz$^{1/2}$ and typical values of laser interferometric noise are assumed. 80 channel links are assumed to operate at 3.5%/ch and 60 channel links are assumed to operate at 4.0%/ch. This allows for margin from the clipping limit to add digital channels. If a laser output power of +12 dBm is assumed, then a 20 km link with 60 channels can have a 4:1 split assuming a 7 dB loss for the splitter. A 15 km 60 channel linkcan have 6:1 splitting and a 10 km 80 channel link can have 8:1 splitting.

Table I
Launch Power Per Link
Required to Achieve 50 dB C/N

	60 Ch	80 Ch
10 km	0.2 dBm	1.1 dBm
15 km	2.4	3.5
20 km	4.7	6.1

In FTLA architectures, more of the system distortion budget would also typically be allocated to the fiber link compared to more conventional fiber to the feeder (FTF) networks. This improves the yield and therefore the cost of high power DFB lasers for FTLA.

Another application of high power DFB lasers is as an intermediate step towards a network with dedicated lasers for groups of about 500 homes. Such an architecture is shown in Figure 5, with all of the splitting done at the head end. In this case, higher performance levels of FTF networks are generally required of the fiber links. This reduces the amount of optical splitting compared to FTLA, but still allows the transmitter to initially be shared by several optical nodes. At the time of a future upgrade, additional lasers can be added at the head end until there is a dedicated laser for each receiver. No changes are required to the network beyond the head end.

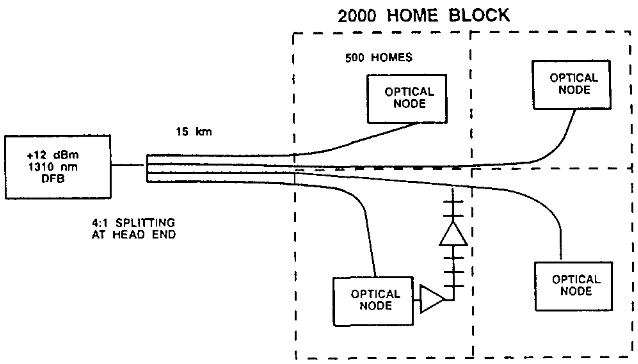

Figure 5. Using high power 1310 nm DFB lasers as an interim step to fiber rich narrowcast architectures.

IV. Summary

DFB laser technology is rapidly evolving to meet the needs of future CATV networks. Two of the main areas of advancement are in the area of bandwidth expansion and optical power improvement. Because of the high inherent dynamic range and 3 dB bandwidths of DFB lasers, no device improvements are required to add digital or other lower dynamic range channels to an AM laser. The only requirements are improvements in the bandwidths of the RF electronics associated with a laser transmitter. High power DFB lasers allow for cost effective solutions for network architectures with fiber penetration to optical nodes serving smaller blocks of homes than current architectures. This can be used to build networks that are better able to provide for anticipated future services as well as for services not yet contemplated.

References

[1] P. Vankwickelgerge, F. Buytaert, A. Franchois, R. Baets, P. Kuindersma, and C. Fredriksz, "Analysis of the Carrier Induced FM Response of DFB Lasers: Theoretical and Experimental Case Studies", IEEE J. Quantum Electron., vol. QE-5, pp. 2239-2254, 1989.

[2] P. Iannone, T.E. Darcie, "Multichannel Intermodulation Distortion in High Speed GaInAsP lasers", Electron. Lett., vol. 23, pp. 1361-1362, 1987.

[3] H. Blauvelt, P. C. Chen, N. Kwong, and I. Ury, "Optimum Laser Chirp Range for AM Video Transmission" Technical Digest Cable '92, pp. 79-85, 1992.

[4] T. R. Chen, P. C. Chen, C. Gee, and N. Bar-Chaim, "A High Speed InGaAsP/InP DFB Laser with an Air-Bridge Contact Configuration", IEEE Photon. Tech. Lett., vol. 25, pp. 776-777, 1989.

[5] A.A.M. Saleh "Fundamental Limit on Number of Channels in SCM Lightwave CATV System", Electron. Lett., vol. 25, pp. 776-777, 1989.

[6] C.J. Chung and I. Jacobs "Practical TV Channel Capacity of Lightwave Multichannel AM SCM Systems Limited by the Threshold Nonlinearity of Laser Diodes", IEEE Photon. Tech. Lett., vol. 4, pp. 289-292, 1992.