CATV POTENTIAL OF EXTERNALLY MODULATED LASERS

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Abstract

In the last few years, DFB lasers have gained widespread use in CATV as the foundation for AM optical transmitter design. More recently, an important new generation of transmitters has emerged. These devices offer much higher optical launch power and spectral purity than is possible from a DFB design. This paper compares these externally modulated transmitters with their DFB predecessors, and explores potential benefits of the technology to CATV.

DIRECT VS. EXTERNAL MODULATION

Direct modulation of a Distributed Feedback laser (DFB) involves summing a bias current with a modulating signal, as shown in Figure 1. In AM CATV applications, the modulating signal is an entire broadband rf spectrum of television channels and other rf carriers spanning a bandwidth of 50-550 MHz or more. The result is an optical "carrier" frequency (wavelength), intensity (amplitude) modulated with the analog composite CATV spectrum.

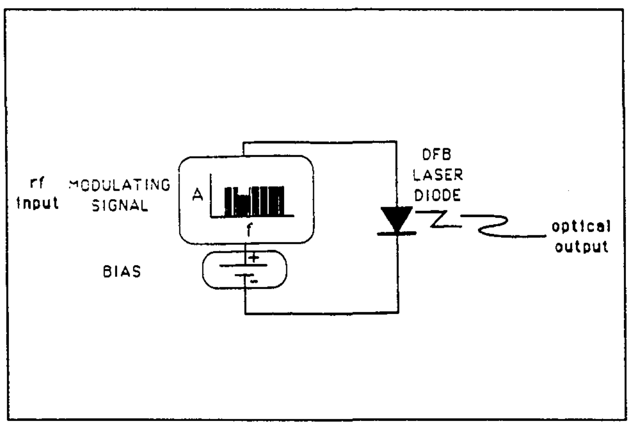

Figure 1.
Direct Modulation Process

In contrast to the DFB optical transmitter, the External Modulation transmitter employs two separate components to create an intensity modulated optical carrier: a solid state laser and an external modulator. The process is pictured in Figure 2.

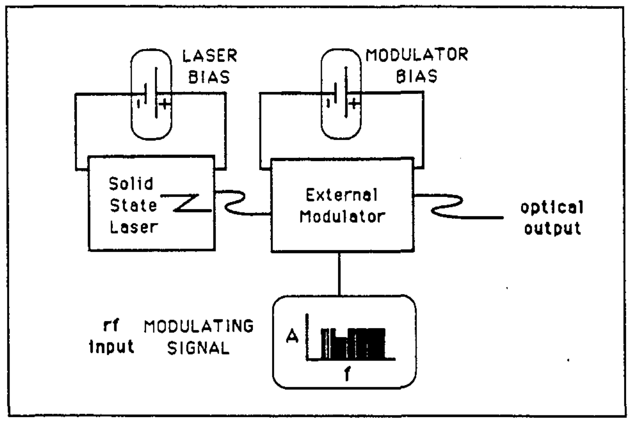

Figure 2.
External Modulation Process

The laser is d.c. biased, and thus emits a c.w. optical carrier having extremely stable amplitude and wavelength. To date, solid state lasers of Nd:YAG composition have been most common.

The YAG's output is coupled via a polarization-maintaining single mode fiber to the input of an external modulator. To date, interferometer designs, such as the Mach-Zehnder modulator, have been most common. Optical carrier energy is split at the input of the modulator, propagated through two parallel paths, and finally recombined. The modulating signal is added to a modulator bias voltage, then fed to conductive strips parallel to the light paths. The properties of the lithium niobate material employed in the modulator cause complementary changes in propagation time to occur along the two light paths as the modulating signal is applied to the conductive strips. Interferometric recombination of optical signals at the output of the modulator naturally creates two optical outputs, each intensity modulated with the input rf spectrum.

The transfer characteristics of a DFB laser diode vary significantly from piece to piece, and in today's lasers is quite linear. In contrast, the transfer characteristic of a YAG laser feeding an interferometer external modulator is quite nonlinear, but very predictably so. The process of "straightening" the YAG/interferometer transfer characteristic is commonly called "linearization." Several techniques of linearization are possible and proven, but their discussion is beyond the scope of this paper.

Typical DFB laser transmitter optical launch powers available today are in the 4-8 mW range. Meanwhile, typical external modulation transmitter optical launch powers are in the 8 mW - 15 mW range, or as much as four times that of the DFB. The additional power translates directly to a longer reacher for the external modulation transmitter. Thus, the same noise and distortion performance which a DFB can offer on an 11 dB optical link may be achievable on a 16 dB optical link with external modulation. The 5 dB difference translates to more than seven miles of additional reach for the externally modulated transmitter.

The spectral purity of the externally modulated transmitter's output is also beneficial to link performance. Today's DFB lasers are susceptible to Interferometric Intensity Noise (IIN).[1] A portion of the light travelling downstream toward the node is reflected backward, then reflected forward again. IIN is caused by both connectors included in the link and Rayleigh backscattering effects. The effect can degrade DFB AM link CNR performance 1-2 dB or more.

The externally modulated transmitter, however, has a much narrower linewidth than the DFB. This causes links using the external modulation transmitter to be immune to IIN degradation.[2]

Another benefit of the external modulation transmitter is its naturally superior second order distortion characteristics compared with a DFB. The transfer characteristic of the DFB usually makes the DFB link second order distortion limited, i.e., maximum transmitter drive level becomes limited by link CSO performance rather than CTB. This makes it more difficult to employ DFB lasers with high channel loadings such as 550 MHz (77 channels). On the other hand, the transfer characteristic of the externally modulated transmitter is symmetrical about its bias point. The symmetry gives the externally modulated transmitter inherently superior CSO performance under conditions of high channel loading, much as the symmetry in a push-pull rf hybrid amplifier produces the same result.

Inherent noise generation in the YAG laser relative to the DFB is another issue where the YAG excels. The Relative Intensity Noise (RIN) of a YAG laser typically runs -170 dB/Hz, compared with a more typical -155 dB/Hz from a DFB. This can result in substantially superior CNR obtainable on an externally modulated link vs. a DFB.

In summary, higher launch power, IIN immunity, much better CSO and lower RIN are all benefits provided by external modulation.

EXTERNAL MODULATION COST

External modulation is naturally a more involved process than direct modulation of a DFB. Accordingly, for applications of only a few links of under 10 km each, the DFB may remain a more economical solution for some time. However, for links which are simply too long for a DFB to reach with acceptable performance, or in cases where many links emanate from one optical transmitter site, the external modulation transmitter can provide savings of 20% to 70% per link, depending upon the application.

Without external modulation AM, the only long-link alternative may be FM or digital transmission, inherently expensive because it requires channel by channel processing. The additional 5 dB of reach offered by an external modulation transmitter over its DFB alternative can translate to a user savings of $250,000 or more per optical link in these applications.

Figure 3 shows the economic benefits of splitting each output of a typical externally modulated transmitter. In this application, the transmitter's high launch power is used to reach many nodes with only one transmitter.

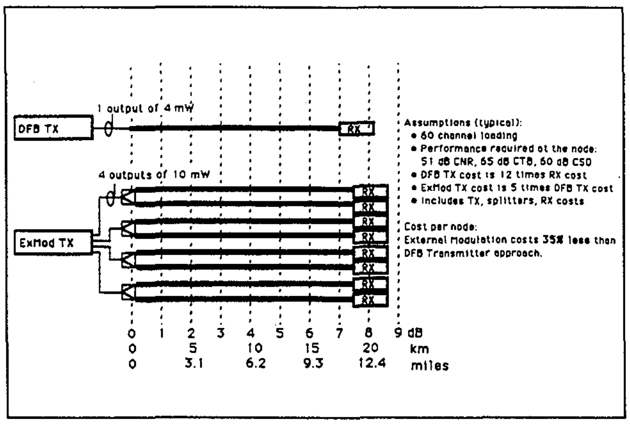

Figure 3.
External Modulation Economic Benefits

The illustration shows one external modulation transmitter doing the work of 8 DFBs. Noise and distortion performance at the nodes is the same in both external modulation and DFB scenarios.

A heavy weighting of cost in the transmitter (vs. receiver or node) side of the optical link is inherent in all CATV optical transmission. This factor causes the cost PER NODE for the DFB solution to be much greater than its external modulation equivalent ... about 55% more in this example!

EXTERNAL MODULATION RELIABILITY

Reliability of an opto-electronic transmission network is naturally a function of the total number of components involved in the network and the individual reliability of each component.

From Figure 3 the application where an external modulation transmitter is split to serve many nodes it is obvious that the component count inside one external modulation transmitter will be much smaller than the total component count of 8 DFB transmitters which would be required to provide equivalent performance. The same would obviously be true in the application where external modulation is used as an alternative to FM or digital transmission, inasmuch as the need for individual channel processing is eliminated with the external modulation transmitter. Thus, from a pure component count viewpoint, the external modulation approach naturally enjoys a much smaller probability of random component failure than alternate optical transmission technologies.

All the components used in an external modulation transmitter are similar in nature to those found in the DFB, with the exception of the solid state laser and external modulator. Therefore, given a consistent quality of manufacturing, examination of reliability of these two components should be sufficient to understand any reliability difference which an external modulation transmitter may exhibit compared to a DFB.

The Mach-Zehnder interferometer typically used as an external modulator is a solid state design using a lithium niobate substrate as a foundation. Lithium niobate is the same material used in the manufacture of a myriad of surface acoustic wave (SAW) filters, a technology in widespread use in both industrial and consumer electronics for decades. Substantial work has been done on both material and device reliability assessment of lithium niobate optical guided wave devices, concluding specific package designs can result in a highly reliable product. A solid mechanical design, similar to that used within a DFB laser package, provides a stable coupling between modulator optics and optical fibers at the modulator input and output. Therefore, the external modulator itself can reasonably be expected to have a reliability comparable with today's DFB lasers.

The solid state Nd:YAG laser typically employed as the light source is structured as shown in Figure 4. A typical "pump" laser diode launches a relatively high c.w. optical power at about 808 nm onto the end of a Neodymium doped YAG crystal rod. This causes the rod to lase and emit a c.w. optical carrier at 1319 nm. It is this optical carrier that is output through an optical fiber to the external modulator.

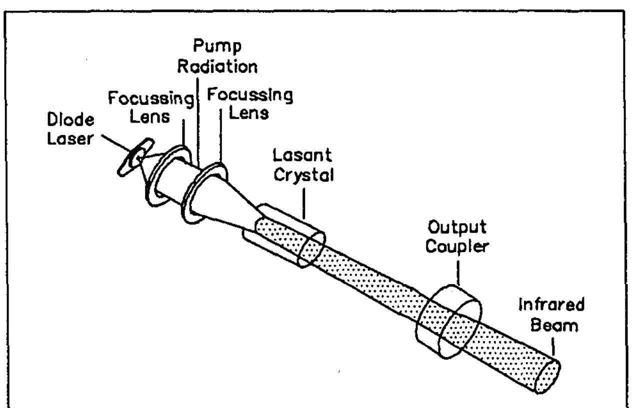

Figure 4.
Nd:YAG Laser Structure

Commercial results to date indicate the pump diode can continuously emit an optical power of 1 watt and still provide a mean time to failure for the external modulation transmitter which approaches today's DFB transmitters' MTTFs.

Keys to achieving this performance include a multi-stripe array laser structure as shown in Figure 5. It is not the total power at the pump facet that threatens lifetime, but the power DENSITY at the facet. The stripe design keeps this optical power density in an acceptable operating range.

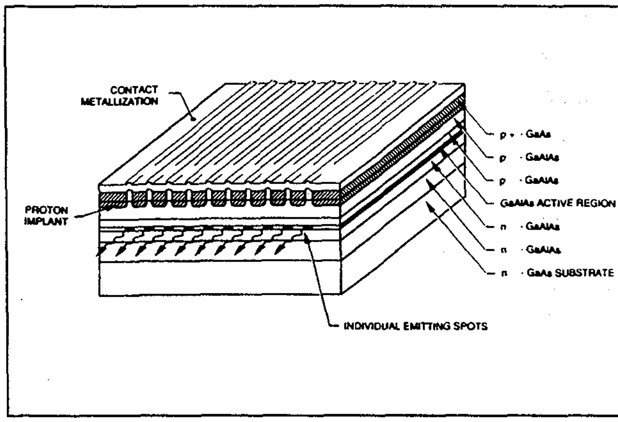

Figure 5.
Pump Laser Diode Structure

Another important life-extending technique is to lower the temperature of the pump facet by using a thermoelectric cooler. Lowering the facet temperature by 10C can double pump life. Thermal management provided by generous heat sinking and a pump package design optimized for c.w. operation can also extend product life.

YAG lasers have been utilized in medical electronics since the 1970's, and pumped YAGs since the '80's. Thus the technology itself is not new ... only its application to CATV optical transmission.

Accelerated life testing is commonly performed today by laser diode manufacturers by operating a sample lot of diodes at one or more temperatures substantially above their normal operating temperature until failure is observed, then attempting to extrapolate life expectancy at normal operating temperatures. But even the best diode manufacturers acknowledge major uncertainties in this process. The true MTTF of either DFB or external modulation transmitters will only be assuredly known after a quantity of both units have performed under normal operating conditions for many years. Since first commercial deployment of ANY AM CATV laser technology took place less than five years ago, no such history for either will be available for years to come. Nevertheless, no evidence has surfaced to date which would indicate either technology is not capable of producing an optical transmitter with an MTTF in excess of ten years.

FIELD DEPLOYMENT RESULTS

Commercial deployment of external modulation transmitters employing an Nd:YAG solid state laser combined with a Mach-Zehnder Lithium Niobate modulator in a CATV application began in the fall of 1991. The first year of deployment has seen tens of units installed at locations throughout North America and Europe. Field proofs of performance have confirmed the technical performance superiority of external modulation over the DFB alternative.

Initial installations are seeing a variety of applications. Many cases utilize the external modulation transmitter for the extended link i.e., a link which would alternately require expensive FM or digital transmission. Many of these situations are AML replacements, and hub or headend eliminations. A number of other cases are utilizing the high optical launch power for its splitability to serve many nodes in an FTF situation.

Some technical references have implied that optical launch powers into a single mode fiber in excess of even 9 mW would result in severe power falloff on links only a few tens of kilometers long due to the Stimulated Brillouin Scattering (SBS) effect[3] characteristic of the fiber. A significant field experience has been the absence of any detectable SBS effects, despite the relatively high launch power available from the external modulation transmitter. Further investigation has revealed that in each technical reference the laboratory research involved utilized a test method and/or equipment which was not typical of today's actual product implementation and field situation. As of this writing, optical powers of up to 20 mW have been successfully launched into an optical fiber installed in the field without any evidence of SBS effects, and evidence exists that substantially higher powers may be operable without SBS problems.

CONCLUSIONS

In any CATV application, the external modulation transmitter's lower RIN, higher launch power, immunity to IIN, and better CSO performance combine to make this technology a superior choice to achieve the best possible technical performance.

From an economics viewpoint, external modulation can save 70% of the cost of the alternative FM or digital link for long reach applications (where DFB reach is simply inadequate). External modulation can reduce cost per node 40% or more below an alternative DFB approach in cases where many optical nodes are involved, such as fiber-to-the-feeder and fiber-to-the-curb system architectures.

There appears to be no technological characteristic which would prevent achievement of external modulation optical transmitter reliability comparable to or in excess of today's DFB transmitters.

The first year of field installations is encouraging and bodes well for the future of external modulation for AM CATV optical links. External modulation may prove to be to the DFB laser what push-pull and power doubling hybrids proved to be to the original single ended amplifiers used by our industry ... a natural successor technology offering improved performance and system economics over its predecessor.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance provided by Orchard Comm., Inc., Crystal Technology, Inc., and Amoco Laser Company in the preparation of this paper.

REFERENCES

[1]Darcie, Thomas E. 1991. Fiber-Reflection-Induced Impairments in Lightwave AM-VSB CATV Systems. In *Journal of Lightwave Technology*, Vol. 9, No. 8, by Thomas E. Darcie, George E. Bodeep, and Adeal A. M. Saleh.

[2]Way, W. I. 1990. Multiple-Reflection-Induced Intensity Noise Studies in a Lightwave System for Multichannel AM-VSB Television Signal Distribution. In *IEEE Photonics Technology Letters*, Vol. 2., No. 5, by W. I. Way, C. Lin, C. E. Zah, L. Curtis, R. Spicer, and W. C. Young.

[3]Aoki, Yasuhiro. 1988. Input Power Limits of Single-Mode Optical Fibers due to Stimulated Brillouin Scattering in Optical Communication Systems. In *Journal of Lightwave Technology*, Vol. 6, No. 5, by Yasuhiro Aoki, Kazuhito Tajima, and Ikuo Mito.