Overcoming Nonlinear Optical Impairments Due to High-Source Laser and Launch Powers

Introduction

Although high-power, erbium-doped fiber amplifiers (EDFAs) allow transmission of up to 65 km or more, there are several effects at these power levels that can degrade signal quality to the point of being unusable for CATV trunking applications. Two important effects the system designer needs to be concerned with are stimulated Brillouin scattering and dispersive intensity noise. The origins of these effects will be discussed as well as techniques used for circumventing their influence on signal quality. To that end, Emcore offers the MDL6000 Series externally modulated fiberoptic transmitter featuring up to 20 dBm SBS suppression capability. Emcore also offers the NMOA Series of EDFAs featuring total saturated output power levels up to 35 dBm. The transmitter and EDFA are shown in Figure 1.

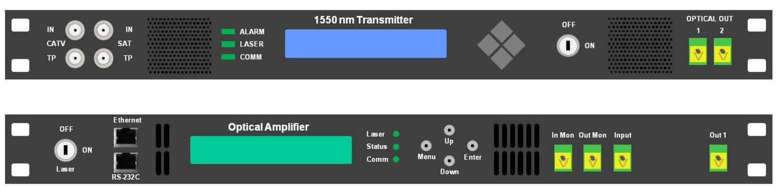

Figure 1. MDL6000 Series CATV Fiberoptic Transmitter and NMOA Series High Power EDFA

Stimulated Brillouin Scattering (SBS)

The nonlinear process of SBS places a relatively low limit on the optical power level that can be launched into a single-mode fiber if no particular suppression techniques are employed. SBS can be most easily viewed as a sort of collision or scattering process involving three waves: the incident optical wave, a backscattered optical wave, and an acoustic wave in the fiber itself (caused by unavoidable vibrations within the glass). The collision process has an associated bandwidth of approximately 20 MHz. This implies that incident optical signals within a 20 MHz spectral width participate in a given scattering process. When an incident optical wave of sufficient power (i.e., greater than the threshold power for SBS to occur) travels down the fiber, scattering that occurs between it and the resulting acoustic wave causes the forward wave to be back-scattered towards the transmitter.

Figure 2 shows the consequences of this process on the transmitted power. Up to the threshold power level (typically +6 dBm to +7 dBm in *SMF-28** fiber at 1550 nm), the output power is a linear replica of the input power (less the normal fiber attenuation). However, the occurrence of SBS causes the fiber's transfer characteristic from input to output to become severely nonlinear due to the backscattering process.

This process has two implications. First, the scattering process can lead to excess noise in the link, thereby degrading the carrier-to-noise ratio (CNR). This is especially pronounced at the lower channel frequencies of the CATV band. The second consequence is apparent from the fiber transfer function in the presence of SBS (see Figure 2). Since the input/output power relation is sublinear, second-order distortions will result.

To circumvent the effects of SBS, the technique of spreading the optical spectrum outside of the SBS bandwidth (20 MHz) is often employed. The result of this technique is illustrated in Figure 2. In this case, a phase modulator is used to broaden the optical spectrum in multiples of 2 GHz. As the RF power to the phase modulator is increased, the amount of SBS decreases since the frequency broadening effectively increases the SBS threshold. The lower curve shows the full effect of SBS with no dither applied. Using this technique, launch powers of up to +16 dBm can be accommodated without suffering significant CNR or composite second-order (CSO) penalties. To increase the SBS threshold above this level, more exotic suppression schemes are necessary.

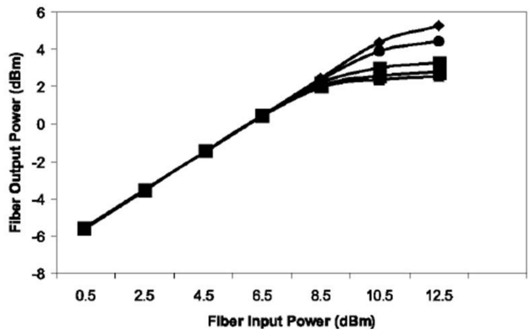

Figure 2. Output Characteristics of a 50 km Length of SMF-28 SMF at 1550 nm

Dispersion-Induced Intensity Noise

Relative Intensity Noise (RIN)

The semiconductor diode lasers used for externally modulated 1550 nm transmitters often have strict noise requirements. The most common noise specification is RIN, which describes the amount of amplitude fluctuations present in the optical field. These fluctuations pass through the modulator and limit the achievable CNR of the link. A typical specification for 1550 nm source lasers is -163 dB/Hz.

Phase Noise

In addition to the inherent amplitude noise of diode lasers, the amount of phase noise present must be carefully controlled. Since single-mode fiber exhibits high amounts of dispersion at 1550 nm, the link itself acts as a form of frequency discriminator to the optical field. The result is that optical phase fluctuations are converted to amplitude fluctuations as the signal passes down the fiber. This residual noise can be referred to as dispersive intensity noise. The levels of dispersive intensity noise (in addition to the inherent RIN) become more pronounced at higher RF frequencies and longer fiber lengths. As systems move into the higher bandwidth and longer fiber-span architectures, the system designer must more closely scrutinize both the phase and amplitude noise properties of the source lasers.

To characterize the amount of phase noise present on the source laser, the laser spectral linewidth is often measured. In the absence of external noise sources (i.e., the laser noise is solely a result of the inherent, spontaneous noise processes within the diode), the spectral linewidth is a valid predictor for the phase noise of the optical field. Typical 65 km supertrunk systems require a source laser spectral linewidth of < 1 MHz.

However, as the required phase-noise levels become smaller in applications characterized by high-channel count or long fiber length, the spectral linewidth measurements can easily become contaminated by low-frequency (< 5 MHz), extraneous noise sources present in the system. Therefore, it is imperative to distinguish between the actual phase fluctuations, which contribute to dispersive intensity noise, and the residual phase noise, which never affects the CATV band.

It has been shown that spectral linewidth measurements can often overestimate the amount of dispersive intensity noise a link would suffer. Therefore, it serves the system designer to develop accurate characterization techniques of laser phase noise within the CATV band such that source lasers can be screened for intended performance.

Benefits of High-Power 1550 nm Transmitters with Advanced SBS Suppression Techniques

Fiber Links Up to 40 km

If the system designer can accomplish sufficient SBS suppression and ensure low levels of dispersive intensity noise, the use of high-power source lasers and/or high-launch power EDFAs greatly expands the network performance for the service operator. With robust, high-power transmitter solutions, the network can achieve greater CNR performance, increase distances between hubs, and possibly lower costs through the elimination of EDFAs.

Currently, commercially available 1550 nm source lasers typically have output powers of 17 to 20 dBm. Taking into account modulator loss and splicing losses, output powers from the two outputs of a 1550 nm transmitter are approximately 10 dBm each. At these power levels, the transmitter is usually followed by an EDFA with 16 dBm to 17 dBm of optical power launched into the fiber.

If the source laser power can be increased (without affecting other characteristics such as RIN and phase noise), the system designer has two options. First, the EDFA can be supplied with higher optical input powers. This will improve the overall link CNR since the EDFA gain saturation is being increased (the output power is relatively constant). Figure 3 shows typical link performance for various source laser powers. 0.25 dB/km fiber attenuation, 4 MHz noise bandwidth, 80 AM-VSB channels at 3% modulation/channel, -163 dB/Hz laser RIN, 9 pA/√Hz receiver noise current, and 4.5 dB (at 0 dBm input) EFDA noise figure are assumed.

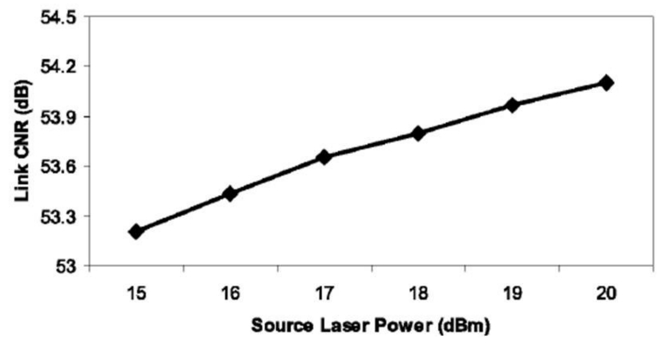

Figure 3. CNR Performance with a 17 dBm Launch-Power EDFA

As Figure 3 shows, the link CNR improves by approximately 0.2 dB for every dB increase in laser power. While this is not negligible, increasing source laser power levels by one or more dB can require considerable effort. Therefore, another strategy that leverages high-source laser powers to a greater extent is examined.

When transmitter output power levels reach the 10 dBm and higher regime, excluding the EDFA from the system can be considered. This has the advantage of not only lowering system cost, but also improving the link CNR performance. Such EDFA-less operation at 1550 nm is shown in Figure 4. Here, the link CNR at fiber lengths of 40 km, 45 km, and 50 km is examined. At 40 km, even 17 dBm source lasers can provide superior CNR performance compared to EDFA-based transmission. 0.25 dB/km fiber attenuation, 4 MHz noise bandwidth, 80 AM-VSB channels at 3% modulation/channel, -163 dB/Hz laser RIN, and 9 pA/√Hz receiver noise current are assumed.

Moreover, as the 19 dBm to 20 dBm level of optical power is approached, a CNR of 54.6 dB can be achieved without an EDFA over 50 km of fiber. Clearly, if the designer has access to such high-power sources, EDFA-less transmitters are the most effective means to leverage this power directly into improved network performance.

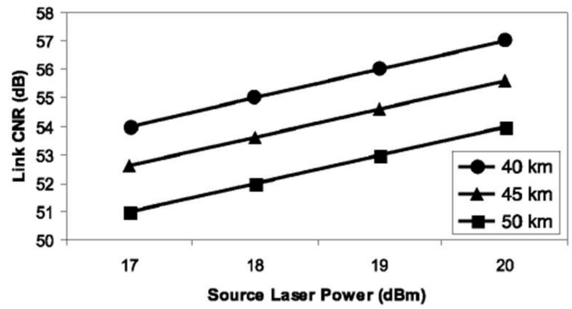

Figure 4. CNR Performance for an EDFA-less Transmitter Architecture

<u>Fiber Links Over 40 km</u>

In addition to high-power source lasers, the capability to support high EDFA launch powers into long fiber lengths also opens up new opportunities for network architectures. The primary challenge here is to overcome SBS effects (as well as other nonlinear effects such as self-phase modulation) at these power levels.

The additional launch power can be utilized in a number of ways.

In distribution networks, the additional SBS suppression capability can be used to span longer lengths of fiber prior to splitting. As fiber length increases above ~10 km, a transmitter with 18 dBm SBS capability can launch more power into a given length of fiber than a transmitter with 16 dBm SBS capability. Also, a transmitter with 18 dBm SBS capability can launch a certain amount of power into a longer length of fiber than a transmitter with 16 dBm SBS capability.

The two fiber links in Figure 5 illustrate how improved SBS suppression can be used to expand distribution networks. 0.25 dB/km fiber attenuation, 4 MHz noise bandwidth, 80 AM-VSB channels at 3% modulation/channel, -163 dB/Hz laser RIN, 9 pA/√Hz receiver noise current, and 4.5 dB (at 0 dBm input) EFDA noise figure are assumed. In some distribution networks, EDFAs with powers as high as 35 dBm, for example, can be used if followed immediately by splitters that limit the optical power launched into any fiber to the SBS limit of the transmitter. However, some distribution networks require launching optical power into a length of fiber before the splitter is reached. In these networks, the SBS suppression capability of the transmitter limits the extent of the distribution network.

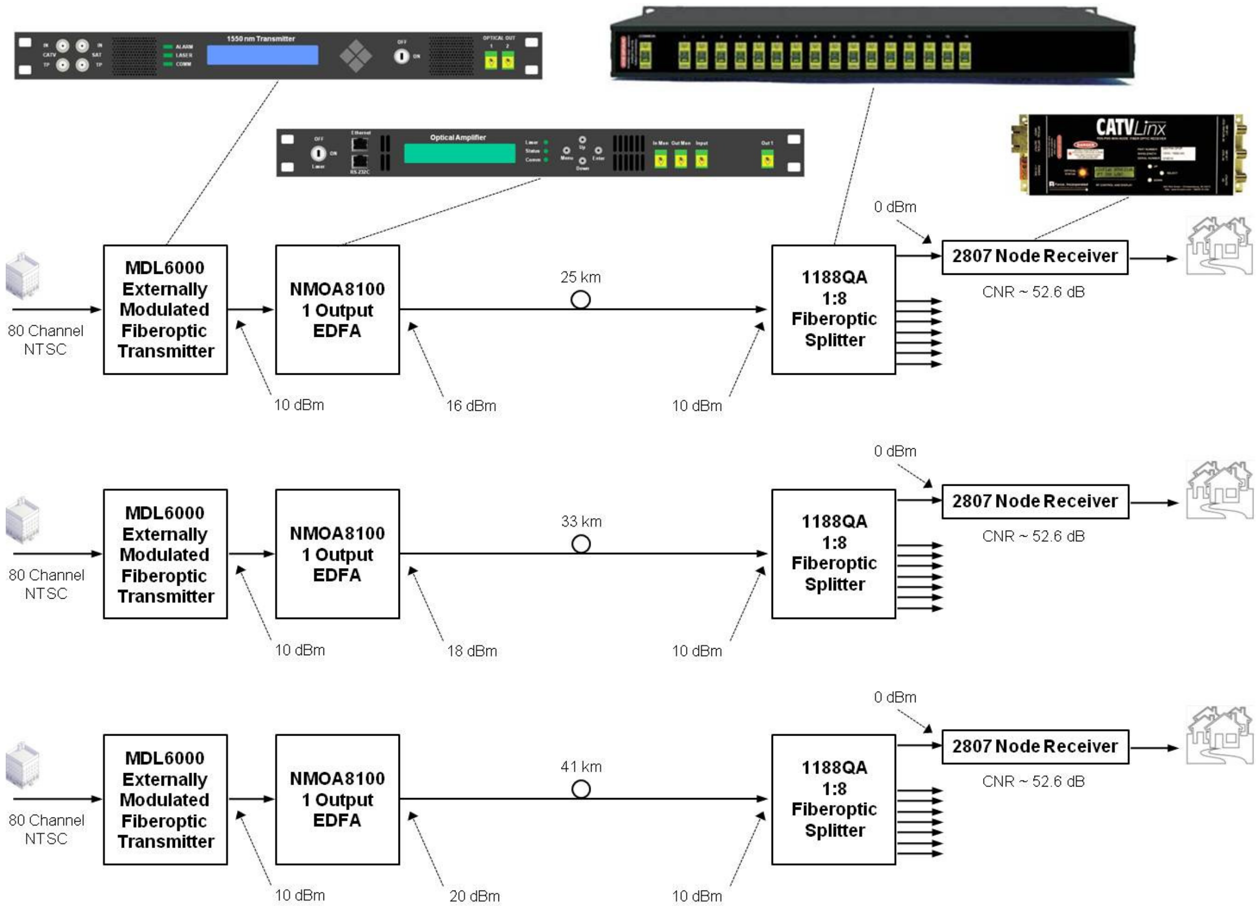

Figure 5. Distribution Network Expansion from 16 dBm to 20 dBm SBS Capability

18 dBm and 20 dBm SBS suppression also allows point-to-point spans of up to 80 km using only one EDFA, depending on fiber attenuation. Launching 18 dBm of optical power does allow an additional 2 dB of fiber loss in the link, however, SPM and various fiber dispersion mechanisms result in a much more challenging CSO environment. An illustration of using higher transmitter SBS capability to increase the length of the fiber link is shown in Figure 6. 0.25 dB/km fiber attenuation, 4 MHz noise bandwidth, 80 AM-VSB channels at 3% modulation/channel, -163 dB/Hz laser RIN, 9 pA/√Hz receiver noise current, and 4.5 dB (at 0 dBm input) EFDA noise figure are assumed. In this case, the penalty incurred for the additional 10 km of fiber is 0.3 dB CNR performance.

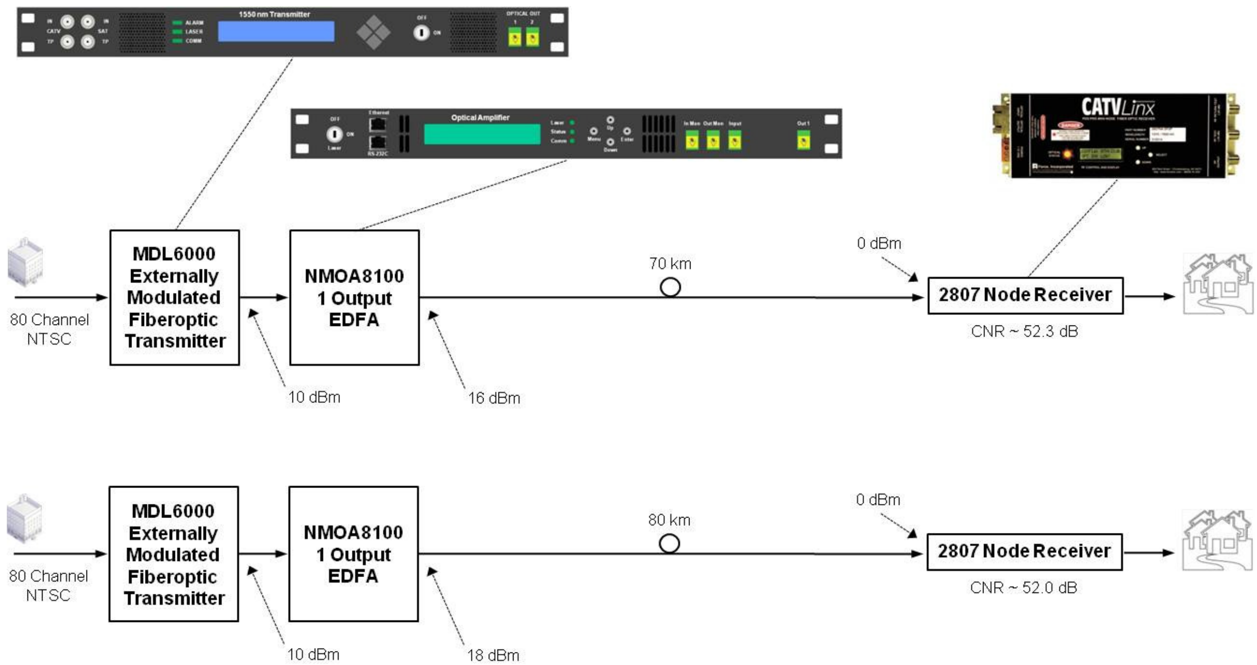

Figure 6. Increasing Link Length with Higher SBS Transmitter Capability

If regenerated links of greater length are envisioned, improved CNRs can be obtained by providing field-deployed line amplifiers (EDFAs) with greater input powers, thereby reducing the overall link CNR. The particular case of a 1550 nm trunking/distribution, optically regenerated architecture is shown in Figure 7. 0.25 dB/km fiber attenuation, 4 MHz noise bandwidth, 80 AM-VSB channels at 3% modulation/channel, -163 dB/Hz laser RIN, 9 pA/√Hz receiver noise current, and 4.5 dB (at 0 dBm input) EFDA noise figure are assumed. In this topology, 1550 nm signals are used through the network from the head end to the receiving nodes. Signals received at the distribution hubs are optically amplified, split, and distributed. Here, through the use of two 18 dBm launch power EDFAs, the link CNR is improved by 1.4 dB over the 16 dBm launch case. It should be noted that in addition to higher SBS suppression, self-phase modulation impairments must also be carefully controlled at these launch powers.

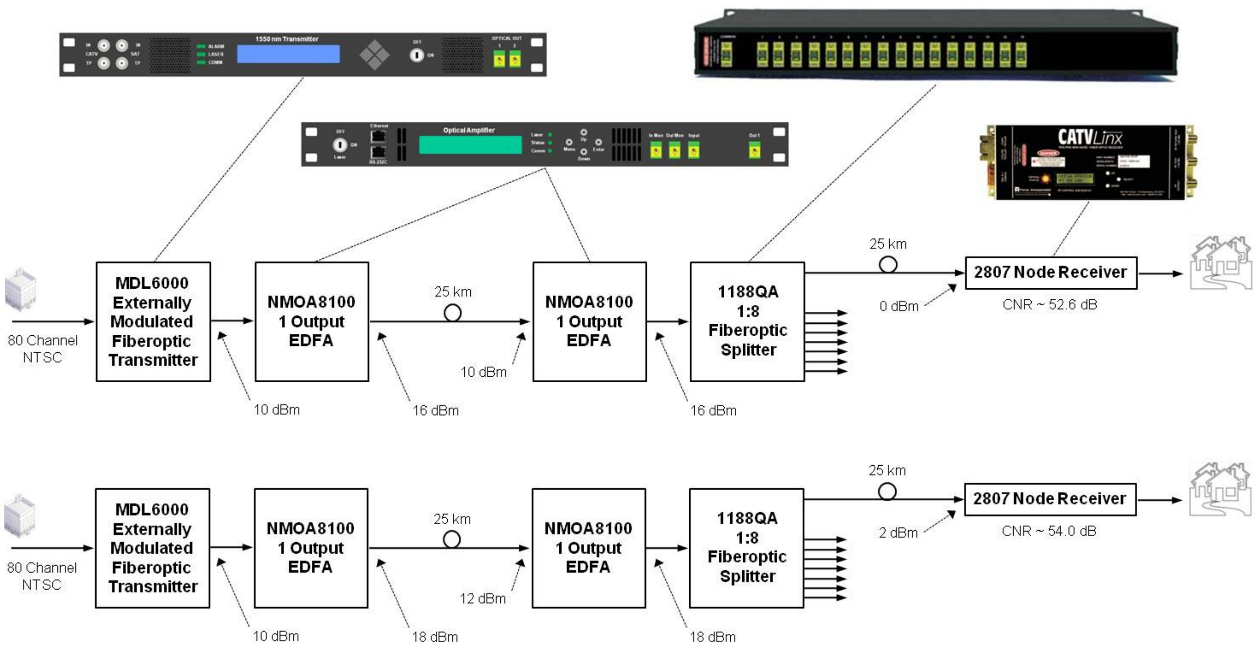

Figure 7. Trunking/Distribution Link with Improved CNR from Higher EDFA Launch Powers

Note: in Figure 7 above, the EDFA and splitter functions may be combined into an 8 output EDFA. The two blocks are separated in this discussion for illustrative purposes.

Summary

In summary, higher-power source lasers and the capability to support higher EDFA launch powers can greatly expand the utility of 1550nm externally modulated transmitters. High-source laser powers in the vicinity of 17 dBm to 20 dBm allow EDFA-less transmitter designs which can achieve superior CNR performance at a lower cost compared to the EDFA-based architectures. On the other hand, having the ability to launch EDFA powers of up to 20 dBm allows the user to extend point-to-point links, achieve higher CNR levels through higher received powers, or improve the performance of optically regenerated distribution links. Clearly, raising the bar on 1550 nm power levels will allow service operators to squeeze more performance per dollar out of their existing networks.

*SMF-28 is a trademark or Corning, Inc.