Filtering Effects in a Spectrum-Sliced WDM System Using SOA-Based Noise Reduction
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Abstract—We present an experimental investigation into the effects of receiver filtering on the intensity noise in a spectrum-sliced incoherent light system incorporating semiconductor optical amplifier (SOA) based noise reduction. Spectral filtering of the SOA output degrades the signal quality, reducing the benefit offered by the SOA. However, narrow filters are required to reduce the crosstalk in high channel density systems. We characterize this tradeoff and find the optimum receiver bandwidth for varying channel spacing configurations in a spectrum-sliced wavelength-division multiplexed (WDM) system.

Index Terms—Optical noise, semiconductor optical amplifier (SOA), spectrum slicing, wavelength division multiplexing (WDM).

I. INTRODUCTION

SPECTRUM-slicing using incoherent sources has been proposed as an attractive and viable solution for cost-sensitive WDM access networks. Though an economical alternative to laser technology, incoherent sources such as light-emitting diodes and erbium-doped fiber amplifiers (EDFA) are limited in performance by the excess intensity noise inherent in such thermal-like sources [1]. For a given channel width, this intensity noise poses an upper limit on the achievable signal-to-noise ratio and the signal quality can only be improved by reducing the bit rate or increasing the channel bandwidth.

A number of intensity noise suppression techniques have been proposed to overcome these limitations and increase achievable system capacity [2]–[4]. One such approach uses the nonlinear gain compression of a saturated semiconductor optical amplifier (SOA) to suppress the intensity noise of the input thermal light [5]. This technique has the added benefit in that, ideally the SOA can also be used for signal modulation and amplification [6]. Reducing the intensity noise enables finer channel granularity and thus higher spectral efficiency. However, the spectral broadening produced by the saturated SOA is more pronounced when narrow, steep input spectral slices are used, and filtering this broadened output at the receiver degrades the signal quality [7].

Therefore, there is a tradeoff between crosstalk and intensity noise that must be considered in the design of high channel density spectrum-sliced systems incorporating SOA-based noise reduction. In this letter, we experimentally characterize this tradeoff and find the optimum channel bandwidth in a 3 × 2.5 Gb/s spectrum-sliced system.

Prior to the three-channel system measurements, the effects of receiver filtering were characterized for a single-channel scenario. These single channel measurements demonstrate the impact of filtering on source intensity noise in the absence of crosstalk. In the three-channel configuration, both the crosstalk and the intensity noise are influenced by the receiver/demultiplexer filter bandwidth. Note that with good receiver filter extinction, the crosstalk will be dominated by the two adjacent channels. Thus, in this study we assume that the three-channel performance is sufficient to represent a higher channel count WDM system.

The experimental setup for the three-channel system is shown in Fig. 1. The amplified spontaneous emission (ASE) from an EDFA is polarized and spectrally sliced into three channels using 0.24 nm (3-dB bandwidth) fiber Bragg gratings (FBGs). The center wavelength of the subject channel (channel 1) was fixed at 1551.3 nm while the crosstalk channels (channels 2 and 3) were tuned to different wavelengths in order to achieve the desired channel spacings. An EDFA is used after each grating in order to ensure sufficient input power to saturate the SOA. The three channels are then individually modulated with nonreturn-to-zero (NRZ) data at 2.5 Gb/s using LiNbO₃ modulators. The measurements presented here are for a 2²⁷ − 1 pseudorandom binary sequence (PRBS), however, no penalty was observed with a 2²³ − 1 PRBS. At the receiver, channel 1 is demultiplexed using a bandwidth-tunable FBG (the 0.24-nm bandwidth was obtained by replacing the tunable FBG with a low dispersion grating identical to the input spectral slice). The dispersion introduced by the receiver filter has a negligible impact on system performance at 2.5 Gb/s. A high-speed sampling scope is used to detect the filtered signal and measure the system Q as a function of receiver filter bandwidth.

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Fig. 1. Three-channel spectrum sliced WDM system incorporating saturated SOAs for intensity noise reduction. The receiver filter is tuned to channel 1.
and relative intensity noise (RIN). For the RIN measurements as a function of received power and receiver filter bandwidth. The system is detector noise limited at power levels low enough to be unnoticed in a routine bit error rate (BER) measurement. However, using a steep 1.3-nm receiver filter increased this noise floor to -2.5 dBm while for narrower receiver bandwidths this limit shifts to lower powers due to the increase in intensity noise. The intensity noise floor of the unfiltered SOA output occurs at Q ≈ 11.5. However, using a steep 1.3-nm receiver filter increased this noise floor to Q ≈ 10.2. Although the signal degradation is noticeable here, the absolute measurement is low enough to be unnoticed in a routine bit error rate (BER) measurement. However, the narrower receiver filters (0.7 and 0.24 nm) introduce significant system penalty. Note from Fig. 4 that due to the flat filter passband, the 3-dB bandwidth of the system output spectrum does not change appreciably as the receiver filter bandwidth is varied.

While Q is a measure of system performance and is influenced by modulation parameters, RIN is a better measure of the signal quality and directly quantifies the level of intensity noise. Thus, we used RIN measurements to characterize the signal degradation caused by spectral filtering at the receiver. For the purposes of this study we also compare the measured RIN of our system to that calculated numerically for the equivalent thermal light spectrum. Using the analysis presented in [9, eq. (7)], we are able to predict the RIN for an arbitrary thermal light spectrum. The measured RIN for the system without noise suppression (no SOA) is -104.5 dB/Hz, which as expected, closely matches the calculated value of -104.8 dB/Hz. However, when SOA-based noise reduction is incorporated, the measured RIN improves significantly (23-dB improvement with no receiver filtering) from that predicted by the thermal light model, indicating a deviation from the Gaussian statistics of incoherent light [10]. The measured RIN and the corresponding thermal light model predictions are shown in Fig. 5. These results clearly show the impact on the noise suppression due to receiver filtering.

The observed signal degradations can be understood qualitatively by considering the nonlinear interactions that occur within the saturated SOA [10]. The small signal gain compression is approximately uniform across the amplifier bandwidth [11], and produces an increased correlation between the frequency components of the input light. A further increase in spectral correlation is caused by the IC-FWM that occurs within the device. These yield reduced fluctuations in the output intensity which consists of the superposition of the powers of the various spectral components. Filtering of this signal modifies the spectral profile, reducing the correlation and thus counteracting the noise suppression benefits offered by the SOA.

Having examined the effects of receiver filtering on the intensity noise alone, we next characterized the tradeoff between crosstalk and intensity noise for the three-channel system by measuring Q as a function of receiver filter bandwidth. The system performance is given in Fig. 6 for channel spacings of 0.6, 0.8, and 1.0 nm. Note that the receiver filter we used had good out-of-band extinction (typically >30 dB), thus minimizing the crosstalk from outside of the receiver filter.
passband. As is expected, the broader receiver filters allow more crosstalk from the adjacent channels. Also shown in the graph is the corresponding Q measurement as a function of filter bandwidth for the single channel only scenario, which represents the intensity noise limit for the system at the varying receiver filter bandwidths.

From Fig. 6, the optimum channel bandwidth for the 0.6-, 0.8-, and 1.0-nm channel spacings are 0.7, 1.0, and 1.4 nm, respectively. The system is intensity noise limited for bandwidths less than the optimum value, after which it becomes crosstalk limited. In each case, the optimum receiver/demux filter bandwidth is greater than the channel spacing, which is in contrast to the system without SOA noise reduction, where the optimal receiver filter bandwidth is approximately half the channel spacing [12]. In systems using SOA-based noise suppression, receiver filtering results in a more dramatic increase in intensity noise in comparison with the thermal light case. This results in the optimum receiver bandwidth being shifted toward a higher level of adjacent channel overlap.

We would like to point out that our experimental setup was not optimized for low cost, as our main objective was to investigate the filtering effects on the noise suppression of the SOA. A more cost-effective system configuration is proposed in [3].

IV. CONCLUSION

We have experimentally characterized the filtering effects on the system performance in a spectrum-sliced WDM system using SOA-based noise reduction. Spectral broadening produced by the saturated SOA is prominent with steep narrow input spectral slices. Filtering of this broadened output degrades the signal quality, reducing the noise suppression benefits of the SOA. However, filtering is required at the receiver to minimize crosstalk, thus imposing a tradeoff between channel crosstalk and intensity noise. We experimentally determined the optimal receiver bandwidth in a three-channel spectrum-sliced system for three different channel spacing configurations. It was found that the optimum receiver bandwidth is wider than the chosen channel spacings due to the substantial signal degradation caused by spectral filtering of the saturated SOA output. This study clearly demonstrates the need to consider the effects of channel and receiver filter shape/width in the design of high channel count spectrum-sliced systems employing SOA-based noise reduction.

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