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Experimental Study on Receiver Filtering Effects in a Spectrum-Sliced Incoherent Light WDM System Using SOA Based Noise Reduction

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Abstract *We investigate optical filtering effects at the receiver in a spectrum-sliced WDM access system incorporating a gain saturated SOA. System performance is shown to have a strong dependence on the receiver filter bandwidth and shape.*

Introduction

The widespread availability of high power incoherent light sources and narrowband filters makes WDM spectrum-slicing an attractive solution for Passive Optical Networks (PONs). However the excess intensity noise present in such thermal-like sources [1] imposes a lower limit on the achievable Bit Error Rate (BER). This error floor can only be reduced by increasing the channel bandwidth or by decreasing the bit rate, thus sacrificing system capacity [2].

Recently, a variety of intensity noise suppression techniques have emerged to counteract these limitations [2-4]. One such approach uses the nonlinearity of a gain saturated semiconductor optical amplifier (SOA) to produce significant suppression of the intensity noise [4,5]. This intensity noise suppression enables the use of narrower channel linewidths, allowing increased channel granularity and spectral efficiency. However, reduced channel spacing requires steeper filters.

In this paper we show how steep filtering at the receiver significantly degrades the noise properties of the SOA output. We characterise the signal quality as a function of the receiver filter bandwidth and quantify the degradation in terms of Q and RIN. Our results demonstrate the importance of considering spectral filtering effects in the design of high-capacity spectrum-sliced WDM systems using SOA based noise reduction.

Experiment

Our experimental setup is shown in Fig. 1. Broadband ASE from an EDFA is polarised and sliced using a 0.24 nm (3 dB bandwidth) fibre Bragg grating (FBG) centred at 1551.10 nm (spectrum shown in Fig. 2a). An EDFA is used after the grating to boost the power level in order to saturate the SOA. The SOA drive current and input optical power (200 mA and +3 dBm respectively) were chosen to operate the SOA in the nonlinear regime for optimal noise reduction. The output of the SOA is modulated at 2.5 Gb/s (PRBS) using an external $LiNbO_3$ modulator. Three filters of different bandwidths (shown in Table 1) are used at the receiver. The resulting output signal is then detected and the system Q measured using a high-speed sampling scope. Signal RIN is also measured at the output of the receiver filter, with the modulator bypassed to produce a continuous wave (CW) signal.

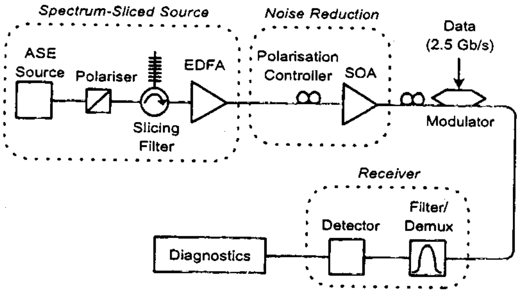

Fig.1: Experimental setup.

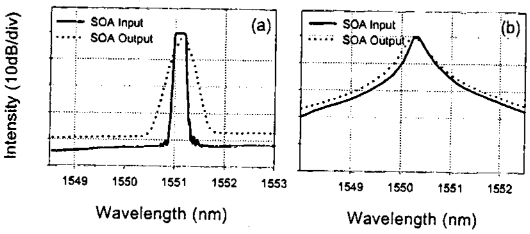

Fig.2: Spectral broadening of the SOA output for two filter shapes, both with ~0.24nm 3 dB bandwidth.

Results and Discussion

The nonlinear noise suppression in the SOA is the result of small signal gain compression and to a lesser degree, intra-channel four wave mixing (IC-FWM) within the saturated SOA [4-5]. The spectral broadening due to the IC-FWM has been observed previously [4] and can be significant, depending on the input bandwidth and spectral shape. This is illustrated in Fig. 2, which shows the SOA spectral response to two filters of approximately the same 3 dB bandwidth (~0.24 nm) but with differing spectral shapes. The spectral broadening is significant with the steep filter (Fig. 2a), which is the spectrum-slicing filter used in our experiment.

Fig.4 shows the Q measurements as a function of receiver filtering, and the corresponding spectra at the detector input are given in Fig. 3. As a point of comparison, the system performance with no SOA-based noise reduction is also shown in Fig. 4. With no post-filtering of the SOA output, the error floor occurs at Q≈11.5 (BER≈10^{-32}), while filter1 changes this floor to Q≈10 (BER≈10^{-23}). Although the performance degradation is noticeable here, the error floor is low enough to be unnoticed in a routine BER measurement. However, filter2 results in an error floor of Q≈6 (BER≈10^{-9}) and filter3 results in an error floor of Q≈4 (BER≈10^{-5}). Note that although filter2 and filter3 are of approximately the same 3 dB bandwidth, filter3 has a smaller 10 dB bandwidth. It is clear that the use of steeper, narrower filters at the receiver results in significant system penalty.

Table 1: Receiver filter bandwidths

	3 dB Bandwidth	10 dB Bandwidth
Filter1	0.5nm	1nm
Filter2	0.24nm	0.5nm
Filter3	0.24nm	0.26nm

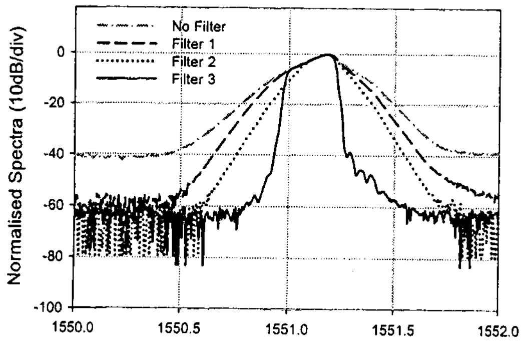

Fig.3: Detector input spectra for the different receiver filters.

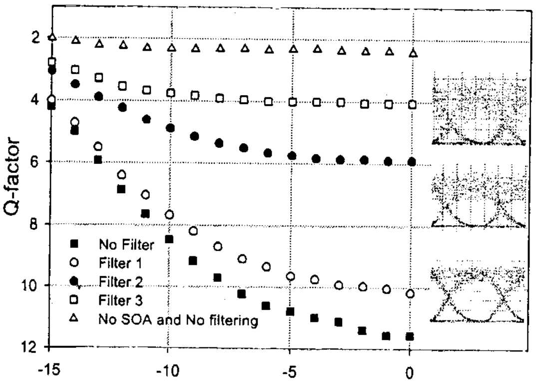

Fig.4: Q measurements for no receiver filtering, filter1, 2, 3 and without SOA noise reduction. Filter 3 is spectrally matched to the spectrum-slicing filter. Inset: eye diagrams for filter1, filter2 and filter3.

We also measured the RIN on the CW signal for the various filters using a 125 MHz high sensitivity photodetector and an electrical spectrum analyser. Table 2 gives the RIN values measured at 100 MHz, for the different receiver filters (input optical power to the detector is -14 dBm). Column1 gives the decrease in 10 dB bandwidth as the signal passes through the receiver filter. This figure of merit is used to quantify the spectral alteration due to the different filters. Also note that the observed RIN increase due to receiver filtering of the SOA output is much larger than would be expected for the equivalent filtering of thermal light (see column 4 in Table 2). RIN values for the equivalent thermal light spectra were calculated using the analysis presented in [6].

Table 2: RIN results at receiver output

	Reduction in 10dB bandwidth	Measured RIN (dB/Hz)	RIN Improvement (dB)	RIN of equivalent thermal light spectrum (dB/Hz)
No SOA	--	-104.6	--	-104.8
No Filter	0%	-129.5	24.9	-106.5
Filter1	13%	-120.3	15.7	-105.9
Filter2	36%	-112.4	7.8	-104.8
Filter3	47%	-109.4	4.8	-104.04

The observed signal degradation can be understood qualitatively by considering the nonlinear interactions within the saturated SOA [7]. The gain compression is approximately uniform across the amplifier bandwidth [8], and produces an increased correlation between the frequency components. This correlation yields reduced fluctuations in the output intensity which consists of the superposition of the powers of the various spectral components. Further filtering of this signal modifies the spectral profile, reducing the correlation and thus counteracting the noise suppression effects of the SOA.

Conclusions

We demonstrate the impact of spectral filtering on SOA-based intensity noise suppression in the context of a spectrum-sliced WDM system. We found that filtering the SOA output to the same bandwidth as the input spectrum slice increased the RIN by 20 dB and reducing the 10 dB bandwidth by as little as 13% added 9 dB to the RIN. Our results show that the receiver filter shape and width should be carefully optimised for both overall noise reduction and minimal cross-talk in high-capacity spectrum-sliced WDM systems.

References

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