Optimising Signal Quality in a Spectrum-Sliced WDM System Using SOA-Based Noise Reduction

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Abstract *We investigate experimentally and numerically the performance impact of optical filtering in a spectrum-sliced incoherent light system incorporating a saturated SOA. Received signal quality can be improved significantly by reducing the SOA linewidth enhancement factor.*

Introduction

High channel-density spectrum-sliced WDM systems have attracted attention as a viable technology for cost-sensitive metropolitan and access networks [1]. However the intensity noise present in spectrum-sliced incoherent light imposes an upper limit on the achievable system performance and increases with decreasing slice bandwidth. A gain-saturated SOA can be used to overcome this limitation and suppress the intensity noise, allowing increased spectral efficiency. In addition to intensity smoothing, the SOA offers further benefits as it can serve as both a modulator and an amplifier.

However, filtering after the SOA (e.g. in a WDM demultiplexer) reduces the noise suppression offered by the SOA, degrading the received signal quality [2]. This effect is more pronounced for narrow channel widths, where the nonlinearities of the SOA cause significant spectral-distortion and broadening. This limits the achievable channel granularity due to the trade-off between intensity noise and cross-talk [3].

In this paper we investigate techniques to improve the received signal quality in spectrum-sliced systems using SOA-based noise reduction. Our experimental observations are supported by numerical simulations which are used to better examine the effects of post-SOA filtering. We demonstrate a strong dependence of the received signal quality on the SOA linewidth enhancement factor. Our results show the potential to significantly improve system performance by optimising the SOA design.

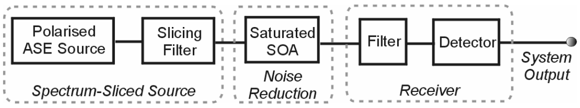

Fig.1: Single channel system block diagram.

Numerical Simulation

To understand post-SOA filtering effects on the intensity-smoothed light, the system shown in Fig. 1 was modelled using the standard field and carrier density rate equations [4]. Although the noise reduction can be modelled by the intensity and carrier density rate equations alone [5], the field equation is required to predict the spectral properties of the SOA output [6], including the effects of post-SOA filtering.

In our travelling-wave SOA model, the amplifier is treated as being comprised of short segments, and the rate equations are solved on this spatial grid using an ordinary differential equation solver. Our model neglects the amplified spontaneous emission noise (ASE) in the SOA. The spectrum-sliced input to the amplifier is modelled by thermal light statistics.

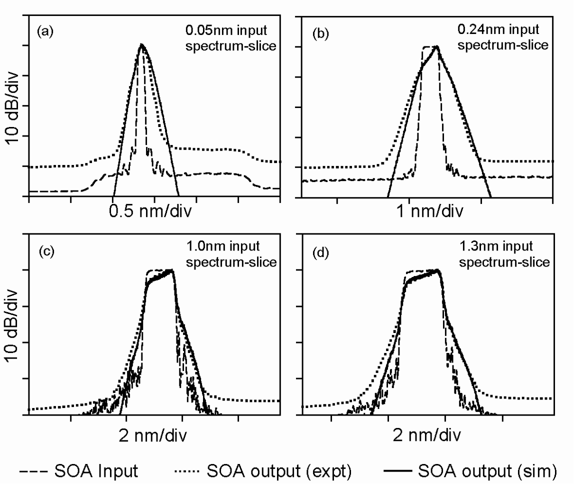

Fig.2: Spectra before and after the saturated SOA for 0.05, 0.24, 1.0 and 1.3nm (3dB bandwidth) filters.

Results and Discussion

We first examine the spectral broadening effects introduced by the SOA for varying spectrum-sliced input bandwidths. The SOA used in this study was operated in deep saturation to ensure maximum noise suppression (for details, see [2]).

As seen in Fig. 2, the numerical model accurately predicts the output spectra, clearly showing the broadening and distortion observed in the experimental measurements. The main discrepancy is the ASE floor, which is not included in the model.

The spectral broadening at the SOA output is caused by phase modulation-induced chirp [4] and to a lesser degree, four-wave mixing within the channel bandwidth. This effect is more pronounced in the narrower spectral slices, where the larger intensity fluctuations (i.e. intensity noise) produce greater phase modulation, as discussed in [6]. This amplitude-to-phase coupling is described in the rate equations by the linewidth-enhancement factor α.

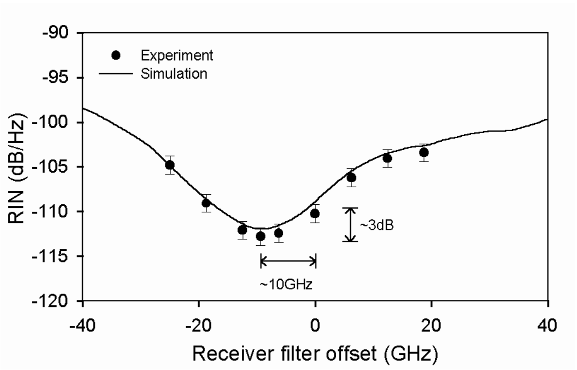

Fig.3: RIN at receiver filter output, as a function of frequency offset between 0.24nm input spectrum slice and 0.24nm receiver filter (same shape as slicing filter).

Phase modulation in the SOA is also responsible for the red-shift of the peak wavelength relative to the input spectrum-slice, as observed in Fig. 2 [4]. This frequency shift can noticeably affect the alignment of the post-SOA receiver filter, and thus, the received signal quality. Fig. 3 shows the relative intensity noise (RIN) at the system output as a function of the frequency offset between the input spectrum slice and the receiver filter (RIN measured at 100MHz). The lowest RIN is obtained when the receiver filter is aligned 10GHz below the input spectrum slice. This illustrates the importance of aligning the receiver filter to the SOA output in narrow-channel systems using SOA-based noise reduction. Post-SOA filtered signal RIN was also characterised as a function of receiver filter bandwidth as shown in Fig. 4. Receiver filters used for this characterisation have similarly shaped transfer functions. Fig. 3 and 4 both show excellent agreement between the experimental and simulation results.

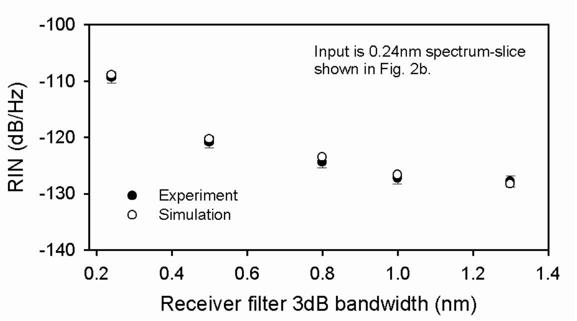

Fig.4: RIN at system output for varying receiver filters (receiver filter aligned to SOA input spectrum-slice). Filter transfer functions are as shown in Fig.2.

Having validated the model accuracy by predicting both the spectral broadening and the effects of post-SOA filtering, we now use the model to assess the impact of the linewidth enhancement factor on the received signal quality. Using a 0.24nm (3dB) input spectrum slice, we calculate the RIN directly after the SOA and at the output of the receiver filter, as a function of α. Simulation results are shown in Fig. 5, for post-SOA receiver filters of 0.24 and 0.5nm (3dB) bandwidths.

As expected [6], the noise suppression directly after the SOA is not affected by α. However, α clearly has a strong effect on the post-SOA filtered signal quality. Typical bulk SOAs have linewidth enhancement factors between 3 and 8 [4] ($\alpha = 5$ was used as a best fit to our experimental data). By reducing α, we obtain a maximum RIN improvement of 11.5dB over our experimental values for the 0.24nm filter and 9dB with the 0.5nm filter. The 10dB bandwidth of the SOA output light is also shown, illustrating the strong influence of α on spectral broadening [6].

These results clearly show that the post-SOA filtered signal quality can be improved significantly by optimising the design of the SOA to reduce the linewidth enhancement factor.

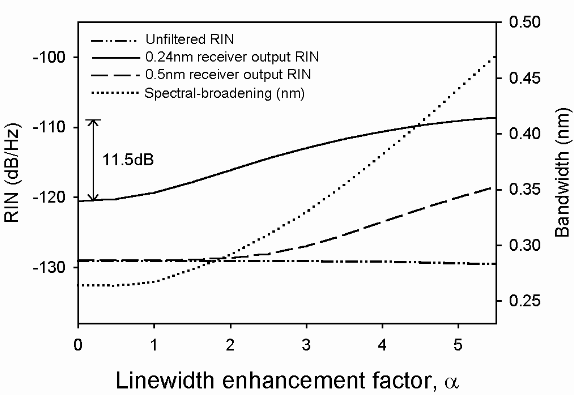

Fig.5: Simulation results vs. alpha: Unfiltered SOA output RIN, RIN at filter output (0.24 and 0.5nm filters), and SOA output 10dB bandwidth.

Conclusions

We have investigated techniques to improve the received signal quality in spectrum-sliced systems incorporating SOA-based noise reduction. Spectral-distortion and post-SOA filtering effects were examined experimentally and numerically. Aligning the receiver filter to compensate for the red-shift introduced by the saturated SOA produced an improvement of ~3dB in the signal RIN. Using simulations, we have also demonstrated that reducing the linewidth enhancement factor of the amplifier can improve the received signal quality by 11.5dB. These optimisations will increase system performance and allow for greater channel granularity and spectral-efficiency in high channel count spectrum-sliced systems using gain saturated SOAs.

References

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