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Research Article

Optimization of Intensity Noise Reduction from an Incoherent Light Source Using Gain Saturated Semiconductor Optical Amplifier in a Spectrum-sliced Channel at 2.5 Gb\S

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Abstract: The "spectrum-slicing" technique employing incoherent light has been shown to be a highly practical, cheap and hence very attractive proposal for future all-optical networks. In this study, the use of Semiconductor Optical Amplifier (SOA) gain saturation for intensity noise reduction of incoherent light is studied with a view to obtaining the optimum SOA injection current and input power conditions to achieve the best possible intensity noise reduction-in terms of OSNR, BER, noise power and Q-factor. The results reported herein give designers knowledge of the best SOA operating conditions to enhance overall system performance, while still obtaining signal gain from the SOA.

Keywords: Amplified Spontaneous Emission (ASE), Bit Error Rate (BER), Optical Signal-to-Noise Ratio (OSNR), Quality (Q) factor, Semiconductor Optical Amplifier (SOA), spectrum-slicing

INTRODUCTION

In present times, developing the capacity of optical fiber networks has become imperative to meet the rapid recent growth in network capacity requirements. Industry's hunger for network capacity grows daily and fueling this hunger are social networking companies like Facebook and Verizon, which create excessive demand son network capacities that far exceed today's availability (Zabinski *et al*., 2013). Additional schemes are therefore, needed in today's bandwidth hungry world. One such scheme is "spectrum-slicing."This has been proven as a promising method for generating wavelength channels as optical carriers in which an incoherent light source, such as the Amplified Spontaneous Emission (ASE) from an Erbium-Doped Fiber Amplifier (EDFA) or other broadband source, is spectrally sliced utilizing a bandpass filter (Chung *et al*., 1993; Connelly *et al*., 2005). Spectrum-slicing therefore introduces a practical and highly cost-effective solution, utilizing one common light source as opposed to expensive, multiple transmitter lasers operating at different wavelengths and which can be exploited in Wavelength Division Multiplexing (WDM) systems (Chung *et al*., 1993).

The technique, however, has one key drawback-the inherently high excess intensity noise from the incoherent light source used-thus affecting system performance and manifesting from square-law characteristics of the photo detection process. System signal quality implementing spectrum-sliced sources have been enhanced by running at low data rates, or alternatively by widening filter channel bandwidth (Pendock and Sampson, 1996; Ymatoya *et al*., 2000), consequently sacrificing system capacity utilization and increasing dispersion arising from the wide spectrum slicing filter. However, performance may also be improved by exploiting the nonlinear gain compression effect of a saturated Semiconductor Optical Amplifier (SOA) included in the set-up to reduce the excess intensity noise-sometimes by up to 10 dB at 600 Mb⁄s in (Kim *et al*., 1999), 16 dB in Connelly *et al*. (2005) and up to 25 dB in McCoy *et al*. (2005). A practical example of the use of the technique has more recently been shown in the medical application area of Optical Coherence Tomography (OCT) to improve the resolution (Lee *et al*., 2011) and reduce the intensity noise (Shin *et al*., 2010). In the latter work, the ASE noise from a Super Luminescent Diode (SLD) source was reduced by amplification using a gain-saturated SOA by 9 dB when measuring the Relative Intensity Noise (RIN). They achieved this lower noise for broadband OCT light sources by using a very basic and simplistic design. This result has impacted towards making practical, economical and low-noise SLD-based sources for applications in OCT today.

In this study, the use of Semiconductor Optical Amplifier (SOA) gain saturation for intensity noise reduction of incoherent light is studied with a view to obtaining the optimum SOA injection current and input power conditions to achieve the best possible intensity

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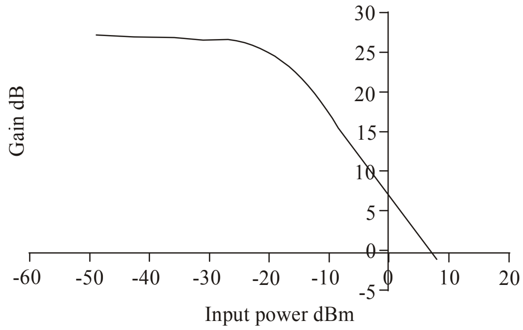


Fig. 1: SOA gain characteristics

noise reduction-in terms of OSNR, BER, noise power and Q-factor.

MATERIALS AND METHODS

SOA characterization: Figure 1 shows the SOA gain response to increasing input powers plotted using ASE output from a 0.48 nm spectrum-slicing band-pass filter (Fig. 2). The system utilizes no additional EDFA and we reach SOA saturation input power by increasing the amplitude in the d.c., bias generator in the ASE source. The unsaturated gain observed is around 26 dB, until the point about -20 dBm input when the gain starts to saturate quite sharply, decreasing almost linearly with increasing input power.

System set up: A block diagram of the set-up we used is shown in Fig. 2. An ASE broadband source is spectrally filtered using an 80 GHz (~0.48 nm) band-pass Bessel filter, centered at 193.1 THz (1552.5 nm). The SOA input power is controlled by an optical attenuator. The preferred channel is modulated using a Mach-Zehnder modulator, with NRZ data at 2.5 Gbits\s. The modulated signal is then filtered with a 100 GHz (~0.8 nm) band-pass Bessel filter. Finally, a PIN photo detector is inserted followed by a 7.5 GHz low-pass Bessel filter. WDM, RF spectrum and eye diagram analyzers are all attached to characterize the noise reduction performance in terms of the OSNR, RIN and Q Factor, respectively.

RESULTS AND DISCUSSION

Figure 3 shows the Q factor response to increasing input powers for 4 different SOA bias currents. At all biases, the Q-factor is seen to increase continuously with input power until the point around 0 dBm input, where it reduces slightly. From Fig. 1 it was seen that at 0 dBm input power the SOA is operating in the highly saturated regime. Interesting to note that increasing the SOA injection current beyond 0.15 A (near the typical SOA model operating point) does not offer any further benefit.

Figure 4 shows the Q-factor values obtained when the SOA was removed, i.e., without the noise reducing SOA in the system. The maximum value obtained is

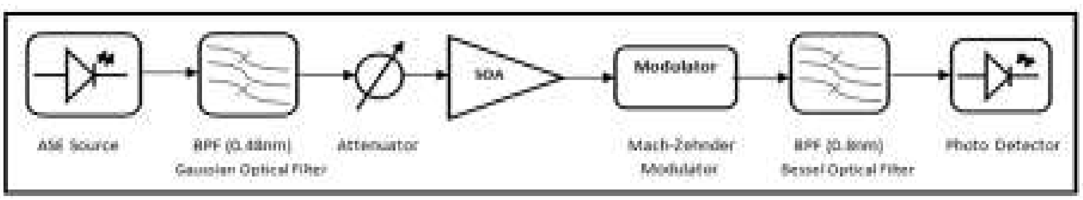
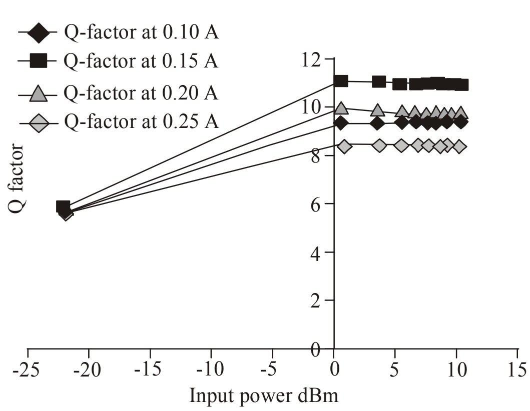
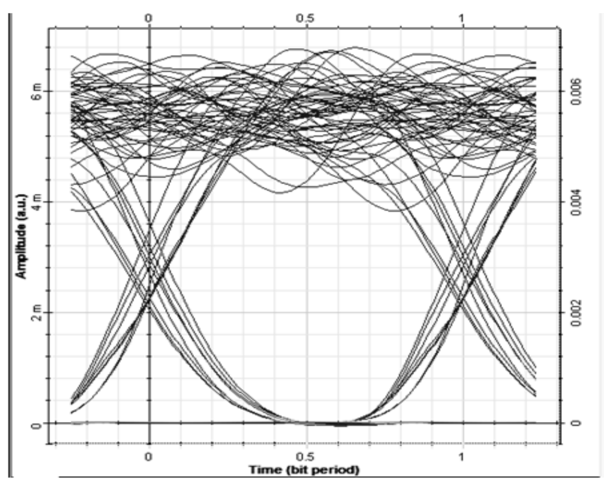


Fig. 2: Simulation set-up

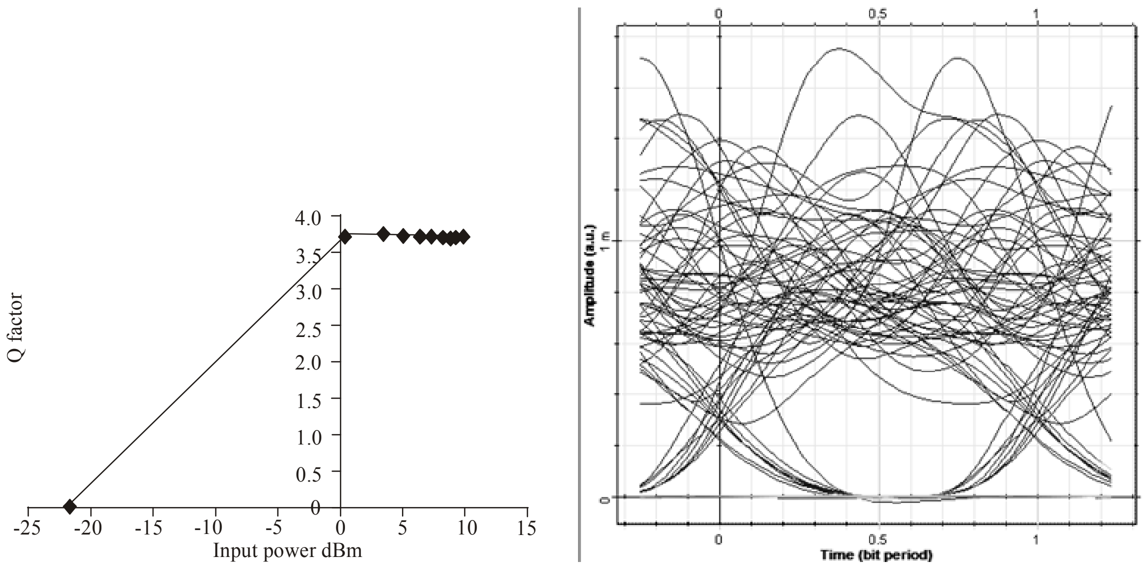


(a)



(b)

Fig. 3: (a) Q factor as a function of input power and SOA injection current, (b) Q factor = 11.2 dB at 0 dBm input power and 0.15A SOA bias current



(a) (b)

Fig. 4: (a) Q factor as a function of input power before SOA, (b) Q factor = 3.7 dB at 0 dBm input power

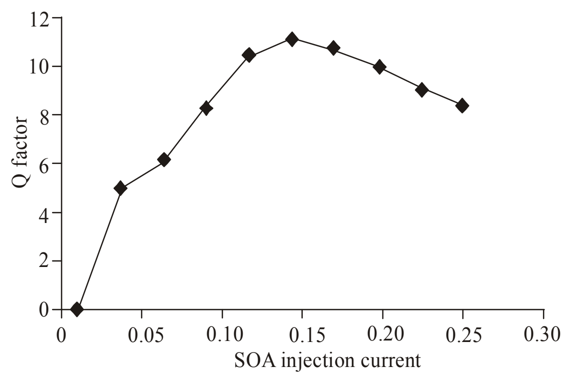


Fig. 5: Q factor at 0 dBm input power with varying SOA injection current

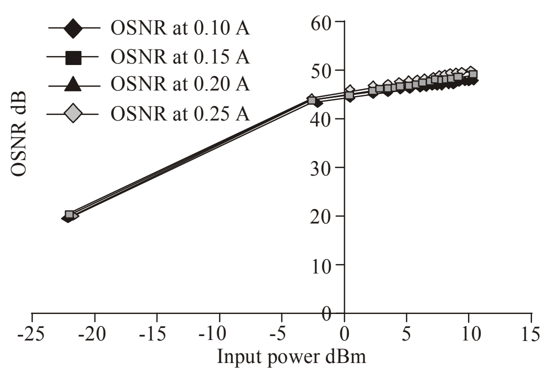


Fig. 6: OSNR as a function of input power and SOA bias current, SOA input OSNR for 0.48 nm spectrum sliced channel is 15 dB/nm

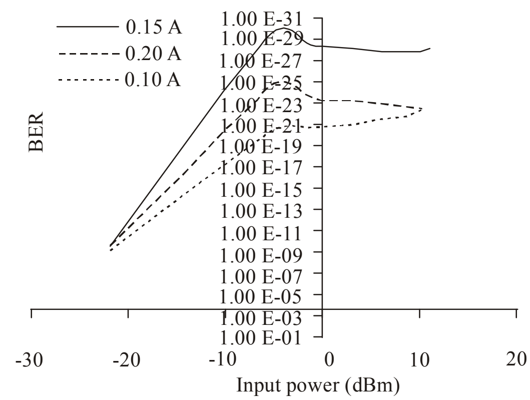


Fig. 7: BER as a function of input power and SOA bias current

clearly unacceptable, around 3.7 at 0 dBm input power and does not improve after this. The Q-factor was also at a maximum at 0 dBm SOA input power in Fig. 3. From Fig. 5 when we measure the Q-Factor with the SOA in the system we reach the value of around 11.5 dB. We can therefore clearly see the effect of the inclusion of the SOA on system performance. Around 0.15A is again the optimum bias here at 0 dB m total input power to SOA-in full agreement with Fig. 3.

In Fig. 6, the OSNR obtained is plotted against SOA input power at various biases. The OSNR at all biases up to 0.25A is shown to continuously increase with increasing SOA input powers. An OSNR enhancement around 20 dB is estimated at about 0.15 A bias, when the input power is increased from -15 to -3 dBm.

Figure 7 shows that the best BER occurs around -5 dBm input power to the SOA, at all three biases used in the figure. The best BER occurs at 0.15A bias. This bias is in full agreement with Fig. 3a, 5 and 6.

CONCLUSION

In this study, we have quantified the merits of using SOA gain compression for intensity noise reduction of light from an incoherent broadband source for future spectrum-sliced systems. We have shown that around -5 to 0 dBm input power and 0.15 a bias, is the best optimum operating conditions in which to run the SOA in order to achieve the highest intensity noise reduction which, in turn, enhances overall system performance. We also recommend that the use of an independent saturating holding beam, inserted separately into the SOA, along with the ASE signal, should be investigated. This could be tailored to ensure that the SOA is always saturated to at least 0 dBm, particularly at the lower input powers, in order to achieve the maximum intensity noise reduction and therefore improve system quality improvement. However, the extra effects on gain that this would cause would need to be accounted for in the system.

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