Research Journal of Applied Sciences, Engineering and Technology 12(7): 700-705, 2016
DOI:10.19026/rjaset.12.2744
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 26, 2015 Accepted: August 20, 2015 Published: April 05, 2016

Research Article

Further Investigation of Intensity Noise Reduction on an Incoherent Light Source using a 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 gain saturation for intensity noise reduction on incoherent light is further studied in terms of the Relative-Intensity-Noise (RIN), with a view to obtaining the optimum SOA injection current and input power conditions to achieve the best possible intensity noise reduction, in conjunction with OSNR, BER and Q-factor results. The results reported herein give designers knowledge of the best SOA operating conditions to enhance overall system performance, whilst still obtaining signal gain from the SOA.

Keywords: Amplified Spontaneous Emission (ASE), Bit error rate (BER) and quality (Q) Factor, Optical Signal-to-Noise Ratio (OSNR), Semiconductor Optical Amplifier (SOA), Spectrum-Slicing (SS)

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 demands on 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." (SS). 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 (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 (Lee *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 (Yamatoya *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 (Tariq and Forsyth, 2014) and up to 25 dB in (McCoy *et al*., 2005). A practical example of the use of the technique has 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.

Research into SS techniques and for reducing the associated intensity noise, are today still far from

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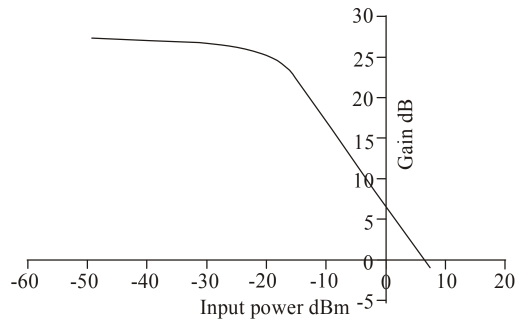


Fig. 1: SOA gain characteristics

declining. Zaineb *et al*. (2012), it was shown that an ultra-narrow (≈0.01 nm) spectrum-sliced incoherent light source permitted the transmission of 10-Gb/s NRZ signals over 20 km SSMF and 0.2-nm-bandwidth optical filter without any dispersion compensation. In Qikai and Hoon (2014), there was shown a novel offset optical filtering technique to reduce the excess intensity noise of the ultra-narrow spectrum-sliced incoherent light source using a gain-saturated SOA running at 12 Gb/s. The offset optical filtering converted the chirp into amplitude to produce destructive interference within the inherent excess intensity noise and therefore improved signal quality. In work done in Kharraz *et al*. (2013), it was reported on the use of SOA gain compression for achieving intensity noise reduction in light from an incoherent broadband source, running at high data rate of 10 Gb⁄s in a narrow spectrum-sliced high-intensity channel of 20 GHz (about 0.16 nm) bandwidth. Data was collected on the performance of the single SOA as noise reducer at various input powers and biases. Improvements of around 20 dB in the RIN were seen here, together with commensurate improvements in both the Signal-to-Noise Ratio (OSNR) and quality factor (Q).

In this study, we improve on our previously published results (Tariq and Forsyth, 2014) by presenting a further optimization scheme for a saturated SOA-based intensity noise reducer which shows the corresponding enhancements in the RIN as well as the OSNR, Bit-Error-Rate (BER) and Q factor.

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 (Johni *et al*., 2014).

SYSTEM SET UP AND RESULTS

A block diagram of the set-up we used is shown in Fig. 2. An ASE broadband source is spectrally filtered using a 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

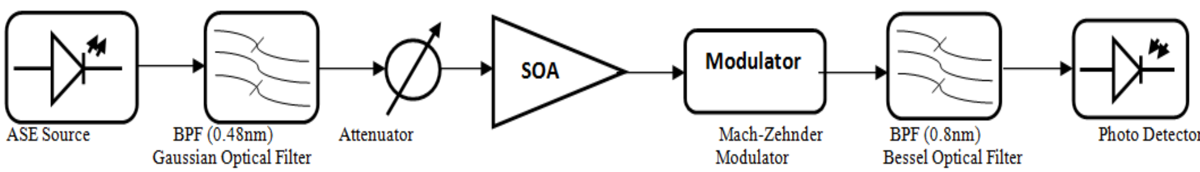
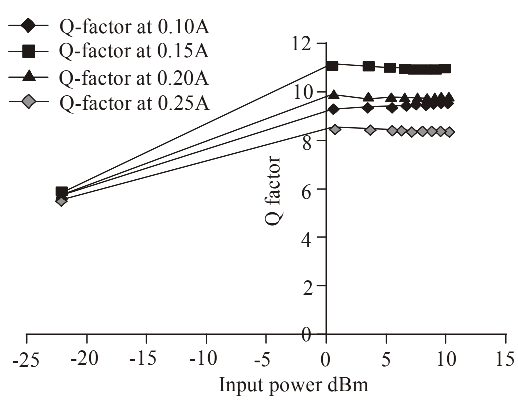


Fig. 2: Simulation set-up



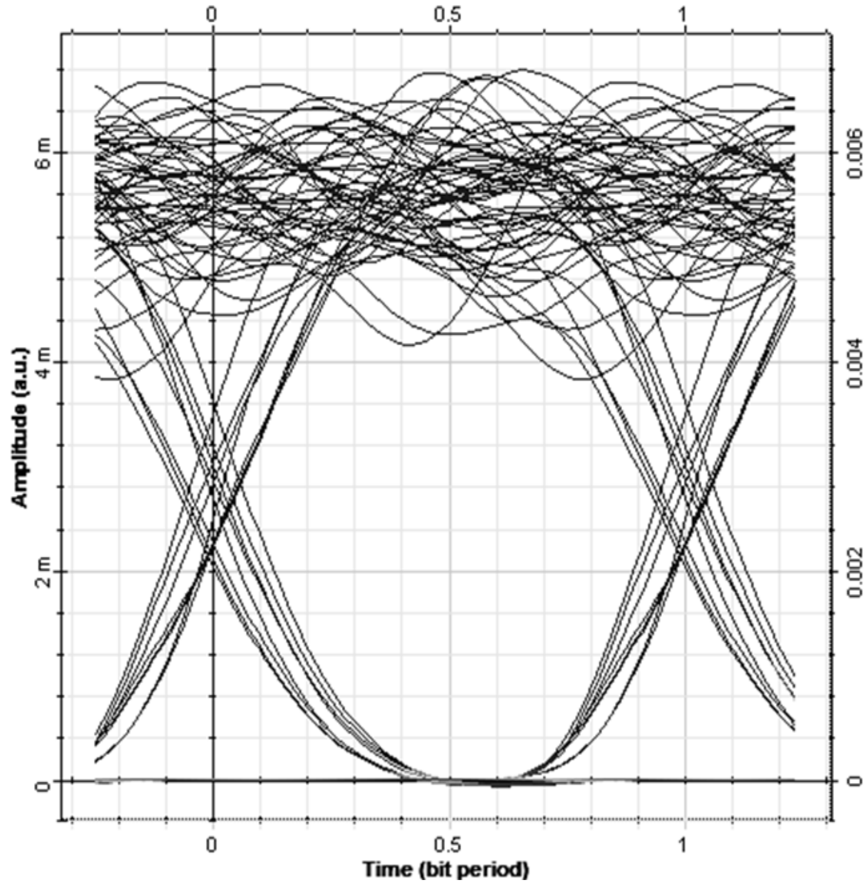


Fig. 3: (a): Q factor as a function of input power and SOA injection current; (b): Q factor = 11.2 dB at 0 dBm input power and 0.15A SOA bias current

Q Factor, respectively. 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 clearly unacceptable, around 3.7 dB 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 dBm total input power to SOA-in full agreement with Fig. 3.

Figure 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 dBm to -3 dBm.

Figure 7 plots the BER as a function of input power and SOA bias current. It 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.

Figure 8, the Relative-Intensity-Noise (RIN) as a function of SOA input power (dBm) at 0.15A drive current is plotted. We see that as the inserted input power into the SOA increases, the noise suppression continuously increases almost linearly. The lowest RIN is measured to be around -103.4 dB/Hz. We also can observe that SOA bias current at all input powers in the saturation regime enhances the noise reduction. To quantify the intensity noise reduction, it can easily be seen from Fig. 8 that around 25 dB in the RIN is suppressed in the SOA input power range from ~ -20 dBm to ~ +10 dBm at 0.15A drive current, then only a

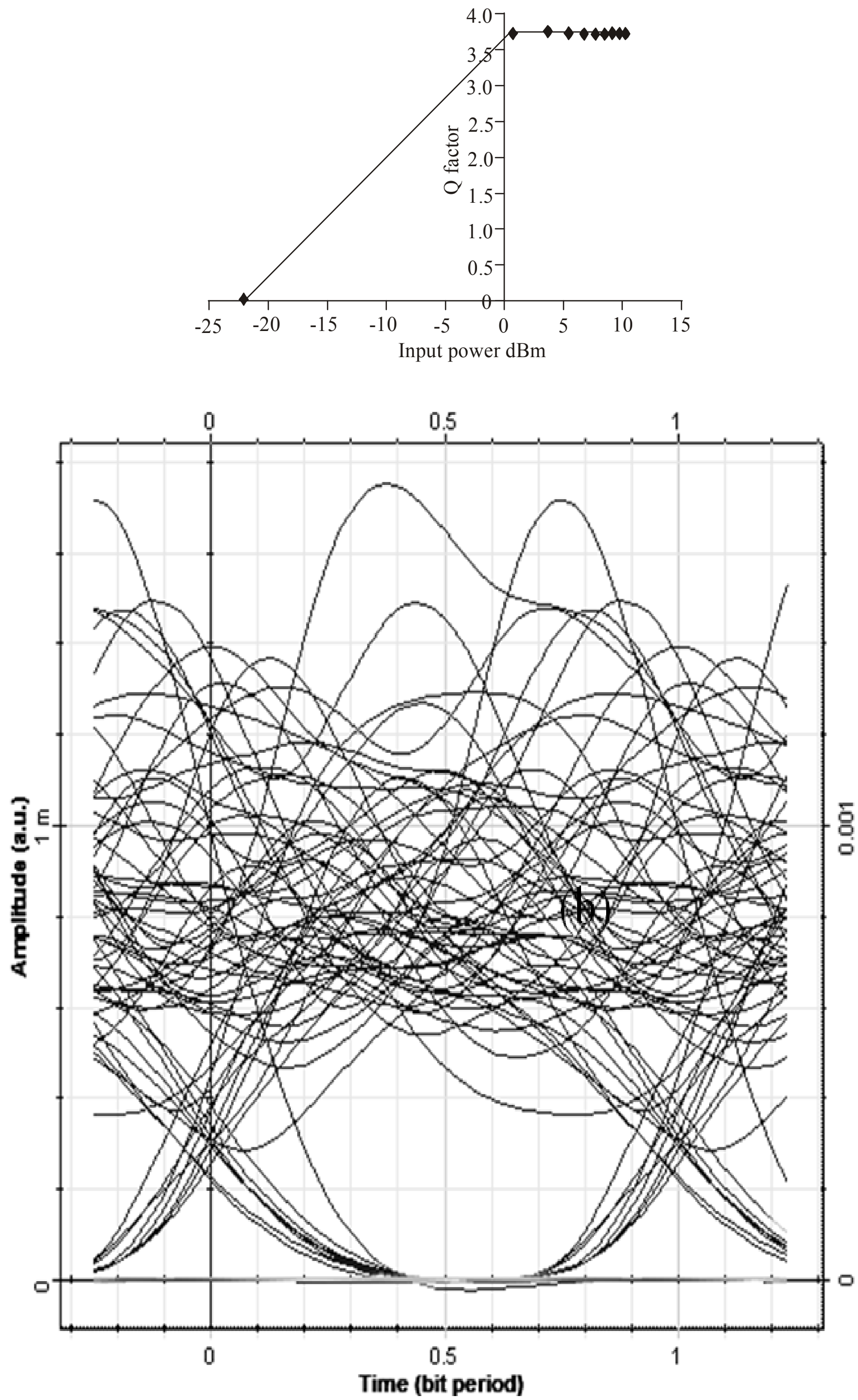


Fig. 4: (a): Q factor as a function of input power before SOA; (b): Q factor = 3.7 dB at 0 dBm input power

slight improvement is inferred when greater input powers are inserted.

Figure 9 plots the RIN as a function of SOA bias current at the nominal input power of 0 dBm. It can be seen that as the SOA drive current increases from 0 to 0.05A, the RIN improves dramatically from around-116 to -131 dB. Here, an improvement of around 15 dB in this measurement parameter is observed, which still holds out around 0.15A bias. Hence, in agreement with previously measured Q, OSNR and BER, we infer that around 0.15A SOA bias current would achieve the optimum intensity noise reduction. However, as seen from previous figures, when the SOA enters to very deep saturation region, all metrics grow to be stabilized and even infrequently worsen marginally at very high SOA biases and insertion powers. We also can infer

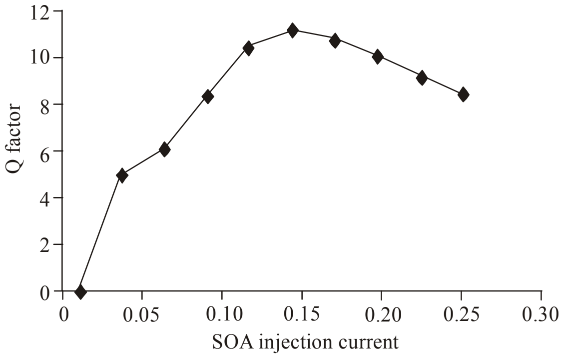


Fig. 5: Q factor at 0 dBm input power with varying SOA injection current

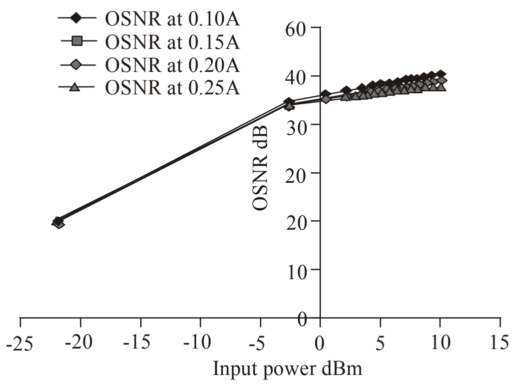


Fig. 6: OSNR as a function of input power and SOA bias current, SOA input OSNR for 0.48 nm spectrum sliced channel is 15 dB/nm

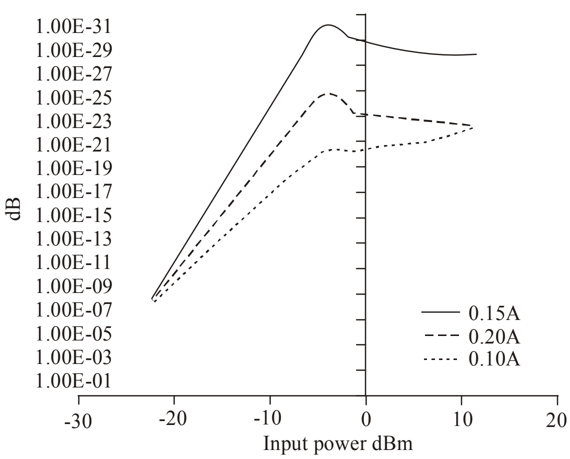


Fig. 7: BER as a function of input power and SOA bias current

from Fig. 9 that increasing the bias current to more than 0.25A may not amount to any more changes in the RIN.

CONCLUSION

In this study, using a new parameter of RIN, we have investigated further the use of SOA gain compression to assess the impact of intensity noise reduction of light from an incoherent broadband source for future spectrum-sliced systems, for improving signal quality for overall system performance. Based on our new RIN measurements combined with previous OSNR, BER and Q factors, we have concluded that around 0 to -5 dBm input power and that around 0.15A bias current are still most probably the best optimum operating conditions in which to run the SOA. The results reported herein will give designers knowledge of the best SOA operating conditions to enhance overall system performance, whilst still obtaining some signal gain from the SOA.

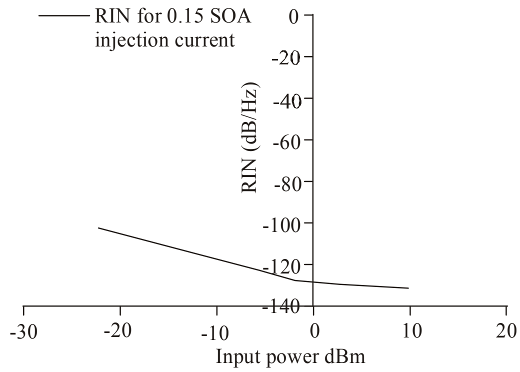


Fig. 8: RIN as a function of input power (lowest RIN = -103.394 dB/Hz)

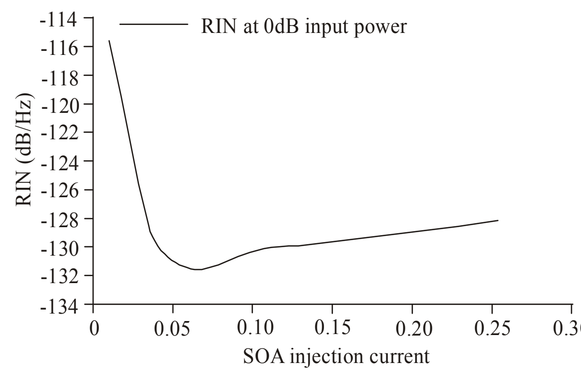


Fig. 9: RIN as a function of SOA bias current

ACKNOWLEDGMENT

The authors would like to thank the Light wave Communication Research Group (LCRG), at Universiti Teknologi Malaysia (UTM) for access to their software for the simulations and would like to thank UHD to support this research.

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