Effects of Weak Input Side Mode Suppression Ratio and Output Filtration on the Intensity Noise of a Self-Seeded Gain Switched Optical Pulses at 2.5 GHz

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ABSTRACT

Mode partition noise is shown to be a cause for concern in terms of the intensity noise induced on a self-seeded gain-switched pulse when filtering is used to increase the Side Mode Suppression Ratio (SMSR) of the output signal to >30dB. The inherent SMSR of a self-seeded gain switched pulse is revealed to be a vital parameter especially when output filtration is used. Our results portray the fact that such a procedure would lead to an introduction of noise on the SSGS pulses if the inherent SMSR is weak, and may ultimately determine whether or not a source is suitable for use in WDM or OTDM optical communication networks.

Keywords: optical communications, optical pulse generation, gain-switching, self-seeding, mode partition noise, Fabry-Perot filters.

1. INTRODUCTION

The development of short wavelength tuneable pulses is particularly important for next generation optical networks [1]. Various pulse generation schemes have been proposed including mode locking, pulse shaping by an external modulator and gain switching [2]. Mode locking requires anti-reflection coated facets and special cavity features, which make the device very sensitive to ambient perturbations such as temperature changes or vibrations. In the case of pulse shaping, the addition of an extra component to the system along with the high insertion loss of a modulator adds to the disadvantages of this technique. Gain switching, on the other hand, being a direct modulation technique is considered to be a very simple and cost efficient technique. Essentially, it involves applying a high amplitude RF signal to a laser diode to excite the first spike of the relaxation oscillation and terminating the electrical signal before the beginning of subsequent spikes resulting in the generation of short optical pulses [3].

One of the most reliable techniques used to create wavelength-tuneable picosecond optical pulses involves either external injection or self-seeding of a gain-switched (SSGS) Fabry Perot (FP) laser. The additional laser required in the case of external injection acts as a potential disadvantage in terms of adding an extra component and cost to the system. Self-seeding, however, merely entails re-injecting a small portion of the output laser light back into the FP laser at one longitudinal mode through the use of an external cavity. To ensure a single-moded output pulse, the optical signal reinjected back into the laser must arrive during the build up of an optical pulse within the active region of the laser. It has been shown that self-seeding is seen as the most straightforward method available to improve the reduced Side Mode Suppression Ratio (SMSR) caused by gain switching and has also been shown to produce very low jitter pulses [4]. The SMSR itself is a vital parameter in characterising SSGS pulses for use in optical communication systems and previous work has demonstrated how variations in SMSR greatly affects the noise induced on a single pulse source [5].

Although previous reports of wavelength selective pulse sources using the SSGS scheme had input SMSR's between 15-30 dB and relied on spectral filtering to increase the output SMSR to > 30 dB [6], such pulses maybe unusable in WDM or OTDM systems. In this work, we show that the effects of degrading the input SMSR of an SSGS pulse that is then output filtered results in the introduction of noise through a process know as the mode partition effect [7]. The mode partition effect is essentially a statistical process of energy fluctuations in each mode with time due to a constant energy transfer between the lasing modes. In effect this demonstrates that a high output SMSR alone is not enough to reduce the effects of intensity noise on the optical pulse.

2. EXPERIMENTAL SETUP

Figure 1 shows the experimental set-up used. The FP laser used was a commercial 1.5 μm InGaAsP device, with a threshold current of about 18 mA and longitudinal mode spacing of 1.1 nm. Gain switching of the laser was carried out by applying a dc bias current of about 13 mA and a sinusoidal modulation signal amplified to a power of about 27 dBm at a frequency of approximately 2.5 GHz. Self-seeding of the gain switched laser diode was achieved by using an external cavity containing a Polarization Controller (PC), a 3 dB coupler and a tunable Fibre Bragg Grating (FBG) with a bandwidth of 0.37 nm. To achieve optimum SSGS pulse generation, the central wavelength of the FBG was initially tuned to one of the longitudinal modes of the gain switched laser. The frequency of the sinusoidal modulation signal was then varied to ensure that the signal re-injected into the laser

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from the external cavity, arrives as an optical pulse is building up in the laser. An operating frequency of 2.478 GHz was found to be suitable.

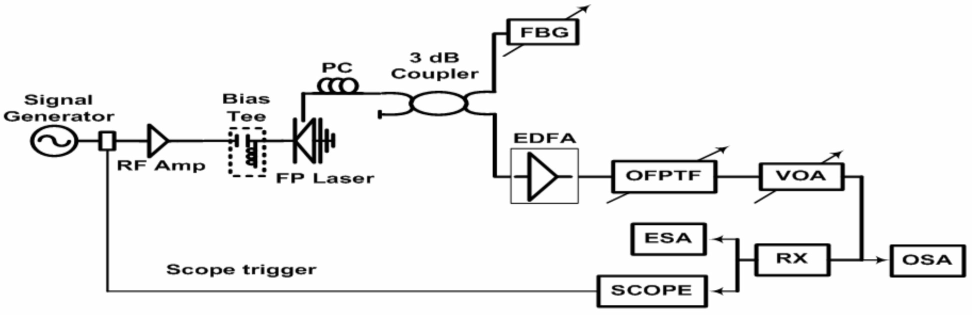

Fig. 1 Experimental setup.

In addition to tuning the FBG and the modulation frequency, we could also vary the amount of light re-injected and hence the SMSR of the optical pulses by adjusting the PC. The pulses at the lower output port of the 3dB coupler (portray the inherent SMSR) are then amplified with the aid of an EDFA after which they are filtered using an Optical Fabry Perot Tunable Filter (OFPTF). The OFPTF had a FWHM passband of about 1 nm and an extinction ratio of about 20 dB. In order to characterize the SNR of the filtered SSGS pulses as a function of the input SMSR, we had to keep the output SMSR constant. When the inherent SMSR of the SSGS signal was high (30 dB) the output SMSR was maintained at 35 dB by tuning the filter away from the central wavelength of the SSGS signal. On the other hand, when the inherent SMSR of the SSGS signal was low (15 dB) the output SMSR was maintained at 35 dB by tuning the filter to the central wavelength of the SSGS signal. The lower and the upper SMSR limits were set by the extinction ratio of the filter (20 dB) which meant that the inherent SMSR could be varied between a range of 15 – 30 dB while still maintaining an output SMSR of 35 dB. However, the tuning of the filter towards and away from the central wavelength meant that the output power of the filtered SSGS signal would vary since it would experience various levels of attenuation at the different portions of the filter's transfer characteristic. To overcome this problem and ensure that the power falling on the detector was always kept constant, a Variable Optical Attenuator (VOA) was added after the filter.

The output pulses were then characterized in the temporal domain using a 50 GHz photodiode in conjunction with a 50 GHz sampling oscilloscope. Pulse characterization in the spectral domain was carried out with the aid of an Optical Spectrum Analyzer (OSA). The high-speed detector was alternated between the oscilloscope and an RF Spectrum Analyzer (RFSA) which was used to measure the RF noise spectrum.

3. RESULTS AND DISCUSSION

The resulting output pulses from the self seeding system measured at the lower output arm of the 50:50 coupler, had a deconvolved pulse width of about 26ps while the wavelength of the FP lasing mode selected via the FBG was 1546.76 nm. Variation of the SMSR of these generated pulses was achieved by simply altering the PC thereby reducing the amount of feedback into the laser. We adjusted the PC to give inherent SMSRs of 15, 20, 25, and 30 dB. As the inherent SMSR was increased, tuning the OFPTF away from the seeded mode allowed the output SMSR to be maintained at ~35 dB ensuring the only variable was the inherent SMSR.

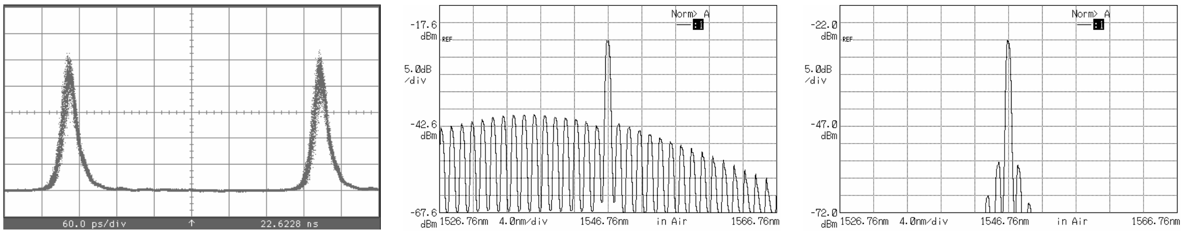

Fig. 2. Inherent SMSR set to 20 dB (a) Pulses (b) Spectrum (c) Filtered spectrum with output SMSR of 35 dB.

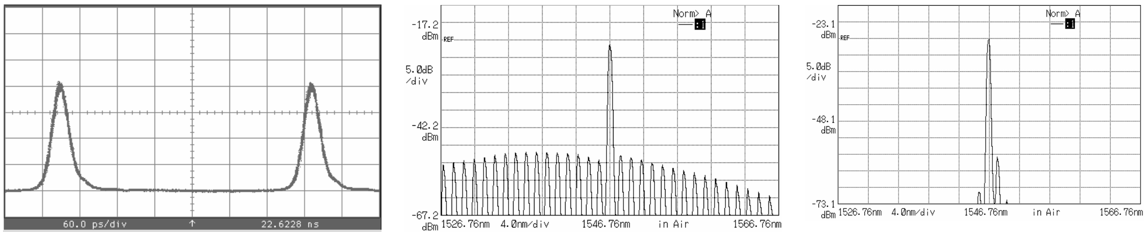

Fig. 3. Inherent SMSR set to 30 dB (a) Pulses (b) Spectrum (c) Filtered spectrum with output SMSR of 35 dB.

However, as already mentioned, this decreased the total power of the signal due to a small portion of the lasing mode been cut off by the filter. In order to maintain a constant output SMSR therefore the optical attenuator was adjusted for each inherent SMSR to keep the optical power at -7dBm.

Figures 2a and 3a show the SSGS pulses at the output of the filter when the input SMSR was set at 20 and 30 dB respectively and the output SMSR maintained at a constant value of 35 dB. It can be seen clearly that the noise level on the output pulse that corresponds to an input SMSR of 20 dB (Fig. 2a) is higher than that of the output pulse corresponding to an input SMSR of 30 dB (Fig. 3a). These observations maybe explained when we consider the fact that for a single-mode source with a large SMSR, the power in the side modes is negligible and therefore the power fluctuations in the lasing mode is also negligible, but when the inherent SMSR decreases, intensity fluctuations in both the main mode and side modes become important. When the optical filter is tuned to select the main lasing mode, there by increasing the SMSR, noise on the transmitted pulse will only be negligible if the inherent SMSR is high. A weak inherent SMSR of the filtered signal would result in an increase in the noise level of the pulse as it passes through the filter due to the mode partition effect. The corresponding inherent SMSRs (20 and 30 dB) spectra are shown in Fig. 2b and 3b while the output spectra are shown in Fig. 2c and 3c, respectively.

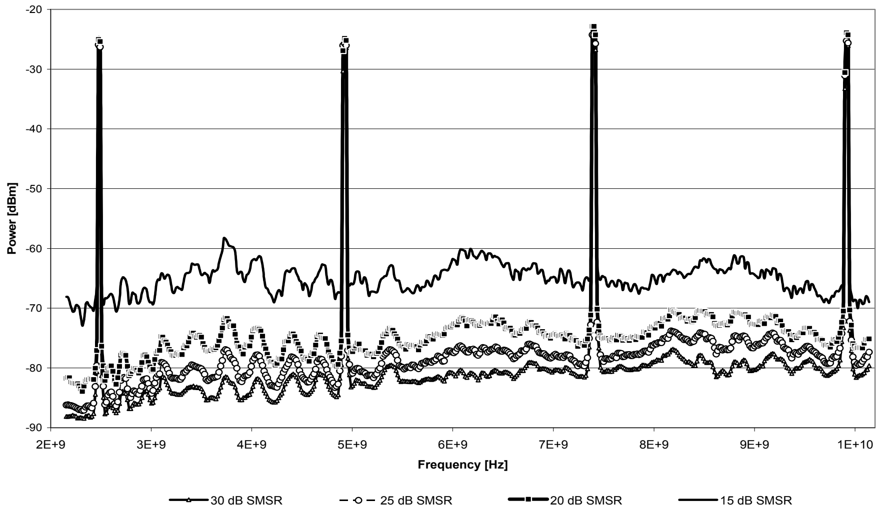

Fig. 4. RF spectrum up to 4th harmonic, RBW = 1MHz.

Table 1. Increase in noise with decreasing inherent SMSR.

Weak to Strong inherent SMSR	**Difference in Noise Floor**
30 → 25dB	4.52dB
25 → 20dB	5.33dB
20 → 15dB	13.16dB

Further characterisation into the noise introduced on the SSGS pulses as the SMSR is degraded was carried out by performing RF spectral measurements on the detected pulses. The latter was carried out, with the aid of an RFSA, in the range of 2 – 10 GHz at a Resolution Band-Width (RBW) of 1 MHz. Figure 4 shows the RF spectrum of the first four harmonics of the pulse train ranging from 2.4 – 10 GHz at a resolution bandwidth of 1 MHz. From the graph we can see an increase in the noise floor for decreasing values of the inherent SMSR while Table 1 clearly shows that the rate of the increase in the noise is higher for weaker inherent SMSR's which is again due to the fact that for large inherent SMSR's the power in the side modes is insignificant so power fluctuation in the lasing mode are also negligible. However for weaker inherent SMSR's intensity fluctuations in the lasing mode and side modes become more noticeable.

4. CONCLUSION

This paper has examined the effect of output filtration on SSGS pulses that exhibit varying levels of inherent SMSR. The results obtained categorically show that a 30 – 15 dB drop in the inherent SMSR of an SSGS pulse train would result in an increase in the noise floor of the detected pulse. Hence, we could conclude that regardless of a high output SMSR, if the inherent SMSR of SSGS pulses are weak then the interaction of MPN with spectral filtering would result in a large amount of amplitude noise on the output pulses. This noise or degradation of the SNR will render such pulses totally unsuitable for data transmission in optical communication systems.

REFERENCES

[1] T. Morioka *et al*.,: 1Tbit/s (100Gbit/s times 10 channel) OTDM/WDM transmission using a single super continuum WDM source," *Electron. Lett., vol. 32, pp. 906–907, 1996.*

[2] S. Kawanishi.: Ultrahigh-speed optical time division multiplexing for very high bit transmission. *IEEE Journal of Lightwave Technology, vol. 6, pp. 1737-1749, 1998.*

[3] P. Anandarajah *et al*.,: self-seeeding of a gain-switched integrated dual-laser source for the generation of highly wavelength- tunable picosecond optical pulses. *IEEE Photonics Technology Letters, vol. 16, 2004.*

[4] M. Schell *et al*.: Low jitter single mode pulse generation by a self-seeded, gain-switched Fabry-Perot semiconductor laser. *Appl. Phys. Lett., Vol. 65, pp. 3045-3047, 1994.*

[5] L.P Barry *et al*: Effects of side mode suppression ratio on the performance of self-seeded gain-switched optical pulses in lightwave communication systems. *IEEE Photonics Technology Letters, vol. 11, pp 1360-1362, 1999.*

[6] K.L. Lee, *et al*.: Subharmonic pulse gating in self-seeded laser diodes for time- and wavelength-interleaved picosecond pulse generation. *IEEE Journal of Quantum Electronics, vol. 40, pp 205-213, 2004.*

[7] N. H. Jensen, *et al*.:Partition Noise in Semiconductor Lasers under CW and Pulsed Operation. *IEEE Journal of Quantum Electronics, vol. QE-23, pp. 71-79, 1987.*