Signal Degradation due to Output Filtering of Self-Seeded Gain-Switched Pulses Exhibiting Weak Inherent SMSR

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Abstract: The authors show the importance of achieving an acceptable level of output side mode suppression ratio, when generating pulses using the self seeded gain switched technique. Experiments carried out on such pulses exhibiting poor side-mode-suppression-ratios that are subsequently filtered to improve the latter, demonstrate that they possess an associated level of noise. This buildup of noise with decreasing inherent side-mode-suppression-ratio is noticed regardless of the improved output filtered side-mode-suppression-ratio of 35 dB that is maintained. The degradation of the signal is due to the mode partition effect and may render these pulses unsuitable for use in high-speed optical communications systems.

Introduction

The development of a source of short optical pulses is extremely important for use in future Optical Time Division Multiplexed (OTDM), and hybrid WDM/OTDM optical communications systems[1]. Picosecond pulse generation can be accomplished by using many different techniques such as gating Continuous Wave (CW) light with an external modulator, mode-locking and gain switching lasers or by using fibre lasers[2]. Mode-locking is one of the commonest techniques that is used to generate short optical pulses at fixed repetition rates. However, it requires specially designed laser structures (thereby introducing cavity complexity) and also requires antireflection coating on the internal laser facet to maintain cavity stability. On the other hand the technique of gain switching, when compared with the above-mentioned alternatives, offers smaller footprint, efficient wavelength stable performance and the ability to produce high repetition rate pulses[3].

One of the simplest, reliable and most attractive options to generate wavelength tunable picosecond optical pulses involves the self seeding of a gain switched Fabry-Perot (FP) laser. Essentially this method involves gain-switching an FP laser, and then feeding back one of the laser modes into the FP diode using a wavelength selective external cavity. Provided that the optical signal re-injected into the laser arrives during the build-up of an optical pulse in the FP laser, then a single-moded, low jitter output pulse can be obtained[4]. Recent experiments using the Self Seeded Gain Switched (SSGS) technique have also demonstrated the generation of multi-wavelength pulses suitable for use in WDM networks[5].

One difficulty associated with the use of SSGS pulses in high-speed optical communication systems maybe Mode Partition Noise (MPN). MPN in digital transmission systems has been known for long time and can severely affect the performance of an optical communication system, even when using DFB lasers with non-ideal Side Mode Suppression

Ratio (SMSR). It is mainly caused by the total optical power, in a multi-longitudinal mode laser diode, remaining relatively constant but the distribution of this power being a stochastic process[6]. The spectral fluctuation in the laser modes may thus manifest itself as an intensity fluctuation (noise) on the transmitted optical signal and this manifestation of noise in optical communication systems due to MPN can occur in two ways. Firstly, the effects of fibre dispersion in long haul links result in temporal fluctuations of received power because the fluctuating modes get separated in time due to the fibre dispersion. Secondly, output optical filtering of the SSGS signal may result in fluctuations in the output power of the signal after the filter, which results in a degradation of the signal quality. An important magnitude to characterize the level of MPN is the SMSR.

In this work, a detailed experimental investigation on the increase in the noise of filtered SSGS pulses[7] with degrading inherent SMSR is presented. Generally, filtering of SSGS pulses is used to either select out a particular wavelength in multi-wavelength SSGS pulses, to improve the inherent SMSR of the SSGS pulses, or to remove Amplified Spontaneous Emission (ASE) power from an EDFA placed after the SSGS setup. Our results show that, although many of the previously reported wavelength tunable SSGS pulse sources use output filtering on pulses that exhibit low inherent SMSRs of about 15 – 20 dB, to achieve final SMSR > 30 dB[8-10], in practice, such pulses may be unsuitable for use in either WDM or OTDM systems. The reason for this lies in the buildup of noise on the filtered optical pulses due to the mode partition effect. Hence, it is vital that any pulse source based on the SSGS technique possesses a large enough inherent SMSR, especially before filtering to prevent the degradation of SNR due to MPN. It is thus important when characterizing such pulses for use in optical systems, that both the SMSR and

the amplitude noise of these pulses should be accurately described, as there maybe a direct relationship between them.

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 25 mA and longitudinal mode spacing 1.1 nm. Gain switching of the laser was carried out by applying a dc bias current of about 17 mA and a sinusoidal modulation signal amplified to a power of about 29 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 0.4 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 was then varied to ensure that the signal re-injected into the laser from the external cavity, arrives as an optical pulse is building up in the laser. An operating frequency of 2.488 GHz was found to be suitable.
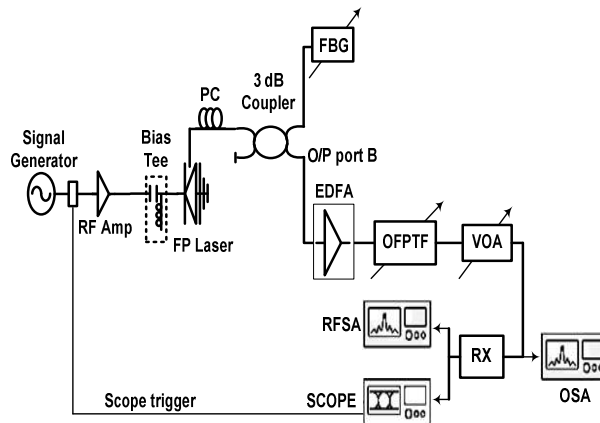
**Figure 1: Experimental set-up for the SSGS pulse degradation characterization**

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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 output port B (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 0.7 nm (84 GHz) and an extinction ratio of about 20 dB. Hence the inherent SMSR of the pulses could be improved by about 20 dB by passing the signal through the centre of filter passband. In order to characterize the noise on the filtered SSGS pulses as a function of the input SMSR, the output SMSR had to be kept 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, 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) with an incorporated inline power meter 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.

Results and Discussion

With the PC adjusted to maximize the feedback into the FP device, the resulting pulses from the SSGS set-up, without output filtration, are shown in Figure 2 (a). Assuming a total response time of about 9 ps for the combination of the photodiode and the oscilloscope, we can deconvolve the output pulse duration to be around 26 ps. Figure 2 (b) shows the spectral output from which we can determine that the FP mode selected using the FBG was at a wavelength of 1547.08 nm. In addition, the SMSR of the signal was 37 dB, and the 3 dB spectral width was about 0.3 nm.
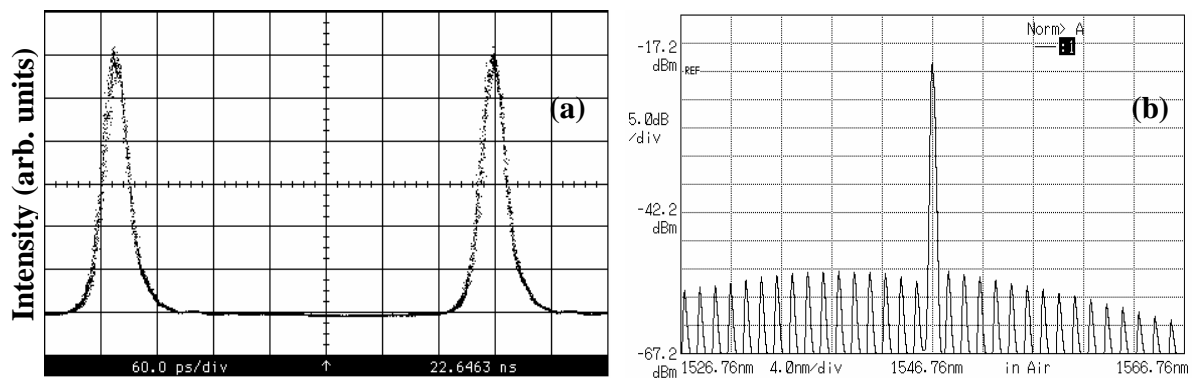
Figure 2: (a) Optical pulse with inherent SMSR of 37 dB (b) Optical spectrum with inherent SMSR of 37 dB

To vary the SMSR of the generated optical pulses from 30 dB down to 15 dB, we simply had to adjust the PC in order to reduce the amount of light fed back into the laser diode. The reduction in feedback and SMSR also resulted in a slight decrease in the pulse duration, and a slight increase in the spectral width, as expected from previous work[11]. Figure 3 (a) and (b) show the SSGS pulses at the output of the filter when the inherent SMSR was set at 30 and 15 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 inherent SMSR of 30 dB {Figure 3

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(a)} is lower than that of the output pulse corresponding to an inherent SMSR of 15 dB {Figure 3 (b)}.
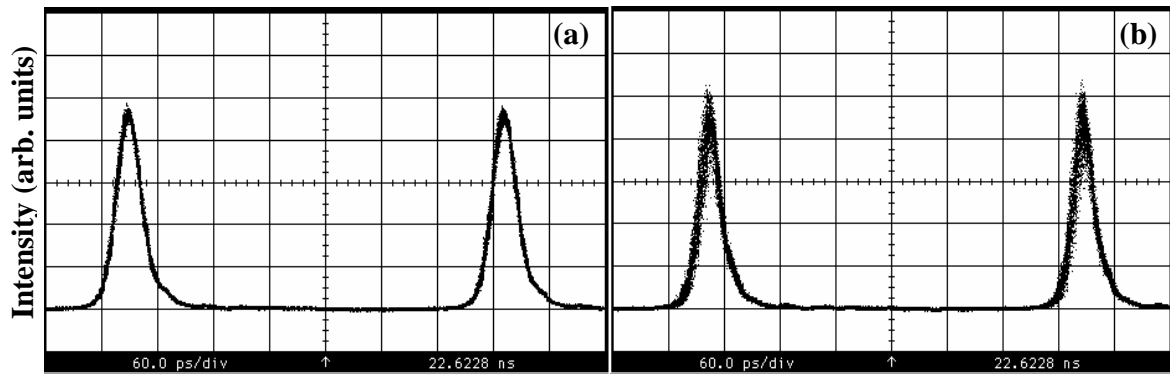

Figure 3: (a) Optical pulse with inherent SMSR of 30 dB (b) Optical pulse with inherent SMSR of 15 dB

The corresponding inherent SMSRs (high and low) are shown in Figure 4 (a) and (b) while the output spectra are shown in Figure 5 (a) and (b) respectively. The output spectra show that even though the inherent SMSR is varied (15-30 dB), by tuning the filter, the output SMSR could still be maintained at a constant 35 dB.
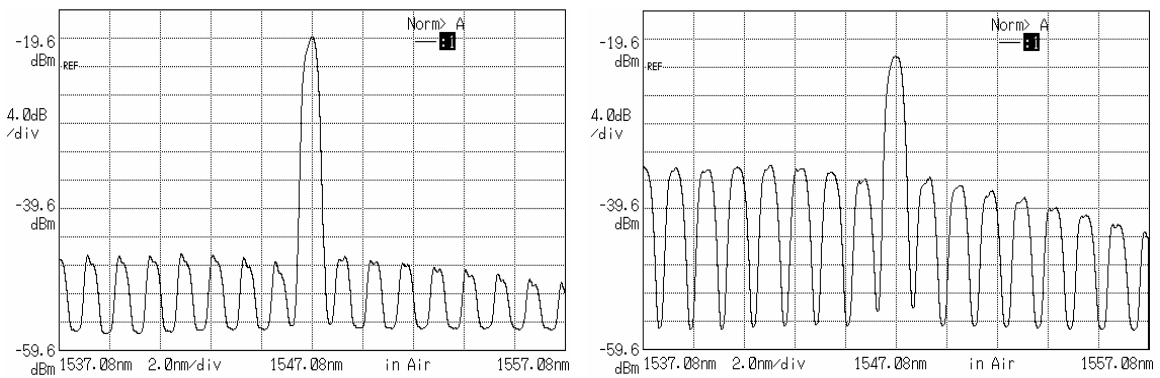
Figure 4(a) and (b): Optical spectra with inherent SMSR of 30 dB and 15 dB respectively
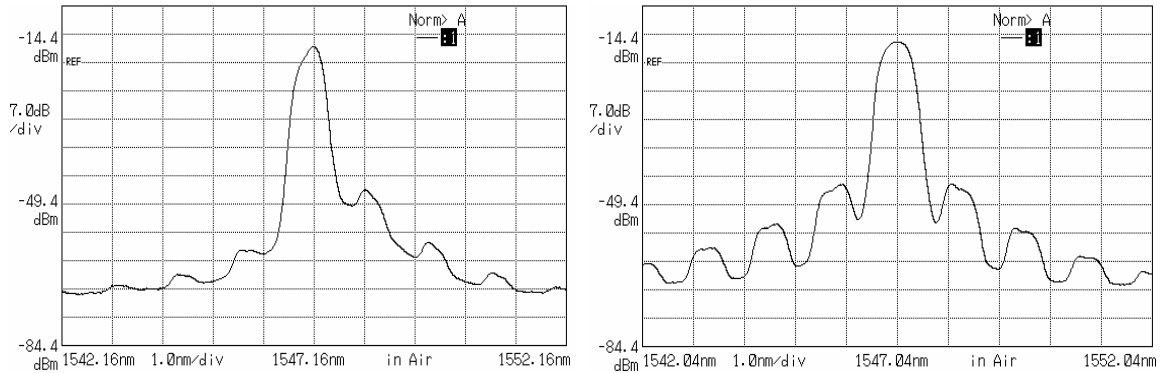
Figure 5: Optical spectra with output SMSR of 30 dB (a) & (b) inherent SMSR of 30 dB & 15 dB respectively

The increase in noise as the inherent SMSR is reduced is associated with the mode partition effect of the FP laser which, as mentioned earlier, essentially involves the energy of each laser mode fluctuating with time, due to a constant transfer of energy between the laser modes[6]. Since only the main mode is transmitted through the optical filter, any temporal fluctuations in the energy level of this mode will result in amplitude noise on the transmitted pulse. Clearly as the SMSR is reduced, the energy in the side mode increases and the fluctuation of the energy in the main mode increases, resulting in additional amplitude noise on the transmitted pulse. To eliminate this noise it is necessary to ensure that the inherent SMSR of SSGS pulses that undergo output filtration must exhibit a high SMSR (total power in the side-modes should be negligible).

A more detailed investigation into the noise introduced on the filtered 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, within a span of 8 GHz over a range of 2 – 10 GHz at a Resolution Band-Width (RBW) of 1 MHz. The measurement carried out over this range includes the fundamental and the first three harmonics of the pulse train and is shown in Figure 6. It can be seen that the power levels of each of the plots, corresponding to the various

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inherent SMSRs (30, 25, 20 and 15 dB) and a constant output SMSR of 35 dB, have been equalized with the aid of the VOA. Also from the graph, we can see an increase in the noise floor for decreasing values of the inherent SMSR. A degrading sweep (30 to 15 dB) of the inherent SMSR with a step width of 5 dB and the corresponding changes in the noise floor are outlined in Table 1 (measured at an offset of about 1 GHz). The table clearly shows that, for a 5 dB change in the inherent SMSR, the increase in the noise level is more at lower inherent SMSRs. This is due to the fact that there is a bigger increase in the percentages of power in the side modes which in turn lead to larger fluctuations in the main lasing mode. The larger fluctuations result in additional amplitude noise on the detected pulse.
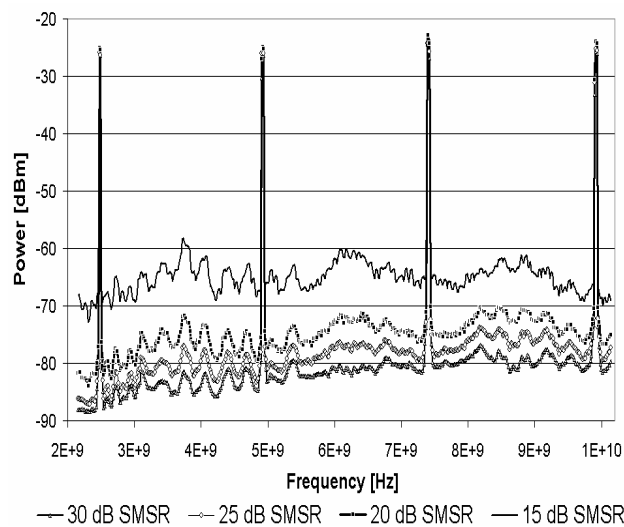
Figure 6: RF spectrum of SSGS pulses exhibiting various inherent SMSRs

On the whole, going from an input SMSR of 30 dB to 15 dB results in the level of the noise floor increasing by about 23 dB even though the output SMSR is maintained at an impressive 35 dB. This result clearly quantifies the difference in the noise floor of an output filtered SSGS pulse that exhibits a weak inherent SMSR (15 dB) and a strong inherent SMSR (30 dB).

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 reduction in the inherent SMSR of an SSGS pulse train would result in an increase in the level of 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. It is thus imperative when characterizing optical pulses generated by the SSGS technique to simultaneously describe the SMSR and amplitude noise of the generated optical pulse train.

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List of Figures

Tables

Table 1: Change in noise floor with decreasing inherent SMSR (offset from carrier = 1 GHz)

Change in Input SMSR	Change in Noise Floor
30 – 25 dB	4.52 dB
25 – 20 dB	5.33 dB
20 – 15 dB	13.16 dB
30 – 15 dB	**23.02** dB