Effect of Side-Mode Suppression Ratio on the Performance of Self-Seeded Gain-Switched Optical Pulses in Lightwave Communications Systems

L. P. Barry and P. Anandarajah

***Abstract*— The side-mode suppression ratio (SMSR) of self-seeded gain-switched optical pulses is shown to be an extremely important factor for the use of these pulses in optical communications systems. Experiments carried out involving pulse propagation through dispersion-shifted fiber and a bandpass optical filter demonstrate that, for SMSR values of less than 25 dB, the buildup of noise due to the mode partition effect may render these pulses unsuitable for use in optical communications systems.**

***Index Terms*— Optical fiber communication, optical fiber dispersion, optical pulse generation, self-seeding, semiconductor laser.**

I. Introduction

THE DEVELOPMENT of a wavelength-tunable source of short optical pulses is extremely important for use in future wavelength division multiplexed (WDM), optical time division multiplexed (OTDM), and hybrid WDM/OTDM optical communications systems [1]. One of the simplest and most reliable techniques available to generate wavelength-tunable picosecond optical pulses involves the self-seeding of a gain-switched Fabry–Perot (FP) laser [2]–[7]. The technique basically 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 reinjected into the laser arrives during the build-up of an optical pulse in the FP laser, then a single-moded output pulse is obtained. This technique has been shown to be capable of producing very low jitter optical pulses [4] with durations around 2 ps, and recent experiments have also demonstrated the generation of multiwavelength pulses suitable for use in WDM networks [7].

Although the generation of optical pulses using the self-seeding gain-switching (SSGS) technique has been widely investigated, the use of such pulses in optical communications systems has not yet been examined. In this letter, we experimentally investigate the effect of the pulse side-mode suppression ratio (SMSR) on the performance of SSGS pulses in optical communications systems. This is achieved by simply examining the propagation of these pulses through two key components of any optical network (i.e., optical fiber and an optical filter), as a function of the SMSR. Our results show that, although many of the previous reported wavelength-tunable pulse sources using the SSGS technique had SMSR's which varied between 10–25 dB as the output pulse wavelength was tuned [6], [7], 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 optical pulses due to the mode partition effect [8], [9]. It is thus vital that any wavelength-tunable pulse source based on the SSGS technique retains a large enough SMSR, at all operating wavelengths, to prevent the accumulation of mode partition noise.

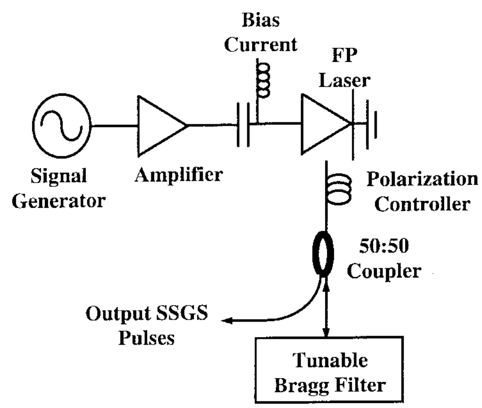

Fig. 1. Experimental setup for SSGS pulse generation.

II. Experimental Setup

Fig. 1 shows our experimental setup. The FP laser used was a commercial 1.5-μm InGaAsP device, with a threshold current of 26 mA and a longitudinal mode spacing of 1.12 nm. Gain switching of the laser was carried out by applying a dc bias current of 17 mA, and a sinusoidal modulation signal with a power of 29 dBm, to the laser diode. The sinusoidal modulation signal had a frequency around 2.6 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 fiber Bragg grating with a bandwidth of 0.4 nm.

To achieve optimum SSGS pulse generation, the central wavelength of the fiber grating was initially tuned to one of the longitudinal modes of the gain-switched laser. The frequency of the sinusoidal modulation was then varied to

Manuscript received May 21, 1999; revised July 28, 1999.

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Publisher Item Identifier S 1041-1135(99)08661-9.

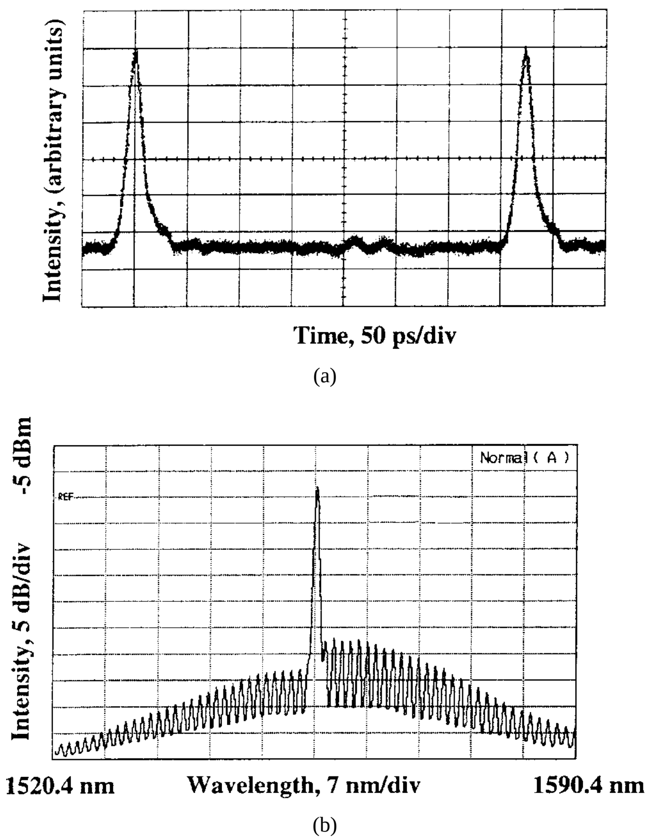

Fig. 2. (a) Optical pulses generated from the SSGS setup. (b) Optical spectrum of SSGS pulses.

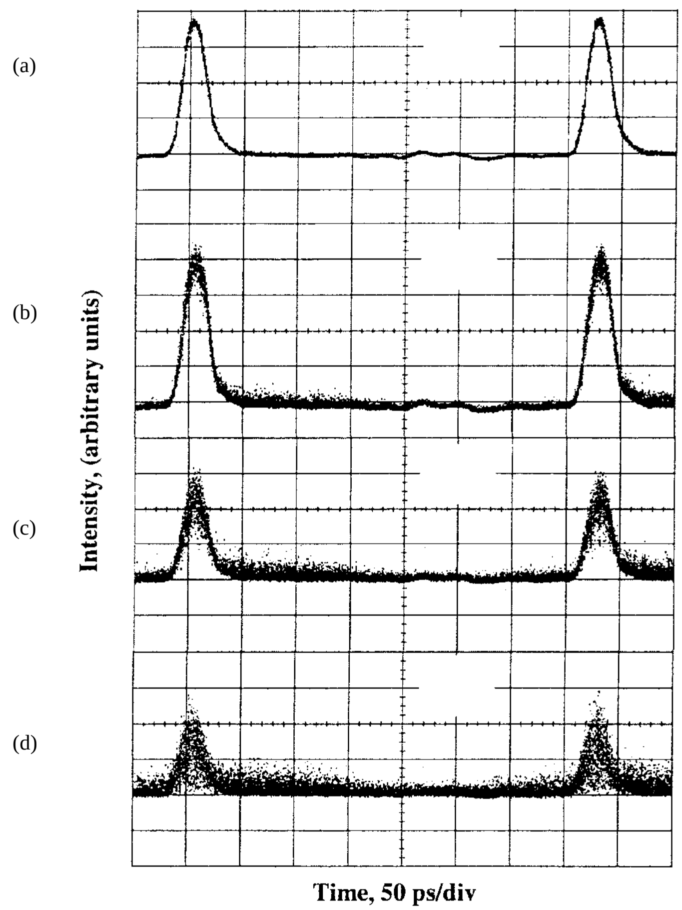

Fig. 3. Output optical pulses after propagation through 10 km of DSF with the input SMSR of the pulses set to: (a) 25 dB, (b) 20 dB, (c) 15 dB, and (d) 10 dB. Persistence of the digitizing oscilloscope display was set to 3 s.

ensure that the signal, reinjected into the laser from the external cavity, arrives as an optical pulse is building up in the laser. An operating frequency of 2.654 GHz was found to be suitable. In addition to tuning the fiber grating and the modulation frequency, we could also vary the amount of light reinjected, and, hence, the SMSR of the output optical pulses, by adjusting the PC. The output pulses after the 50 : 50 fiber coupler were characterized in the temporal domain using a 50-GHz photodiode in conjunction with a 50-GHz HP digitizing oscilloscope. Pulse characterization in the spectral domain was carried out using an optical spectrum analyzer.

III. Results and Discussion

With the PC adjusted to maximize the feedback into the FP device, the resulting output pulses from the SSGS set-upwere as shown in Fig. 2. 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 15 ps. From the spectral output, we can determine that the FP mode selected using the Bragg grating was at a wavelength of 1555.4 nm. In addition, the SMSR of the signal was 30 dB, and the 3-dB spectral width was about 0.6 nm. To vary the SMSR of the generated optical pulses from 30 dB down to 10 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 [10], [11].

The optical pulses from the SSGS were initially propagated through 10 km of dispersion-shifted fiber (DSF), and the effect of a varying SMSR on the pulse propagation was investigated. With the SMSR set to 30 dB, the only effect of the fiber transmission was a slight broadening of the pulses due to the fiber dispersion [$D = 1.8$ ps/(km.nm) at 1555 nm]. However, as the SMSR was reduced, the noise level on the transmitted signal began to increase. Fig. 3(a)–(d) shows the output pulses after fiber propagation corresponding to input SMSR's of 25, 20, 15, and 10 dB, respectively. From this figure, we can see the noise level on, and between, the transmitted pulses beginning to appear as the SMSR was reduced from 25 to 20 dB. When the SMSR was set to 15 and 10 dB, the noise on the optical pulses after transmission became even more obvious. This noise would clearly make the use of these pulses unfeasible in optical communication systems.

The increase in noise as the SMSR is reduced is associated with the mode partition effect of the FP laser [8]. The mode partition effect is basically a fluctuation of the energy in each laser mode with time, due to a constant transfer of energy between the laser modes. When an optical pulse with a multimoded spectrum propagates in a dispersive fiber medium, the laser modes travel at different speeds and, hence, spread out in the temporal domain. The spectral fluctuation in the laser modes will thus manifest itself as an intensity fluctuation

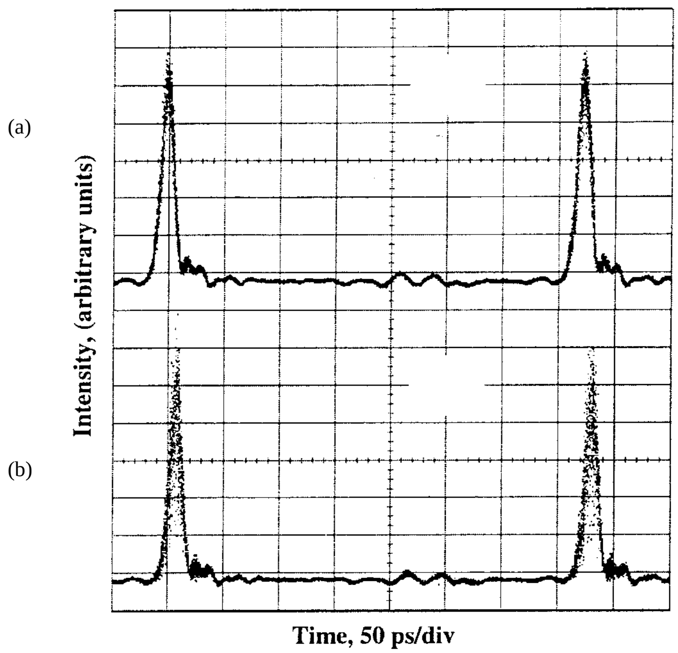

Fig. 4. Optical pulses at output of an FP filter with the SMSR of the input signal set to: (a) 20 dB and (b) 15 dB. Persistence of the digitizing oscilloscope display was set to 3 s.

(noise) on the transmitted optical signal after fiber propagation. To eliminate this noise, it is necessary to use a single-moded laser pulse in which the total power in the side modes is negligible. From our experiment, we have seen that, with a SMSR of 25 dB or greater, the noise on the optical pulse after propagation is essentially negligible, because the total pulse power in the side modes is negligible. However, as the SMSR is reduced and the power in the side modes becomes nonnegligible, the energy fluctuation of the modes results in an increasing noise level on the transmitted pulses.

We then investigated the effect of a varying SMSR on the propagation of the optical pulses through a tunable FP filter with a 3-dB bandwidth of 0.8 nm. The filter was tuned to select out the main operating mode from the SSGS pulse spectrum. With the input pulse SMSR at 30 dB, the only effect on the optical pulse was a slight reduction in its duration. However, as the SMSR was reduced, the pulse after the optical filter developed a large amount of amplitude noise. Fig. 4 displays the output pulses when the SMSR of the input signal was 20 and 15 dB, respectively. The amplitude noise on the pulses is once again due to the mode partition effect [9]. 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.

IV. Conclusion

We have examined the effect of SMSR on the propagation of SSGS optical pulses through optical fiber and an optical filter. Our results show that the performance of SSGS pulses in WDM and OTDM communications systems is highly dependent on the SMSR of the generated pulses. If the SMSR is not large enough, then the interaction of the mode partition effect with either fiber dispersion, or spectral filtering, results in a large amount of amplitude noise on the transmitted optical pulses. This noise will render such pulses totally unsuitable for data transmission in optical communications.

References

[1] T. Morioka, H. Takara, S. Kawanishi, O. Kamatani, K. Takiguchi, K. Uchiyama, M. Saruwatari, H. Takahashi, M. Yamada, T. Kanamori, and H. Ono, "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] M. Cavelier, N. Stelmakh, J. M. Xie, L. Chusseau, J. M. Lourtioz, C. Kasmierski, and N. Bouadama, "Picosecond ($<$2.5 ps) wavelength tunable ($\sim$20 nm) semiconductor laser pulses with repetition rates up to 12 GHz," *Electron. Lett.*, vol. 28, pp. 224–226, 1992.

[3] L. P. Barry, R. F. O'Dowd, J. Debeau, and R. Boittin, "Tunable transform limited pulse generation using self-injection locking of a FP laser," *IEEE Photon. Technol. Lett.*, vol. 5, pp. 1132–1134, 1993.

[4] M. Schell, W. Utz, D. Huhse, J. Kassner, and D. Bimberg, "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] Y. C. Lee and C. Shu, "Optimized operation of self-seeded gain-switched laser diode for electrically wavelength-tunable singlemode pulses," *IEEE Photon. Technol. Lett.*, vol. 7, pp. 275–277, 1995.

[6] D. Huhse, M. Schell, W. Utz, J. Kassner, and D. Bimberg, "Dynamics of single-mode formation in self-seeded Fabry–Perot laser diodes," *IEEE Photon Technol. Lett.*, vol. 7, pp. 351–353, 1995.

[7] C. Shu and S. P. Yam, "Effective generation of tunable single- and multiwavelength optical pulses from a Fabry–Perot laser diode," *IEEE Photon Technol. Lett.*, vol. 9, pp. 1214–1216, 1997.

[8] N. H. Jensen, H. Olesen, and K. E. Stubkjaer, "Partition noise in semiconductor lasers under CW and pulsed operation," *IEEE J. Quantum Electron.*, vol. QE-23, pp. 71–79, 1987.

[9] D. Curter, P. Pepeljugoski, and K. Y. Lau, "Noise properties of electrically gain-switched 1.5 μm DFB lasers after spectral filtering," *Electron. Lett.*, vol. 30, pp. 1418–1419, 1994.

[10] L. P. Barry, B. C. Thomsen, J. M. Dudley, and J. D. Harvey, "Characterization of 1.55 μm pulses from a self-seeded gain-switched Fabry–Perot laser diode using frequency-resolved optical gating," *IEEE Photon. Technol. Lett.*, vol. 10, pp. 935–937, 1998.

[11] S. Bouchoule, N. Stelmakh, M. Cavelier, and J.-M. Lourtioz, "Highly attenuating external cavity for picosecond-tunable pulse generation from gain/Q-switched laser diodes," *IEEE J. Quantum Electron.*, vol. 29, pp. 1693–1700, 1993.