

Control Signal Generation From Flag Pulses to Drive All-Optical Gates

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Abstract—All-optical gate control signal generation is demonstrated from flag pulses, using a Fabry–Pérot filter followed by a semiconductor optical amplifier. Ten control pulses are generated from a single flag pulse having less than 0.45-dB amplitude modulation. By doubling or tripling the number of flag pulses, the number of control pulses increases approximately by a factor of two or three. The circuit can control the switching state of all-optical switches, on a packet-by-packet basis, and can be used for nontrivial network functionalities such as self-routing.

Index Terms—All-optical gate, all-optical signal processing, Fabry–Pérot (FP) filter, semiconductor optical amplifier (SOA).

I. INTRODUCTION AND CONCEPT

THE OUTSTANDING performance improvement and cost reduction of passive optical components and optical semiconductor-based devices has helped to spur intense research interest and development in all-optical signal processing concepts for application in optical fiber network systems [1], [2]. Besides the potential speed advantage that all-optical techniques may afford [3], they also promise to reduce the number of optical–electrical–optical conversions and, thus, the complexity of network systems. Optical packet switching is one such key application area that may benefit from all-optical techniques and which is expected to significantly improve network resource utilization by providing bandwidth on demand, flexibility, and granularity [4], [5]. The core switching elements in an all-optical packet switch will be all-optical gates and so far a large number of all-optical switching experiments have been performed to prove feasibility [6]. In these experiments, even though optical data switch optical data, the initial signals driving the laser sources are electrically generated. On the other hand, for an all-optical switching node to operate, it is crucial to be able to generate, without the intervention of electronics, the optical signals controlling the node gates from bits embedded in the packet headers. The switching state of an all-optical gate is determined for each incoming data pulse by a single bit “1” or “0,” in order to switch it or not. This single flag bit may be considered as decision or routing bit. Given that the state of an all-optical switch must remain the same for the duration of a data packet, this flag bit must be replicated as many times as the bits in the packet. The generated sequence of replicas of the flag bit is the all-optical gate control signal. This is the signal that determines whether the gate will switch or not the

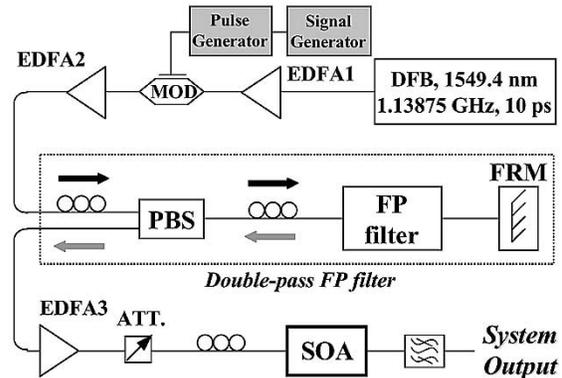


Fig. 1. Experimental setup.

incoming data packets. For example, for an all-optical 2×2 switching element [7] that may be used to self-route a packet, the routing information consists of only one flag bit and the gate controlling signal must consist of a continuous sequence of “1s” of length equal to the packet length. The flag bit would be contained in the packet header and a recently demonstrated method for separating all-optically the header from the packet payload may be applied to extract it [8]. In the present work, we show, for the first time to our knowledge, the generation from a single flag bit of the control signal for an all-optical 2×2 switch, consisting of a sequence of continuous “1s.” We also show that the control sequence may be extended with the use of repetitive flag bits.

The circuit proposed here comprises of a Fabry–Pérot (FP) filter arranged in a double-pass configuration, followed by a semiconductor optical amplifier (SOA). The circuit operation relies on the memory properties of the FP filter to generate a sequence of amplitude-modulated pulses at a repetition rate equal to its free spectral range (FSR), which is chosen to be equal to the line rate [9]. The SOA is operated under heavy saturation and is used as a hard limiter to suppress the resulting amplitude modulation in this signal. The double-pass configuration for the filter is chosen because it assists to increase significantly its lifetime [10]. The number of control pulses required must be equal to the packet length and depending on the packet format this can be large. For this circuit to generate hundreds of control bits from a single flag bit, the FP filter must be chosen to have an appropriately high finesse. This is, however, undesirable because it results in a controlling signal with a significant tail/decay time, which in turn requires the use of significant guard-bands between packets. We show that if a repetitive stream of flag bits is used, the duration of the controlling signal may be increased to any length. The repetitive stream of flag bits could be generated

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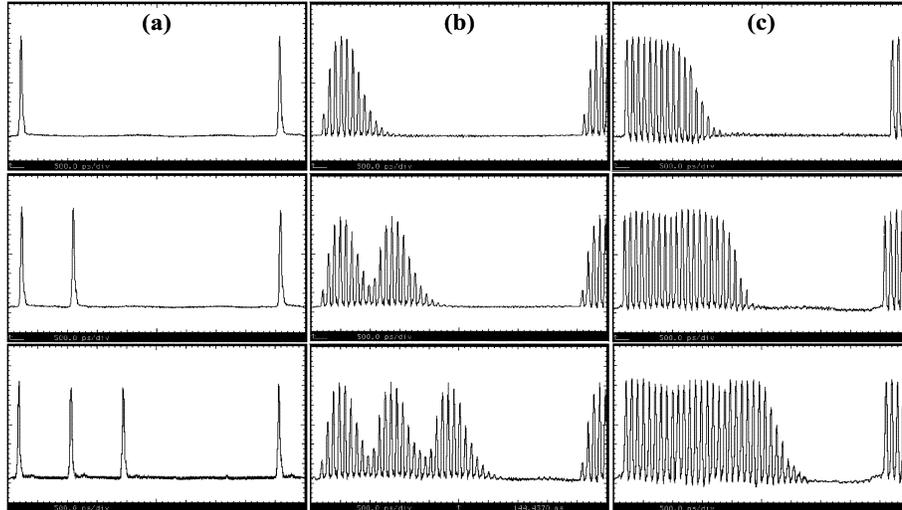


Fig. 2. Oscilloscope traces of (a) decision/flag pulses, (b) output after double-pass in FP filter, and (c) control pulse sequence after SOA. The rows correspond to one, two, and three flag bits at the circuit input. Time base is 500 ps/div.

from a repetitive flag signal embedded in the packet [6] or else it could be overlaid in the packet in form of a subcarrier multiplexed signal [11]. Either of these will result in receiver complication so as to separate the flag signal. Otherwise, the flag signal could be generated all-optically from the flag bit with the use of a second FP filter with FSR chosen so as to provide the required flag rate. This method is, in principle, preferable since the transmitter node remains simple and no synchronization is needed at the receiver node.

II. EXPERIMENT

The experimental setup is shown in Fig. 1. The initial pulse train was produced by a gain-switched distributed feedback laser at 1549.4 nm and was operated at 1.138 75 GHz to produce 10-ps pulses after linear compression in dispersion compensating fiber. The pulse train was amplified in erbium-doped fiber amplifier (EDFA 1) and modulated at 227.75 MHz with a Li:NbO₃ amplitude modulator to generate the flag pulses. The resulting low rate pulse train was further amplified in EDFA 2 and fed into the FP filter through the ordinary axis of a fiber polarization beam splitter (PBS), so that a single polarization state entered the double pass arm (black arrow in Fig. 1). The FP filter was an antireflection-coated fused quartz substrate with an FSR of 10.326 GHz and finesse equal to 20.7. For optimum performance, the polarization state of the incident beam was adjusted with a polarization controller before the FP filter. At its output, a Faraday rotator mirror (FRM) was used to reflect the pulse train back into the FP filter. The output pulses were obtained at the extraordinary axis of the PBS taking advantage of the 90° polarization rotation at the FRM (gray arrow in Fig. 1). Following this, the pulses were amplified in EDFA 3 and launched into a commercially available 1.5-mm-long SOA, with a small signal gain of 24 dB at 1549.4 nm, 3-dB polarization gain dependence, and 65-ps gain recovery time, when driven at 700 mA. The SOA output was monitored after filtering with a 1-nm filter.

III. RESULTS AND DISCUSSION

Fig. 2 shows the experimental results recorded on a 30-GHz sampling oscilloscope. Fig. 2(a) is the flag signal at the input of the FP filter, Fig. 2(b) is the signal after double passing through the FP filter, and Fig. 2(c) is the signal at the output of the SOA. The upper, middle, and bottom rows record results when the circuit is triggered from one, two, or three flag pulses, respectively, with the multiple flag pulses separated by 4.39 ns. When the controlling generator of the control signals was triggered with a single flag pulse, it generated a sequence of ten pulses with amplitude modulation by less than 0.45 dB. With two and three decision/flag pulses, the circuit generated sequences of 18 and 25 pulses, respectively, with amplitude modulation of less than 0.45 dB. Consequently, by doubling or tripling the number of decision pulses, the length of the generated sequence of control pulses increases approximately by a factor of two or three. In all cases, the generated signal rose from the first bit and had a 1/e decay tail of about six pulses. The sharp rise time is a result of gain saturation in the SOA, while the decay time is controlled by the effective FP lifetime. The average required energy per pulse at the input of the SOA was calculated to be about 200 fJ and microwave spectral analysis revealed that the timing jitter of the generated control pulses was about 760 fs.

The performance of the circuit was further investigated with a simulation tool based on the transfer function of the FP filter, the equations describing the saturation and recovery of the SOA [12] and using the parameters of the experimental setup. The simulation tool can be used to estimate the total number of control bits generated and to optimize the repetition rate of the flag pulses and finesse of the FP filter against the resulting amplitude modulation. Fig. 3(a) and (b) depicts the simulated results for the amplitude modulation of the generated sequences of control pulses versus the repetition rate of the flag signal, for different filter finesesses, for 10- and 40-GHz line rates. Fig. 3(a) also shows the experimental result in the gray circle. All the curves show that the amplitude modulation of the flag signal goes through a range of low values. The rate of the flag signal

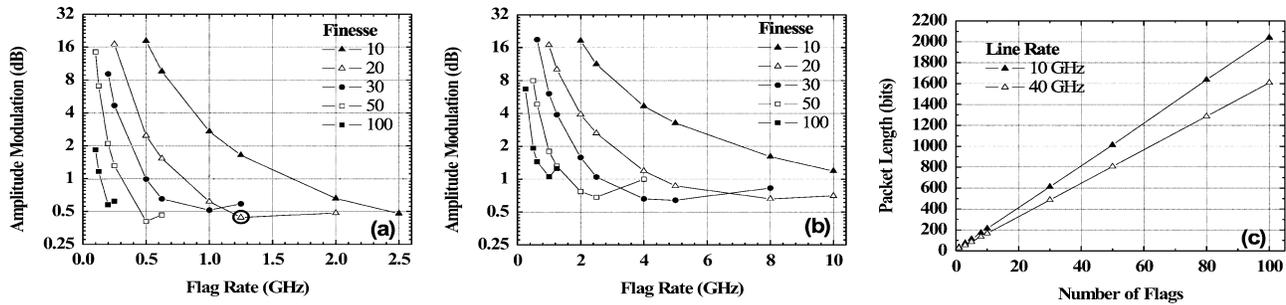


Fig. 3. Calculated amplitude modulation of control pulses for different flag rates and FP finesse for (a) 10- and (b) 40-GHz line rates. The black circle indicates the experimental point. (c) Calculated packet length versus number of flags for control generation at 10 and 40 GHz.

must then be chosen to lie within this range depending on the filter finesse and since the flag signal occupies data timeslots, it is obviously best to be kept to as low a rate as possible. Fig. 3(c) shows the number of control bits that may be obtained from the circuit against the number of inserted flag bits for the case of FP finesse 50 for 10- and 40-GHz line rates and demonstrates that the number of required control bits may be generated for any packet length. For example, the system could sustain asynchronous transfer mode cells that are 53 B (424 b) long at both 10- and 40-GHz line rates. Indeed, Fig. 3(c) shows that for an FP finesse equal to 50, the required number of flags are 22 and 27 at 10- and 40-GHz line rate, respectively. Moreover, Figs. 3(a) and (b) indicate that the corresponding flag rates should be 500 MHz and 2.5 GHz for minimum amplitude modulation.

IV. CONCLUSION

We have demonstrated a technique for the generation of controlling signals to drive all-optical gates. The circuit is capable of producing a sequence of controlling pulses from a single flag pulse embedded in the header of the data packet. The number of the generated control pulses can be adjusted by using multiple flag pulses. The amplitude modulation of the generated controlling signal may be designed to be low and in the present demonstration at 10 GHz was less than 0.5 dB. The proposed circuit can be used after an address separation circuit to generate the control signals of 2×2 all-optical switches of a packet switched network node.

REFERENCES

- [1] K. E. Stubkjaer, "Semiconductor optical amplifier-based all-optical gates for high-speed optical processing," *IEEE J. Select. Topics Quantum Electron.*, vol. 6, pp. 1428–1435, Nov./Dec. 2000.
- [2] H. Avramopoulos, "TDM devices and their applications," in *Proc. Optical Fiber Communication Conf. (OFC 2001)*, vol. Tutorial Sessions, WE, Anaheim, CA.
- [3] K. L. Hall and K. A. Rauschenbach, "100-Gbit/s bitwise logic," *Opt. Lett.*, vol. 23, no. 16, pp. 1271–1273, Aug. 1998.
- [4] T. S. El-Bawab and J.-D. Shin, "Optical packet switching in core networks: Between vision and reality," *IEEE Commun. Mag.*, vol. 40, pp. 60–65, Sept. 2002.
- [5] M. J. O'Mahony, D. Simeonidou, D. K. Hunter, and A. Tzanakaki, "The application of optical packet switching in future communication networks," *IEEE Commun. Mag.*, vol. 39, pp. 128–135, Mar. 2001.
- [6] S. A. Hamilton, B. S. Robinson, T. E. Murphy, S. J. Savage, and E. P. Ippen, "100 Gb/s optical time-division multiplexed networks," *J. Lightwave Technol.*, vol. 20, pp. 2086–2100, Dec. 2002.
- [7] G. Theophilopoulos, M. Kalyvas, C. Bintjas, N. Pleros, K. Yiannopoulos, A. Stavdas, H. Avramopoulos, and G. Guekos, "Optically addressable 2×2 exchange bypass packet switch," *IEEE Photon. Technol. Lett.*, vol. 14, pp. 998–1000, July 2002.
- [8] C. Bintjas, N. Pleros, K. Yiannopoulos, G. Theophilopoulos, M. Kalyvas, H. Avramopoulos, and G. Guekos, "All-optical packet address and payload separation," *IEEE Photon. Technol. Lett.*, vol. 14, pp. 1728–1730, Dec. 2002.
- [9] M. Jinno and T. Matsumoto, "Optical tank circuits used for all-optical timing recovery," *J. Lightwave Technol.*, vol. 28, pp. 895–900, Apr. 1992.
- [10] K. Yiannopoulos, K. Vysokinos, E. Kehayas, N. Pleros, K. Vlachos, H. Avramopoulos, and G. Guekos, "Rate multiplication by double-passing Fabry-Pérot filtering," *IEEE Photon. Technol. Lett.*, vol. 15, pp. 1294–1296, Sept. 2003.
- [11] G. Rossi, T. E. Dimmick, and D. J. Blumenthal, "Optical performance monitoring in reconfigurable WDM optical networks using subcarrier multiplexing," *J. Lightwave Technol.*, vol. 18, pp. 1639–1648, Dec. 2000.
- [12] M. Eiselt, W. Pieper, and H. G. Weber, "SLALOM: Semiconductor laser amplifier in a loop mirror," *J. Lightwave Technol.*, vol. 13, pp. 2099–2112, Oct. 1995.