All-optical three-input logic minterms generation using semiconductor optical amplifier-based Sagnac interferometer

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All-optical three-input logic minterms generation using semiconductor optical amplifier-based Sagnac interferometer

L. Lei, F. Da Ros, J. Xu, C. Peucheret, J. Dong and X. Zhang

All-optical three-input logic minterms are generated at 42 Gb/s with a Sagnac interferometer using cross-phase modulation in a semiconductor optical amplifier. To the best of our knowledge, this is the first time that high-speed logic operations with more than two inputs have been experimentally demonstrated in a Sagnac interferometer. Correct and clear temporal waveforms are successfully observed. Bit-error-ratios and optical signal-to-noise ratios are measured to demonstrate the effectiveness of the method. As the basic units of combinational logic operations, logic minterms are promising candidates to construct reconfigurable and programmable logic functions.

Introduction: The rising interest in fast and efficient systems for optical computing and signal processing is leading research towards the investigation of photonic digital processing functionalities such as all-optical logic operations. Among those, logic minterms, defined as the results of AND functions between input logic signals, where each input signal appears only once either in its inverted or non-inverted form, play an important role since any combinational logic function can be realized by combining the corresponding logic minterms [1]. Based on this concept, optical reconfigurable and programmable logic operations are increasingly analysed [2, 3].

In this letter, 42 Gb/s three-input logic minterms are generated with a semiconductor optical amplifier (SOA)-based Sagnac interferometer. Although some simple logic gates with two inputs have already been realized using a Sagnac configuration, to the best of our knowledge, this is the first time that logic operations with more than two inputs are experimentally demonstrated at high speed in such a scheme. Correct and clear temporal waveforms of the logic minterms are successfully achieved, and the effectiveness of the method is demonstrated by bit-error-ratio (BER) and optical signal-to-noise (OSNR) measurements. The proposed approach has the potential to implement complex programmable logic operations.

Experimental setup and operation principle: The experimental setup of the proposed scheme is shown in Fig. 1. Three return-to-zero differential phase shift keying (RZ-DPSK) signals are generated from the transmitter with a bit rate of 42 Gb/s and duty cycle of 33%. The wavelengths are 1548.88 nm (λ_A), 1552.07 nm (λ_B) and 1555.29 nm (λ_C), respectively. The signals are then amplified to 16 dBm by an erbium-doped fibre amplifier (EDFA) and demodulated by a 1-bit delay interferometer (DI). For all three channels, the DI-based demodulation enables the simultaneous generation of complementary intensity-modulated data patterns at the DI's two outputs. The DI performs as a precoder in which both inverted and non-inverted on-off keying (OOK) data patterns are generated from the DPSK signal. Two arrayed waveguide gratings (AWGs) with a free-spectral range (FSR) of 1.6 nm are then employed to demultiplex the six precoded signals. Among those, three signals, each at a different wavelength, are selected and coupled as the control signal of the Sagnac interferometer. Optical delay lines (ODLs) are introduced to synchronise the different data streams. Afterwards, the control signals are amplified and coupled into the Sagnac loop with a 10 dB coupler. A synchronous clock signal at a wavelength of 1563.83 nm acts as the probe signal. It is launched into the loop through a circulator and split into clockwise (cw) and counter-clockwise (ccw) components by a 3 dB coupler. The respective average powers of the coupled control signal and cw clock are 13.8 dBm and 1.1 dBm. The SOA is placed asymmetrically within the loop, thus the cw component reaches the SOA first and is phase-modulated by the coupled control signal. The ccw clock pulse reaches the SOA before the next coupled control pulse and after the carriers have recovered. Thus, the cw component experiences a phase difference $\Delta\phi$ compared to the ccw component. When all the selected precoded signals are in the low logic state, both components acquire the same phase shift (i.e. $\Delta\phi=0$), resulting in a high logic state at the constructive interference output port. On the contrary, a $\Delta\phi$ value equal to an odd multiple of π can be achieved when at least one of the control signals is in a high logic state, leading to a low logic state at the constructive interference output [4]. For example, if A, B, and C are selected as control signals, the minterm $\overline{A}\overline{B}\overline{C}$ can be achieved at the constructive output. It should be noted that, since the coupled control signal is composed of three different precoded signals at different wavelengths, it has a multilevel intensity (e.g. '0', '1', '2', '3'). The power of the '1' level is sufficient to saturate the SOA, which guarantees a similar $\Delta\phi$ even when the intensity of the coupled control signal is at level '2' or '3'. By permuting the different control signals, a full set of three-input logic minterms can be obtained.

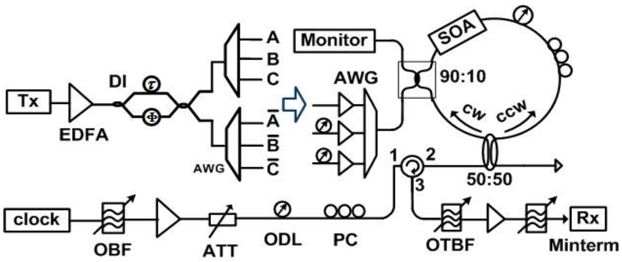

Fig. 1 *Experimental setup for all-optical 3-input minterms generation*

Experimental results: In the proof-of-concept experiment, three-input logic minterms are demonstrated with a 62-bit user pattern. Compared to a standard 2^6-1 pseudo-random binary sequence where only 5 consecutive zeros are present, the self-defined pattern explores the extremes of the recovery processes of the SOA with a much longer string of consecutive zeros. The final logic minterms are obtained at port 3 of the circulator after filtering by two optical tunable bandpass filters (OTBFs) whose 3 dB bandwidths are 1.95 nm and 2.65 nm, and central wavelengths are 1564.02 nm and 1562.34 nm, respectively. Taking the minterm $\overline{A}\overline{B}\overline{C}$ (labelled m_0 according to the nomenclature in Fig. 4) as an example, the spectra before and after filtering are shown in Fig. 2. Although some additional frequency components are generated by four-wave mixing, they do not deteriorate the logic result significantly due to the use of steep-edged filters. The temporal waveforms of the precoded signals after wavelength demultiplexing and the final three-input logic minterms (i.e. m_0-m_7) are shown in Fig. 3 and Fig. 4, respectively. Clear data pulses are observed and the logic states are easily distinguished. Small intensity ripples can be observed on the low level of the logic minterm results. This can be attributed to two reasons. First, as the carrier recovery time (i.e. 25 ps at I= 300 mA and

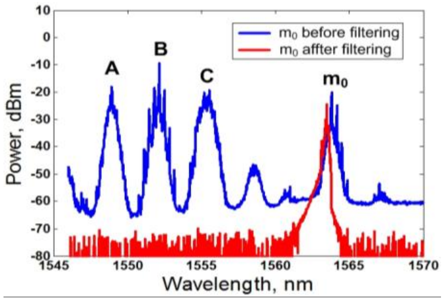

Fig. 2 *Measured spectra of m_0 before and after filtering.*

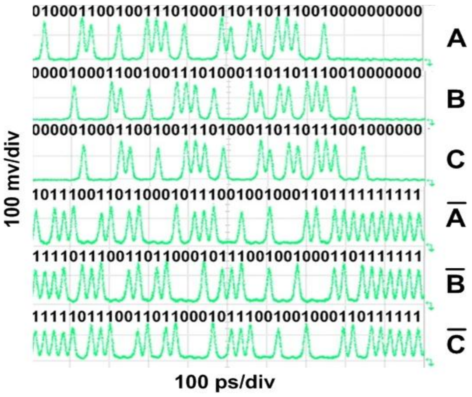

Fig. 3 *Temporal waveforms of the precoded signals.*

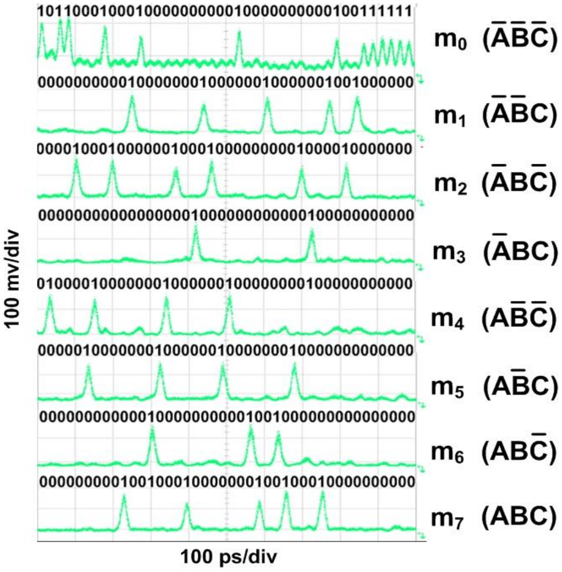

Fig. 4 *Temporal waveforms of the three-input logic minterms.*

T= 20ºC) of the SOA used in our experiment is not fast enough, the phase shifts induced on the probe pulses are not identical when the coupled control signal carries successive ‘1’. Second, the multi-level power (i.e. ‘1’, ’2’, ’3’) of the coupled control signal leads to slightly different saturation conditions of the SOA, which also induces different phase shifts on the probe pulses. Therefore, the interference at the Sagnac loop output is incomplete, causing the observed degradations to the final logic results. Nevertheless, as shown in Fig. 4, error-free performance is achieved with an average power penalty of 5.9 dB for m_1 to m_7. About 4 dB power penalty deviation is measured among m_1 to m_7, which is simply due to the significant difference of the ratios between the number of ‘1’s and ‘0’s in all the minterms. For the same reason, the deviation would go up to 12 dB if m_0 was included. In the experiment, error-free performance of m_0 could not be achieved since it would require too high average received power. However, the OSNR of m_0 still reaches 32 dB, as shown in Fig. 2, and the correct logic information can be clearly identified according to the waveform. The ultimate limitation of the scheme for operating at even higher bit rates is the carrier recovery time of the SOA.

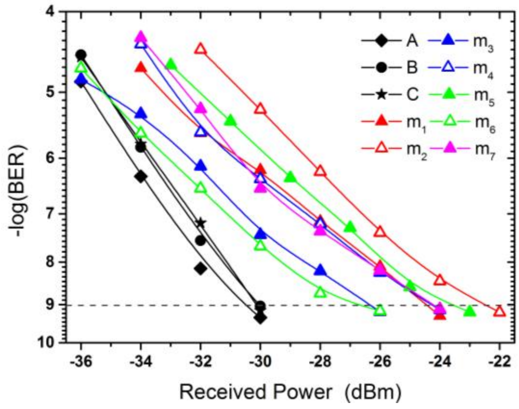

Fig. 4 *BER measurements of the precoded signals and logic minterms.*

Conclusion: All-optical three-input logic minterms have been generated at 42 Gb/s through cross-phase modulation in an SOA-based Sagnac interferometer. Correct and clear temporal waveforms have been achieved and the operation of the scheme has been validated by BER and OSNR measurements. As basic logic units, minterms can be used to construct any combinational logic operation, which lays the foundation for all-optical programmable logic devices.

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