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All-optical dual-direction half-subtracter based on sum-frequency generation

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Abstract

We report a simple method to realize all-optical dual-direction half-subtracter at 40 Gb/s based on sum-frequency generation (SFG) using only one periodically poled lithium niobate (PPLN) waveguide. The SFG process generates the Borrow outputs and the combination of the outputs from PPLN after SFG results in the Difference. The operation performance of the proposed scheme is simulated, including eye diagrams, Q-factor, extinction ratio, and tunability. For different input optical powers, the length of the PPLN waveguide is optimized.

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Keywords: Nonlinear optics; All-optical logic gates; Dual-direction half-subtracter; Sum-frequency generation (SFG); Periodically poled lithium niobate (PPLN)

1. Introduction

All-optical signal processing concepts and techniques have attracted considerable interests during the past few years. Many approaches have been proposed to implement various fundamental all-optical logic functions such as AND, OR, XOR, and NOR [1], based on which some complex logic operations including shift register [2], half-adder [3–6], half-subtracter [6] have also been recently achieved in the optical domain. All-optical half-subtracter is the basic building block of a data processor performing binary subtraction, dual-direction binary counting, encryption and decryption of secure network data, as well as optical arithmetic-logic units. In the previous study [6], it has been demonstrated that all-optical half-subtracter can be realized by employing two semiconductor optical amplifiers, showing impressive performance. The Borrow ($\overline{X} \cdot Y$) and Difference ($X \oplus Y$, or XOR) of the half-subtracter ($X - Y$) are generated using cross-gain modulation in two parallel arranged semiconductor optical amplifiers. However, such kind of half-subtracter may have some trouble to operate at 40 Gb/s due to the limitation of the carrier's recovery time of semiconductor optical amplifier. Moreover, additional spontaneous emission noise associated with semiconductor optical amplifiers is not beneficial to obtain high operation performance. These, therefore, can not fulfill the increasing requirements for future high-speed and high-performance optical networks. In addition, simultaneous use of several semiconductor optical amplifiers may suffer from the increase of system complexity and cost.

Periodically poled lithium niobate (PPLN) waveguide is a promising candidate to be applied to high-speed all-optical signal processing for its distinct advantages of high nonlinear coefficient, ultra-fast response, complete transparency to bit rate and data format, and no excess noise [7]. Based on various second-order nonlinear interactions

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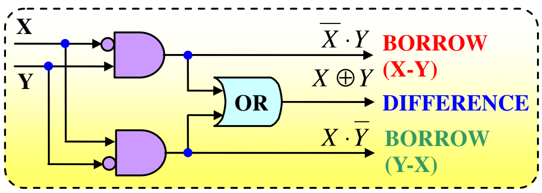
and their cascading, PPLN waveguide has seen wide applications in all-optical wavelength conversions [8–17], all-optical format conversions [18], all-optical AND/NAND [19,20], NOT [21,22], and switchable OR/XOR [23] logic gates. In this paper, we propose another simple realization of all-optical dual-direction half-subtracter by exploiting the sum-frequency generation (SFG) with only one PPLN waveguide required. The eye diagrams, Q-factor, extinction ratio, tunability are analyzed and the waveguide length is optimized.



X	Y	DIFFERENCE (X-Y) / (Y-X)	BORROW (X-Y)	BORROW (Y-X)
0	0	0	0	0
0	1	1	1	0
1	0	1	0	1
1	1	0	0	0

Fig. 1. Electronic logic diagram and truth table of a dual-direction half-subtracter.

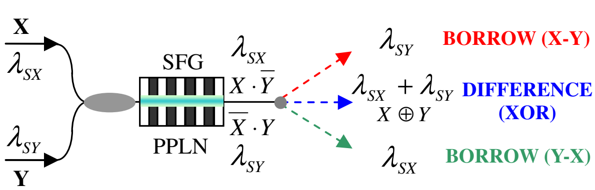


Fig. 2. Schematic diagram of the single-PPLN-based dual-direction half-subtracter by using SFG process.

2. Principle of operation

The electronic logic diagram and truth table of a dual-direction half-subtracter are shown in Fig. 1. Fig. 2 illustrates the schematic diagram of the proposed single-PPLN-based dual-direction half-subtracter simply by using SFG process. Two input signals with independent data streams X (λ_{SX}) and Y (λ_{SY}) are launched into the PPLN waveguide and participate in the SFG nonlinear interaction. Previous researches on SFG focused mostly on the new generated sum-frequency wave but gave no attention to the incident optical waves [14,15]. In fact, during the SFG process, one photon from signal X and another photon from signal Y are converted into one photon at the wavelength of a sum-frequency wave. For two continuous-wave (CW) input signals, both signals X and Y are consumed as the sum-frequency wave is produced. For two independent data streams X (λ_{SX}) and Y (λ_{SY}), the output data bit at λ_{SY} is equal to '1' only when input X and Y data bits are '0' and '1', respectively. Therefore, the output data stream at λ_{SY} with a logic function of $\overline{X}\cdot Y$ is obtained, which corresponds to the Borrow of $X-Y$ as shown in Fig. 1. Similarly, the output data stream at λ_{SX} takes the logic result of $X\cdot\overline{Y}$, which is the Borrow of $Y-X$. At the same time, by combining the two outputs $X\cdot\overline{Y}$ at λ_{SX} and $\overline{X}\cdot Y$ at λ_{SY} from PPLN, we can obtain $X\cdot\overline{Y}+\overline{X}\cdot Y$ ($X\oplus Y$), which equals XOR operation yielding the Difference of dual-direction half-subtracter $X-Y$ or $Y-X$.

3. Theoretical model and simulation results

The proposed dual-direction half-subtracter and its operation performance are calculated based on the coupled-mode equations describing the SFG process under the slowly varying envelope approximation as follows [13,22]:

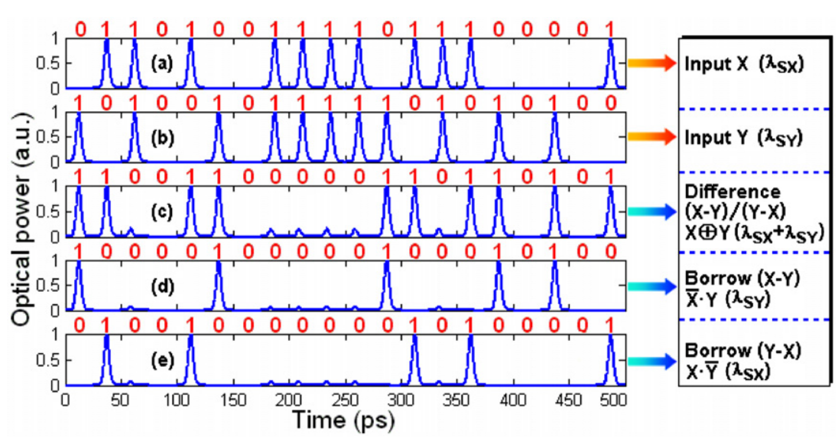


Fig. 3. Input and output waveforms for dual-direction half-subtracter. (a) Input signal X, (b) input signal Y, (c) difference output (XOR), (d) borrow output of $X-Y$, and (e) borrow output of $Y-X$.