A Reconfigurable All-Optical AND/OR Logic Gate using Multilevel Modulation and Self-Phase Modulation

Li Huo, Chinlon Lin, Chun-Kit Chan and Lian-Kuan Chen
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N. T., Hong Kong SAR, China.
Tel: +852-2609-8385, Fax: +852-2603-5032, Email:lihuo@ie.cuhk.edu.hk

Abstract: We demonstrated a reconfigurable and polarization-independent all-optical logic gate based on multilevel modulation and self-phase modulation. Reconfigurable logic AND and OR operations were realized by simply adjusting the center frequency of an optical band-pass filter.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

Simple high-speed all-optical logic gates will be among the key elements for the all-optical switching nodes in future optical networks to perform on-the-fly bit-level optical signal processing functions such as address recognition, label swapping, and data encryption, etc [1]. A reconfigurable logic gate is highly preferred as it can provide a more flexible set of networking functions. Recently, reconfigurable logic gates have been demonstrated using four-wave-mixing in semiconductor optical amplifiers [1] and self-phase modulation (SPM) or cross-phase modulation in a nonlinear optical loop mirror [2]. In principle, these schemes required a stringent polarization control on the input signals, thus hindered their applications in the optical networks. In this paper, we proposed and demonstrated a reconfigurable logic gate based on optical multilevel modulation in an electro-absorption modulator (EAM) and intensity-dependent frequency shift in SPM [3]. Logic AND and OR operations were realized using the same configuration and working condition. Re-configuration between the two logic operations was achieved simply by adjusting the center frequency of an optical band-pass filter in the logic gate. Compared with the previous schemes, ours exhibited polarization independent operation and long time stability. An error-free operation of such logic gate was demonstrated at 10 Gb/s for both the logic AND and OR operations.

2. Principles and Experimental Setup

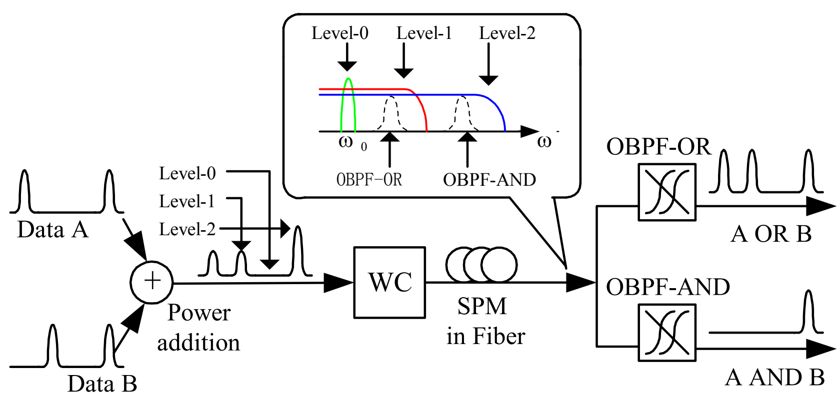

Fig. 1. Operation principle of the multilevel modulation based reconfigurable AND/OR logic gate

The working principle of the proposed reconfigurable logic gate is illustrated in Fig. 1. Two data streams, data A and data B, with the same optical power are fed into a power addition module, which generates a three-level output signal. The three-level signal is then converted to a new wavelength by a wavelength converter (WC). After that, it is boosted and launched into a section of optical fiber in which SPM broadens the different intensity levels to different spectral widths. The zero level (level-0) has the narrowest broadening, while the highest level (level-2) gets the widest spectral width. When an optical band pass filter (OBPF) is placed at the spectral region covered by both level-1 and level-2 spectra but not covered by the level-0 spectrum, logic OR operation is achieved. When it is placed at the spectral region covered by level-2 spectrum but not by level-0 and level-1 spectra, logic AND operation is achieved. Hence, the logic AND and OR operations can be achieved simultaneously by using two fixed OBPF or can be reconfigured between them by utilizing a tunable OBPF.

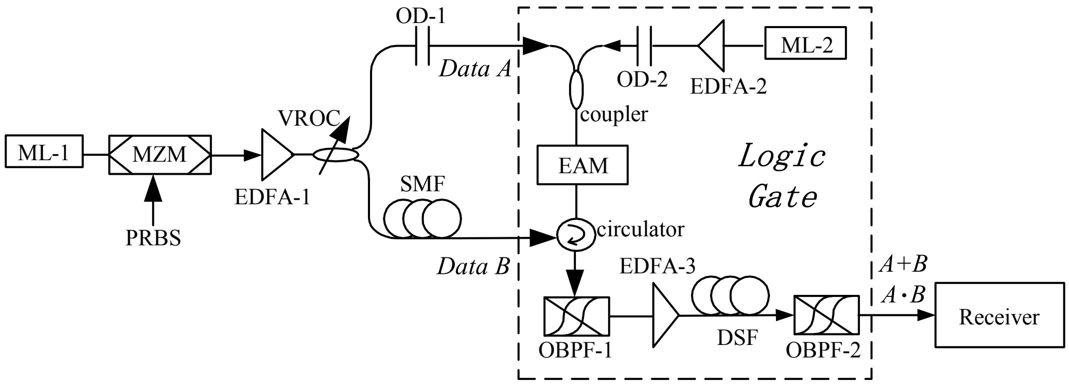

Fig. 2. Experimental Setup.

Fig. 2 depicts the experimental setup. A 10-GHz, 3-ps optical pulse train at 1545.2 nm was generated by the mode-locked laser-1 (ML-1) and was modulated by 2^7-1 pseudo random bit sequence (PRBS) via a $LiNbO_3$ Mach-Zehnder modulator (MZM). Then the signal was amplified using the Erbium-doped fiber amplifier-1 (EDFA-1) before it was split by a variable ratio optical coupler (VROC) into two branches to emulate the two input data streams. The two signals were de-correlated using 1-km single mode fiber (SMF). The power addition and wavelength conversion function in Fig. 1 was achieved simultaneously by utilizing cross-absorption modulation (XAM) in an EAM. The two data streams were properly aligned by the optical delay-1 (OD-1) before being launched into the -3.13V-reverse-biased EAM from the opposite directions to avoid the homodyne interference. The optical powers injected into the both sides of EAM were 13 dBm. OD-1 was adjusted to make the counter-propagating optical pulses collide in the EAM. Since there were totally three in-chip optical power level combinations, a three-level time window in EAM was created through XAM. Therefore, when a second pulse train from the another mode-locked laser (ML-2) at 1554.7 nm was fed into the same EAM, the three-level information was transcribed to the new wavelength. The output power of EDFA-2 was 6 dBm. The optical delay-2 (OD-2) was used to make the pulses peak in the middle of the time window of the EAM. The wavelength converted three-level signal was filtered out from the circulator with a 2-nm optical band-pass filter-1 (OBPF-1) centered at 1554.7nm and was amplified by the EDFA-3 to a power level of 9 dBm. Then the signal was launched into a 4-km long dispersion shifted fiber (DSF), where SPM broadened the three-level optical spectrum to different spectral widths. Finally, a tunable optical band-pass filter (OBPF-2) with a 3-dB bandwidth of 0.2 nm was deployed to filter out different spectral regions. When the center frequency of OBPF-2 was selected as 1555.5nm, logic AND operation was realized. When the center frequency was changed to 1556.5nm, logic OR operation was achieved.

3. Results and Discussions

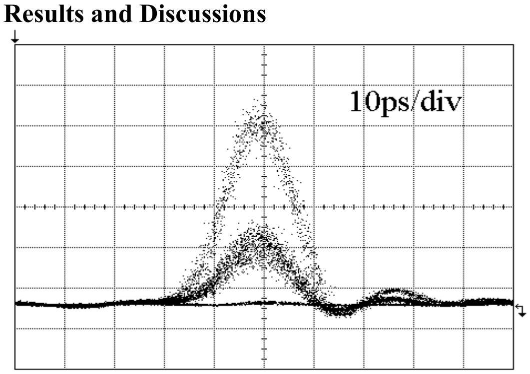

Fig. 3. Eye diagram of the wavelength converted three-level signal

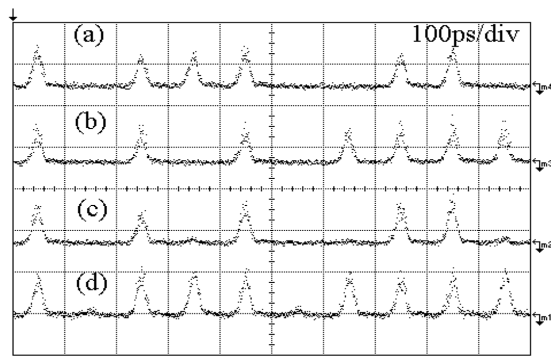

Fig.4. Waveforms for the input data, and the resulting logic outputs (a) data A, (b) data B, (c) A AND B, (e) A OR B

Fig.3 shows the eye diagram of the wavelength converted three-level signal. Some intensity fluctuations in level-1 and level-2 were observed in the three-level signal. This was caused by the pattern effect in the EAM, originated from the relatively long carrier sweep-out time in our device. The problem can be alleviated by using EAM with faster sweep-out characteristics. Fig. 4(a)-(d) shows the captured waveforms of the input data, and the obtained logic AND and logic OR outputs. As neither the XAM in the EAM nor the SPM in the DSF was polarization sensitive, no performance degradation in the waveforms or in the eye diagrams was observed by changing the polarization states of the two input data streams. This polarization independent feature also resulted in the long-time stability of such logic gate.

Fig. 5 shows the bit-error-rate (BER) curves for the input data, the outputs of the logic AND and the logic OR operations. It is shown that error-free operation was achieved for both the logic AND and the logic OR operations. However, there were 3-dB power penalty for the logic AND operation and 4.5-dB power penalty for the logic OR operation at the BER level of 10^{-9}. This was mainly attributed to the intensity fluctuation of the wavelength converted three-level signal. The fluctuation was further amplified by the modulation instability in the DSF. The eye diagrams of the logic AND and the logic OR outputs were also shown in the insets of Fig. 5. The residual eye penalty was due to the lack of optimal operation condition. The optimal operation with respect to the input power of EDFA-3, the property of DSF, the wavelength position and the bandwidth of OBPF-2 depends on the pulse width and the level spacing of the three-level signal. At the anomalous dispersion operation region of the DSF, though higher input power would broaden the spectrum even more, the noise is amplified as well due to modulation instability effect. Therefore, the power of EDFA-3 in the experiment was limited to be around 9 dBm, resulting in the residual eye penalty. The employment of the narrow-band OBPF-2 could differentiate different spectral regions, but it was also sensitive to the noise and the amplitude jitter. Therefore, we believe that after further optimization of the operation parameters, more reduction of the residual eye penalty could be obtained. Currently, the operation was demonstrated at 10 Gb/s. This was mainly constrained by the modulation bandwidth of the EAM. Recent results of 80-Gb/s wavelength conversion and 3R regeneration based on XAM in an EAM [4] indicated the possibility of upgrading the operation to a much higher speed.

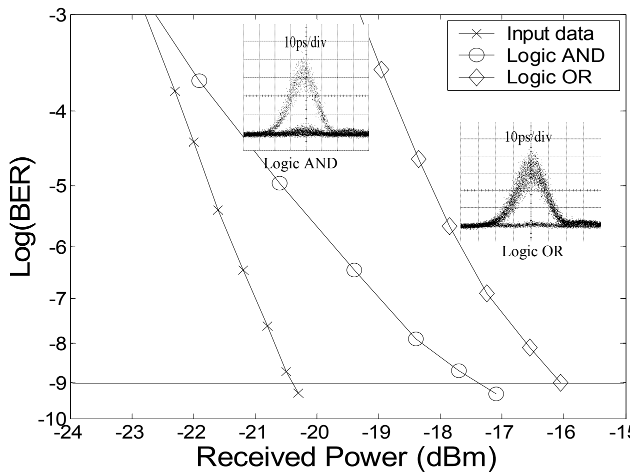

Fig. 4. BER curves for the input data (cross), the AND function (circle), and the OR function (diamond). The eye diagrams corresponding to the AND and OR functions are also presented as the insets, time scale: 10ps/div

4. Conclusions

We have experimentally demonstrated a novel reconfigurable all-optical logic gate based on multilevel modulation and intensity-dependent frequency shift in SPM. Logic AND and OR operations were realized using the same configuration and working condition. Reconfiguration between the two logic operations was achieved simply by adjusting the center frequency of an optical band pass filter in the logic gate. Error-free operation for both logic operations was achieved at 10 Gb/s. The logic gate features with polarization-independent operation and can potentially work at a much higher speed.

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