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All-Optical XNOR Gate using Fiber Optical Parametric Amplifier

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Abstract
An all-optical XOR gate based on four-wave mixing and cross gain modulation in an optical parametric amplifier is presented. Ultra-fast response time can be achieved due to the sole use of parametric effects.

1. Introduction

All-optical exclusive-OR (XOR) gates have been of high popularity due to its myriad of functions, including comparison of data patterns [1], data encryption/decryption, or parity checking [2]. These can also be accomplished by XNOR gates since the XNOR output is the negation of the XOR output; a detector detecting for 1's at XOR output can easily be configured to detect 0's at a XNOR output to provide the same functionality.

All-optical XNOR gate based on FWM and XGM has been implemented using a semiconductor optical amplifier (SOA) in Ref. [3]. However, its bit rate is limited by the SOA's carrier recovery time in XGM process. On the other hand, fiber-based optical signal processing, including all-optical sampling by FWM effect [4] and inverted and non-inverted wavelength conversion by XGM effect [5], has been investigated previously because of ultra-fast response of nonlinear effect in optical fibers. Therefore, fiber-based all-optical logic gates should be capable of overcoming the speed limit of their SOA-based counterparts using similar effects. In this paper, we report an all-optical 10Gb/s non-return to zero (NRZ) XNOR gate utilizing XGM and FWM effects in fiber optical parametric amplifier (OPA).

2. Principle of Operation

The operation principle of producing a XNOR gate using a combination of AND, NOR, and OR gates is similar to that as shown in Ref. [3]. Except it required an extra probe input, which acted as the output of a NOR gate. In our design, the XGM output is obtained directly from the OPA pump, since it is possible to achieve strong pump depletion as demonstrated in Ref. [6]. The OPA pump depletes itself whenever one or more signals are present, because it transfers a majority of its power to the signal(s). Hence, if XGM effect is present in the pump, it is equivalent to a NOR operation on the two input signals. Furthermore, strong FWM effect occurring on the two signals will produce new FWM peaks, where the peaks closest to the two signals tend to be the strongest. Since the generation of these new peaks require the presence of both signals in the nonlinear medium, these peaks are essentially the AND output of the two signals. By combining the XGM and FWM products, this results in a XNOR output. Fig. 1 summarizes the operation principle.

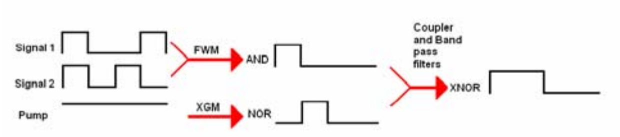

Fig. 1. Operation principle of an all-optical XNOR gate.

3. Experimental Setup

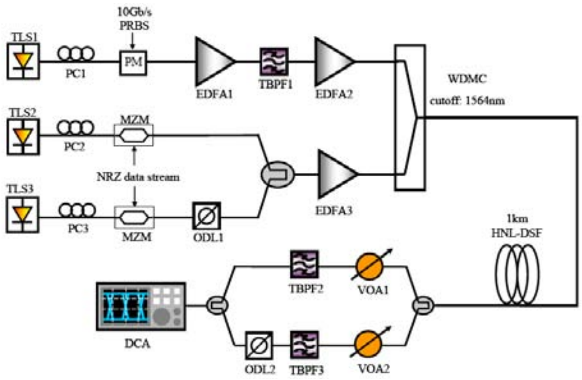

Fig. 2. Experimental Setup. ODL: Optical delay line. WDMC: WDM band coupler. VOA: Variable optical attenuator. MZM: Mach-Zehnder modulator. PC: Polarization controller. DCA: Digital communications analyzer. All couplers are 50/50 couplers unless otherwise stated.

The experimental setup is shown in Fig. 2. The nonlinear medium used was a spool of 1km highly nonlinear disersion-shifted fiber (HNL-DSF) with nonlinear coefficient of $14W^{-1}\ km^{-1}$ and zero dispersion wavelength of 1560nm. The pump wavelength was set at 1561.8nm, which was phase modulated with a 10Gb/s 2^{23}-1 pseudo-random binary sequence (PRBS) to suppress stimulated Brillouin scattering (SBS) [7]. It was then connected to an erbium doped fiber amplifier (EDFA1) to reach output power of 23dBm. The tunable band pass filter (TBPF1) significantly suppressed the amplified spontaneous emission (ASE) noise from the EDFA. After that, the pump was amplified to 27dBm at EDFA2 before entering the WDM coupler.

The two signals' wavelengths were set at 1566.9nm and 1568.5nm. They were amplitude modulated with an identical NRZ 10Gb/s bit sequence. The tunable delay line delayed one of the signals such that they were unsynchronized by one bit. They were then coupled together using a 50/50 coupler before amplified by EDFA3 to a total output power of about 15dBm.

The amplified pump and signals were then coupled together using a WDM coupler with a cutoff wavelength of 1564nm. The combined waveform was then injected into the HNL-DSF. The output of the HNL-DSF was split by a 50/50 coupler, where one output branch filtered out the pump wavelength, while the other filtered out an idler produced by FWM from the two signals. The attenuators at each branch reduced optical power to prevent damage to the tunable band pass filters (TBPF2 & 3) and ensured the 1's from the pump and the FWM peaks are of the same power. The optical delay line (ODL2) was used to compensate the path difference between the two branches. They were then recombined using another 50/50 coupler and the output was monitored from a digital communication analyzer (DCA).

4. Results and discussion

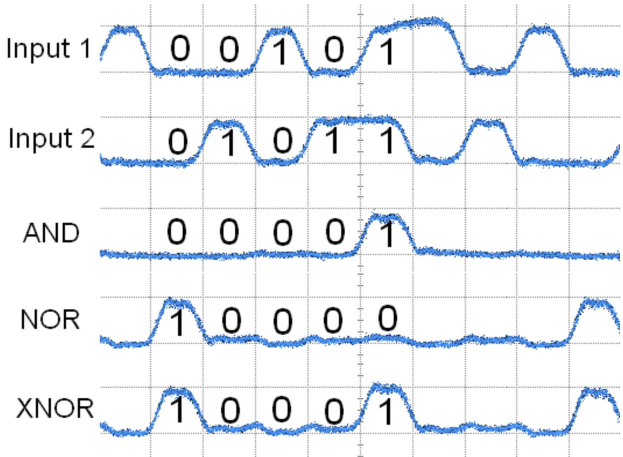

Fig. 3. Input and output waveforms

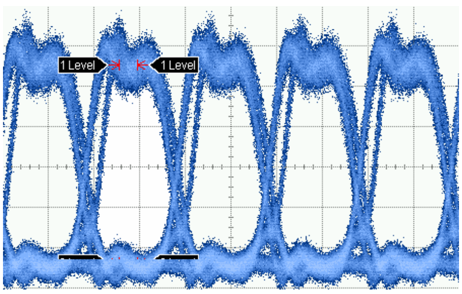

Fig. 4. Eye diagram of the resultant XNOR signal

Fig. 3 illustrates the inputs and outputs of the AND, NOR, and XNOR gates. It can be seen from the figure that the AND output produces a '1' only when both the inputs are '1'. The NOR output produces a '1' only when both inputs are '0'. The last coupler output acted as an OR gate, where it combines the output of the AND and NOR gates to generate the XNOR.

Figure 4 shows the eye diagram of the resultant XNOR gate. The extinction ratios of the XNOR, NOR, and AND outputs are about 11dB, 12dB, and 24dB, respectively. The extinction ratio of the output (XNOR) is dominated by the NOR gate because it is generally difficult to deplete the pump by 100% [6], leaving a small residual power at off-state. This can be improved by optimizing the phase-matching condition [6]. Note that as the output signals generally preserve the pulse shapes of input signals, it could be expected that this XNOR gate can support higher bit rate operation.

5. Conclusion

We have successfully demonstrated an all optical XNOR gate using a single stage OPA. The minimal distortion at the output reveals a possibility for higher bit rate operation. Since this XNOR gate is generated from NOR and AND gates, this device is capable of providing AND and NOR outputs simultaneously in addition to its normal XNOR output, which may be useful in simplifying implementation of compound logic gates.

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7. References

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