All-optical NRZ-OOK to RZ-QPSK conversion using parallel SOA-MZI OOK/BPSK converters

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Abstract: We propose a novel all-optical NRZ-OOK/RZ-QPSK modulation format converter using parallelized SOA-MZIs and demonstrate the proof-of-the-principle experiment at 10.7 GSymbol/s by using the test parallel SOA-MZI OOK/BPSK converters.

OCIS codes: (060.5060) Phase modulation; (070.4340) Nonlinear optical signal processing

1. Introduction

Differential phase-shift-keying (DPSK) modulation formats are promising techniques to enhance the performance for long-haul transmission systems [1], [2]. The differential quadrature PSK (DQPSK) modulation format, which has twice as high spectral efficiency as differential binary PSK (DBPSK), has been extensively studied for the 40 Gb/s long-haul densely wavelength division multiplexed (DWDM) systems. Therefore, it is likely that at a gateway node between long-haul backbone network and metro area network (MAN), a transparent modulation format conversion between the PSK signals and conventional on-off-keying (OOK) becomes a key technique for seamless photonic networking in the near future. We have proposed an all-optical OOK to BPSK converter using semiconductor optical amplifier-based Mach-Zehnder interferometer (SOA-MZI) [3]. All-optical OOK/BPSK conversion based on optical fiber nonlinearity have been reported [4]. To the best of our knowledge, however, all-optical modulation format conversion from OOK to QPSK has never been investigated. In this paper, we propose for the first time an all-optical modulation format conversion from NRZ-OOK to RZ-QPSK. The converted waveforms and spectra at the bit-rate of 21.4 Gb/s are experimentally demonstrated to confirm the principle of operation by using the test parallel SOA-MZI OOK/BPSK converters. We also confirm that the fixed output pattern after balanced receiving can be generated in agreement with the calculated pattern from the fixed input patterns.

2. Principle of Operation

Figure 1 shows the schematic diagram of the proposed modulation format converter. The basic configuration consists of an SOA-MZI OOK/BPSK modulation format converter (SOA-MZI#1) on the upper arm and a phase shifter and another SOA-MZI#2 in tandem on the lower arm. The SOA-MZI OOK/BPSK converters convert NRZ-OOK data signal to RZ-BPSK data signal by using cross-phase modulation (XPM) in SOA.

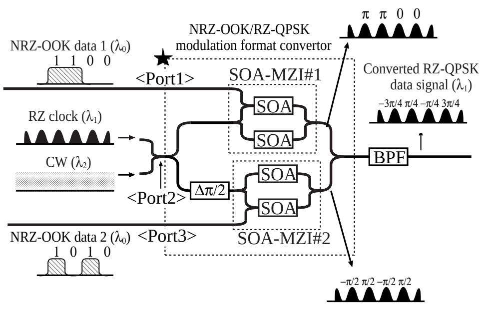

Fig. 1. Schematic diagram of the proposed modulation format converter.

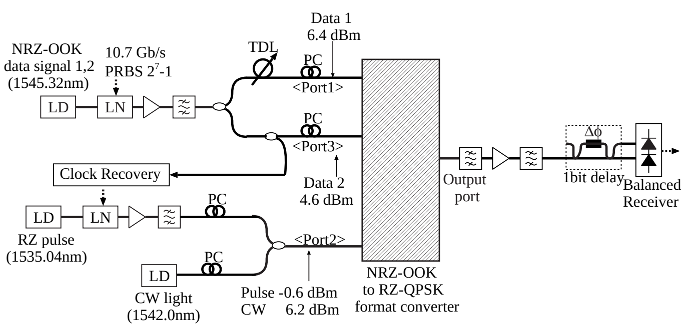

Fig. 2. Experimental setup.

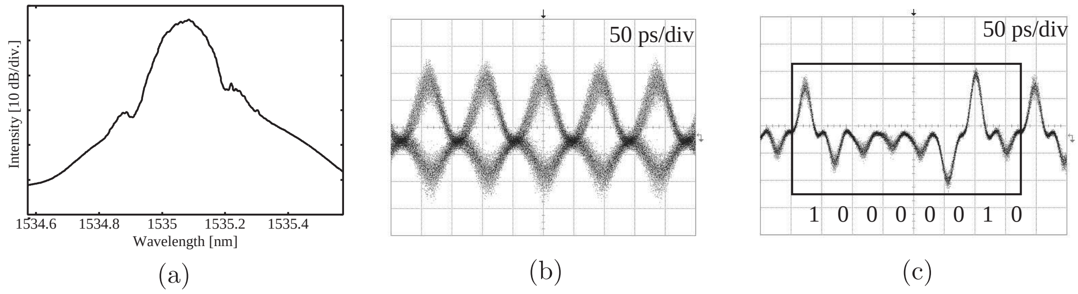

Fig. 3. Results of measurements. (a) Optical spectra of converted signal, (b) eye diagram of electric signal after receiver, and (c) fixed output pattern.

NRZ-OOK signal pulses 1 and 2 with the wavelength of λ_0 are launched into the upper arm of the MZI (port 1) and the lower arm of the MZI (port 3), as control pulses 1 and 2, respectively. RZ-clock pulse sequence with λ_1 and CW light with λ_2 are launched into the MZI (port 2) as a probe pulse and an assist light, respectively. According to the NRZ-OOK data 1 "1" or "0", the phase of the probe pulse after passing through SOA-MZI#1 shifts either by "0" or "π", respectively. On the other hand, when the NRZ-OOK data 2 is "0" or "1", the probe pulse after passing through SOA-MZI#2 has the phase of "$\pi/2$" or "$-\pi/2$" due to the $\pi/2$ phase shifter. The probe pulses after passing through SOA-MZI#1 and #2 have the equal peak power and cause orthogonal interference in each combination of the control pulses 1 and 2. The probe pulse after interference has the same peak amplitude as the incoming signals due to the orthogonal interference and four different phase values depending on the combination of the control pulses 1 and 2. Therefore, NRZ-OOK data signal can be converted to RZ-DQPSK data signal.

3. Experiments

Figure 2 shows the experimental setup for the proposed format conversion. The NRZ-OOK data signals 1 and 2 were generated by modulating a CW of 1545.32 nm in a lithium niobate (LN) modulator with 10.7 Gb/s pseudo random binary sequence of length 2^7-1. The RZ clock pulse was generated by modulating a CW of 1535.04 nm in a LN modulator by using the regenerated clock from NRZ-OOK data 2. The RZ clock pulse was coupled with CW assist light of 1542.0 nm. The converted signal was received by a balanced receiver after passing through a 1-bit delay interferometer, in which the phase adjuster has a phase shift of "$\pi/4$".

While figure 3 (a) shows the optical spectrum of the converted signal as the carrier suppressed QPSK signal, (b) shows a clear eye opening after the balanced receiver. Figure 3 (c) shows the fixed output pattern after the balanced receiver, which corresponds to the calculated pattern "10000010" from fixed input data 1 "00110101" and data 2 "01010011". The above mentioned results reveal that the NRZ-OOK signal can be converted into an RZ-QPSK signal using the proposed method.

4. Conclusions

We have proposed a novel modulation format conversion scheme from NRZ-OOK to RZ-QPSK by using parallelized SOA-MZIs. We have experimentally demonstrated the operation of the proposed converter at 10.7 Gs/s using the test parallel SOA-MZI OOK/BPSK converters. This work was partially performed under management of the OITDA supported by New Energy and Industrial Technology Development Organization (NEDO).

References

1. A. H. Gnauck and P. J. Winzer, "Optical phase-shift-keyed transmission," *IEEE J. Lightwave Technol.*, vol. 23, pp. 115–130, 2005.
2. G. Charlet, "Progress in optical modulation formats for high-bit rate WDM transmissions," *IEEE J. Selected Topics in Quantum Electronics*, vol. 12, pp. 469–483, 2006.
3. K. Mishina, A. Maruta, S. Mitani, T. Miyahara, K. Ishida, K. Shimizu, T. Hatta, K. Motoshima, and K. Kitayama, "NRZ-OOK-to-RZ-BPSK modulation-format conversion using SOA-MZI wavelength converter," *IEEE J. Lightwave Technol.*, vol. 24, pp. 3751–3758, 2006.
4. C. S. Langhorst, R. Ludwig, M. Galili, B. Huettl, F. Futami, S. Watanabe, and C. Schubert, "160 Gbit/s all-optical OOK to DPSK in-line format conversion," in *Conf. Proc. of ECOC 2006*, Paper PD Th4.3.5, Cannes, France, 2006.