All-optical format conversion from inverse-return-to-zero to non-return-to-zero using a Mach-Zehnder delay interferometer

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Abstract. All-optical format conversion from inverse-return-to-zero (inverse-RZ) to non-return-to-zero (NRZ) is realized by using a half-bit-delay Mach-Zehnder delay interferometer. Experimental results demonstrate that the converted NRZ signal has better receiver sensitivity than the back-to-back inverse-RZ signal.
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Subject terms: all-optical format conversion; Mach-Zehnder delay interferometer; inverse-return-to-zero; non-return-to-zero.

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1 Introduction

Future all-optical networks are likely to integrate both wavelength division multiplexing (WDM) and optical time-division multiplexing (OTDM). In order to improve the flexibility of optical networks, all-optical format conversion has received much interest.[1] Several schemes for format conversion among on-off keying (OOK) formats have been reported,[2–5] including non-return-to-zero (NRZ), return-to-zero (RZ), and carrier-suppressed return-to-zero (CSRZ). Conversion methods from OOK to phase-shift keying (PSK) are also proposed to link metro networks and wide-area networks.[6]

However, no all-optical format conversion from inverse-return-to-zero (inverse-RZ) to non-return-to-zero (NRZ) has been reported up to now. The inverse-RZ format has received increasing interest as the downstream signal format to facilitate the upstream data remodulation in a wavelength-division multiplexing passive optical network (WDM PON).[7,8] The NRZ format, preferred in local networks, has the merits of lower bandwidth requirements, higher timing tolerance, and data-standard compatibility. The format conversion from inverse-RZ to NRZ can be used in connecting and interfacing optical network units (ONUs) and optical local area networks.

In this letter, 10-Gbit/s all-optical format conversion from inverse-RZ to NRZ is experimentally demonstrated by using a half-bit-delay Mach-Zehnder delay interferometer (MZ DI). In our experiment, the inverse-RZ signal is generated through the scheme presented in Ref. 9. The duty cycle of inverse-RZ is around 50%, and the delay time between the two arms in the MZ DI is 50 ps. The proposed scheme is simple and can offer sensitivity improvement. The measured bit error rate (BER) shows a receiver sensitivity improvement of about 1.7 dB after format conversion.

2 Experimental Setup

Figure 1 shows the experimental setup. A distributed feedback (DFB) laser operating at 1550.3 nm (output power: 5.4 dBm) is modulated by two cascaded $LiNbO_3$ Mach-Zehnder modulators (MZMs) to apply RZ modulation. First, a pseudorandom binary sequence (PRBS) with length 2^7-1 and a 10-GHz clock signal are amplified by wideband electrical amplifiers (TGA4819-SL), and then they are used to drive the MZMs. Both of the two MZMs are biased at their quadrature points. MZM1 is used to generate the NRZ signal. The NRZ signal is then converted to an ≈50%-duty-cycle RZ signal by pulse carving with MZM2 driven by the clock. Bit synchronization is also needed in RZ signal generation. An erbium-doped fiber amplifier (EDFA) amplifies the signal to 10 dBm, an optical band-pass filter (OBPF) with a bandwidth of 2 nm suppresses amplified spontaneous emission (ASE) noise, and a variable optical attenuator (VOA) is used to reduce the power to the proper level (3.6 dBm).

To obtain the inverse-RZ signal, cross-gain modulation (XGM) in a semiconductor optical amplifier (SOA) is obtained by injecting a continuous-wave probe beam (1554.6 nm, −8.3 dBm) and the 10-Gbit/s RZ pulses. Another technique for inverse-RZ generation[7] in the electrical domain, using a logic AND operation, can also be used. An OBPF with central wavelength 1554.6 nm is used to select the converted inverse-RZ signal. A MZ DI is used to realize format conversion. The differential delay between the two arms is 50 ps. Proper thermal insulation was applied to make the MZ DI demodulator more stable.

The principle for format conversion from inverse-RZ to NRZ based on half-bit-delay MZ DI is shown in Fig. 2. The alternation between two opposite-phase levels in the middle of each 1 bit at the destructive port is not expressed in the figure. In principle, the inverse-RZ signal with a duty cycle of 50% can be converted into a standard NRZ signal at the constructive port, and a modified NRZ with a phase jump π in the middle of each 1 bit can be obtained at the destructive port.

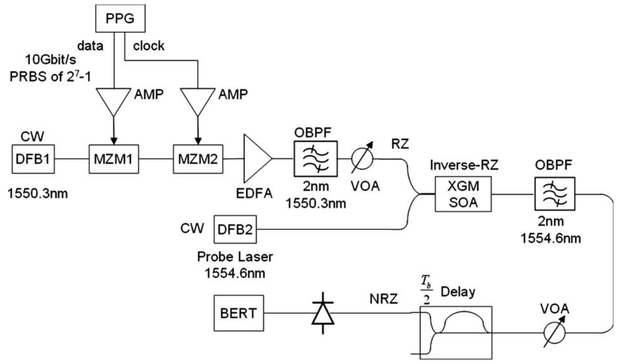

Fig. 1 Experimental setup.

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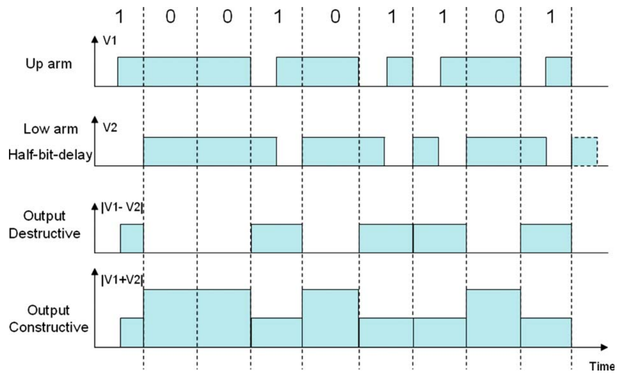

Fig. 2 Principle for format conversion from inverse-RZ to NRZ.

3 Results and Discussion

Figure 3(a)–3(d) show the eye diagrams of the original RZ signal, inverse-RZ signal, converted NRZ signal at the constructive port, and converted NRZ signal at the destructive port, respectively. The amplitude variation at the bottom of the eye diagram in Fig. 3(c) is the residual ripple. It can be alleviated by adjusting the duty cycle of inverse-RZ to exactly 50%. The nonuniformity in the amplitude and polarization of the pulses interfereing in the MZ DI also contributes to the ripples in the eye diagrams. The eye diagram at the destructive port is illustrated in Fig. 3(d), which is closely related to the modified duobinary signal, or *alternate mark inversion* (AMI) signal. There are two pulses with opposite phase level in each 1 bit. The notch in the middle of 1 bit is caused by the destructive interference of the adjacent pulses. This kind of modified NRZ can be easily converted into conventional NRZ by using techniques demonstrated in Refs. 3 and 4

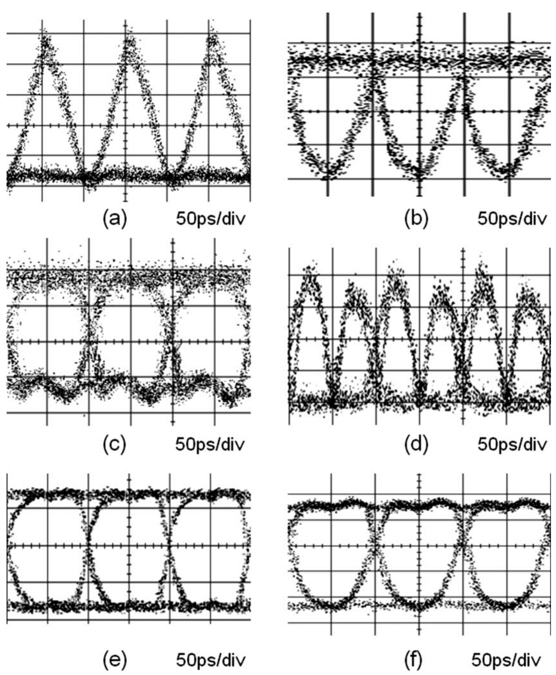

Fig. 3 Eye diagrams: (a) of the RZ signal, (b) of the inverse-RZ signal, (c) of the converted NRZ signal at the constructive port of the MZ DI, (d) of the converted NRZ signal at the destructive port of the MZ DI, (e) of the converted NRZ signal detected by the bandwidth-limited PD (constructive port), (f) of the converted NRZ signal detected by the bandwidth-limited PD (destructive port).

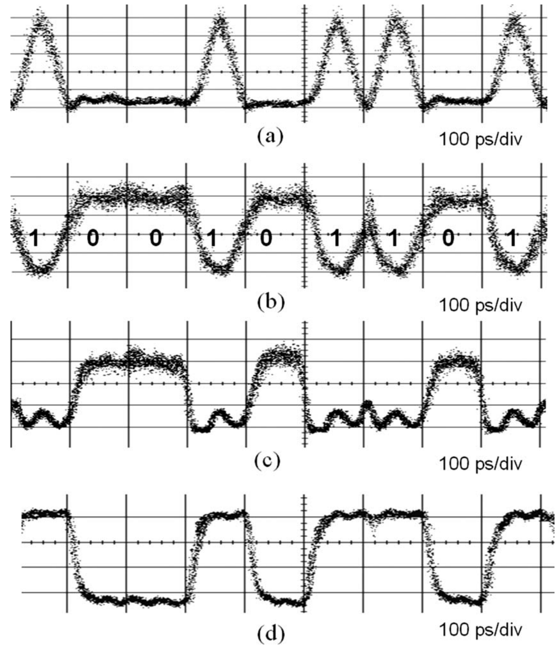

Fig. 4 Waveform diagrams of fixed data pattern: (a) inverse-RZ signal, (b) converted NRZ signal (destructive port), (c) converted NRZ signal (constructive port).

Figure 3(e) and 3(f) show the eye diagrams of the converted NRZ signals detected by a 10-Gbit/s photodetector (PD, PT10XGC) at the constructive port and the destructive port, respectively. By using a bandwidth-limited receiver, the total integrated noise can be reduced. Therefore the received signal quality of the converted NRZ signal can be improved.[10] To further prove the effectiveness of our scheme, we use a fixed data pattern to serve as the input data and observe the output of the MZ DI. Waveform diagrams are shown in Fig. 4.

The BER measurements before and after the conversion from inverse-RZ to NRZ are shown in Fig. 5. The receiver sensitivity is −17.7 dBm at the BER of 10^{-9} for the back-

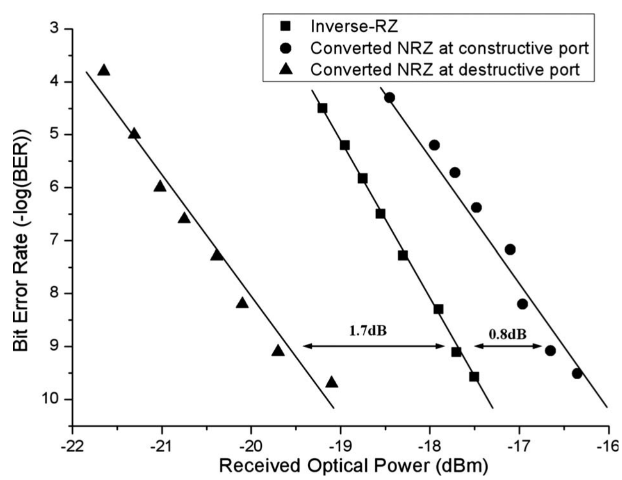

Fig. 5 BER curves in the format conversion process.

to-back inverse-RZ signal. The sensitivities for converted NRZ signals respectively at destructive port and constructive port are −19.4 and −16.9 dBm. Compared to the inverse-RZ signal, a −1.7-dB power penalty is observed for the converted NRZ signal at the destructive port, and a 0.8-dB power penalty is observed for the converted NRZ signal at the constructive port. The positive power penalty at the constructive port is caused by the extinction-ratio degradation. At the destructive port, as expected, the receiver has higher sensitivity for the NRZ format then for the inverse-RZ format,[8] which is due to the signal format conversion.

4 Conclusion

10-Gbit/s all-optical format conversion from inverse-RZ to NRZ has been demonstrated. A duty cycle of 50% for the inverse-RZ signal is needed to realize optimal format conversion. The input inverse-RZ signal is converted into a standard NRZ signal at the constructive port. At the destructive port, the modified NRZ signal with a phase jump in the middle of each 1 bit is obtained. In the experiments, a clear eye opening of the converted NRZ signal is observed, and a negative power penalty of −1.7 dB is measured

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References

1. D. Norte, E. Park, and A. E. Willner, "All-optical TDM-to-WDM data format conversion in a dynamically reconfigurable WDM network," *IEEE Photonics Technol. Lett.* **7**(8), 920–922 (1995).
2. J. J. Yu, G. K. Chang, J. Barry, and Y. K. Su, "'40 Gbit/s signal format conversion from NRZ to RZ using a Mach-Zehnder delay interferometer," *Opt. Commun.* **248**, 419–422 (2005).
3. L. Xu, B. C. Wang, V. Baby, I. Glesk, and P. R. Prucnal, "All-optical data format conversion between RZ and NRZ based on a Mach-Zehnder interferometric wavelength converter," *IEEE Photonics Technol. Lett.* **15**(2), 308–310 (2003).
4. C. G. Lee, Y. J. Kim, C. S. Park, H. J. Lee, and C. S. Park, "Experimental demonstration of 10-Gb/s data format conversion between NRZ and RZ using SOA-loop-mirror," *J. Lightwave Technol.* **23(2)**, 834–841 (2005).
5. W. Li, M. Chen, Y. Dong, and S. Xie, "All-optical format conversion from NRZ to CSRZ and between RZ and CSRZ using SOA-based fiber loop mirror," *IEEE Photonics Technol. Lett.* **16**(1), 203–205 (2004).
6. 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," *J. Lightwave Technol.* **24**(10), 3751–3758 (2006).
7. G. W. Lu, N. Deng, C. F. Chan, and L. K. Chen, "Use of downstream inverse-RZ signal for upstream data re-modulation in a WDM passive optical network," in *OFC/NFOEC*, Paper OFI8 (2005).
8. S. Y. Kim, E. S. Son, S. B. Jun, and Y. C. Chung, "Effects of downstream modulation formats on the performance of bidirectional WDM-PON using RSOA," in *OFC/NFOEC*, paper OWD3 (2007).
9. T. Miyazaki and F. Kubota, "Superposition of DQPSK over inverse-RZ for 3-bit/symbol modulation-demodulation," *IEEE Photonics Technol. Lett.* **16**(12), 2643–2645 (2004).
10. B. Razavi, *Design of Integrated Circuits for Optical Communications*, McGraw-Hill, New York (2002).