Delay-Asymmetric Nonlinear Loop Mirror for Bit-Rate Variable RZ-to-NRZ Format Conversion

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Abstract: We demonstrate RZ-to-NRZ pulse format conversion at tunable bit-rates using a delay-asymmetric nonlinear loop mirror. The input RZ-OOK signals are converted to NRZ-OOK signals with a power penalty less than 3 dB.

OCIS codes: (190.4370) Nonlinear optics, fiber, (190.4380) Nonlinear optics, four-wave mixing, (060.5295) Photonic crystal fibers, (060.4510) Optical communications

1. Introduction

Communication systems deployed for optical networks of different coverage are optimized for use with different signal formats and bit rates. As an example, return-to-zero on-off keying (RZ-OOK) is needed for OTDM systems owing to its enhanced time domain usage efficiency for high speed communications; while non-return-to-zero on-off keying (NRZ-OOK) is suitable for DWDM systems because of its high spectral efficiency. To adapt these different requirements, all-optical format conversion between RZ-OOK and NRZ-OOK formats becomes critical. The conversion can be achieved using cross-phase modulation (XPM) in a nonlinear optical loop mirror (NOLM) [1], offset filtering after XPM spectral broadening in a dispersion-shifted fiber [2], cross gain compression in semiconductor optical amplifiers (SOAs) [3,4], and SOA-based interferometric devices [5,6]. However, the format conversion based on the combined effects of XPM and walk-off [1] in the NOLM is difficult to control; the spectrum of the converted NRZ using the approach in [2] is not good for transmission due to the XPM-induced chirp; the SOA-based devices suffer from limited carrier recovery time.

Recently, we have demonstrated a delay-asymmetric nonlinear loop mirror (DANLM) for DPSK demodulation [7,8]. Tunable optical delay between two interference branches can be readily achieved in The DANLM. In this paper, we demonstrate bit-rate variable RZ-to-NRZ format conversion based on the DANLM. By tuning the pump wavelength, error-free format conversions at 10 Gbit/s and 12.5 Gbit/s have been simply achieved. The waveforms and the spectra of the converted NRZ-OOK signals are analyzed.

2. Experiment

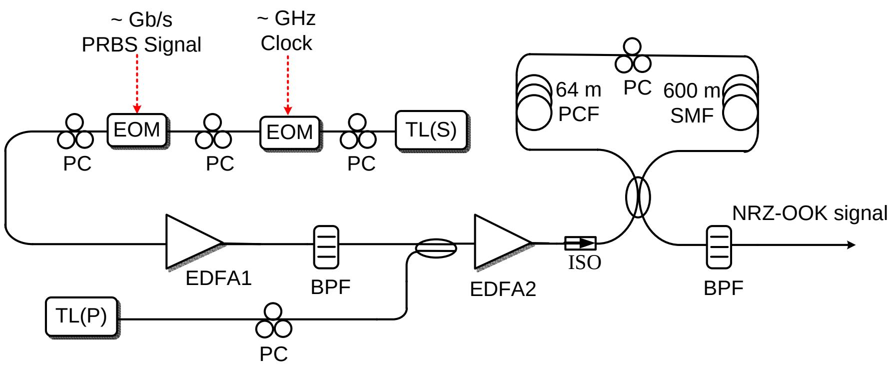


Fig. 1. Experimental setup of the delay-asymmetric nonlinear loop mirror (DANLM) for bit-rate variable RZ-to-NRZ format conversion. TL: tunable laser; EOM: electro-optic modulator; PRBS: pseudo random binary sequence; EDFA: erbium-doped fiber amplifier; PC: polarization controller; PCF: photonic crystal fiber; SMF: single mode fiber; BPF: bandpass filter; ISO: isolator.

Fig. 1. shows our experiment setup. A tunable laser at 1549.3 nm is used to generate a RZ-OOK signal (PRBS, 2^{31}-1) by employing two electro-optic modulators (EOMs), one for pulse carving and the other for intensity modulation. The signal passes through EDFA1 to facilitate control of the power ratio between the signal and the pump. The ASE noise from EDFA1 is filtered out by a BPF. The pump is produced by another tunable laser. It is combined with the signal through a 3 dB coupler and launched together to the DANLM after

amplification by EDFA2. A BPF is used at the output port of the DANLM to extract the converted NRZ-OOK signal at the idler wavelength.

3. Results and Discussion

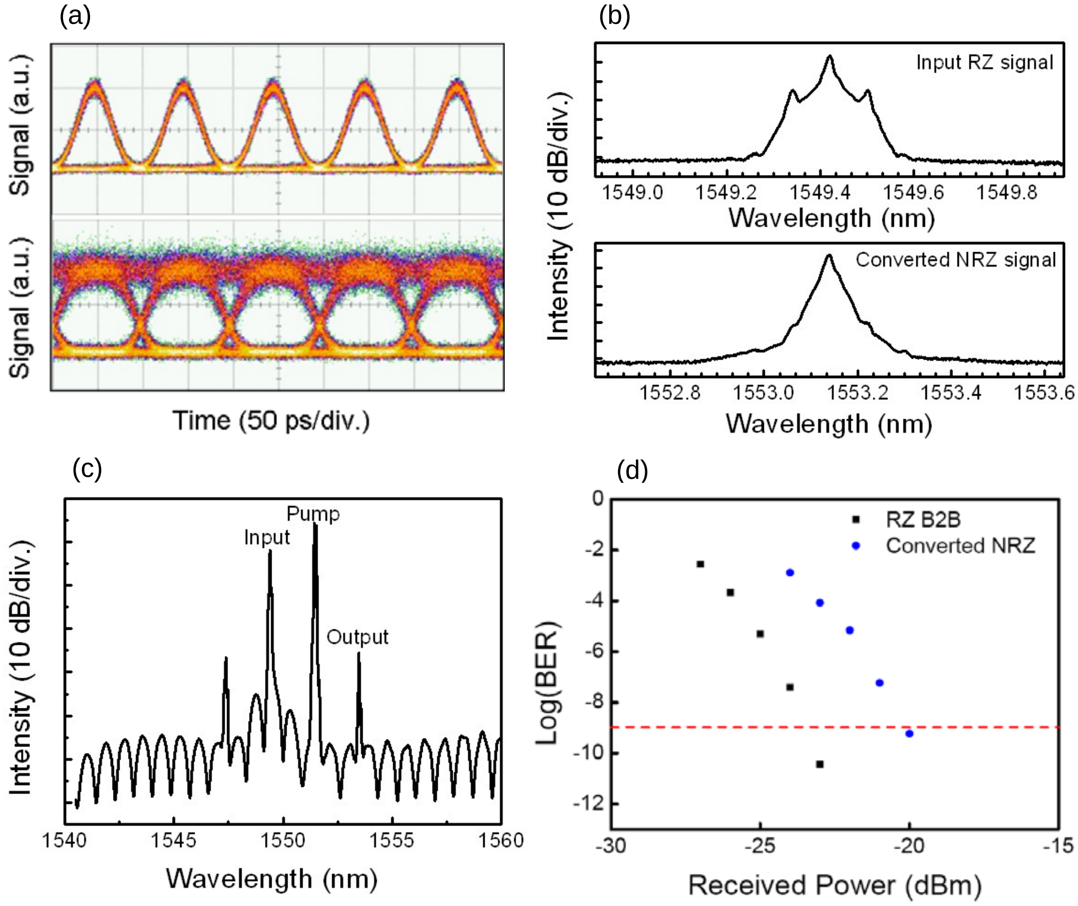
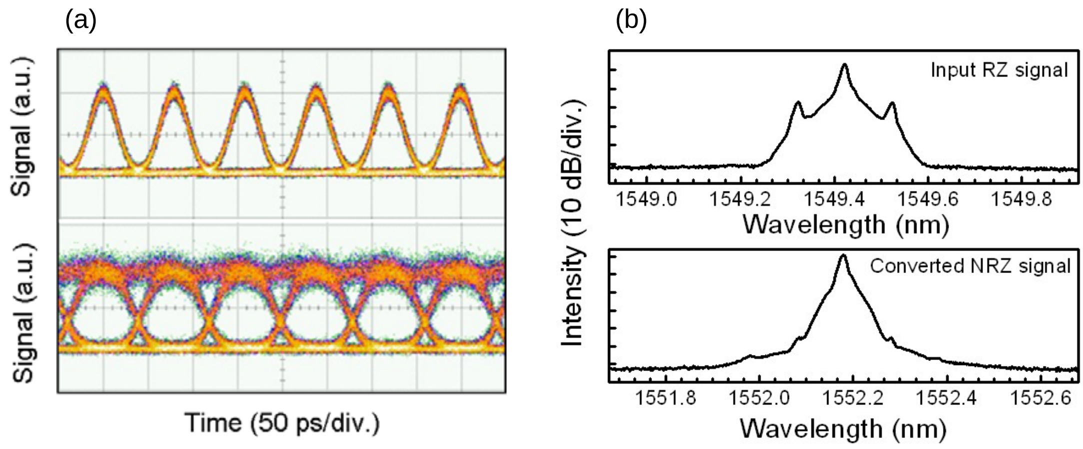


Fig. 2. (a) eye diagrams of the 10 Gbit/s input RZ-OOK signal (top) and the converted NRZ-OOK signal (bottom); (b) spectra of the 10 Gbit/s input RZ-OOK signal (top) and the converted NRZ-OOK signal (bottom); (c) corresponding optical spectrum showing four-wave mixing between the signal and the pump; (d) 10 Gbit/s BER measurement of the back-to-back RZ signal and the converted NRZ signal.

Fig. 2 plots the results of RZ-to-NRZ format conversion for 10 Gbit/s RZ-OOK input signal. The wavelength difference between the signal and the pump is ~2.5 nm as shown in Fig. 2 (c), introducing ~50 ps relative delay between the two counter-propagating branches of the DNALM. Hence, the two sidebands of the input RZ-OOK signal are suppressed as shown in Fig. 2 (b). The generation of the converted NRZ-OOK signal (shown in Fig. 2 (a)) thus follows. The noise at the output signal is caused by ASE noise in the EDFA and noises transferred from four-wave mixing and from interference inside the DANLM. Owing to the slight degradation, a power penalty of ~2.5 dB is observed at the error free detection level (BER=10^{-9}) as shown in Fig. 2 (d).



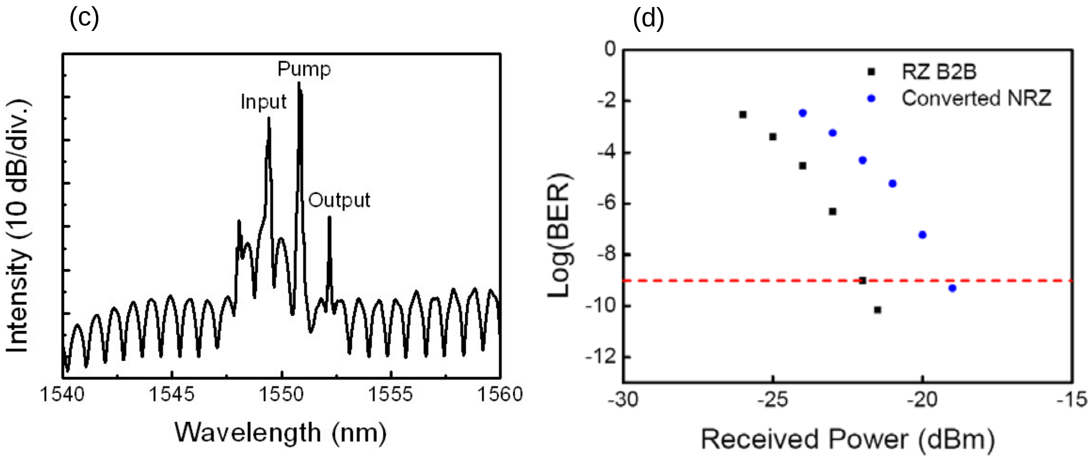


Fig. 3. (a) eye diagrams of the 12.5 Gbit/s input RZ-OOK signal (top) and the converted NRZ-OOK signal (bottom); (b) spectra of the 12.5 Gbit/s input RZ-OOK signal (top) and the converted NRZ-OOK signal (bottom); (c) corresponding optical spectrum showing four-wave mixing between the signal and the pump; (d) 12.5 Gbit/s BER measurement of the back-to-back RZ signal and the converted NRZ signal.

In order to demonstrate bit-rate variable operation of the DANLM for RZ-to-NRZ format conversion, a 12.5 Gbit/s RZ-OOK signal is used as the input. By tuning the pump wavelength, the spectral separation between the signal and the pump is changed to be ~2 nm, introducing ~40 ps relative delay between the two interferece branches to achieve the conversion. The results for 12.5 Gbit/s input RZ-OOK signal are depicted in Fig. 3. The measured BER performance in Fig. 3(d) shows that error-free detection can be obtained at a received power level of -19 dBm. A power penalty of ~2.7 dB is observed.

The DANLM-based RZ-to-NRZ format conversion can be operated over a large range of bit rates. For operation at a high bit rate, the SMF can be replaced by one with a smaller dispersion, thus keeping a sufficiently large spectral spacing between the pump and signal to facilitate filtering of the output NRZ signal. Pulse broadening inside the loop can also be reduced. Other types of format conversion, such as NRZ to pseudo-RZ format conversion, can also be achieved at variable bit rates using the DANLM.

4. Conclusions

Bit-rate variable RZ-to-NRZ format conversion has been demonstrated at 10 and 12.5 Gbit/s using the delay-asymmetric nonlinear loop mirror. The working principle of the approach is by tunable wavelength conversion and dispersion-induced relative delay together with interference between the counter-propagating branches inside the DANLM. Error free operations have been obtained for both 10 and 12.5 Gbit/s format conversion with power penalties of ~2.5 and ~2.7 dB, respectively.

Acknowledgment

This work is supported by the RGC of Hong Kong through projects CUHK 415907, 416808, and 416509

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