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RESEARCH ARTICLE

All-optical format conversion from RZ-QPSK to NRZ-QPSK

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Abstract We proposed and demonstrated an all-optical format conversion from return-to-zero quadrature phase shift keying (RZ-QPSK) to non-return-to-zero QPSK (NRZ-QPSK) at 40 Gb/s using a half bit delay interferometer (DI). Due to the constructive interference in the DI, the format conversion was achieved with the phase information preserved. *Q* penalty for the format conversion was less than 1.8 dB for *I* and *Q* data.

Keywords format conversion, fiber optics communications, modulation

1 Introduction

All-optical modulation format conversion is an essential function in providing flexible management and interface for optical time division multiplexed (OTDM) and wavelength division multiplexed (WDM) networks [1]. Recently, the phase shifted keying (PSK) modulation format has attracted more attention, due to its improved performance and robustness to transmission nonlinearities and better receiver sensitivity with balanced detection compared with the conventional on-off keying (OOK) format [2]. On top of the binary PSK (BPSK) data format, the quadrature phase shift keying (QPSK) format has additional advantages, such as lower symbol rate, higher spectral efficiency and better dispersion tolerance [3,4]. In the past, various conversion schemes for OOK and DPSK had been proposed and demonstrated in many papers [5–7]. To our best knowledge, there is no demonstration between different types of QPSK format until now.

In this paper, we proposed and demonstrated an all-optical format conversion from return-to-zero quadrature phase shift keying (RZ-QPSK) to non-return-to-zero QPSK (NRZ-QPSK) at 40 Gb/s using a half bit delay interferometer (DI). Thanks to constructive interference, the amplitude of the input RZ-QPSK was constructively extended to NRZ-QPSK format, while the phase information was kept unchanged. Results show the conversion with a reasonable *Q* penalty less than 1.8 dB.

2 Principle

The scheme of experimental setup is shown in Fig. 1(a). The continuous wave (CW) beam from a distributed-feedback (DFB) laser was modulated by two Mach-Zehnder modulators (MZMs) to generate a RZ-DPSK signal, which was further modulated by a phase modulator (PM) to generate the RZ-QPSK signal. The first MZM and the PM were driven by the 20 Gb/s data and (PRBS 215-1) from a pattern generator. The RF delay was used to make sure that the two signals were in phase. A span of 1 km single mode fiber (SMF) was utilized to achieve a de-correlation between *I* and *Q* data. A tunable optical delay line (ODL) was used to align the two data. Two polarization controllers (PCs) were used to ensure the best modulation performance. A DI (DI 1) with half bit delay (40 G FSR) and a 0.3 nm bandwith filter were used to achieve the conversion from RZ-QPSK to NRZ-QPSK. A subsequent DI 2 with one bit delay (20 G FSR) was used to demodulate the converted NRZ-QPSK. The final results can be observed by Agilent 86100C digital sampling oscilloscope.

The working principle is presented in Fig. 1(b). By controlling the working condition of the DI 1, the original RZ-QPSK signal (the red curve) is constructively interfere with the signal after a half bit delay (the dash green curve). The blue curve is the converted NRZ-QPSK signal at the constructive output of DI 1. For the phase transit part of the RZ-QPSK signal, the original and the delayed pulses experience destructive interference under the constructive condition, resulting in dip at every phase transitions of the original pulses. The depth of the dips is proportional to the

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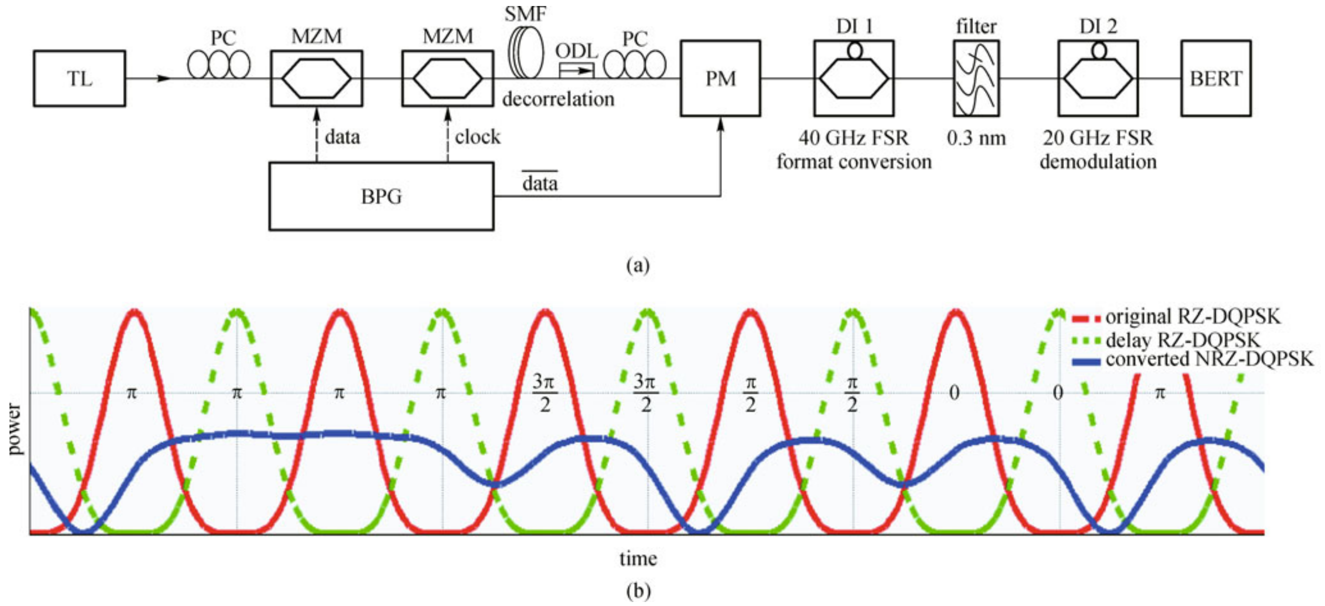

Fig. 1 Experimental setup (a) and operation principle (b) for format conversion from RZ-QPSK to NRZ-QPSK

phase differences between adjacent pulses, as indicated in Fig. 1(b).

3 Experimental results

Experimental results show that the proposed converter works well for the QPSK signal. The measured spectra before and after the conversion, as well as the corresponding demodulated I and Q data are shown in Figs. 2(a) to 2(f), respectively. The eye diagrams of the proposed format conversions are measured and presented in Fig. 3. The first row in Fig. 3 indicates the results with a regular commercial QPSK modulator and the corresponding demodulated I and Q data. The second row shows the original RZ-QPSK signal and corresponding demodulated signals. The third row shows converted NRZ-QPSK signal and corresponding demodulated signals. Results show that the RZ-QPSK signal can be successfully converted to the NRZ-QPSK signal, with two-level different amplitude dips appearing at the phase transition. The dips, which look the same as the NRZ-QPSK signal generated from a commercial IQ modulator, were due to the destructive interference caused at the original adjacent bits with different phase information. After demodulating the converted RZ-QPSK with the DI 2, the obtained results from a single-end detector are shown in Fig. 3.

Due to the available experimental facility, no precoding was applied to the original QPSK signal. Hence, the format conversions performance of the scheme cannot be characterized by measuring the bit-error-rate (BER). Instead, the Q factors of the converted and the back-to-back NRZ-QPSK signals were measured to characterize the conversion performance. The Q factor penalty was calculated, and is shown in Table 1. It can be seen from the results that the Q penalty for the format conversion was less than 1.8 dB for the demodulated signals.

4 Conclusions

In conclusion, we successfully demonstrated an all-optical format conversion for QPSK format based on a DI. By extending the constructive interference from OOK to QPSK, the conversion from RZ-QPSK to NRZ-QPSK at 40 Gb/s can be achieved with a reasonable Q penalty, which was less than 1.8 dB. The format conversion from the RZ-QPSK signal to NRZ-QPSK signal can be achieved successfully for the 33%, 50% and 66% RZ-QPSK signal based on the constructive interference in the DI with a half bit delay. Too low or large duty cycle RZ-QPSK signals induce large fluctuation on the amplitude of the converted NRZ-QPSK signals.

Table 1 Q factor penalty results for the QPSK format conversions for I and Q data

demodulated signal	I_{AMI}	I_{DB}	Q_{AMI}	Q_{DB}
Q penatly	1.71 dB	1.28 dB	1 dB	0.74 dB

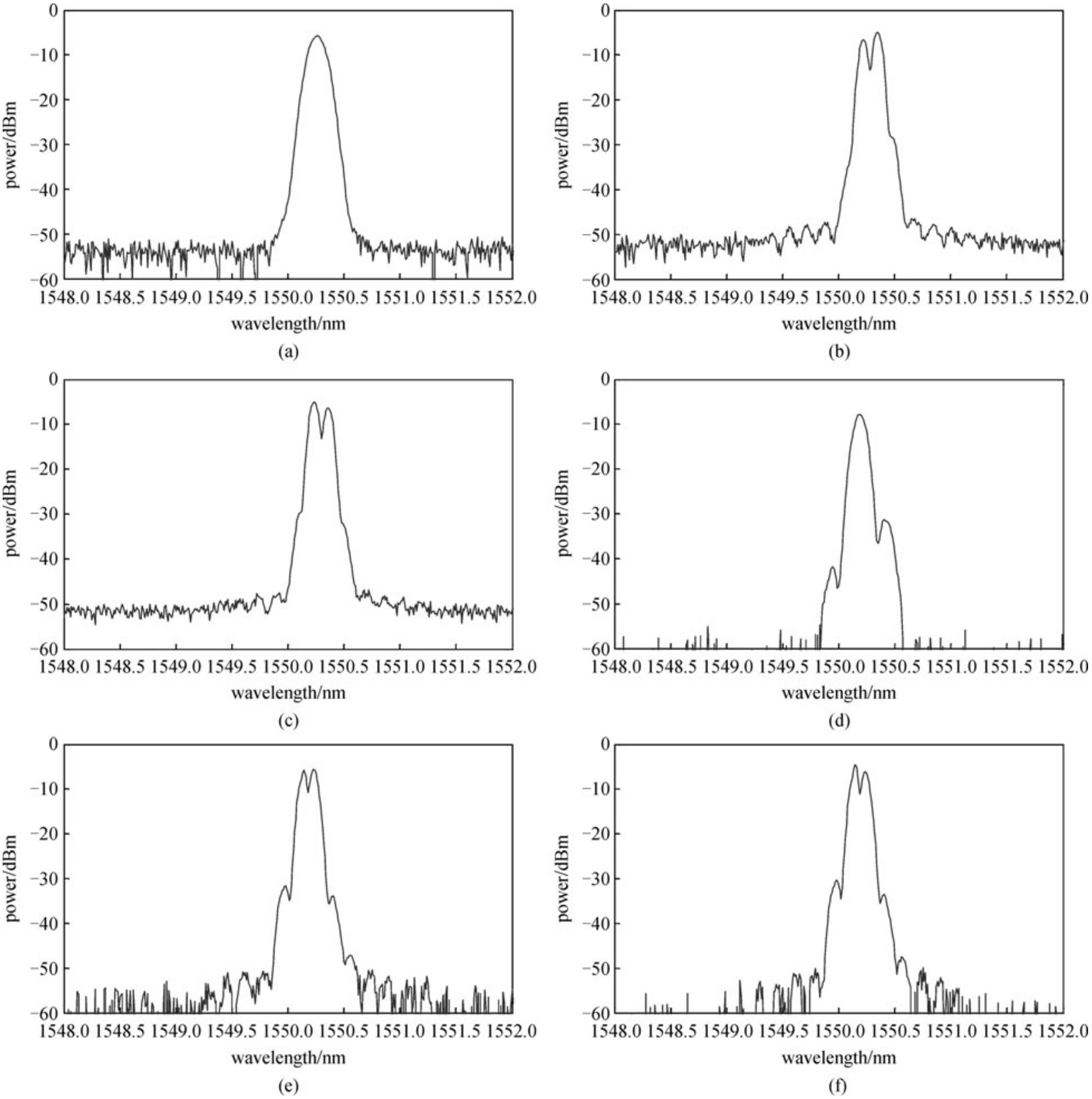

Fig. 2 Measured spectrum for format conversion. (a)–(c) Spectrum of original input RZ-QPSK signal, demodulated *I* and *Q* signal; (d) – (f) spectrum of converted NRZ-QPSK signal, demodulated *I* and *Q* signals of NRZ-QPSK

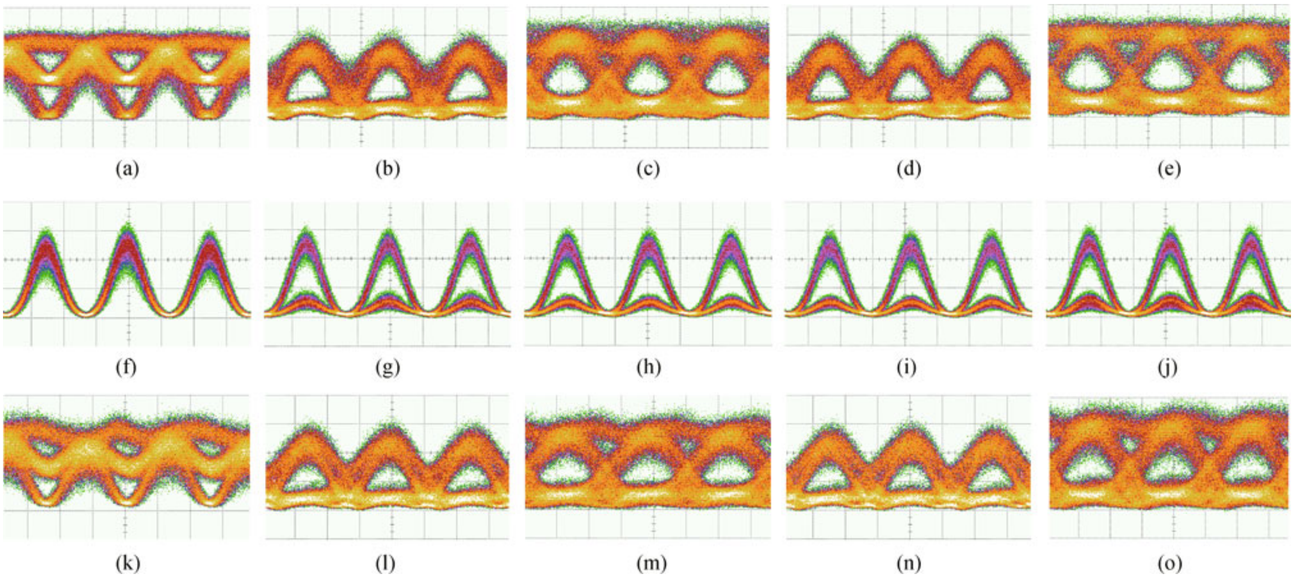

Fig. 3 Eye diagrams of (a) back to back NRZ-QPSK signals modulated by a regular commercial QPSK modulator and the demodulated; (b) alternative mark inversion (AMI); (c) duobinary (DB) signal of the *I*; (d) AMI and (e) DB signal of the *Q* of original NRZ-QPSK. Eye diagrams of (f) original RZ-QPSK signals and the demodulated; (g) AMI and (h) DB signal of the *I*; (i) AMI and (j) DB signal of the *Q* of original RZ-QPSK. Eye diagrams of (k) converted NRZ-QPSK signals and the demodulated; (l) AMI; (m) DB signal of the *I*; (n) AMI and (o) DB signal of the *Q* of converted NRZ-QPSK

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