Mitigation of Pattern-induced Degradation in SOA-Based All-Optical OTDM Demultiplexers by using RZ-DPSK Modulation Format

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Abstract We propose and demonstrate the employment of RZ-DPSK modulation format in OTDM systems to mitigate the pattern-induced degradation in SOA-based all-optical demultiplexers. Experimental results show superior performance of RZ-DPSK over RZ-OOK with negligible power penalty.

Introduction

In high-speed optical time-division multiplexed (OTDM) systems, semiconductor optical amplifier (SOA)-based interferometric switches are attractive as they provide narrow switching window with much less switching power than fiber-based devices. Different configurations for SOA-based interferometric switches, including terahertz optical asymmetric demultiplexer (TOAD), ultrafast nonlinear interferometer (UNI) and SOA Mach-Zehnder interferometer (SOA-MZI) [1-3] were proposed and demonstrated previously. However, employing the conventional return-to-zero on-off keying (RZ-OOK) modulation format with large signal power suffers from pattern dependent gain modulation in the SOA, which further leads to severe pulse-to-pulse intensity fluctuation. Thus, error-free performance could only be obtained by reducing the input signal power, at the expense of degraded optical signal-to-noise ratio (OSNR). In addition to the gain transparent approach [4], OTDM with constant-intensity modulation format is a feasible solution to eliminate the pattern dependent distortion. Demultiplexing of 80-Gbit/s OTDM signal with pulse position modulation (PPM) was demonstrated using UNI [5] and the tolerance against the pattern effect was reported. In this paper, we propose to employ return-to-zero differential phase-shift-keying (RZ-DPSK) as the data modulation format in OTDM systems. RZ-DPSK offers constant pulse intensity, as a consequence, it avoids the pattern dependent gain modulation in SOA at high input signal power. Thus, data pattern effect is alleviated, enabling much higher aggregate data rate with narrow pulses. This paper reports, for the first time, high-speed OTDM demultiplexing using TOAD with RZ-DPSK modulation format. Negligible pattern-induced degradation with little power penalty (< 0.4dB) is achieved.

Experiment and result

Fig. 1 shows the experimental setup. A mode-locked fiber laser (MLFL) was used as a 10.61-GHz optical pulse source. Owing to the poor pulse-to-pulse coherence of the MLFL output, the optical pulses from the MLFL were regenerates by an interferometric wavelength converter. The converted optical pulse stream had a FWHM pulsewidth of about 10 ps and at a center wavelength of 1547 nm. The extinction ratio was better than 33 dB. The resultant RZ optical pulse stream was fed into an optical phase modulator, in which the SOA (Samsung OA40B3A) was driven by a DC bias current of 80mA. A 10.61-GHz control optical pulse stream, with a pulse energy of about 150 fJ, was injected into the TOAD to extract a 10.61-Gb/s data signal from the aggregate 42.44 Gbit/s data stream. The DPSK modulated optical pulse stream was then amplified and time-division multiplexed, via fiber delay lines, to an aggregate data rate of 42.44 Gbit/s. The all-optical time-division demultiplexer was implemented by a terahertz optical asymmetric demultiplexer (TOAD), in which the SOA (Samsung OA40B3A) was driven by a DC bias current of 80mA. A 10.61-GHz PIN receiver was performed in this experiment. Finally, the bit-error-rate (BER) performance of the detected signal was examined by an error detector. The BER performance of the demultiplexed signals is depicted in Fig. 2. The input signal power of the aggregate 42.44-Gb/s RZ-DPSK data stream was about 2 dBm and the chosen PRBS length for a single OTDM channel was 2^2^4^-1. The back-to-back receiver sensitivity (at a BER of 10^-9) of the 10.61-Gb/s RZ-DPSK signal was about ~20.7 dBm, while the power penalties of the four demultiplexed OTDM channels varied from 0.2 to 0.4 dB only. The eye diagram of a demultiplexed signal shown in the inset indicated a clear eye opening with an extinction ratio better than 15 dB. Moreover, the peak power fluctuation of the optical pulses was very small, as the pattern-dependent gain modulation of the SOA was
mostly alleviated by using the input RZ-DPSK signal.

Fig. 2 Bit-error-rate performance of the demultiplexed 10.61-Gbit/s RZ-DPSK channels.

Fig. 3 shows the BER curves for the demultiplexed signal with RZ-DPSK modulation format at different sequence lengths, namely $2^7-1$, $2^{15}-1$ and $2^{31}-1$, and they were found to be very close to the baseline (back-to-back) curve, with only 0.2-dB power penalty. This proved the effectiveness of using RZ-DPSK modulation format to mitigate the pattern-induced degradation in TOAD. To investigate and compare the advantage of using RZ-DPSK over the conventional RZ-OOK modulation format, we have also performed the same experiment with 10.61-Gb/s RZ-OOK data signal, using the same TOAD configuration. The BER curves for the demultiplexed signal with RZ-OOK modulation format were also presented in the inset of Fig. 3, showing about 3-dB power penalty and the existence of error floor at low BER for the cases with sequence lengths of $2^{15}-1$ and $2^{31}-1$.

We have also examined the dependence of the receiver sensitivity (at a BER of $10^{-9}$) of the demultiplexed RZ-DPSK signal on the input signal power level. Significant improvement in the receiver sensitivity was observed (see the solid circles in Fig. 4), as the input signal power was gradually increased. This was due to the improved OSNR for the output signal, in addition to the alleviated pattern dependent degradation. The receiver sensitivity degradation at the low input signal power could be attributed to the relatively large fixed control pulse intensity, as the control pulse power was kept constant. This led to extinction ratio degradation in the demultiplexed signal. Such degradation could be further alleviated by optimising the control pulse power for different signal power level. For the case of using RZ-OOK signal, a U-shaped input power dependence for RZ-OOK signal was observed, as shown in Fig. 4. The induced power penalty was at least 3 dB or above. At higher input signal power, pattern dependent degradation in the gain-saturated SOA inside the TOAD severely corrupted the demultiplexed signal, in spite of the improvement in the output OSNR. As a result, it was clearly shown that RZ-DPSK modulation format has much better input power dynamic range over the RZ-OOK modulation format in SOA-based all-optical demultiplexing in OTDM systems.

Fig. 3 Bit error rate (BER) measurement demultiplexed RZ-DPSK signal of 10.61-Gbit/s PBRS with lengths of $2^7-1$, $2^{15}-1$ and $2^{31}-1$. Solid symbols: back-to-back; Open symbol: demultiplexed channel. Inset: all-optical demultiplexing with input RZ-OOK modulation format. (Signal pulse energy: 40 fJ, control pulse energy: 150 fJ)

Fig. 4 Receiver sensitivity at BER of $10^{-9}$ as a function of 42.44-Gbit/s aggregate signal power with RZ-DPSK (solid symbol) and RZ-OOK (open symbol) modulation format respectively.

Summary
In this paper, RZ-DPSK modulation format has been investigated for all-optical OTDM demultiplexing using TOAD. The results show superior performance and robustness over RZ-OOK modulation format in terms of its tolerance against the pattern dependent degradation and the improvement of output OSNR.

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References