Patterning Effect Avoidance of SOA-based Demultiplexer in 80-Gb/s OTDM System Using RZ-DPSK Modulation Format

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Abstract
The use of RZ-DPSK modulation format in OTDM systems is proposed to avoid patterning effects in SOA-based all-optical demultiplexers. Demultiplexing of 80-Gb/s RZ-DPSK OTDM signal was successfully demonstrated with high input power dynamic range.

1 Introduction

In high-speed optical time division multiplexed (OTDM) systems, each channel has to be extracted from an ultra-high speed aggregate signal stream at bit rates up to hundreds of gigabits per second. This imposes stringent requirement for OTDM demultiplexers to have very narrow transmission windows of a few picoseconds. Among the existing OTDM demultiplexing techniques, Semiconductor optical amplifier (SOA) based interferometric switches have attracted much research attention because they are small in size and are suitable for system integration. Besides, they require little switching power to completely switch out the desired OTDM channel. Different configurations for SOA-based interferometric switches, including terahertz optical asymmetric demultiplexer (TOAD), ultrafast nonlinear interferometer (UNI) and SOA Mach-Zehnder interferometer (SOA-MZI) have been proposed and demonstrated previously [1-3]. However, in these conventional methods, the incoming signal was mostly encoded in return-to-zero on-off-keying (RZ-OOK) modulation format. Thus, when the SOA was operated in saturation regime, pattern dependent modulation for both the phase and the gain in the SOA led to severe pulse-to-pulse intensity fluctuation and poor extinction ratio. 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).

To solve this problem, we propose to employ return-to-zero differential phase-shift-keying (RZ-DPSK) as the data modulation format in OTDM systems. Since RZ-DSPK offers constant pulse intensity, it can avoid the pattern dependent gain modulation in the SOA. As a result, better tolerance against patterning at high input signal power can be achieved and thus enables higher aggregate data rate with narrow pulses. In this paper, we demonstrate and characterize all-optical OTDM demultiplexing of 80-Gb/s RZ-DPSK signals using TOAD with effective mitigation of pattern-induced degradation.

2 Experiments and Results

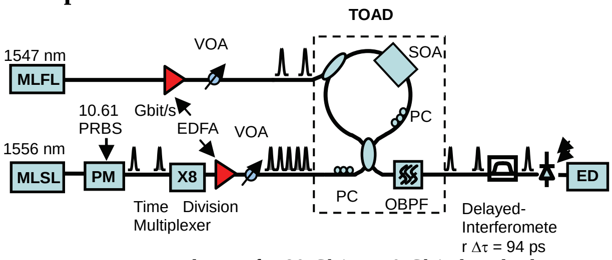

Fig. 1. Experimental setup for 80-Gb/s to 10-Gb/s demultiplexing.

Fig. 1 shows the experimental setup. A mode locked semiconductor laser (MLSL) was used as the signal pulse source. The generated optical pulse stream from MLSL had a FWHM pulsewidth of about 1.5 ps at a center wavelength at 1556 nm. The RZ optical pulse stream was then fed into an optical phase modulator (PM), modulated by a 10.61-Gbit/s pseudo-random bit sequence (PRBS) for differential phase-shift-keying (DPSK) encoding. The modulated optical pulse stream was then amplified and time-division multiplexed, via fiber delay lines, to an aggregate data rate of 84.88-Gbit/s. The all-optical time division demultiplexer was implemented by a terahertz optical asymmetric demultiplexer (TOAD), in which the SOA was driven by a DC bias current of 80 mA and was operated at 20^{o}C. To control the input power level injected into the TOAD, a variable optical attenuator (VOA) was inserted. A 10.61-GHz control optical pulse stream, with pulse energy of about 150 fJ, was generated by a mode locked fiber laser (MLFL) injected into the TOAD to extract a 10.61-Gb/s data signal from the 84.88-Gb/s aggregate data stream. The demultiplexed signal was filtered out with a 1-nm optical bandpass filter (OBPF), and sent to a fiber-based delayed-interferometer (DI), with a relative delay of 94 ps, for DPSK demodulation. Single arm detection using a 10-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 (ED).

The insets in Fig. 2 shows the eye-diagrams of the eight demultiplexed OTDM channels detected by a 45-GHz-PIN detector, with a PRBS length of 2^{31}-1. Clear eye opening was obtained. The small peak fluctuation and uneven spacing between channels were attributed to the imperfect power splitting ratio and delay time in the 40-Gb/s to 80-Gbit/s section of the multiplexer. Fig. 2 shows the BER performance of the demultiplexed signals.

The power penalties of the eight demultiplexed OTDM channels varied from 2.3 to 2.5 dB. The possible sources for the induced penalty included the imperfection of the multiplexer/demultiplexer, such as the deviation of the coupling ratio of the optical coupler and the polarization instability. Impairments could also arise from the multiplexing where the relatively broad pulsewidth and the insufficient pulse extinction ratio might have induced phase-to-amplitude conversion during the multiplexing.

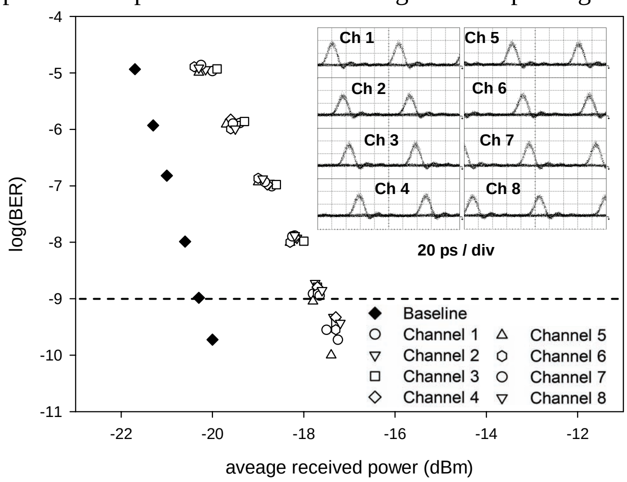

Fig. 2. Bit-error-rate performance of the demultiplexed 10.61-Gbit/s channels from 80-Gb/s OTDM signals. Solid symbol: back-to-back; open symbol: demultiplexed 10.61-Gbit/s channels. PRBS length: 2^{31}-1

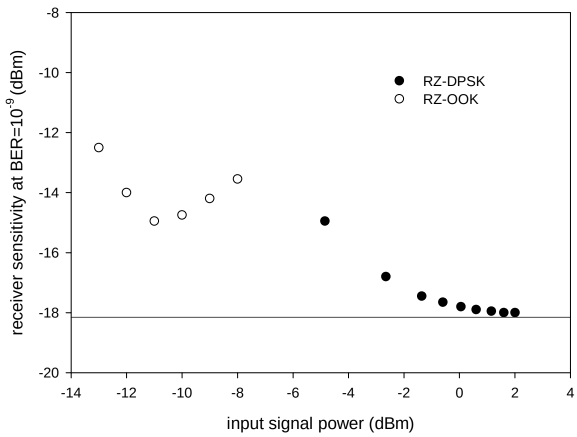

Fig. 3. Receiver sensitivity at BER at 10^{-9} as a function of 84.88-Gbit/s aggregate signal power with RZ-DPSK (solid symbol) and RZ-OOK (open symbol) modulation format respectively. PRBS length: 2^{31}-1

Fig. 3 shows the dependence of the receiver sensitivity of the demultiplexed signal at a BER of 10^{-9} on the input signal power level for both the RZ-DPSK and RZ-OOK modulation formats, using the same TOAD configuration, for fair comparison. A U-shaped input power dependence for RZ-OOK was observed. For input signal power higher than -11 dBm, large power penalty was induced due to the signal corruption caused by pattern dependent degradation in the gain saturated SOA inside the TOAD, in spite of the improvement in the output OSNR. On the other hand, receiver sensitivity was improved along with increasing input signal power for RZ-DPSK, due to the improved OSNR of the output signal, in addition to the alleviated pattern dependent degradation associated with gain saturation of the SOA in the TOAD. Obviously, the input power dynamic range of RZ-DPSK modulation format is much better than that of RZ-OOK modulation format for all-optical demultiplexing in OTDM systems.

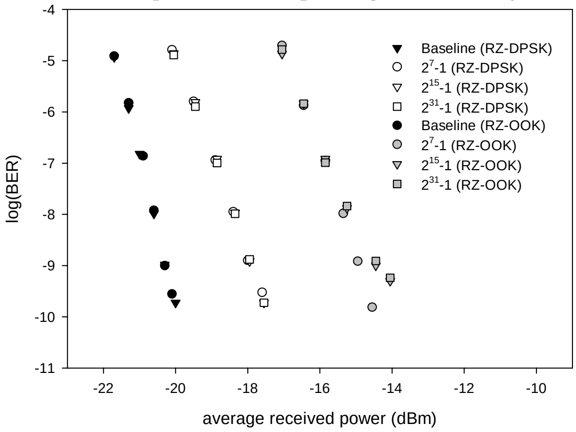

Fig. 4. Bit error rate (BER) measurement of 10.61-Gbit/s PRBS with lengths of 2^{7}-1, 2^{15}-1 and 2^{31}-1. Black symbol: proposed back-to-back; White symbol: demultiplexed channels for RZ-DPSK; Grey symbol: demultiplexed channels for RZ-OOK. (Signal pulse energy: 20 fJ, control pulse energy: 150 fJ)

To further verify the tolerance against pattern dependent degradation by using RZ-DPSK rather than RZ-OOK, BER performance of one of the demultiplexed channels was also examined for different PRBS pattern lengths, namely 2^{7}-1, 2^{15}-1 and 2^{31}-1, for both RZ-DPSK and RZ-OOK formats. The results are depicted in Fig. 4. It is shown that the BER curves for the RZ-DPSK signal at different PRBS pattern lengths are very close to each other. Nevertheless, the BER curves of the RZ-OOK case shows variation in the BER performance at different pattern lengths; and at least 5.5-dB power penalty was observed. BER error floor was also observed for both pattern lengths of 2^{15}-1 and 2^{31}-1. This further proved the effectiveness of using RZ-DPSK modulation format to mitigate the pattern-induced degradation in TOAD.

3 Conclusion

In this paper, all-optical demultiplexing of an 80-Gb/s RZ-DPSK OTDM signal via a TOAD has been demonstrated and characterized. The results show superior performance and robustness over RZ-OOK modulation format in terms of its tolerance against the pattern dependent degradation, and the improved output OSNR. With the availability of narrow optical pulse source, RZ-DPSK is a more feasible and robust modulation format for future ultra-high speed OTDM systems. This work was partially supported by a grant from the Research Grants Council of Hong Kong SAR, China, (Project No. CUHK4386/02E).

4 References

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