All-optical RZ-DPSK OTDM De-Multiplexing using Optical Parametric Amplifier with a Clock-Modulated Pump

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Abstract

RZ-DPSK OTDM demultiplexing from 40 to 10Gbps is achieved using OPA with clock-modulated pump. <1.3-dB penalty and ~28-dB gain were achieved for four demultiplexed channels.

Introduction

Optical time-division multiplexing (OTDM) technology is a promising technique to realize ultra-fast optical transmission systems. A variety of on-off keying (OOK) OTDM de-multiplexing schemes have been proposed and experimentally demonstrated based on highly nonlinear fiber (HNLF) [1,2], semiconductor optical amplifier (SOA) [3], or electroabsorption modulator [4]. Among them, the scheme based on an optical parametric amplifier (OPA) using a pulse pump [2] is quite useful to the transmission systems, thanks to its capability of de-multiplexing the OTDM data while simultaneously offering power amplification.

Recently, phase modulated formats, such as return-to-zero differential phase shift keying (RZ-DPSK), have attracted lots of attentions, especially for the long-haul transmission systems. It is desirable to explore the all-optical de-multiplexing scheme for RZ-DPSK OTDM systems [5, 6]. In this paper, we propose and experimentally demonstrate an all-optical RZ-DPSK OTDM de-multiplexing scheme using an OPA with a sinusoidal-clock-modulated pump. In the experiment, 40-Gb/s RZ-DPSK OTDM signal is de-multiplexed to 10-Gb/s data with around 28-dB gain and less than 1.3-dB power penalty for each de-multiplexed channel. The proposed scheme is potentially low-cost and easy to implement, as only a sinusoidal clock is employed for pump modulation.

Operation Principle

Since the parametric gain is exponentially dependent on the pump power in OPA, the input signal of OPA experiences a selective amplification with a narrow gating window, when the pump is intensity-modulated by a sinusoidal clock. If the input is CW light, input light can be carved into chirped Gaussian pulses after OPA [5]. When the input of OPA is an OTDM signal, with sufficiently narrow gating window, one tributary channel can be selectively amplified, and de-multiplexed from input OTDM signal. Because of the modulation transparency characteristics of the parametric process, the phase information could be preserved in this process. Therefore, it also can be applied in the de-multiplexing scheme for RZ-DPSK OTDM systems.

Experiment and results

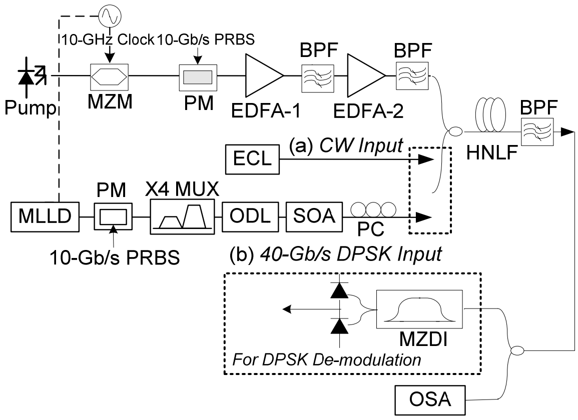

Figure 1: Experiment setup

Fig. 1 shows the experiment setup. An external cavity laser (ECL) at 1550.5 nm was used as pump, which is close to the zero dispersion wavelength of the HNLF. The pump light was first intensity-modulated by a Mach-Zehnder modulator driven by a 10-GHz sinusoidal clock. Then it was phase-modulated by the following phase modulator driven by 10-Gb/s 2^{31}-1 PRBS data to suppress the stimulated Brillouin scattering (SBS) in the nonlinear fiber. After power amplification through two cascaded EDFAs, the pump light was combined with input signal by a 10-dB coupler, and then fed into a piece of HNLF. The HNLF used in the experiment has a zero dispersion wavelength of 1549.1 nm, dispersion slope of 0.02 ps/nm^2/km, and nonlinear coefficient γ of 30 W^{-1}km^{-1}. The power of pump launched into HNLF was measured as around 28 dBm. After the HNLF, a tunable filter with bandwidth of around 1 nm was used to filter out the amplified and gated signal. In the case with input of 40-Gb/s RZ-DPSK OTDM, the filtered signal was fed to a Mach-Zehnder delay interferometer (MZDI) and a following balanced photo-detector for phase de-modulation.

To characterize the gating window in the OPA with a clock-modulated pump, a CW light from an ECL was at first used as an input signal. It was set at 1525.2 nm, which is the gain peak of the OPA. The CW's power launched to the HNLF was measured as around -19 dBm. After HNLF, the input CW light was

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carved to a narrow pulse train because of the selective application in the OPA. The pulse shape was measured using an optical auto-correlator, as shown in Fig. 2(a). Around 12.4-ps FWHM pulse-width was observed. The corresponding optical spectrum is shown in Fig. 2(b) with measured spectrum bandwidth of around 0.45 nm.

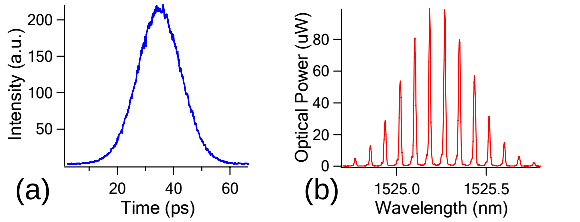

Figure 2: (a) measured auto-correlation trace and (b) the corresponding spectrum with CW input

With the gating window of around 12.4 ps, it is possible to de-multiplex 40-Gb/s RZ-DPSK OTDM signal to 10-Gb/s tributaries. To demonstrate the RZ-DPSK OTDM de-multiplexing scheme, the input signal was replaced by a 40-Gb/s RZ-DPSK OTDM data. As shown in Fig. 1, a semiconductor mode-locked laser (MLLD) was used to generate a 10-GHz optical pulse train at wavelength of 1525 nm with measured pulse-width of around 2 ps. The optical pulse train was then modulated by a phase modulator using another 10-Gb/s 2^{31}-1 PRBS data, and multiplexed to 40-Gb/s OTDM through an OTDM multiplexer. Because of the lack of S-band EDFA, a SOA (BOA1004, Convega) was used to amplify the 40-Gb/s data at 1525nm. A tunable optical delay line was inserted to adjust the relative time-offset between pump and input signal to selectively de-multiplex different channels. The launched power of 40-Gb/s OTDM to HNLF was measured as -19 dBm.

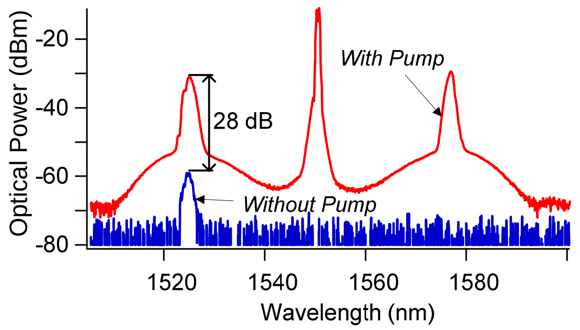

Figure 3: Measured optical spectra with/without pump after HNLF when the input was 40-Gb/s RZ-DPSK OTDM signal

The optical spectra after HNLF with and without pump were measured and shown in Fig. 3. A 28-dB gain was observed for the input signal. To assess the performance of the proposed RZ-DPSK OTDM de-multiplexer, the bit-error-rate (BER) of original input 10-Gb/s and the de-multiplexed four 10-Gb/s RZ-DPSK tributaries were measured and shown in Fig. 4.

It shows that, less than 1.3-dB power penalty at BER of 10^{-9} was obtained for all of the de-multiplexed four tributaries. The power penalty should be attributed to the chirp induced by the SOA and the degradation caused by the phase modulation in the pump. The eye diagrams of the input RZ-DPSK at 10 Gb/s and 40 Gb/s, and one de-multiplexed channel (CH1) after de-modulation are shown in Fig. 5.

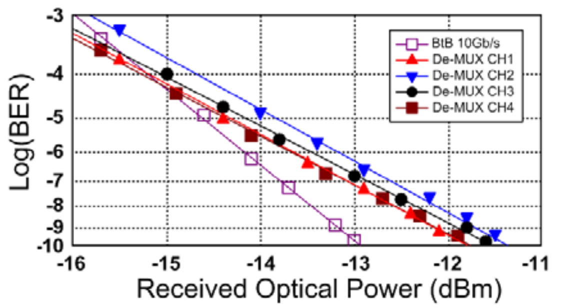

Figure 4: Measured BER curves for the input 10-Gb/s RZ-DPSK and de-modulated four 10-Gb/s RZ-DPSK channels after OPA

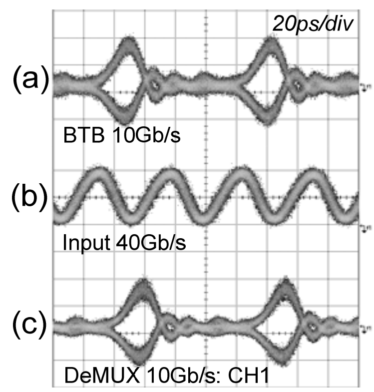

Figure 5: Measured eye diagrams of (a) de-modulated back-to-back 10-Gb/s RZ-DPSK, (b) input 40-Gb/s RZ-DPSK, and (c) de-modulated 10-Gb/s RZ-DPSK (CH1) after de-multiplexing

Conclusions

All-optical de-multiplexing for RZ-DPSK OTDM signal is simply achieve through an OPA with a sinusoidal-clock-modulated pump. Less than 1.3-dB power penalty and around 28-dB gain were obtained for all of the four de-multiplexed channels from input 40-Gb/s RZ-DPSK OTDM.

References

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