All-Optical NRZ-to-RZ Format Conversion based on Optical Parametric Amplifier

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Abstract: We demonstrate a 10Gb/s modulation-format conversion from nonreturn-to-zero to return-to-zero using pulsed-pumping optical parametric amplifier. The relationship between the gain and the output pulsewidth is investigated. Power penalty is improved by >3dB after the conversion.

I. Introduction

The two standard data formats, return-to-zero (RZ) and nonreturn-to-zero (NRZ) have been highly recommended to be employed in all-optical networks with a combination of optical-time-division multiplexing (OTDM) and wavelength-division multiplexing (WDM). It is widely recognized that the NRZ data format is usually employed in WDM networks requires less bandwidth per channel, while the RZ data format can be adopted to increase the total transmission capacity in OTDM networks with a better receiver performance [1]. Previous research effort in exploring various all-optical techniques for NRZ-to-RZ conversion include injection locking of a Fabry-Perot laser diode (FPLD) [2], four-wave-mixing (FWM) in semiconductor optical amplifier (SOA) [3] and spectral filtering of an cross phase modulation (XPM) broadened signal spectrum [4]. However, the above schemes suffer from several constraints, for example, operating bit-rate is limited by the slow carrier recovery time of FPLD and SOA, phase information is lost in XPM with no gain. These problems can be overcome by employing fiber-based optical parametric amplifier (OPA). OPA-based conversion can be accompanied by its large net gain, flexible gain bandwidth and ultra-fast response time. Also, the signal phase information can be preserved. In addition, with the use of pulsed-pumping scheme, one can obtain an even wider gain spectrum due to its high peak pump power and a relatively short fiber with less severe zero-dispersion wavelength λ_0 fluctuation [5], [6].

In this paper, we utilize the merits of pulsed-pump OPA to convert NRZ signals to RZ counterparts over a wide gain spectrum. Relationship between parametric gain and pulsewidth is experimentally analyzed and measurement of bit-error-rate (BER) has been recorded at both signal and idler wavelengths.

Fig. 1 demonstrates the operating principle of the data format converter based on OPA. The NRZ pulse train λ_s is time-synchronized with the local RZ sinusoidal clock λ_p, which serves as the pulsed-pump. They are fed into the input port of the OPA. The NRZ signal is amplified only when the pump gates on. Due to the exponential dependence of the parametric gain on the pump power, pulse narrowing effect of OPA is realized such that the pulsewidths of the RZ signal and generated idler will be narrower than that of the clocked pump [7], [8].

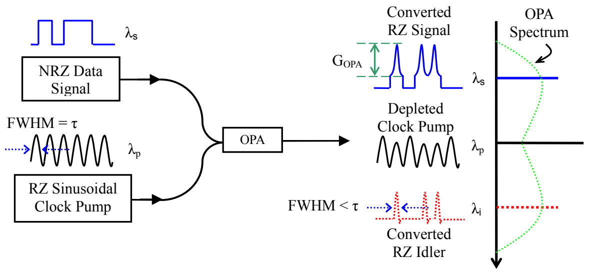

Fig. 1. Operating principle of the NRZ-to-RZ data format converter based on pulsed-pump OPA. FWHM: full width at half maximum.

II. Experiment

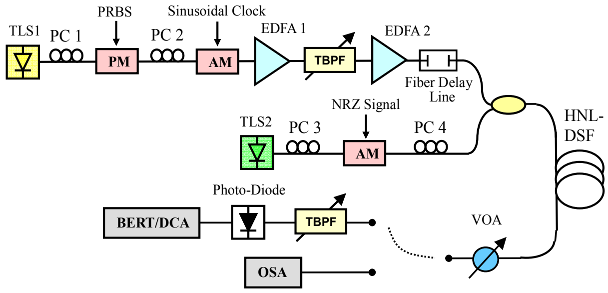

Fig. 2. Experimental setup.

The experimental configuration is shown in Fig. 2. The nonlinear media consisted of a 500m of highly nonlinear dispersion-shifted fiber (HNL-DSF) with a λ_0 of 1554nm and $\gamma = 10.4W^{-1}km^{-1}$. The pulsed-pump λ_p was a tunable laser source TLS1, which was chosen at 1556 nm and intensity modulated by a 10GHz sinusoidal pulse train with pulsewidth of 50ps through the amplitude modulator (AM). The erbium-doped fiber amplifier (EDFA 1) served as the preamplifier to a booster EDFA 2. A tunable bandpass filter (TBPF) was used to reduce amplified spontaneous emission (ASE) noise. A NRZ signal was provided by TLS2, which was tuned from 1525 to 1576nm and intensity modulated by a 10Gb/s, 2^7–1 pseudo-random bit sequence (PRBS). The fiber delay line synchronized the pump with the signal in time domain. The polarization controller (PC 4) was adjusted to align the signal with the pump so as to maximize the parametric gain. The pump and the signal were then combined with the use of a coupler and fed to the HNL-DSF. The average input power of the pump and the signal were 24.7 and -5dBm, respectively. The output spectrum was observed from the optical spectrum analyzer (OSA). A TBPF with a 3dB-bandwidth of 0.65nm was used to filter out either the output signal or the idler. We then measured their waveforms and BER using the digital communication analyzer (DCA) and BER tester (BERT), respectively.

III. Result and Discussion

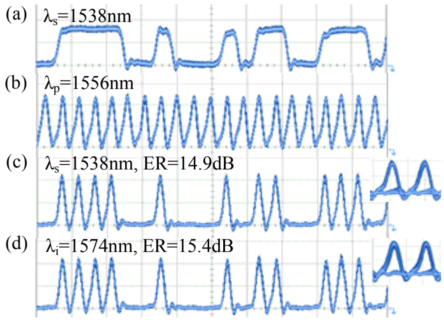

Fig. 3. Timing diagram of (a) NRZ signal, (b) sinusoidal modulated pump, (c) OPA converted RZ signal and (d) its idler.

Fig. 3(a) and (b) illustrate the NRZ signal at 1538nm and the time synchronized pump at 1556nm, respectively. The original NRZ signal (Fig. 3(a)) is converted to a RZ signal at its original wavelength and its corresponding idler is generated at 1574nm, depicted in Fig. 3(c) and (d), respectively. The signal gain is recorded to be 18dB. Their pulsewidths measured at FWHM are 30 and 29ps, respectively. The insets show their eye diagrams with extinction ratios (ERs) of 14.9 and 15.4dB, respectively. The relatively lower ER at the signal wavelength is due to the residual power of the NRZ signal.

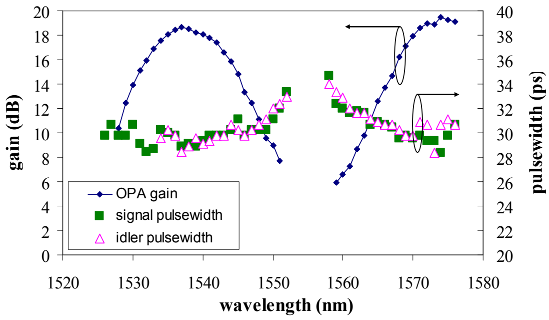

Fig. 4. Parametric gain of the pulsed-pump OPA and measured pulsewidths of RZ signal and idler.

We then widely tune the signal wavelength from 1525 to 1575nm to investigate the conversion performance over the OPA spectrum. Fig. 4 shows the OPA gain can attain 10dB over the bandwidth of 50nm, with maximum gain over 18dB. The reason of higher gain peak measured on the longer wavelength side is owing to the pump induced Raman amplification [5]. The pulsewidths of both the signal and the idler are recorded and plotted versus signal wavelengths. The pulsewidths maintain between 28 to 34ps. Results show that narrower pulsewidth can be obtained in higher gain region (> 12dB) indicating OPA effect is the dominating factor for pulse compression.

Fig. 5(a) and (c) show the eye diagrams of signals tuned at 1534 and 1545nm, respectively, while those of the corresponding idlers are shown in Fig. 5(b) and (d). Their ERs are over 15dB, respectively, which indicating a stable performance of NRZ to RZ conversion with high ER can be maintained over a wide spectral range.

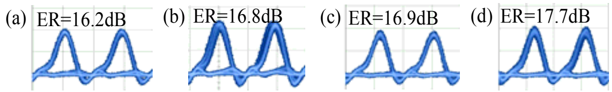

Fig. 5. Eye diagrams of (a) λ_s=1534nm and (b) its idler; (c) λ_s=1545nm and (d) its idler.

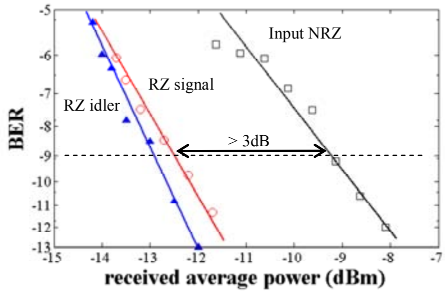

Fig. 6. Measured BER curves for the input NRZ signal and converted RZ signal and its corresponding idler.

To evaluate the performance of the proposed converter, the receiver sensitivities of the converted RZ signal (1538nm) and idler (1574nm) are measured and compared with that of the input NRZ signal. Fig. 6 shows that negative power penalty can be obtained, which is mainly due to the change of data format. At BER of 10^{-9}, the receiver sensitivities of the RZ signal and its idler are -12.5 and -13dBm, respectively, showing 3.3 and 3.8dB improvement of power penalties over the input NRZ signal. The higher sensitivity of idler should be attributed to its higher ER comparing with that of the signal. The receiver sensitivity gains are more or less the same by tuning wavelengths within the high OPA gain regions (> 12dB) due to small variation in pulsewidths and ERs.

IV. Conclusion

We have demonstrated a NRZ-to-RZ data format conversion based on OPA using clocked pump. 10Gb/s NRZ signals are successfully converted to RZ format with net gain as high as 18dB and conversion bandwidth over 50nm. Results show that OPA could be a promising solution for data format conversion in WDM-OTDM interface in ultra-fast optical communication network.

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VI. References

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