Dynamic Range of Wavelength Exchange in Highly Nonlinear Dispersion-Shifted Fiber

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Abstract: We investigate the signal dynamic range of wavelength exchange using 10Gb/s 2^{31}-1 PRBS. Data exchanging between two wavelengths is achieved with signal dynamic range ~20dB. Bit-error-rate of <10^{-9} is maintained with power penalties of <2dB.

OCIS codes: (190.4410) Nonlinear optics, parametric process; (060.2330) Fiber optics communications

1. Introduction

Wavelength exchange (WE) relies on four-wave mixing (FWM) in highly nonlinear dispersion-shifted fibers (HNL-DSFs) has been extensively studied in recent research [1-3]. Simultaneous swapping of two signals could be achieved by a suitable choice of wavelengths of both continuous-wave (CW) pumps either at the normal-dispersion region (denoted as WE I) [1] or the anomalous-dispersion region (denoted as WE II) [3]. Past experimental results showed that WE II can exhibit a nearly-complete exchange characteristic since the pump induced Raman amplification on the exchanged signals can be avoided by deploying the two pumps at the longer wavelength region with respect to the two signals [3]. WE may find many applications in modern optical communication networks, such as all-optical packet switching [4] and optical time division multiplexing (OTDM) [5]. Thus, it is necessary to have a comprehensive study on its performance under practical networking conditions. We have recently investigated the wavelength tuning range of WE II in the anomalous-dispersion region [6]. A tuning range of 15 nm could achieve with performance slightly degraded when one of the signals was tuned near the zero-dispersion wavelength λ_0 of the fiber. The reason was owing to the pump induced parametric amplification on the exchanged signals near the λ_0 [7]. However, in practical networking systems, signals arrive at the processing nodes via different routes and thus experience different condition in the transmission link, such as fiber loss, nonlinear effect, and unequal amplification of different regenerators. Therefore, the signals may possess different power levels upon the arrival at the processing node. Even though the powers of the two signals can be equalized by simply deploying a variable optical attenuator at the input end of the processing node, in our case, the wavelength exchanger, the WE performance may vary with different power levels. Thus, it is worthwhile to investigate the operational range of the signal powers to maintain a nearly-complete WE performance. So, we define this operational range as the dynamic range, as shown in Fig. 1.

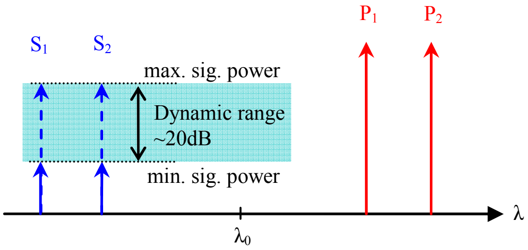

Fig. 1. The proposed approach for investigating the dynamic performance of WE II.

In this paper, we study for the first time, to the best of our knowledge, the dynamic range of WE II with the two pumps (P_1 & P_2) located at the anomalous-dispersion region and the two signals (S_1 & S_2) located at the normal-dispersion region. The wavelengths of the pumps and the signals are located symmetrically to the λ_0 of the HNL-DSF, as depicted in Fig. 1. By adjusting the input power of the signals, the dynamic range performance of WE II can be investigated. Result shows that WE II with dynamic range of ~20 dB is achieved. The performance of the WE II over this range is also quantified by the measurement of eye diagrams and bit-error-rate (BER).

2. Experiment

The experimental setup is shown in Fig. 2. The wavelength exchange consisted of a 1 km of HNL-DSF with zero-dispersion wavelength λ_0 of 1541 nm, a dispersion slope of 0.03 ps/nm^{2}km and a fiber non-linearity coefficient γ of 12 W^{-1}km^{-1}. The two pumps were prepared by two tunable laser sources, TLS 1 and TLS 2, which were fixed at 1549 nm and 1554 nm, respectively. They were phase-modulated (PM) by a 10Gb/s 2^{23}–1

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pseudo-random bit sequence (PRBS) to suppress stimulated Brillouin scattering (SBS). Erbium-doped fiber amplifier (EDFA) 1 served as the preamplifier to a booster EDFA 2. Two tunable bandpass filters (TBPF) with 2 nm bandwidth were inserted after EDFA 1 so as to filter out the two pumps separately and reduce amplified spontaneous emission (ASE) noise. Two polarization controllers (PC 3 and 4) were used to control the state of polarization (SOP) of the two pumps such that orthogonal pump configuration could be maintained by minimizing the power of the spurious FWM components. The exchange efficiency was shown to be higher by using orthogonal pump allocation [1]. The two pumps were then combined with the use of a bandpass filter (BPF), which has a passband of 1547–1549.5 nm. Wavelengths of the two signals, prepared by TLS 3 and TLS 4, were fixed at 1534 nm and 1529 nm, respectively. They were amplitude-modulated with a 10 Gb/s 2^{23}–1 PRBS. PC 6 and 8 aligned the signals with the orthogonal pumps. EDFA 3, with a gain bandwidth of 1528–1560 nm, was used to compensate for the insertion losses of the amplitude modulators (AMs). A variable optical attenuator (VOA 1) was inserted after EDFA 2 to adjust the input pump powers; while VOA 2 was used to control the input signal powers launching into the HNL-DSF in order to investigate the dynamic range performance of WE. A 80/20 coupler combined 80% of the pump powers and 20% of the signal powers. In our experiment, the input powers of the two pumps were measured to be 20 and 20.4 dBm; while the powers of the two signals were varied between -5 and 13 dBm. A TBPF was used at the fiber output to filter out the exchanged signals. They were then sent to the digital communication analyzer (DCA) and BER tester (BERT) for eye diagrams and BER measurements, respectively.

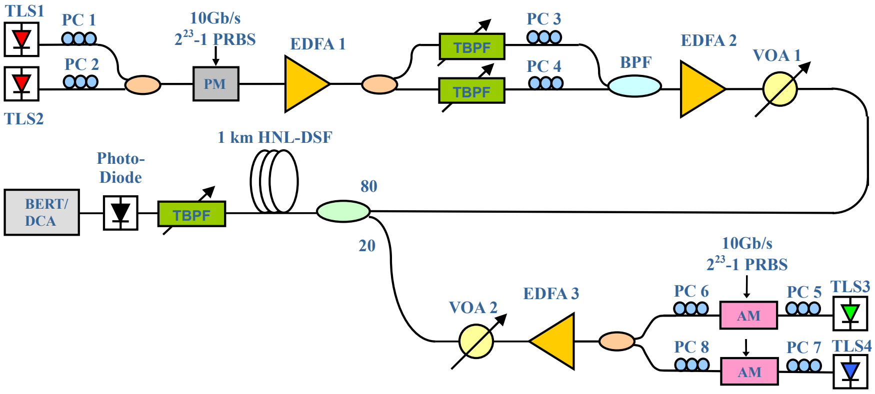

Fig. 2. Experimental configuration of the wavelength exchange.

3. Results and Discussion

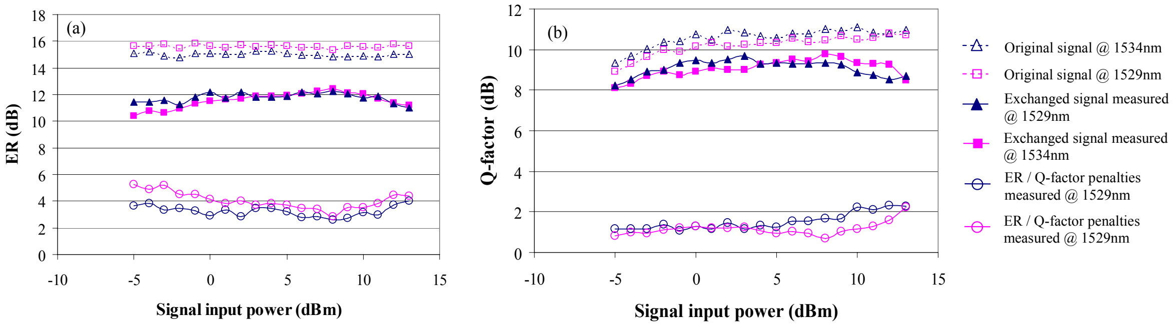

Fig. 3. (a) ERs and (b) Q-factors among exchanged signals over the available dynamic range.

The Q-factors and extinction ratios (ERs) of the exchanged signals over the dynamic range are plotted in Fig. 3 using 10 Gb/s 2^{23}-1 PRBS. It shows that good performance of WE can be successfully maintained over a wide dynamic range of 18 dB (-5 to 13 dBm) with Q-factors >8 dB and ERs of the eyes >10 dB. The dynamic range was limited by the output power of EDFA 3 and the sensitivity of the photo-detector in our experiment, otherwise a wider dynamic range of WE could be recorded. In order to investigate the exchange performance, the Q-factors and ERs of the exchanged signals were compared with the original ones. Here, we introduce two quantitative measurements called the ER and Q-factor penalties and are defined as the difference of ERs and Q-factors, respectively, between the exchanged and the original signals at a certain signal power in decibels (see Fig. 3). It can be observed that the penalties can be maintained over the available dynamic range with variation less than 3 dB. The performance of WE was slightly degraded at relative high or low signal levels due to stronger spurious FWM terms and poor signal-to-noise ratio (SNR), respectively.

To evaluate the performance of WE II, the receiver sensitivities of the exchanged signals were measured and compared with their corresponding original signals. We considered three cases, they were signal powers at: (1) -5 dBm, (2) 6 dBm, and (3) 13 dBm, which corresponded to the best (case 2) and the worst cases (cases 1 &

3) at the edges of the available dynamic range. Their eye diagrams are shown in Fig. 4. It illustrates that clear eye openings are observed in all cases. The noisy mark level is caused by the EDFA ASE noise from the two pumps. It is suggested that the ASE noise of the pumps can be suppressed by a fiber-Bragg grating (FBG) with a narrow bandwidth and a high suppression level [8]. The measured BER curves for the exchanged signals are plotted in Fig. 5. At BER of 10^{-9}, the receiver sensitivities of the original signals at 1534 and 1529 nm are -27.2 and -27.8 dBm, respectively; while that of the exchanged signal are measured to be -26.5 and -27 dBm, respectively in the best case (i.e. case 2). The power penalties incurred in the wavelength exchange are <1dB. In cases 1 and 3, the power penalties slightly increase to ~2 dB owing to the degradation of Q-factors and ERs. Nevertheless, the results indicate a steady performance of WE can be achieved when it is operated in different signal power levels.

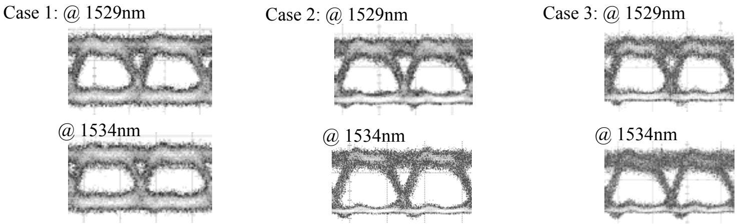

Fig. 4. Measured eye diagrams of the exchanged signals in the three cases (please refer to the text for detail).

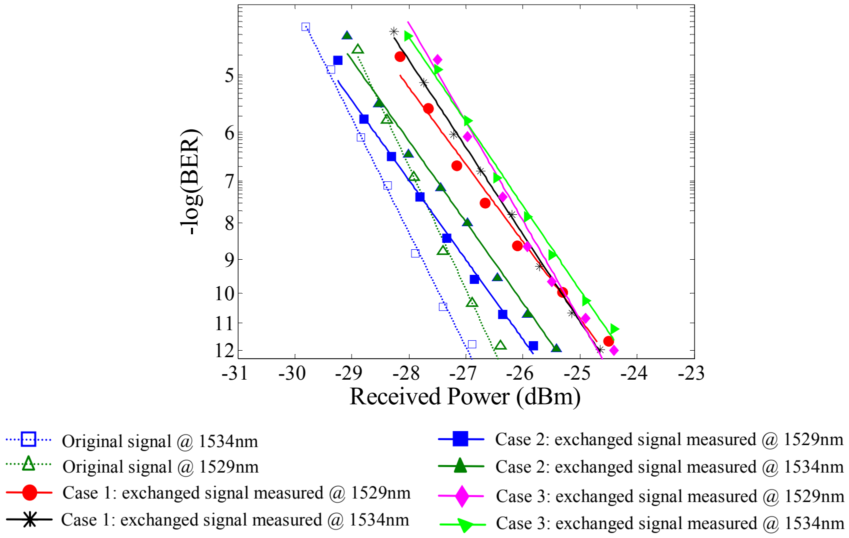

Fig. 5. Measured BER curves for the exchanged signals before and after WE in the three cases.

4. Conclusion

We have successfully demonstrated the performance of WE II and investigated the dynamic range of WE II with two pumps located in the anomalous dispersion region. Results show that the dynamic range can achieve over ~20 dB with clear eye openings observed. BERs of $<10^{-9}$ is maintained with power penalties of at most 2 dB. The results provide a more comprehensive insight into the performance of WE II when operated under practical conditions.

5. Acknowledgment

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