Experimental Demonstration of Optical Regeneration of DP-BPSK/QPSK Using Polarization-Diversity PSA

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Abstract: We experimentally investigate a polarization-diversity phase-sensitive amplifier (PSA) for phase regeneration of 25-Gbaud DP-BPSK and DP-QPSK signals and show effective reduction on phase noise in both polarizations. BER measurements and reduced phase noise are achieved for both polarizations.

OCIS codes: (060.4370) Nonlinear optics, fibers, (070.4340) Nonlinear optical signal processing.

1. Introduction

To meet growing demands on network capacity and reach, advanced modulation formats with high spectral efficiency have become increasingly important. Phase modulation formats, such as binary phase-shift keying (BPSK) and quadrature phase-shift keying (QPSK), have been shown to provide higher robustness to fiber nonlinearities and better transmission performance as compared to other formats. However, phase noise still imposes strict requirements on system designs by limiting the maximal reach of phase modulation formats. Phase-sensitive amplification (PSA) has been reported to effectively mitigate such phase noise; however, the polarization alignment between pump and signal must be maintained [1-4]. Recently we explored a third-order nonlinearities based polarization-diversity PSA structure using highly nonlinear fiber (HNLF) to enable polarization-insensitive phase regeneration of BPSK/QPSK signals [5].

In this paper, we investigate a polarization-diversity PSA structure employing bi-directional second-order nonlinearities, such as second harmonic generation (SHG), in a periodically poled Lithium Niobate (PPLN) crystal on orthogonal polarizations separately to enable dual-polarization signal regeneration. We experimentally demonstrate that phase noise can be effectively squeezed regardless of the signal's state of polarization. Bit error rate (BER) measurements show the improvement in the system performance. At BER of 1e-3, OSNR improvement of 3.6 dB and 0.4 dB for dual-polarized (DP)-BPSK and DP-QPSK could be achieved, respectively.

2. Concept

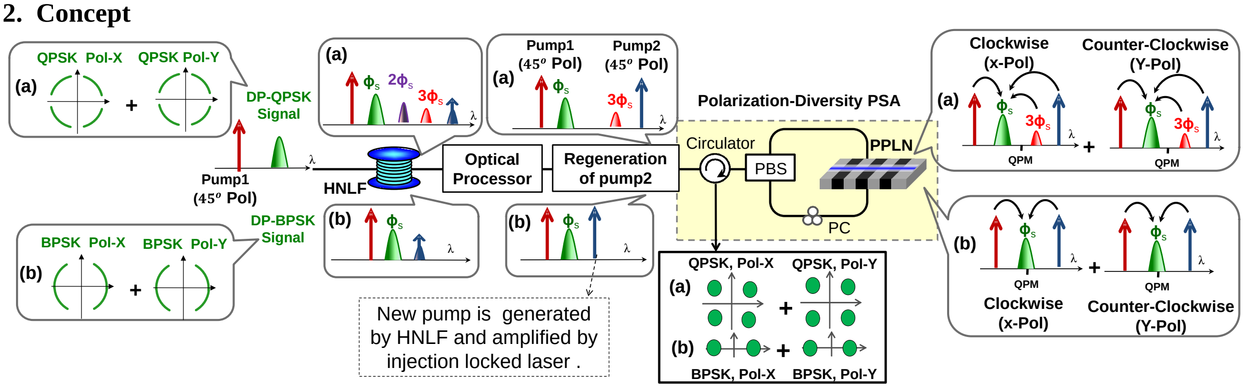

Fig. 1. Conceptual diagram of phase regeneration of dual-polarization signals by using a polarization-diversity PSA: (a) QPSK, (b) BPSK.

The conceptual diagram of phase regeneration of DP-BPSK/QPSK signal is illustrated in Fig.1. Incoming signal (*e.g.*, BPSK or QPSK) in two polarizations after passing through the HNLF generates a pump (*i.e.*, pump2) which is coherent with the signal and local CW pump (*i.e.*, pump1). For the QPSK signal in addition to the new pump, we also generate the third-order harmonic of the signal. Using an optical processor, we filter the signals and pumps into different paths. Then, using an injection lock laser, we amplify the pump2. To implement simultaneous dual-polarization signal regeneration, we employ a polarization-diversity loop. Using a polarization beam splitter (PBS), two polarizations are separated into opposite directions of the loop which contains the PSA stage. As a result, we use one PSA to regenerate two polarizations. In the PSA stage, a PPLN crystal is used. For the BPSK signal regeneration, we adjust the quasi phase matching (QPM) wavelength of the PPLN crystal on the signal wavelength. Utilizing the sum frequency generation (SFG) and frequency generation (DFG) processes, the signal conjugate is generated on the signal's wavelength. Thus, the signal could be combined with its conjugate, *i.e.*, $e^{j\varphi}+\alpha\, e^{j(-\varphi)}$, which is basically the PSA process for BPSK signal. For the QPSK signal, we adjust the QPM wavelength between the third-order harmonic and the signal. Utilizing the same SFG and DFG processes, the conjugate of the third-order harmonic of the signal is generated on the signal. In other words, we implement the function of $e^{j\varphi}+\alpha\ e^{j(-3\varphi)}$ for the QPSK signal which is the process of regeneration for QPSK signal. Finally, the regenerated signal is separated into another fiber and then coupled to the coherent analyser for BER measurements.

3. Experimental Setup

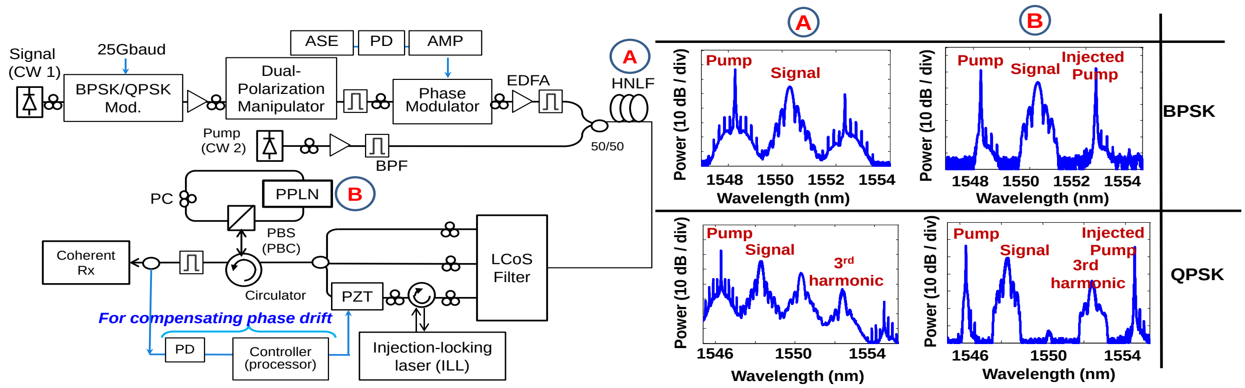

Fig. 2. Experimental setup for DP–BPSK/QPSK signal regeneration. PBS: polarization beam splitter,PD: photo-diode,PC: polarization controller.

The experimental setup for the DP-BPSK/QPSK signal regeneration is shown in Fig. 2. A nested Mach-Zehnder modulator is used to generate the 25-Gbaud BPSK/QPSK data (PRBS 2^{31}-1) on the CW signal. The dual-polarization signal is generated using the dual-polarization manipulator. The DP signal is then amplified by an EDFA and combined with a CW pump, and sent through the HNLF to generate the new pump and the third harmonic for the QPSK signal. A Liquid Crystal on Silicon (LCoS) filter is used to split the signal into three paths. The signal and the third harmonic for QPSK data are sent via the first path, and the pump1 is sent via the second path. Via the third path, the newly generated idler is sent to an injection lock laser to be amplified and cleaned out of the high bandwidth noise, resulting in a new pump (*i.e.*, Pump2). The output of the three paths are combined and sent through the polarization-diversity loop. In that loop, we split two polarizations into two opposite directions of the loop, in which a 5-cm-long PPLN crystal is used. The output of the loop is filtered and sent to the coherent receiver for BER measurement. Because we have separated the pumps and signals into three optical paths, their coherency can be distorted due to the temperature variations or vibrations. To compensate these variations that change the phase of the signal, we get the feedback from the output and use a digital controller and a fiber stretcher (PZT) on one path to stabilize the phase variations [6].

4. Results and Discussion

Fig. 3 shows the experimental results of the DP-BPSK/QPSK regeneration. Fig. 3(a) shows that the amount of phase noise on the BPSK and QPSK signal is reduced after regeneration for both of polarizations. Moreover, the bit error rate measurements are shown in Fig. 3(b). We could improve the BER for the BPSK and QPSK regeneration by 3.6 dB and 0.4 dB OSNR at BER of 1e-3, respectively. The amount of BER improvement for the QPSK signal is less than BPSK regeneration. By further optimizing the system, we may greatly improve the regeneration performance.

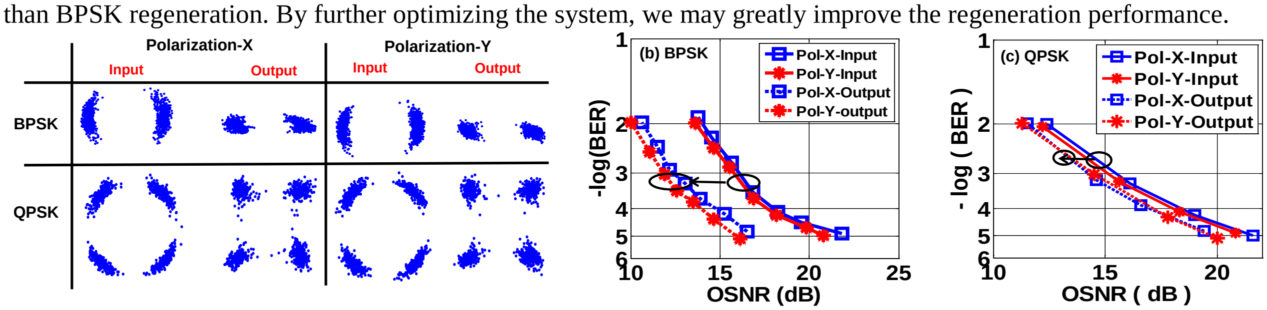

Fig. 3. Experimental results of DP-BPSK/QPSK regeneration. (a) Constellation for both polarizations. (b) BER measurements of DP-BPSK signals. (c) BER measurements of DP-QPSK signals.

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5. References

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