Experimental Demonstration of Tunable and Automatically-Locked Homodyne Detection for Dual-Polarization 20-32-Gbaud QPSK Channels using Nonlinear Mixing and Polarization Diversity

M. Ziyadi[(1)], A. Mohajerin-Ariaei[(1)], A. Almaiman[(1)], Y. Cao[(1)], M. R. Chitgarha[(1)], P. Liao[(1)], Y. Akasaka[(2)], J.-Y. Yang[(2)], M. Sekiya[(2)], J. Touch[(3)], M. Tur[(4)], C. Langrock[(5)], M. M. Fejer[(5)], A. E. Willner[(1)]

1) Ming Hsieh Department of Electrical Engineering, University of Southern California, 3740 McClintock Ave, Los Angeles, CA 90089, USA
2) Fujitsu Laboratories of America, 2801 Telecom Parkway, Richardson, TX 75082, USA
3) Information Sciences Institute, University of Southern California, 4676 Admiralty Way, Marina del Rey, CA, 90292, USA
4) School of Electrical Engineering, Tel Aviv University, Ramat Aviv 69978, Israel
5) Edward L. Ginzton Laboratory, 348 Via Pueblo Mall, Stanford University, Stanford, CA 94305, USA
ziyadi@usc.edu

Abstract: We experimentally demonstrate a tunable homodyne receiver on polarization multiplexed QPSK signals. PPLN waveguides inside the polarization diversity loops are used to frequency/phase lock the signals with the LO. Open eye diagrams with BER measurements are shown.

OCIS codes: (060.2360) Fiber optics links and subsystems; (190.4223) Nonlinear Wave Mixing.

1. Introduction

Optical homodyne systems are known to provide superior sensitivity and performance as compared to heterodyne system, with the disadvantage that homodyne requires more complexity in hardware/software.[1] This added complexity is due to the requirement that the local oscillator (LO) in the receiver should have the same frequency and phase as the incoming data signal, i.e., the frequencies must be equal and "locked" to each other.

Previous approaches for carrier recovery include: (a) transmitting the carrier along with the data signal [2,3], (b) using a laser LO in the receiver coupled with a phase locked loop (PLL) and signal processing algorithms to ensure locking [4], and (c) using optical signal processing and an optical feedback loop.[5]

A recent report showed homodyne detection in which the LO is automatically "locked" to the incoming data signal without the need for feedback or phase/frequency tracking.[6] By using nonlinear wave mixing, the produced signal conjugate is utilized to coherently add the signal and the LO with an appropriate complex weight. However, that demonstration was for a system that did not accommodate polarization multiplexing, which is quite valuable for many high-capacity systems.

In this paper, we experimentally demonstrate tunable and automatically-locked homodyne detection for dual-polarization 20-32-Gbaud quadrature-phase-shift-keying (QPSK) channels using nonlinear mixing and polarization diversity. In our proposed scheme, we generate the signal conjugate in a nonlinear element inside the polarization diversity loop structure, and the input signal could be automatically phase/frequency locked to the LO in another stage. Open eyes are obtained for both in-phase and quadrature components of the QPSK signals at 20/32 Gbaud. The BER performance of the proposed homodyne detection scheme is also measured.

2. Concept

Figure 1 shows the concept of the proposed homodyne detection scheme for polarization multiplexed (dual-polarized) signals. At first, we sent the input signal ($S(t) = S_X(t)\hat{x} + S_Y(t)\hat{y}$) with a pump (*i.e.*, pump-1 with electric field of E and 45^0 of polarization) as the LO into a polarization diversity loop (PDL) structure which contains a periodically poled lithium niobate (PPLN) waveguide. In the PDL, two polarizations are separated into opposite directions inside

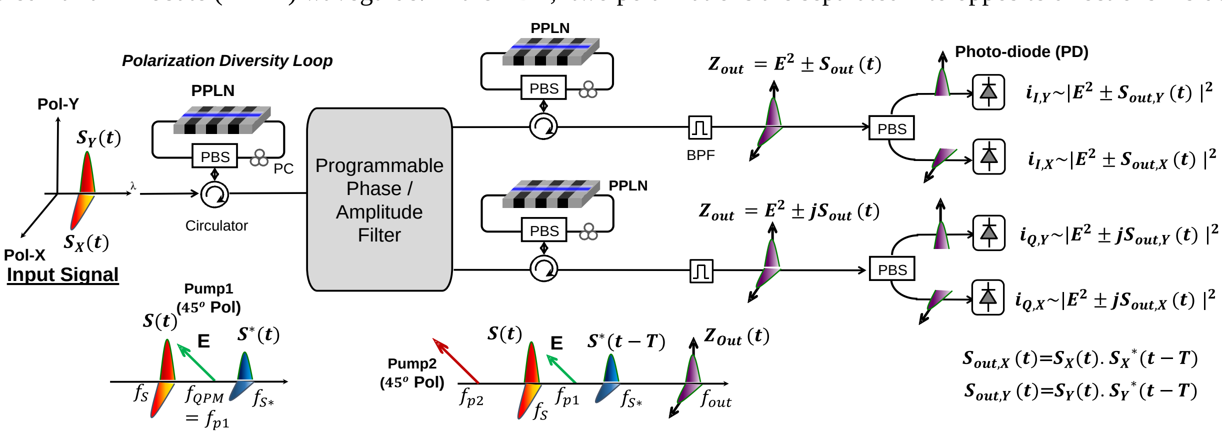

Fig. 1. Concept of the proposed homodyne detection scheme for polarization multiplexed signal.

the loop by using a polarization beam splitter (PBS). Due to a second harmonic generation (SHG) and difference frequency generation (DFG) processes, we could generate the conjugate copy of the signal $S^*(t)$. A phase/amplitude filter induces a one symbol time delay (T) between the signal and its conjugate copy and adjusts the phase and amplitude of the signals. In the second stage, we sent the signals with another pump (*i.e.*, pump-2) with 45 degree of polarization to another set of PPLN crystals inside the PDLs. In this stage, the LO at f_{QPM} generates a signal (E^2) at $2f_{QPM}$ in a SHG process. Moreover, simultaneously the signal combined with the generated delayed conjugate copy generates the signal of $S_{out}(t) = S(t).S^*(t-T)$ at $2f_{QPM}$ in a sum-frequency-generation process. Since we have generated the conjugate copy using the LO, the two generated signals at $2f_{QPM}$ are phase and frequency locked to each other. In other words, we could automatically lock the LO into the incoming dual-polarized signal. We used pumpe-2 to convert the signal at $2f_{QPM}$ back to the C-band. Finally, the outputs of the multiplexing stage are separated using a PBS and sent to photodiodes to capture in-phase (I) and quadrature (Q) components of the signal to implement simultaneous dual-polarized signal homodyne detection.

3. Experimental Setup

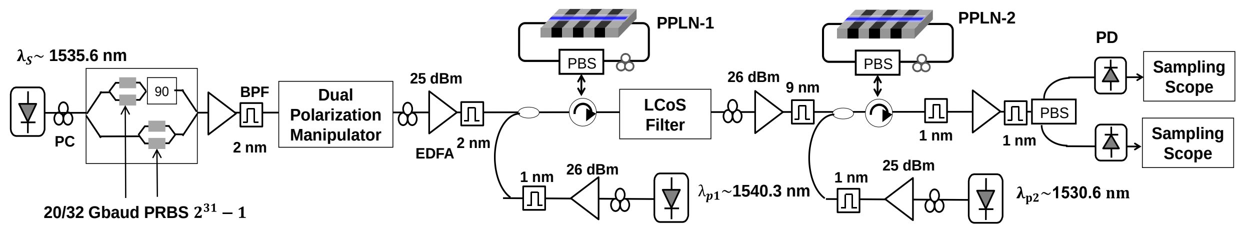

Fig. 2. Experimental setup. PC: Polarization Controller, BPF: Band Pass Filter, EDFA: Erbium Doped Fiber Amplifier

Figure 2 shows the experimental setup. A nested I/Q modulator is used to generate the 20/32-Gbaud QPSK data (PRBS 2^{31}-1) at 1535.6 nm. The signal is sent to a polarization manipulator to generate the polarization multiplexed signal. The signal is then amplified and coupled with an amplified ~1540.3 nm CW pump and sent to a PPLN waveguide to generate the copy at 1546.3 nm. The output of the first PPLN including the signal, the CW pump and the conjugate copy is sent to a programmable filter based on liquid crystal on silicon (LCoS) technology for adjusting delay, phase and complex weights. All the signals are amplified and coupled with another amplified 1530.6 nm CW laser and sent to the second PPLN to mix the signal and the conjugate copy and lock them with the first pump. The QPM wavelength of the second PPLN waveguide is temperature tuned to QPM of the first PPLN. The multiplexed signal is then filtered, amplified and sent to a PBS to split two polarizations and then sent to photodetectors to capture the eye diagram in sampling scope and perform the bit-error rate measurements.

4. Results and Discussion

In Fig. 3, the results of the scheme are shown. Fig. 3(a) shows the optical spectra of the output of PPLN waveguides and the eye diagrams of I and Q components of both polarizations of X and Y of the incoming QPSK signal at 20 Gbaud. Tunablity of this scheme is investigated by changing the baud rate to 32-Gbaud and results are shown in Fig. 3(b). The open eye diagrams could be achieved using a sampling scope. Fig. 3(c) shows the BER measurements obtained by on-line processing on the data at the output of the sampling scope.

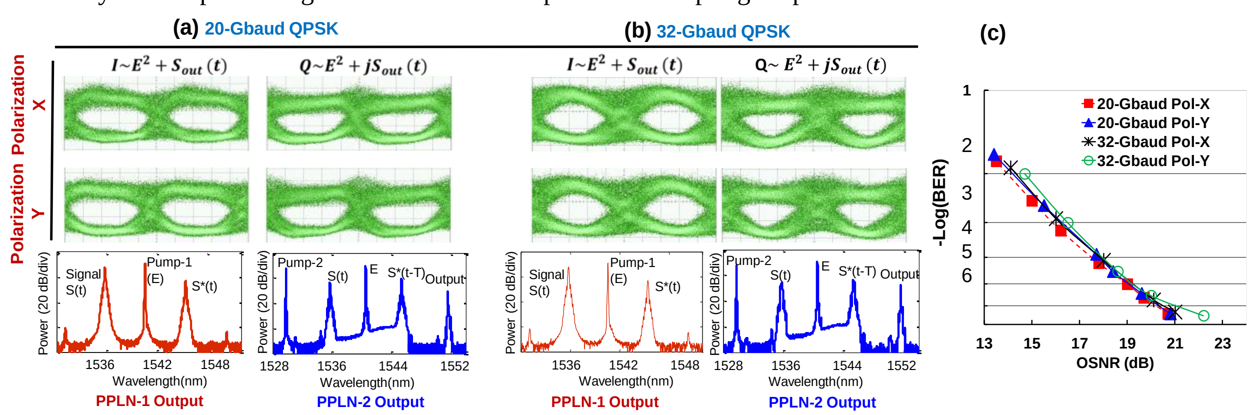

Fig. 3. Experimental results for proposed homodyne detection scheme of polarization multiplexed QPSK signals (a) Optical spectra of the PPLNs output and eye diagrams of I and Q for both polarizations of X and Y at 20 Gbaud. (b) Results at 32-Gbaud. (c) BER measurements.

Acknowledgements: The authors would like to thank the support of CIAN, and NSF.

5. References

[1] G. P. Agrawal, "Fiber-Optic Communication Systems," Wiley (2002).
[2] S. Shinada et al., Optics Express, vol. 20, no. 26,(2012)
[3] T. Miyazaki, et al., IEEE PTL. 17, 1334 – 1336 (2005)
[4] L. G. Kazovsky, JLT., vol. 4, no. 2, pp. 182–195 (1986).
[5] M. J. Fice, et al., JLT., 29, 1152-1164 (2011)
[6] M. R. Chitgarha, et al., ECOC 2014, paper Tu.3.6. (2014).