Tunable Homodyne Detection using Nonlinear Optical Signal Processing to Automatically Lock a "Local" Pump Laser to an Incoming 20-to-40-Gbaud QPSK Data Signal

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Abstract *We propose and demonstrate tunable homodyne detection using nonlinear optical signal processing to automatically lock a "local" pump laser to an incoming 20-to-40-Gbaud QPSK data signal. Open eyes are obtained for both in-phase and quadrature components of the signal after ~200-km transmission over SMF-28 and DCF fibers. The BER performance of the proposed homodyne detection scheme is also compared with the conventional intradyne receiver.*

Introduction

It has been known for decades that optical homodyne detection provides better performance and is inherently 3-dB more sensitive than optical heterodyne detection [1]. However, homodyne-systems require that the local oscillator have the same frequency and phase as the incoming data signal, *i.e.*, the data signal and local oscillator are equal and "locked" to each other.

One previous approach for carrier recovery includes transmitting the carrier along with the data signal [2-4]. With this approach, the carrier: (a) occupies some part of the spectrum and polarization state, and (b) suffers from fiber loss and can accumulate phase noise. Another approach is to have a local laser oscillator in the receiver, for which a phase locked loop (PLL) and signal processing algorithms ensure the locking of the local laser to the same frequency and phase [5]. However, this tends to be fairly complex and requires time to "lock".

Additionally, there have been optical methods to recover the carrier of an incoming data signal using nonlinear processing, but these techniques typically required an optical feedback loop for stabilization [5]. A laudable goal would be to enable optical homodyne detection for which the local laser oscillator is automatically "locked" in frequency and phase to the incoming data signal without the need for feedback or phase/frequency tracking.

In this paper, we propose and demonstrate tunable homodyne detection using nonlinear optical signal processing to automatically lock a "local" pump laser to an incoming 20-to-40-Gbaud QPSK data signal. In our proposed scheme, the conjugate of the signal is utilized to coherently add the signal and the local oscillator with an appropriate complex weight [6]. Open eyes are obtained for both in-phase and quadrature components of the signal after transmission over ~160-km SMF-28 and ~40-km DCF. The BER performance of the proposed homodyne detection scheme is also compared with the conventional intradyne receiver.

Concept

The conceptual block diagram of the proposed homodyne detection scheme is shown in Fig. 1. In this scheme, first, quadrature-phase-shift-keyed (QPSK) along with CW pump are injected into a periodically-poled-lithium-niobate (PPLN) waveguide to produce a phase conjugate copy of the original signal. The signal and its conjugate copy are then sent into a programmable phase and amplitude filter. In this filter, one symbol delay between signal and its conjugate copy is induced, the relative phase between the pump and the signal is compensated, and the required amplitude levels of the signals are adjusted. Therefore, if the original signal can be denoted by S(t) and the injected CW laser is E, the conjugate copy at the filter output is $S^*(t-T_s)$ where T_s is one symbol period. These signals (*i.e.*, original signal, the conjugate copy, and the CW pump) are then sent to the second nonlinear stage in order to create the mixing product of signal and the copy combined with the CW pump with an appropriate weight. This can be denoted as $S_{Mux}(t) = E^2+AX(t)$, where $X(t) = S(t).S^*(t-T_s)$. By sending the output to photodetectors and setting A to ±1 or ±j, similar to a 90^0 optical hybrid, both in-phase and quadrature components of the X(t), can be obtained. Moreover, if both constructive and destructive multiplexing of the signal and the CW pump are simultaneously generated, a balanced photodiode can realize

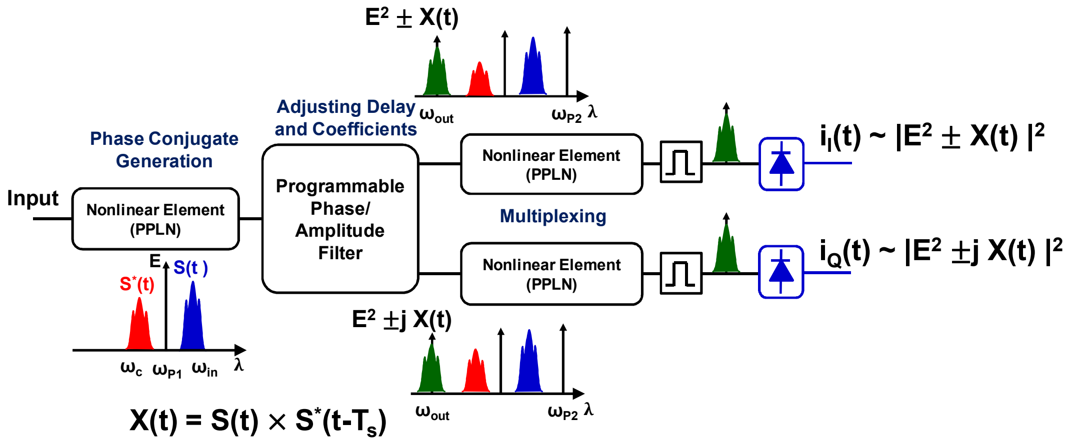

Fig. 1: Operational principle of the proposed homodyne detection scheme

the 3-dB improvement for both I and Q components of the signal.

Experimental Setup

The experimental setup for the homodyne detection scheme is depicted in Fig. 2. A nested Mach-Zehnder modulator is used to generate the 20/25/40-Gbaud QPSK data (PRBS 2^{31}-1) at either 1555 nm or 1554.1 nm. The signal is sent to a 200-km optical fiber link (~160-km SMF-28 and ~40-km DCF) to perform transmission experiment before detection in the proposed homodyne scheme. The signal is then amplified and coupled with an amplified ~1550.6nm CW pump and sent to a PPLN waveguide in order to produce the phase conjugate of the signal. The quasi phase matching (QPM) of the first PPLN is set to the wavelength of CW pump. The output of the first PPLN is sent to a programmable filter based on liquid crystal on silicon (LCoS) technology for adjusting the delay, phase and the complex weights. The signal, the conjugate copy, and the first CW pump are amplified and coupled with another amplified 1560 nm CW laser and sent to the second PPLN in order to perform mixing between the signal and the conjugate copy and multiplexing 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 photodetector to capture the eye diagram and perform the bit-error measurement. In this figure the spectra of the first and second PPLN waveguides are also depicted for two different input signals at different wavelengths. As can be seen, the multiplexed signal is always in frequency and phase locked with respect to the generated carrier.

Results and discussion

The performance of the system is assessed by implementing the proposed homodyne detection scheme on 20/25/40 Gbaud QPSK signals. In Fig. 3(a) the spectra of the first and second PPLN waveguides are shown for 20-Gbaud QPSK data. In order to show the performance of the system in creating all four possible combinations of the local oscillator with the incoming data channel, the E^2+X(t), E^2-X(t), E^2+jX(t), and E^2-jX(t) are generated and sent to a photodiode in the proposed homodyne receiver. The resultant open eye diagrams for all of these combinations are shown. In Fig. 3(b) and 3(c), the same results are shown for 25 and 40-Gbaud QPSK signals, respectively. As can be seen, the system shows significant sensitivity and is data rate transparent. To reconfigure the

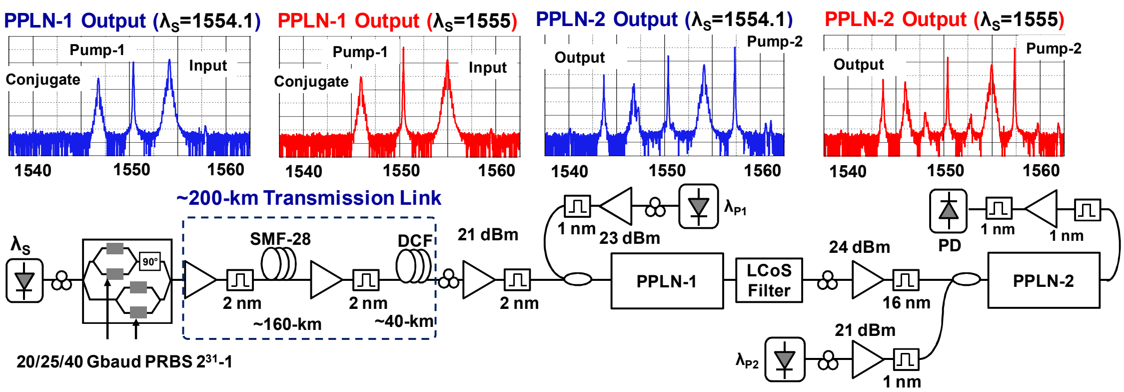

Fig. 2: Experimental setup. PPLN: Periodically Poled Lithium Niobate Waveguide, BPF: Bandpass Filter,PD: photodiode setup of a the proposed homodyne detection scheme

system to a new baud rate, only the induced delay between the signal and its conjugate copy needs to change in the programmable filter. Because the local oscillator is automatically "locked" in frequency and phase to the incoming data signal the proposed homodyne receiver does not require phase and frequency recovery. Fig. 4(a) shows the four eye diagrams for 20-Gbaud QPSK detection using the proposed homodyne scheme after 200-km transmission. Fig. 4(b) shows the BER performance of the proposed homodyne detection scheme and compares it with the conventional intradyne detection scheme. In the former scheme the BER measurement can be performed in real-time and the BER curves are obtained up to ~1×10^{-9} whereas the latter approach needs off-

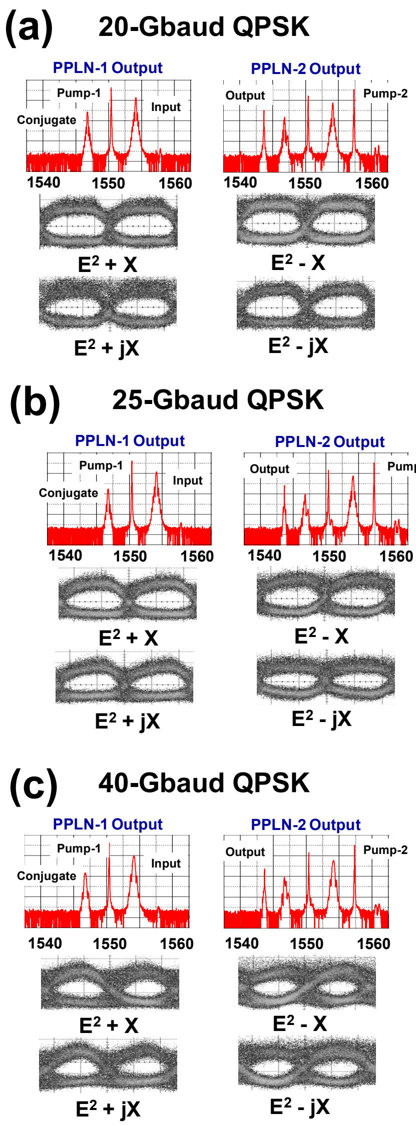

Fig. 3: (a), (b),(c) optical spectra of the first and second PPLN waveguides output for homodyne detection of 20- 25- and 40-Gbaud QPSK signals and the eyes correspond to all possible combination of the CW pump and the incoming data signals

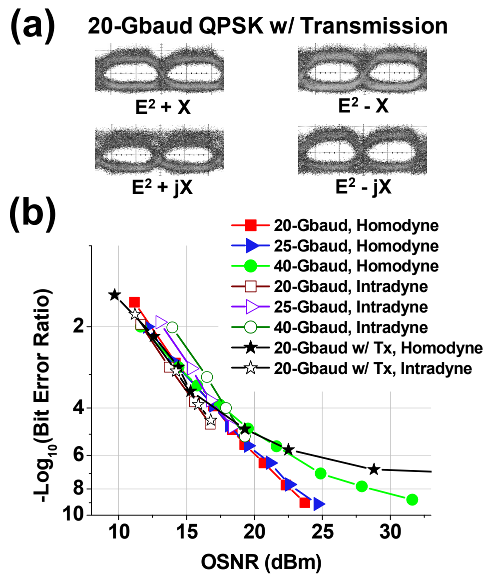

Fig. 4: (a) Eye diagrams for 20-Gbaud QPSK detection after 200-km transmission (b)The comparison between the BER performance of the proposed homodyne receiver and the conventional intradyne receiver

line processing to measure the BER and it is limited to ~ 1×10^{-5} BER. Although, we did not use the balanced detection method which can theoretically improve the performance by 3-dB, our proposed homodyne detection scheme shows similar performance at 25 and 40-Gbaud to the intradyne with phase and frequency recovery mechanism using DSP. For 20-Gbaud QPSK, however, the intradyne performs ~ 1.7 – dB better at BER of ~ 1×10^{-5}.

Acknowledgements

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