Experimental Demonstration of Simultaneous Phase Noise Suppression and Automatically Locked Tunable Homodyne Reception for a 20-Gbaud QPSK Signal

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Abstract: We experimentally demonstrate simultaneous phase noise suppression and automatically locked tunable homodyne reception for 20-Gbaud QPSK signal. The phase noise deviation can be reduced by a factor of ~3. Open I/Q eyes are obtained after the noise mitigation.

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1. Introduction

Homodyne systems are well known to offer improved performance over heterodyne systems [1]. However, true homodyne systems require the locking of the incoming signal to the laser local oscillator (LO) in both frequency and phase [2-4].Various methods have been reported to achieve such locking, including: (a) transmitting the carrier along with the data [3], (b) using an electronic phase locked loop (PLL) [2], and (c) using nonlinear processing and an optical feedback loop [4].

A homodyne technique was recently published that enabled automatic locking in frequency and phase without the need for feedback or phase/frequency tracking [5]. By using a pump LO laser at the receiver and nonlinear wave mixing, the produced signal conjugate is delayed and used to coherently add the signal and the LO with an appropriate complex weight. Additionally, there was another technique that was published that enabled phase noise mitigation, which used some of the same capabilities of nonlinear wave mixing to multiply the signal with its delayed conjugate [6]. In this paper, we combine these two approaches in a single operation. We experimentally demonstrate the simultaneous phase noise suppression and automatically locked tunable homodyne reception for a 20-Gbaud QPSK signal. The phase noise (e.g., laser phase noise) of an incoming signal is filtered by multiplying the signal to its delayed conjugate, which is produced by a "local" pump. Simultaneously, in the same nonlinear device, the noise mitigated signal is automatically locked to the "local" laser. The standard deviation of the phase noise can be reduced by a factor of ~3. Open eyes are obtained for the both in-phase and quadrature components of the signal after the noise mitigation.

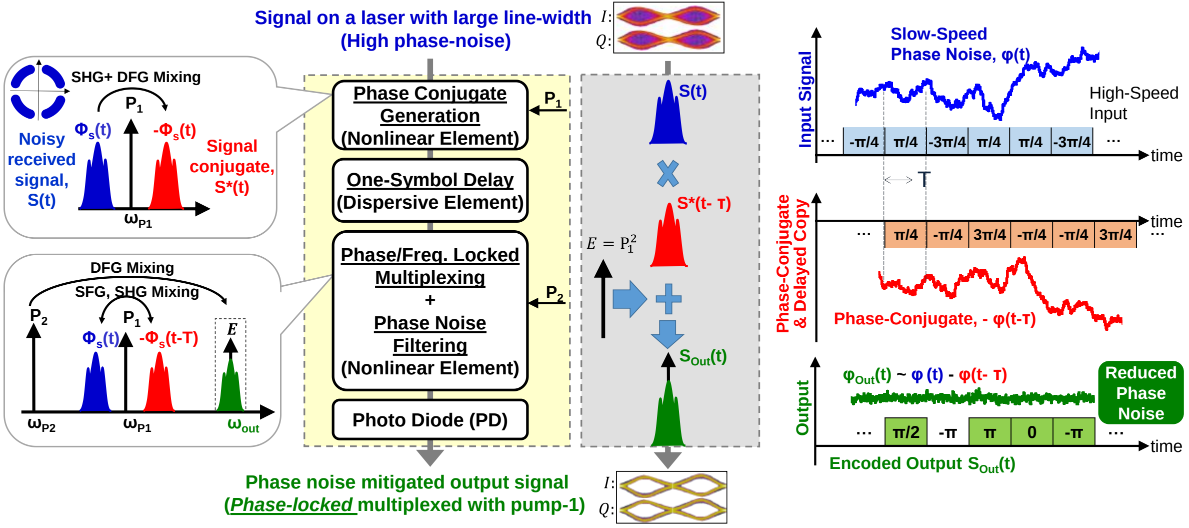

Fig. 1. The concept of the homodyne phase noise mitigation scheme. Low frequency components of the phase noise (e.g., laser phase noise) of an incoming signal is filtered by multiplying the signal to its delayed conjugate. Simultaneously, the noise mitigated signal is automatically locked to a "local" laser, P_1, and sent to a PD for detection.

The conceptual block diagram of the homodyne phase noise mitigation scheme is shown in Fig. 1. A QPSK signal, which is received on a laser with large line-width or contaminated with phase noise, along with a CW pump, P_1, are injected into a nonlinear wave mixer to generate the conjugate copy of the original signal. The signal and its conjugate copy are then sent into the delay stage to apply one bit delay between them. The signals with a second CW pump are injected into a second nonlinear stage. In this stage two tasks will be done simultaneously: 1) phase noise mitigation by coherently mixing the product of the signal and its delayed conjugate. We denote the noise mitigated signal by $R(t) \propto exp(j\Phi_s(t) - \Phi_s(t-T))$. Since the phase of the original signal consists of both data and the phase noise, then $\Phi_{\text{out}}(t) = [\Phi_D(t) - \Phi_D(t-T)] + [\varphi_N(t) - \varphi_N(t-T)]$. The first bracket is only a decoding of the original data. The second bracket can be viewed as a filter on the phase noise which is able to filter out low frequency components of the phase noise (e.g., laser phase noise). 2) Phase-locked multiplexing by the "local" laser P_1: this can be done by multiplexing the noise mitigated signal $R(t)$ with the CW pump, P_1, with an appropriate relative complex coefficient adjusted in a programmable filter. The final optical output can be denoted as $S_{out}(t) = E + wR(t)$, where $E = P_1^2$. By sending the output to photo-diodes and setting w to ±1 or ±j, similar to a 90^0 optical hybrid, both in-phase and quadrature components of the noise mitigated input signal can be obtained.

3. Experimental Setup

The experimental setup is depicted in Fig. 2 (a). A nested Mach–Zehnder modulator is used to modulate 20-Gbaud QPSK data (PRBS 2^{31}-1) at ~1538 nm. The signal is phase modulated with an ASE source to emulate phase noise with different powers and bandwidths. The noisy signal is coupled with a CW pump around 1541 nm and sent to a periodically-poled-lithium-niobate (PPLN-1) waveguide. The signals then sent to a ~25 m DCF and a SLM filter for adjusting the phases. The resulting signals are amplified and coupled with another CW pump around 1530 nm and sent to PPLN-2 waveguide to 1) coherently mix the signal and its conjugate copy, and, 2) to phase-locked multiplex the first pump in the output. The multiplexed signal is then filtered, amplified and sent to a photodiode.

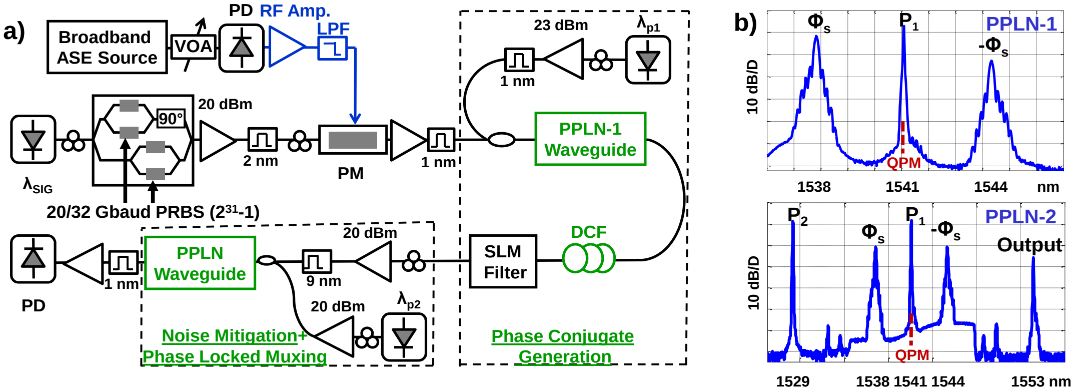

Fig. 2. (a) Experimental setup. DCF: Dispersion compensating fiber, SLM: Spatial light modulator (b) Optical spectra of PPLN-1, PPLN-2.

4. Results and Discussion

The performance of the system is assessed by implementing the proposed homodyne phase noise mitigation scheme on 20-Gbaud QPSK signals which are degraded by inducing phase noise at different powers and bandwidths. Both in-phase and quadrature-phase components of the data signal are detected. Fig. 3(a) shows the I/Q eye diagrams of the detected noise-mitigated signal for phase noise with 300MHz, 750 MHz and 3300 MHz spectral density bandwidths and for three different power levels. As it can be seen, the phase noise reduction is significant especially for the phase noise with lower bandwidth. Here, the reduction factor is defined as the ratio of input phase noise standard deviation over the output phase noise standard deviation. In Fig. 3(b) the performance of the system is assessed by measuring this reduction factor in the three levels of phase noise and for different noise-bandwidths.

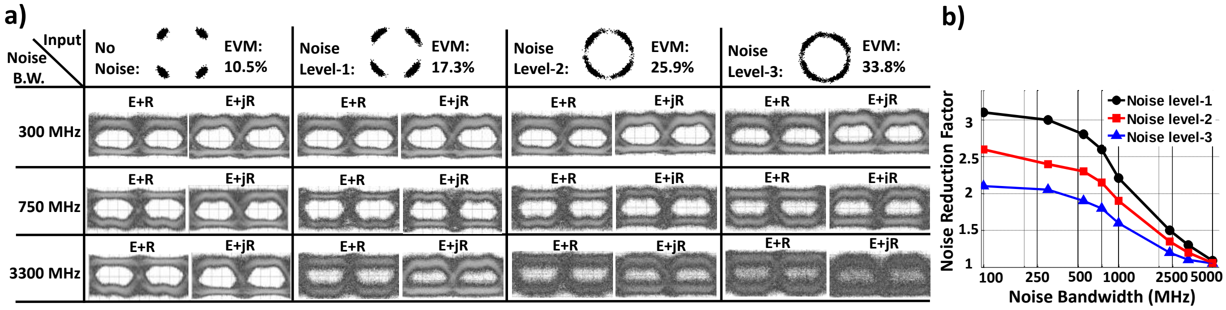

Fig. 2. (a) The I and Q eye diagrams of the detected 20-Gbaud QPSK signals with three different power levels of induced phase noise and for three different noise-bandwidths. (b) Phase noise reduction factor for three levels of induced phase noise with different noise-bandwidths.

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