Experimental Demonstration of Tunable Homodyne Detection for Two Channels Simultaneously using Nonlinear Optical Signal Processing to Automatically Lock a Single "Local" Pump Laser to Two 20-Gbaud BPSK Data Signals

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Abstract: we demonstrate homodyne detection for multiple channels using nonlinear optical signal processing to automatically lock a single "local" pump laser to these data channels simultaneously and perform experimental demonstration with two 20-Gbaud BPSK channels.
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1. Introduction

As is well know, optical homodyne detection provides better performance and is inherently 3-dB more sensitive than optical heterodyne detection [1]. To achieve this advantage, homodyne systems require that the local oscillator (LO) have the same frequency and phase as the incoming data signal, i.e., the data signal and local oscillator frequency are equal and "locked" to each other.

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

Recently, an approach was published that enabled 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 [6]. By using a pump LO laser at the receiver and nonlinear wave mixing, the produced signal conjugate is utilized to coherently add the signal and the LO with an appropriate complex weight.

In this paper, we experimentally demonstrate tunable homodyne detection for two channels simultaneously using nonlinear optical signal processing to automatically lock a "local" pump laser to two 20-Gbaud binary-phase-shift-keyed (BPSK) data signals. This is achieved by utilizing the inherent fundamental phase locking property deduced between the local pump and the generated conjugate copy in a nonlinear interaction. The Eye diagrams of the generated output is captured and bit error rate (BER) is measured.

2. Concept
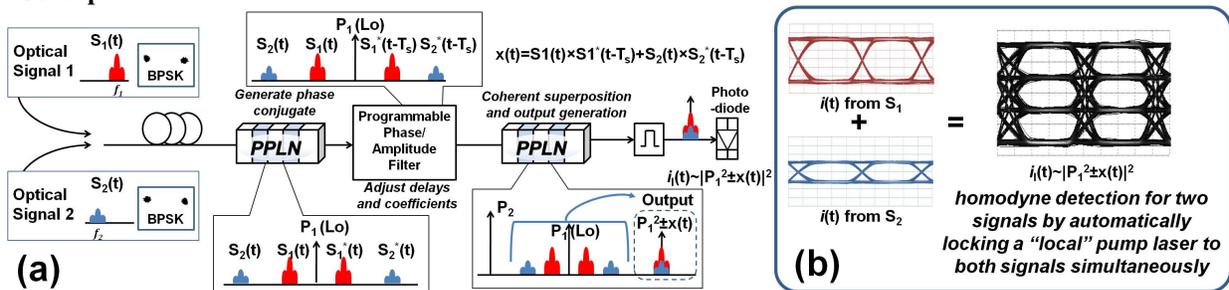
Fig. 1: (a) Concept of simultaneous homodyne detection of two channels by automatically "locking" both signals to a single local laser.
(b) Predicted output has 4 levels as a superposition of two simultaneously locked BPSK signals arriving at a photodiode.

The concept is depicted in Fig.1 (a). If two signals, $S_1(t)$ and $S_2(t)$ at frequencies f_1 and f_2 respectively were sent to a nonlinear device such as periodically-poled-lithium-niobate (PPLN) along with pump P_1 at f_{QPM} (QPM: Quasi-phase matching point), conjugates will be generated in the following form $S_i*(t)=P_1{}^2\times S_i*(t)$ at $f_{Si*}=2f_{QPM}-f_{Si}$. Here, P_1 will play the role of the Lo in this system. Afterwards, a programmable filter is used to add one symbol delay between the signals and the conjugate copies. Thus $S_i*(t)$ becomes $S_i*(t-T_s)$. Finally, another PPLN is used. In this PPLN, at $2f_{QPM}$, a superposition of the pump's second-harmonic $P_1(t)^2$ with the signals' sum-frequency-generation $x(t)=S_1(t)\times S_1(t-T_s)+S_1(t)\times S_1(t-T_s)$ is generated. The final pump (P_2) interacts in a difference-frequency-generation

manner to allow the previous superposition to be converted back to the C-band as an output at $f_{out}=2f_{QPM}-f_{P2}$. Fig.1 (b) shows the predicted electrical output at photodiode $i_I(t)\sim|P_1\pm x(t)|^2$ as an addition of the two signals locked together to the local laser (P_1). Locking occurs because: $\Phi_{P1,out}(t)=-\Phi_{P2}(t)+2\Phi_{P1}(t)$ and $\Phi_{Si,out}(t)=-\Phi_{P2}(t)+2\Phi_{P1}(t-T_s)+\Phi_{Si}(t-T_s)-\Phi_{Si}(t)$; where: $\Phi_{Si}(t)$, $\Phi_{Pi}(t)$, $\Phi_{P1,out}(t)$ and $\Phi_{Si,out}(t)$ are the signal phase, pump laser phase, phases of pump lasers and signals at the output frequency f_{out}, respectively. However, at low phase-noises, $\Phi_{P1}(t-T_s)\approx\Phi_{P1}(t)$. Thereafter, at photo-diode, the electrical signal is a function of the phase difference $\Phi_{Si,out}(t)-\Phi_{P1,out}(t)\approx\Phi_{Si}(t-T_s)-\Phi_{Si}(t)$ which is independent to the local pump phase $\Phi_{P1,out}(t)$. In other words, phase locking has occurred. Moreover, the output can be tuned to be either $i_I(t)=|P_1-x(t)|^2$ or $i_I(t)=|P_1+x(t)|^2$ by adjusting Φ_{P1} in the programmable filter. Furthermore, balanced detection may be utilized for 3dB improvement as described in [6].

3. Experiment
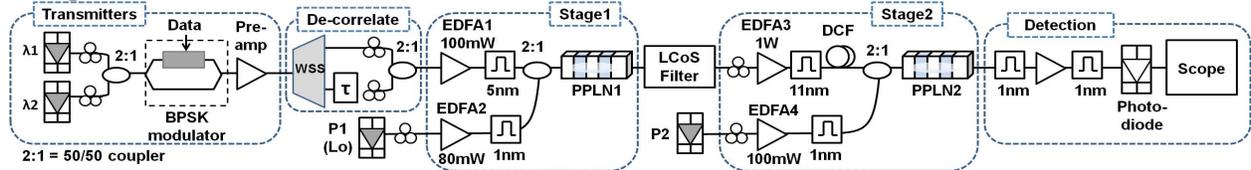
Fig.2: Experimental setup for the simultaneous homodyne detection for two locked signals to a single local laser.

Fig.2 shows the experimental setup. Two signals are generated by coupling two lasers at $\lambda_1=1535.78$nm and $\lambda_2=1537.32$nm and sending them to a BPSK modulator with PRBS $2^{15}-1$ at 10- and 20-Gbaud. The two channels pass through a wavelength selective switch (WSS) to de-correlate the data. Afterwards, in stage1, the signals are amplified in EDFA1 and combined with pump P_1 (Lo) with $\lambda_{P1}=\lambda_{QPM}=1540.40$nm to generate the conjugates. Then, Liquid Crystal on Silicon (LCoS) filter is used to fine tune the relative phases and delays. In stage2, a pump at $\lambda_{P2}=1530.42$nm is launched into PPLN2 along with the output from stage1 which is amplified and pass through dispersion compensating fiber (DCF) (25m and 100m for 10G- and 20-Gbaud, respectively) to introduce one symbol delay between signals and conjugates. Finally, PPLN2 output is filtered and sent to a photo-diode. Detected signal is recorded and processed offline for BER measurement, while eye diagrams were captured using sampling scope.

4. Results
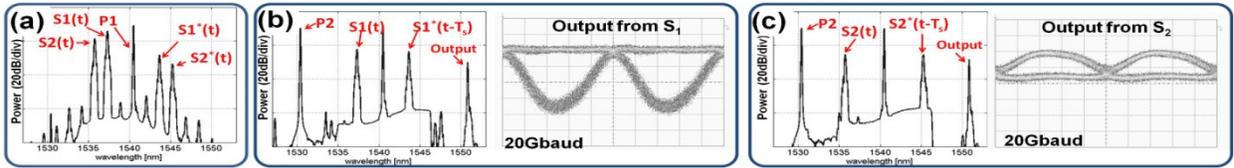
Fig3: 20-Gbaud experimental results: (a) Spectrum after stage1, (b) and (c) spectrums and eyes for homodyne detection of signals separately.

Fig.3, (a) depicts the spectrums after stage1 that has signals, conjugates and the "locking" pump P_1 . Fig.3 (b) and (c) show 20-Gbaud spectrums after stage 2 as well as eye diagrams for the case of homodyne detecting signals channels S_1 and S_2 once at a time when the other channel is blocked in the LCoS filter. Thereafter, Spectrums for the simultaneous homodyne detection of both signals is shown in Fig.4(a). Eye diagrams for the proposed two channels simultaneous detection scheme at 10-Gbaud and 20-Gbaud are presented in Fig.4 (b) and (c). In addition, the performance is assessed in BER curves in Fig.4(d) against the measured total incoming power from both channels before stage1. It should be noted that to detect the 4-level superimposed homodyne signal, $S_2(t)$ must have 3dB less power than $S_1(t)$ which can be managed inside the LCoS filter.
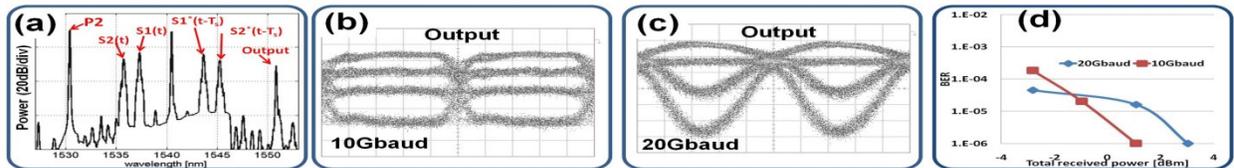
Fig4: Experimental results (a) 20-Gbaud spectrum for simultaneous homodyne detection for S_1 and S_2.
(b) and (c) Eye diagrams at 10- and 20-Gbaud. (d) BER performance for the simultaneous homodyne detection approach.

5. Acknowledgment

6. References
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