Demonstration of Tunable and Automatic Frequency/Phase Locking for Multiple-Wavelength QPSK and 16-QAM Homodyne Receivers using a Single Nonlinear Element

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Abstract: We experimentally demonstrate a tunable homodyne receiver on multiple-wavelength QPSK and 16-QAM channels at 20/30 Gbaud. A single PPLN waveguide is used to frequency/phase lock the signals with their tones. Open eye diagrams with BER measurements are shown.

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

1. Introduction

It is well recognized that homodyne systems have the potential for high receiver sensitivity. However, such systems require phase and frequency locking between the incoming signal and the local oscillator (LO), such that the phase and frequency offset is zero [1]. This requirement has generally kept other systems at the forefront, including intradyne and heterodyne [2]. In general, there have been reports of homodyne receivers: (i) utilizing complex electronic circuitry,[3] (ii) creating an optical phase-locked loop that requires the help of electronic circuits,[4,5] and the transmission of a fixed pilot tone from a transmitter [6,7]. Recently, there has been a report of a single channel bit-rate-tunable optical approach that automatically locks the phase/frequency of the incoming data to a LO using nonlinear wave mixing.[8] However, that method does not enable: (a) a single homodyne receiver to lock and recover multiple WDM channels, or (b) the recovery of different modulation formats.

In this paper, we experimentally demonstrate tunable and automatic frequency/phase locking for multiple-wavelength QPSK and 16-QAM homodyne receivers using a single nonlinear element. In our proposed scheme, we use a single nonlinear element to frequency/phase lock the pilot tone of the data channels to their signals at the receiver. We consider different cases of the WDM transmitters and implement the homodyne detection of the channels in that only nonlinear element. Open eyes are obtained for both in-phase and quadrature components of the QPSK and 16-QAM signals at 20/30 Gbaud. The BER performance of the proposed homodyne detection scheme is also measured.

2. Concept

Figure 1 shows the concept of the proposed comb-based WDM homodyne receiver. In this scheme, we consider two cases for the transmitter side. The first case is about a multichannel transmitter with only one laser source that could be a coherent WDM channels with a single coherent pilot tone (Fig. 1(a)). The second scenario is about the channels from different laser sources and each transmitter sends a pilot tone beside of the data channel. For the mentioned two scenarios, we could detect the signals using the proposed comb-based WDM homodyne receiver shown in the figure. In this scheme, in a process of sum-frequency-generation (SFG), the pilot tone (A_p) combines with one of the pump lines of the comb source at the receiver side, $A_{rec.1}$ to generate a new pump at $2f_{QPM}$ where f_{QPM} is the quasi phase

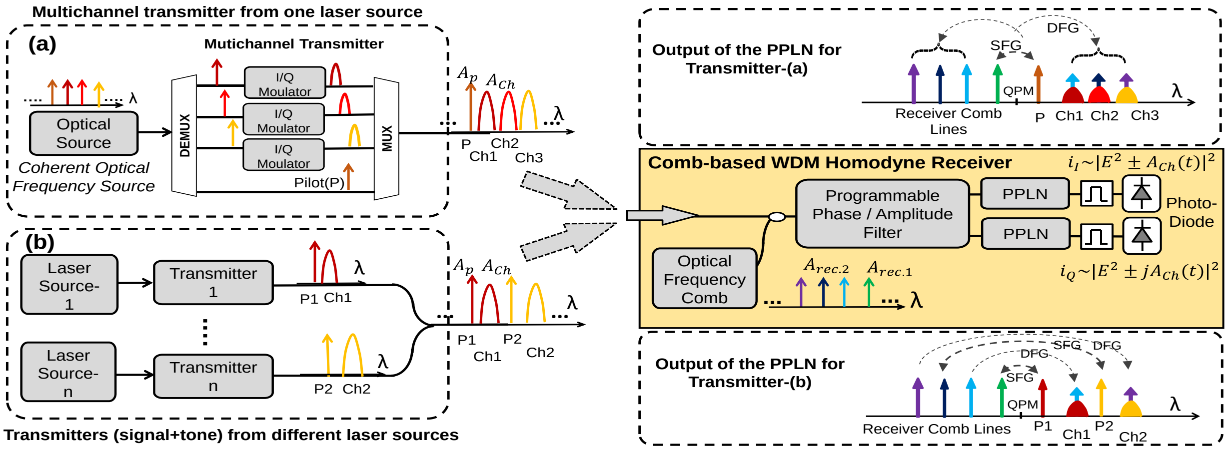
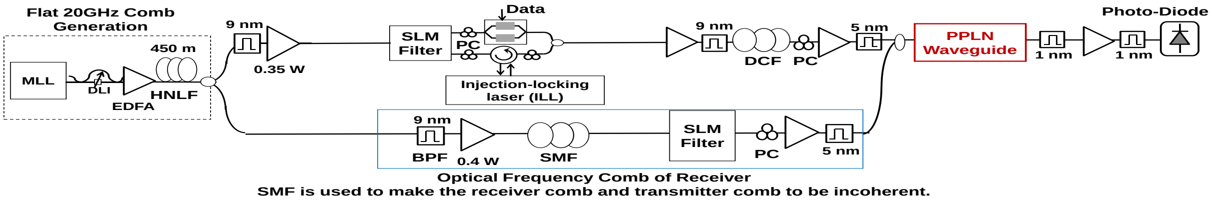


Fig. 1. Concept of comb-based WDM homodyne receiver for two types of transmitters, (a) Multichannel transmitter from one laser source, (b) Transmitters from different laser sources. For the homodyne detection, a PPLN waveguide is used to copy the pilot tone onto the signal.

matching (QPM) frequency of the PPLN. Another frequency line of the receiver comb $A_{rec.2}$ is used to copy the second harmonic wave onto the data channel, A_{Ch} using difference-FG (DFG). In other words, at the data channel frequencies we could generate the signal of $\alpha A_{rec.1} \times A_{rec.2}^{*} \times A_p + A_{Ch}$ which shows that the pilot tone could be copied onto the data channel by keeping the frequency and phase locking condition. By sending the filtered channels to photodiodes (PD) and setting α to ±1 or ±j inside the spatial light modulator (SLM) filter, both in-phase and quadrature components of the $A_{Ch}(t)$, can be obtained. Moreover, this scheme is tunable in terms of the signal baud rate and modulation format.

3. Experimental Setup



Optical Frequency Comb of Receiver
SMF is used to make the receiver comb and transmitter comb to be incoherent.

Fig. 2. Experimental setup. MLL: Mode Lock Laser, DLI: Delay Line Interferometer, BPF: Band Pass Filter, PC: Polarization Controller

Figure 2 shows the experimental setup. A mode-locked laser with a 10GHz repetition rate followed by a DLI and HNLF generates a broad spectrum comb as a source for the transmitters and the receiver. A 30 km SMF is used to introduce independence between the transmitter and receiver sides' combs. In the transmitter side, in a SLM filter, we choose 3 lines of the comb to be sent to a IQ modulator to modulate 20/30-Gbaud signals. On the other port of the SLM filter, one of the comb fingers as a pilot tone of the signals is selected and sent into an ILL to be amplified. For the second scenario, we choose 2 lines of comb for channels and two other lines as the corresponding tones to the ILLs. In the receiver side, the signals and tone are sent into a 4-cm long PPLN with QPM of ~1550.5 nm along with the frequency lines of comb at the receiver side. Inside the PPLN crystal, we could be able to generate the continuous wave locked tones on the data channels. The desired signal is then filtered and sent to a photodiode to be detected.

4. Results and Discussion

In Fig. 3, the spectra of the output of the PPLN is shown for 20/30-Gbaud QPSK data for 3-WDM channels. The open eye diagrams for I and Q parts of the signals is obtained after detection of the signals in a PD followed by an 80-GSample/sec real time scope. The result for one channel 20Gbaud 16-QAM is shown in Fig. 3(c). Figure 3(d) shows the BER measurements obtained by off-line processing on 2^{15}-1 PRBS data at the output of the real time scope.

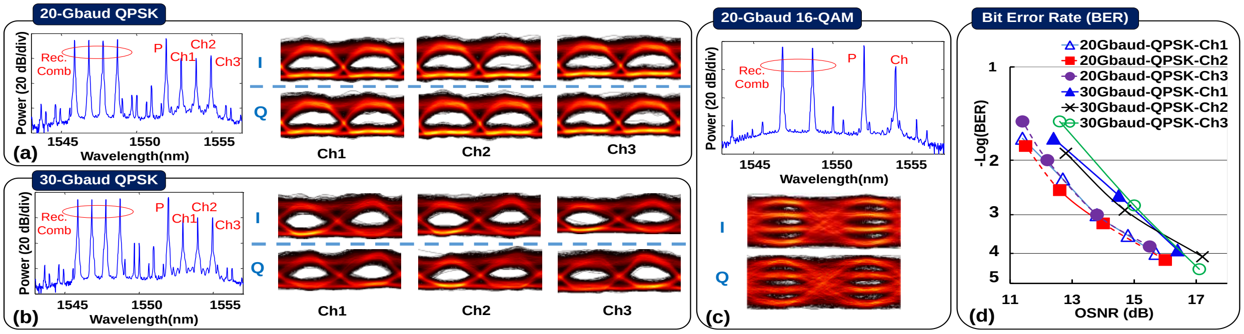


Fig. 3. Experimental results for 3-coherent WDM channels with one pilot tone, (a) Optical spectrum and eye diagrams of 20Gbaud QPSK signals. (b) Homodyne results of 30Gbaud QPSK channels. (c) Homodyne of one channel 20Gbaud 16-QAM. (d) BER measurements.

Figure 4(a) depicts the experimental results of the homodyne detection of two independent channels with their pilot tones. Figure 4(b) shows the detection results of only channel-2. Detection of each channel independently and separately could achieve 1.8 dB OSNR improvement at BER of 1e-3 based on BER curves in Fig. 4(c).

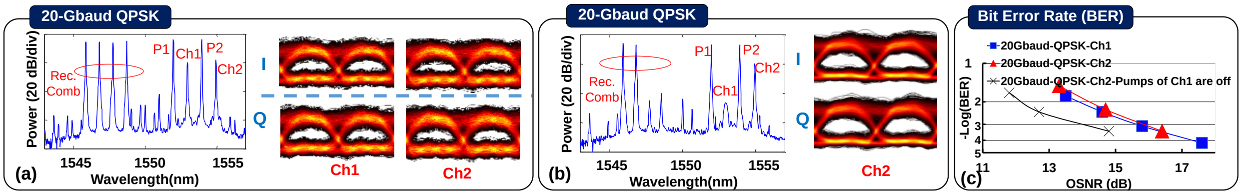


Fig. 4. Experimental results of two channels sent from independent laser sources (a) Optical spectrum and eye diagrams of the detected 20Gbaud QPSK channels. (b) Results of 20Gbaud QPSK channel-2 when the pumps of the channel-1 are off at the receiver. (c) BER measurements

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