Silicon Photonics 630-Gb/s Complementary Polarization-Diversity Coherent Receiver with 9-Mrad/s Polarization Tracking Speed for Self-Coherent Homodyne Detection

Honglin Ji[1,3*], Zhen Wang[2], Xingfeng Li[2], Jingchi Li[2], Ranjith Rajasekharan Unnithan[1], Weisheng Hu[2,3], Yikai Su[2], William Shieh[1]

[1]Department of Electrical and Electronic Engineering, The University of Melbourne, VIC 3010, Australia.
[2]State Key Lab of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University, Shanghai 200240, China.
[3]Peng Cheng Laboratory, Shenzhen, China.
*Author e-mail address: *honglinj@student.unimelb.edu.au / jihl@pcl.ac.cn*

Abstract: We demonstrate the first on-chip complementary polarization-diversity coherent receiver (C-PDCR) for rapid polarization tracking of remote LO. Based on electronic MIMO DSP, the polarization tracking speed can reach 9 Mrad/s with negligible performance degradation for a 70-Gbaud dual-polarization (DP) PCS-64QAM signal with 630-Gb/s data rate (net rate 485 Gb/s). © 2022 The Author(s)

1. Introduction

Short-reach optical networks aggregate the Internet traffic from various merging applications such as video streaming services requiring ever-increasing capacity. Moreover, the transceiver cost dominates the overall expenses of short-reach optical networks. Therefore, the multi-channel parallel optics based on low-cost intensity modulation and direct detection (IMDD) is still preferred but it is challenging to further scale the transmission rate due to its inefficient modulation format and component bandwidth limitation. As a result, coherent detection offering high spectral efficiency and receiver sensitivity starts to attract attention away from the IMDD. However, the conventional polarization-diversity coherent receiver (PDCR) could be integrated on the chip except for the relatively-expensive narrow-linewidth local oscillator (LO) [1-2], which impedes its commercial application. To tackle this difficulty of conventional PDCR, the intuitive way is to adopt self-coherent homodyne detection employing a separate fiber for LO delivery, which can simultaneously lower the receiver cost and DSP complexity by omitting the carrier/phase recovery [3]. However, the self-coherent homodyne detection system needs to track the state of polarization (SOP) of remote LO to guarantee equal carrier power for two polarizations. Under some extreme weathers such as thunderstorms, the SOP varying rate can exceed Mrad/s [4]. Up until now, the engineered adaptive/automatic polarization controller (APC) in an endless manner for the conventional PDCR is only with less than 300-rad/s tracking speed for 600-Gb/s DP signal [5]. To further improve the polarization tracking speed, we have proposed and demonstrated C-PDCR [6] using discrete components based on electronic MIMO DSP for polarization tracking.

In this paper, we demonstrate the first silicon photonics C-PDCR using remote LO for the reception of a 70-Gbaud probabilistic constellation shaped (PCS) 64-QAM DP signal with 630-Gb/s data rate (net rate 485 Gb/s). By using the recursive least squares (RLS) algorithm-based MIMO, the achieved polarization tracking speed can reach 9 Mrad/s with negligible generalized mutual information (GMI) degradation and even beyond 10 Mrad/s with shorter MIMO coefficients updating period, which provides a promising solution for the short-reach optical interconnects.

2. Silicon photonics integrated C-PDCR

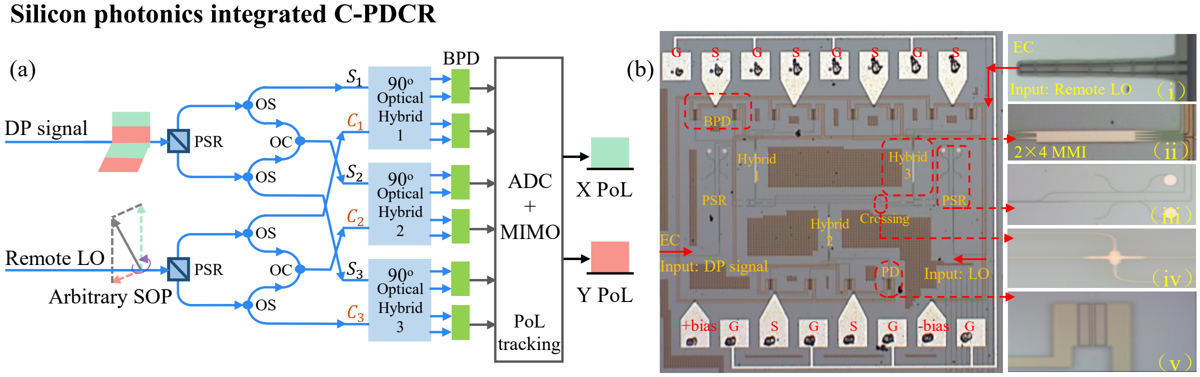

Fig. 1: (a) Schematic of proposed C-PDCR to accommodate remotely delivered LO with arbitrarily varying SOP. (b) Micrograph of the integrated C-PDCR chip with a footprint of 1.3×1.2 mm^2. PSR: polarization splitter/rotator. OC/OS: optical coupler/splitter. BPD: balanced photodetector. PoL: polarization. SOP: state of polarization. EC: edge coupler. MMI: multimode interference.

The proposed receiver structure of C-PDCR is illustrated in Fig. 1(a). Distinguished from the conventional PDCR, the proposed C-PDCR without the APC could accommodate the random SOP of the remotely delivered LO. To combat the polarization fading issue, the third 90-degree optical hybrid (the middle one) is introduced to provide complementary polarization detection (CPD). The fast evolution of the remote LO SOP could be tracked based on the electronic DSP using MIMO for dual-polarization recovery. The micrograph of the integrated C-PDCR chip using three optical hybrids is presented in Fig. 1(b), which is fabricated on a silicon-on-insulator (SOI) wafer with a 220-nm-thick silicon layer. To support polarization-diversity detection, both the received optical signal and remote LO are coupled into the silicon waveguides via the edge couplers. With the polarization splitter/rotator (PSR) for the received DP signals/LO, the TE mode is obtained from the through port while the TM mode is finally converted to the TE mode at the cross port [7]. The optical couplers/splitters and 90-degree optical hybrids in Fig. 1(a) for the integrated C-PDCR chip are all based on multimode interference. The 3-dB bandwidth of the integrated photodetectors exceeds 35 GHz with -3V bias voltage, which is supplied via the bias tees and probes. The balanced photodetection is realized by using two parallel photodetectors. The insets in Fig. 1(b) present the enlarged views of corresponding components.

3. Experiment and results

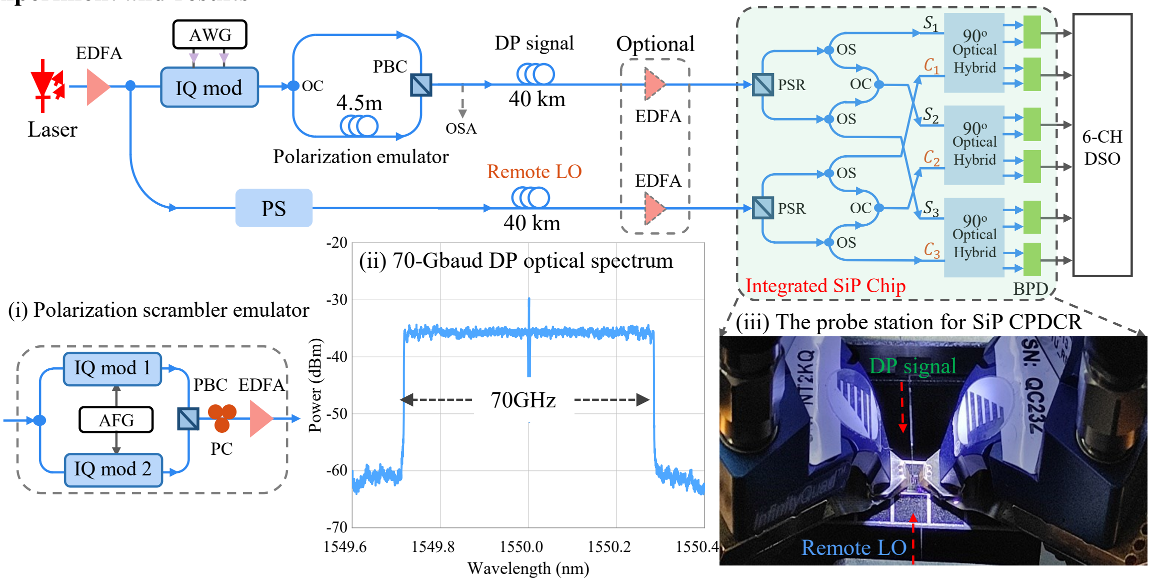

Fig. 2: Experimental setup for measuring the on-chip C-PDCR. IQ mod: IQ modulator. AWG/AFG: arbitrary waveform/function generator. PC: polarization controller. PBC: polarization beam combiner. EDFA: Erbium-doped fiber amplifier. OSA: optical spectrum analyzer. 6-CH DSO: 6-channel digital sampling oscilloscope. PS: polarization scrambler.

To validate the on-chip C-PDCR, we employ an experimental setup shown in Fig. 2. The transmitted signal is a 70-Gbaud OFDM signal with a 100-GSa/s sampling rate. The employed modulation format for the OFDM signal is PCS-64QAM with an entropy of 4.5 bits/symbol. The DP signal is generated by using a polarization emulator, in which a 4.5-m fiber is deployed for polarization de-correlation. The inset (ii) shows the optical spectrum of the generated DP signal with 70-GHz bandwidth. The remote LO for the C-PDCR originates from the same laser source for self-coherent homodyne detection. The 70-Gbaud DP signal and the homogenous LO propagate over a pair of 40-km fibers. Before the remote LO delivery, a polarization scrambler (PS) is employed to depolarize the LO with various SOP changing rates. The emulated PS illustrated in inset (i) composes of two low-bandwidth IQ modulators driven by two radio signals $cos(2\pi ft)$ and $sin(2\pi ft)$, respectively, and one manual PC for covering the whole Poincaré sphere. At the receiver side, the 6 electrical outputs from the BPDs are sampled by a 6-channel 80-GSa/s oscilloscope. The deployed probe station for the integrated C-PDCR chip is presented in inset (iii), which couples the high-speed photoelectric signal out to the oscilloscope. Due to the limited response of the probes, two EDFAs are employed for both the remote LO and DP signals to boost the optical input power and enhance the chip electrical output power for alleviating the strong bandwidth limitation effect of the probes. In practice, the two EDFAs are not needed to meet the low cost for short-reach applications. At the receiver side, the RLS-based 6×4 real-valued MIMO is implemented for both polarization tracking and polarization recovery.

To guarantee the optimal operation, LO to signal power ratio (LOSPR) is first investigated and controlled through the two receiver-side EDFAs. The result is depicted in Fig. 3(a) for both BtB and 40-km transmission. At the LOSPR of 4 dB, the efficiency of the on-chip C-PDCR is maximized. To reveal the robustness of the on-chip C-PDCR for combating the polarization fading effect, we select a special SOP of remote LO with output power fading of one

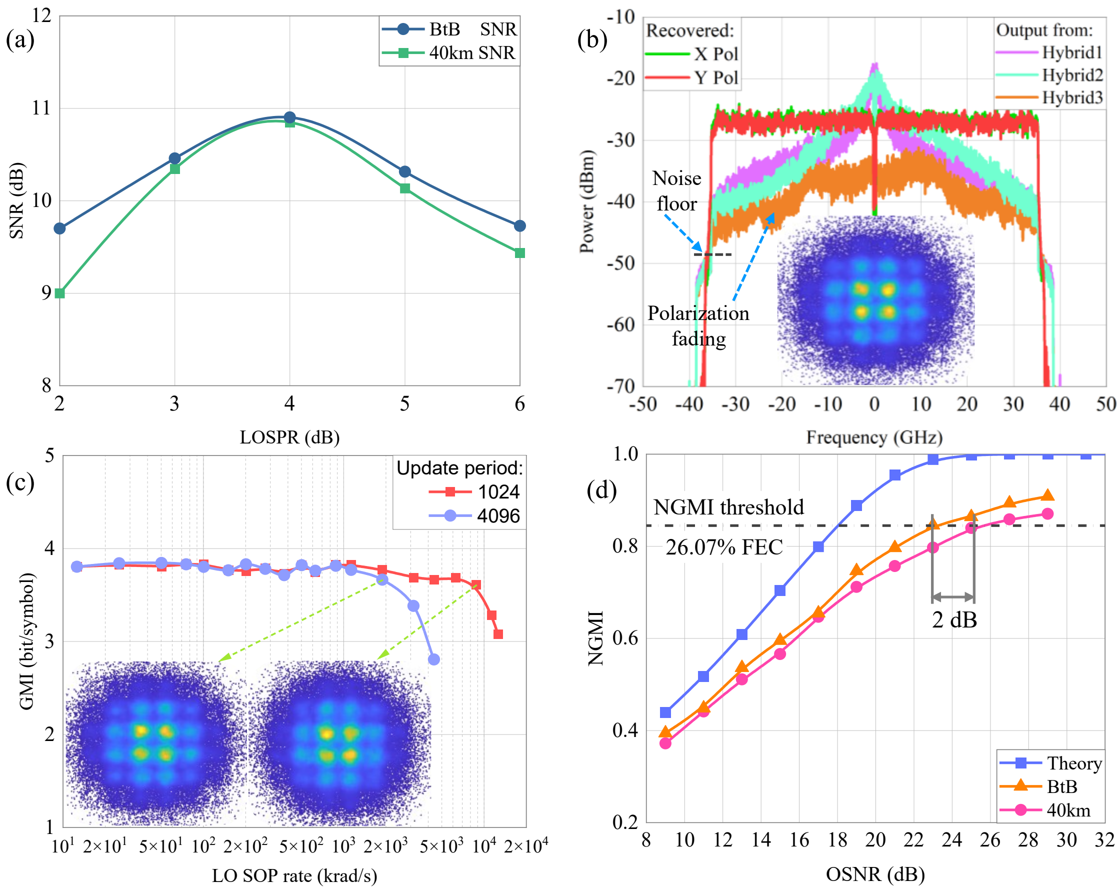

Fig. 3: (a) Achieved SNR under different LOSPR at BtB and 40-km fiber transmission. (b) Electrical spectra of the three 90-degree optical hybrid outputs after complex signal forming and the recovered DP signal after MIMO when polarization fading occurs. (c) GMI performance at 40-km transmission as a function of LO SOP rotation speed by using different coefficients updating period for MIMO. (d) NGMI performance as a function of OSNR for the on-chip C-PDCR with 630-Gb/s data rate.

90-degree optical hybrid and compare the electrical spectrum before/after the MIMO. As illustrated in Fig. 3(b), the transmitted DP field signal is successfully retrieved and the recovered PCS-64QAM constellation demonstrates its effectiveness. Fig. 3(c) explores the polarization tracking capability of the implemented RLS-based MIMO algorithm in the experiment. To cope with the fast evolution of the remote LO, the coefficients of the deployed MIMO are updated once every 4096 samples or 1024 samples for this 630-Gb/s transmission experiments. The polarization tracking speed of the implemented MIMO algorithm can reach 2 Mrad/s for the coefficients updating period of 4096 symbols and 9 Mrad/s for the coefficients updating period of 1024 symbols with negligible GMI performance degradation. The polarization tracking speed can be further improved to be beyond 10 Mrad/s with shorter coefficients updating period. The OSNR performance of this integrated C-PDCR is shown in Fig. 3(d). The targeted NGMI threshold is 0.845 using 26.07% FEC overhead [8]. The required OSNR for BtB and 40-km transmission is 23 dB and 25 dB, respectively. The 2-dB OSNR sensitivity difference could result from the optical noise on the remote LO after fiber transmission. Excluding the FEC overhead, the net data rate is 485 Gb/s and the achieved electrical spectral efficiency of this on-chip C-PDCR chip is 12.76 bit/s/Hz in this experiment.

4. Conclusions

We have demonstrated an integrated C-PDCR chip with the capability of fast polarization tracking for the reception of the 630-Gb/s DP PCS-64QAM signal. The polarization tracking speed of the implemented algorithm can reach 9 Mrad/s with negligible GMI performance degradation. This manifests that our proposed C-PDCR could be a promising solution for short-reach applications deployed in diverse electromagnetic and mechanical environments.

5. References

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