Self-Homodyne Coherent Systems for Short-Reach Optical Interconnects

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Abstract: Self-homodyne coherent detection scheme is promising for short-reach optical interconnect for its significantly reduced complexity and compatibility with legacy coherent infrastructure without sacrificing spectral efficiency. Solutions towards practical use are presented here with future perspectives. © 2023 The Author(s)

1. Introduction

With continuous traffic growth driven by explosive digital applications such as AI, cloud computing, VR/AR or even the Metaverse, the optical transmission is penetrating the short-reach interconnect especially datacenters [1]. 800G/1.6T is anticipated necessary to support pluggable optical transceivers in less than 10 km. Recently, OIF has launched standardization work in progress to enable interoperable 800ZR and 800LR, therefore it is indispensable to discover feasible technical solutions for cost effective short reach optical transmissions.

Although the cost-effective multi-lane intensity modulation and direct detection (IMDD) scheme dominates short reach for decades, it is difficult to cope with terabit and beyond optical interconnects due to inherent defects, such as poor receiver sensitivity, limited spectrum efficiency (SE) and chromatic dispersion (CD) induced power frequency-selective fading. Limited by the high cost and power-consumption, traditional coherent detection is too complicated to be used in short reach thus various self-coherent schemes have been proposed. Unlike IMDD, these schemes can retrieve full complex-valued fields, allowing the compensation of CD via DSP. Moreover, by transmitting a pilot tone generated from transmitter laser together with a modulated signal for self-coherent reception, they are generally with much larger laser linewidth tolerance, the potential to omit digital phase noise and frequency offset estimations, as well as the possibility to employ low-cost large-linewidth distributed feedback (DFB) lasers.

Among them, Kramers-Kronig receiver (KKR), employing single-sideband modulation with a frequency-offset pilot tone, has been proposed to retrieve complex-valued fields with a single-ended photodiode. It can also eliminate signal-signal beating interference (SSBI) without scarifying SE or any iteration. Even so, the KK algorithm is generally performed at an oversampling rate a few times faster than the Nyquist sampling rate, because of its nonlinear operations. This becomes the bottleneck of its practical application. As an alternative, orthogonal self-homodyne coherent (oSHC) schemes, including Stokes vector receiver (SVR) and polarization-tracking (PT-) oSHC scheme, has been proposed to deliver the pilot tone and signal with orthogonal polarizations, which can retrieve signal fields without nonlinear operations. Thereinto, SVR recovers the transmitted Stokes vector by means of linear transform in Stokes domain, which exactly contains the beating term of signal and pilot tone. PT-oSHC scheme use an adaptive polarization controller (APC) to recover the state of polarization (SOP) in optical domain by tracking the SOP of the pilot tone. Thus, the signal and pilot can be split for reception with single-polarization coherent receiver (SPCR). However, the two-dimensional modulations conspicuously limit their capacity.

Apparently, significant efforts have been devoted in this domain however it is still difficult to satisfy below requirements simultaneously: high SE and compatible hardware/DSP structure in line with commercial intradyne coherent (IC), relaxed parameters of laser linewidth and wavelength stability, near baud-rate sampling, etc. In this paper, we will demonstrate recently developed Self-homodyne coherent detection technique and discuss the pathway to overcome the abovementioned restrictions.

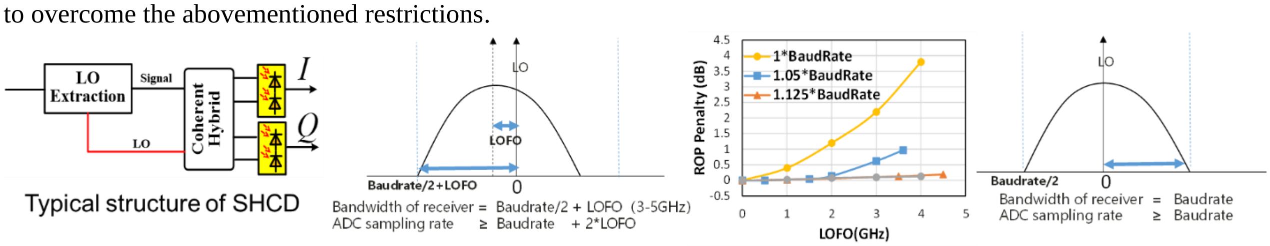

Fig. 1 Infrastructure of SHCD and its comparison with intradyne.

2. Architecture and Principle

The proposed SHCD architecture is shown in Fig. 1. The signal and pilot tone (LO) are transmitted through parallel channel (fiber pair or SDM fiber) and extracted at the receiver. Ideally, within affordable relative path delay between signal and LO, the frequency offset and carrier phase recovery can be neglected, thus further enables the baud-rate ADC sampling to reduce the complexity and power consumption jointly. Next, we will discuss key issues to enable real applications of SHCD.

3. Polarization-tracking enabled real-time SHCD transmission

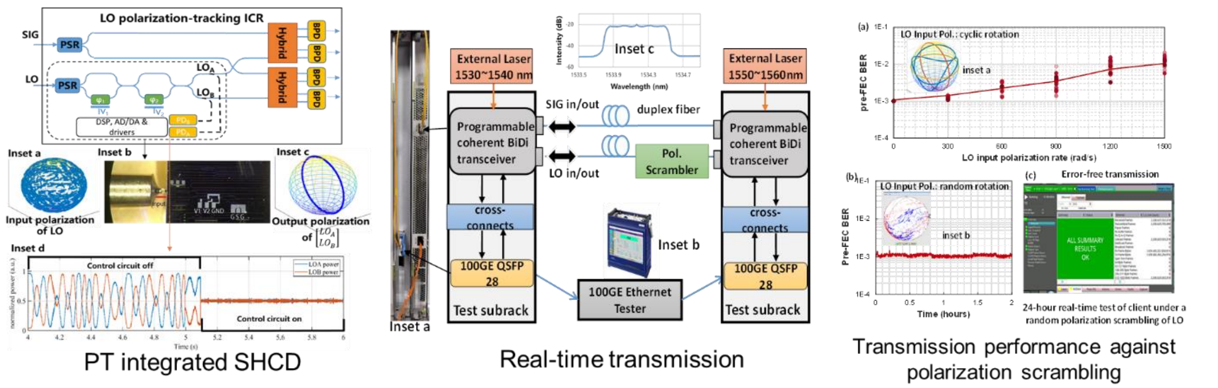

Fig. 2 Integrated polarization tracking enabled real-time transmission SHCD.

As shown in Fig. 2, we first proposed a polarization-tracking integrated coherent receiver (PT-ICR) in compact silicon photonics (SiP) platform, tracking up to 300 rad/s without a performance penalty [2]. This system allows the use of an uncooled LD with a large linewidth and reduces the complexity of digital signal processing (DSP) compared to that in a classical coherent system. A successful real-time demonstration with 600-Gb/s DP-64QAM using uncooled large-linewidth DFB lasers is conducted. After that, the APC technology was proposed in a Bi-Di optical interconnect [3]. By using the reciprocity property of optical fibers, the polarization wandering of the local oscillator (LO) is relevant to that of the counter-propagating signal within the same fiber. One APC realized the polarization tracking and compensation for LO and the counter-propagating signal simultaneously. The power-consuming 2x2 MIMO DSP can be eliminated hence a real-time MIMO-free 800Gb/s single-carrier SHCD has been achieved with 400rad/s SOP rotation, which is probably the simplest-ever DSP-based coherent transceivers for practical DCN applications.

4. Polarization-pilot-multiplexed SHCD transmission

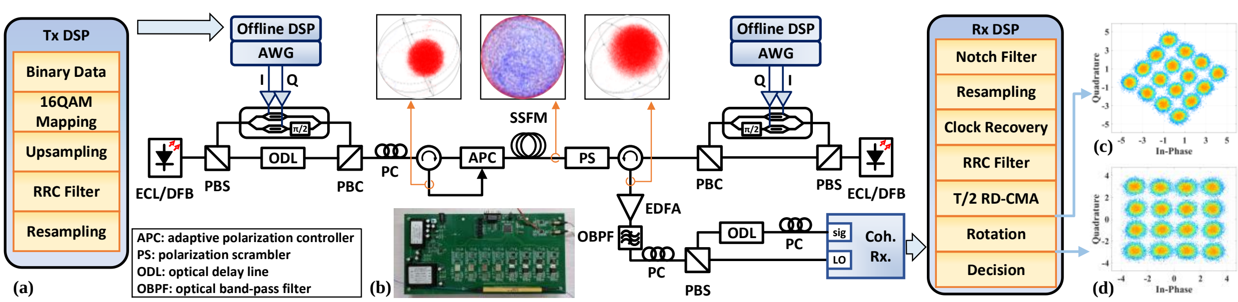

Fig. 3 Proposed BiDi SHCD system using optical polarization split of the signal and the LO, and the experimental results.

Another interesting Bi-Di SHCD scheme is the polarization-multiplexed of signal and LO, as shown in Fig. 3 [4]. A continuous wave (CW) light is divided into two tributaries by a polarization beam splitter (PBS). One tributary is used as the LO, while the other one is sent to a single polarization I-Q modulator (IQM) and modulated by an electrical signal. Then the modulated optical signal and LO are combined by a polarization beam combiner (PBC). The key idea of this system is to stabilize the SOPs of the upstream and downstream light by an APC, permitting that the signal and LO can be optically split by the PBS at the receiver side. Considering the Bi-Di operation has two fiber counts, the total data throughput is the same as our previously proposed SHCD system. 50Gbaud 16QAM and 64QAM single carrier single polarization transmission are performed. The path length mismatch, carrier-carrier beat noise and wavelength dependence are investigated in detail.

5. Distance extension technique for the SHCD scheme

An often-raised issue regarding the SHCD deployment is the power loss and distance restriction. Unlike the traditional IC scheme, which uses a strong LO laser at the receiver to achieve high sensitivity, the SHCD suffers from severe power splitter loss of laser, as well as twofold propagation loss of parallelly delivered signal and remote LO. These drastically reduce the power budget of SHCD schemes. So far, experimental demonstrations of the PT-SHCD schemes are mainly within 10 km. As a result, despite the enormous benefits of various SHCD schemes, they are hard to address metro-DCI applications beyond 10 km. To overcome this drawback, the key is to develop cost-efficient amplification, which should be anticipated capable to concurrently compensate the loss of both signal and remote LO for SHC applications, as the system performance depends on the beating of signal and remote LO.

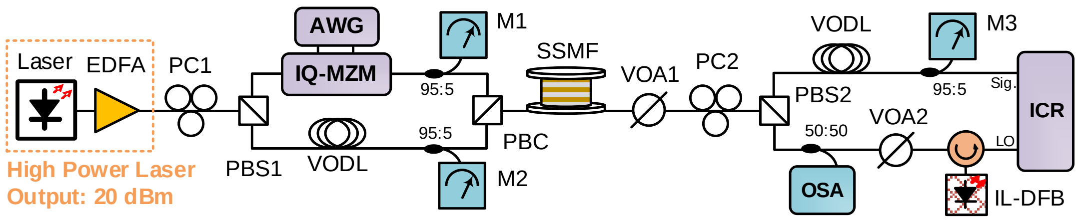

Fig. 4 Proposed injection locking enabled Metro-DCI SHCD system.

We recently proposed two solutions to achieve the distance extension. As shown in the Fig. 4, we utilized the optical injection locking at receiver side to regenerate optical carrier, hence achieved an amplifier-free low-CSPR PDM-SHD for medium-reach metro-optical network [5]. Single polarization 240-Gbps (60GBaud-16QAM) transmission along 75km SMF has been achieved even without CPR algorithms, meeting the ZR standard. It has been further confirmed that the fiber birefringence induced polarization fading can be readily eliminated by the transmitter side polarization scrambling and the receiver side injection locking [6], showing its potential for long term stable SHCD transmission.

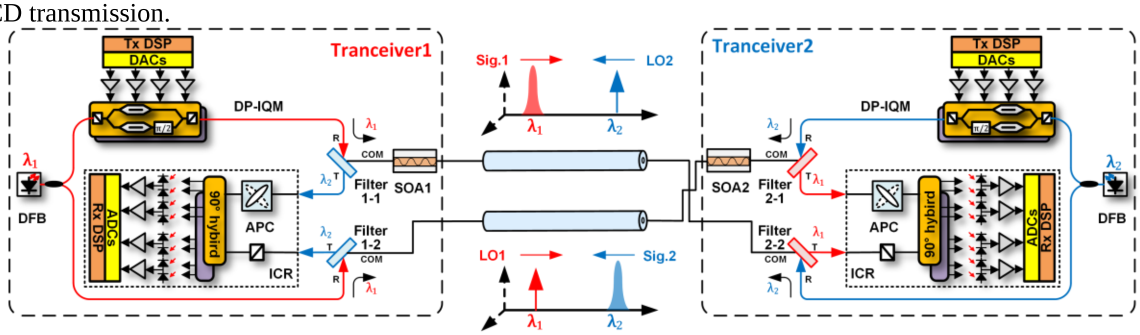

Fig. 4 Schematic of the proposed gain-clamped SOA enabled reach-extended SHC bidirectional transmission system.

Another example is shown in Fig. 5. Bi-Di operated semiconductor optical amplifiers (SOAs), with the signal gain clamped by counter-propagating remote LO, are utilized to simultaneously achieve linear signal amplification and remote LO regeneration [7]. By suppressing the stimulated Brillion scattering (SBS) in LO propagation using the build-in dithers of lasers, successful 400G dual-polarization 16QAM transmissions are demonstrated over 50km and 75km links under transmitter laser power respectively of 13.7 dBm and 18.5 dBm. The nonlinear phase and pattern-dependent distortions during signal amplification are demonstrated to be greatly mitigated by accelerating the gain recovery with proper clamping LO.

6. Conclusions

With the state-of-the-art technologies, we believe SHCD is promising to build future full SE while low-cost coherent system for optical interconnection not only in short reach scenario.

Acknowledgments

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