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Gain-Clamped SOA Enabled Reach-Extended Self-Homodyne Coherent Bidirectional Transmission for Inter-DCI Applications

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Abstract *We propose a reach-extended self-homodyne coherent bidirectional system utilizing gain-clamped SOA as both linear-booster signal amplifier and LO regenerator. Successful 400G transmissions over 50-km and 75-km links are demonstrated with simple maximum-likelihood phase recovery, yielding a cost-efficient solution for future inter-datacentre interconnects. ©2022 The Author(s)*

Introduction

Explosive big data services speed up the development of super or hyper datacentres. Tens-of-kilometres inter datacentre interconnects (DCIs) become increasingly important [1]. The interface speed of next-generation DCIs is expected to reach 800G or 1.6T [2]. Owing to the inherent defects such as chromatic dispersion (CD) induced power fading and poor receiver sensitivity, the intensity modulation and direct detection (IMDD) scheme is difficult to cope with such high interface speed even within <2-km intra-datacentre networks [3]. Meanwhile, despite of the supreme benefits of high sensitivity, high spectrum efficiency and good tolerance to propagation effects, the traditional intradyne coherent scheme is still regarded too expensive and too power-consuming for short-reach applications, primarily on account of the needs of expensive narrow-linewidth lasers and power-hungry digital signal processing (DSP). As a compromise, many self-coherent schemes have been proposed with less implementation complexity, compatibility with large-linewidth distributed feedback (DFB) lasers as well as omission of digital phase recovery and frequency offset estimation [4–8]. Among them, self-homodyne coherent (SHC) schemes utilizing adaptive polarization controller (APC) are proposed to preserve the architecture and advantages of intradyne coherent scheme to the most extent, which is regarded as one of the most promising coherent-lite solutions [8,9]. The main concept is to utilize a remote local oscillator (LO) generated from transmitter laser for coherent reception. In addition to the general benefits of self-coherent schemes, the SHC system is possible to employ baud-rate-sampling receiver and DSP without significant performance penalty [10]. It is also regarded as one of the most promising approaches to realize cost-efficient bidirectional (BiDi) transmissions [11,12]. SHC-BiDi transmission with the polarization rotation of the counter-propagating LO and signal simultaneously compensated by a BiDi-operated APC is demonstrated, without needs of multiple input multiple output (MIMO) equalizer [12].

However, the attractive SHC-BiDi scheme is still not applicable for inter-DCI applications. So far, demonstrations of SHC-BiDi scheme are mainly within 10-km reach [6–8]. Under 15.5-dBm transmitter laser power, the 600G DP-64QAM SHC-BiDi system is evaluated to handle the maximum link loss of a 5-km standard single mode fibre (SSMF) [10]. A key constrain is the lack of cost-efficient amplifiers enabling simultaneous amplifications of signal and LO. In SHC scheme, both signal and LO suffer from significant propagation loss and power splitter loss of transmitter (Tx) laser, making the power budget limited. The semiconductor optical amplifier (SOA) is low-cost, integratable and with available gain in nearly all communication bands (O, E, S, C and L) [13], which is tempting for SHC-BiDi scheme. Unfortunately, SOA is unsuitable to amplify high-speed amplitude- and phase- modulated signal for the serious nonlinear distortions, including self-gain modulation (SGM) induced pattern effect [14] and self-phase modulation (SPM) induced nonlinear phase distortion [15,16].

In this paper, we propose a cost-efficient reach-extended SHC-BiDi system utilizing bidirectional-operated SOA with signal gain clamped by counter-propagating LO. The SGM and SPM effects of SOA can be well suppressed, enabling both linear-booster amplification of signal and regeneration of LO, which can significantly improve the power budget of SHC-BiDi scheme for inter-DCI applications.

Principle of the SOA enabled reach-extended SHC-BiDi scheme

The proposed gain-clamped SOA enabled reach-extended SHC-BiDi scheme is illustrated in Fig. 1. For each transceiver, the modulated signal and a remote LO generated from the same transmitter laser are together delivered to receiver through a

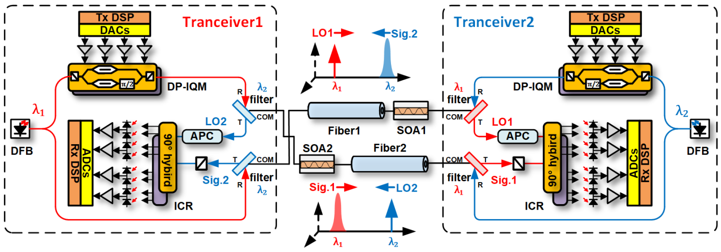

Fig. 1: Schematic of the proposed gain-clamped SOA enabled reach-extended SHC bidirectional transmission system.

full-duplex fibre (or a multi-core fibre). To avoid the impairments of Rayleigh scattering and stimulated Brillion scattering (SBS), bidirectional transmission is realized via DFB lasers operating at different wavelengths, which are presented in red (λ_1) and blue (λ_2). To obtain the desired wavelength, as well as avoiding the impact of SOA facet reflection on detection, signal and LO are added to the BiDi links by reflected (R) ports of two 3-ports optical filters (R ports: λ_1/λ_2) but dropped by the transmissive (T) ports of another two 3-ports optical filters (T ports: λ_1/λ_2). The reach extending is achieved by bidirectional operated SOAs, as both linear-booster amplifier for signal and regenerator for LO. Taking the amplifications of downstream Sig.1 and upstream LO2 for example, the Sig.1 and the counter-propagating LO2 will be simultaneously injected to the SOA2 from two opposite directions. The relatively strong LO2 serve as saturating assist light to clamp the carrier density and speed up the gain recovery of SOA2 [17]. As a result, the nonlinear distortions for Sig.1 amplification can be greatly suppressed, and LO2 can obtain gain for regeneration with the bidirectional operated SOA2. Sig.2 and LO1 have similar conditions.

Experiment setup and results discussions

Fig. 2 (a) depicts the experimental setup. Without loss of generality, downstream transmission consisting of Sig.1, LO1 and LO2 is conducted to validate the proposed scheme. LO2 is used to clamp gain of SOA2 (Inphenix, IPSAD 1501) for Sig.1 amplification. And SOA1

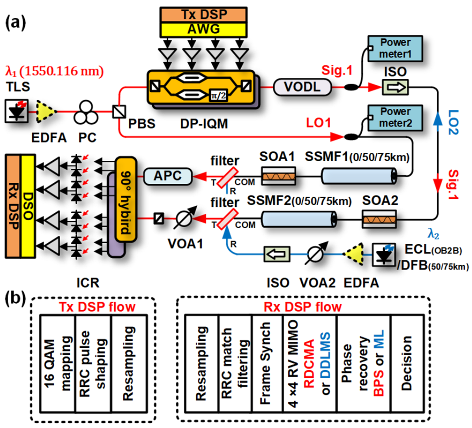

Fig. 2 (a) Experimental setup; (b) Tx and Rx DSP flow.

(Inphenix, IPSAD 1501/1522C) is used as a regenerator for LO1. Owing to the limited output power (<13.7 dBm) of the tunable laser source (TLS, Yenista, linewidth ~1 MHz), the Erbium doped optical fibre amplifier (EDFA) in conjunction with TLS/DFB will be used to emulate high-power DFB lasers only in 75-km transmission. The polarization controller (PC) and polarization beam splitter (PBS) are used to adjust the carrier (LO1) to signal (Sig.1) power ratio (CSPR). 50-GBaud dual-polarization (DP) 16QAM baseband signal, with pulse shaped by 0.2-rolloff root-raised cosine (RRC) filter, is generated via the arbitrary waveform generator (AWG, Keysight M8196A) operating at 90 GSa/s. Subsequently, the signal is modulated on the optical field via a commercial DP IQ modulator (DP-IQM). The variable optical delay line (OVDL) is utilized to match the propagation delays of Sig.1 and LO1, with Tx power monitored by power meters (PMs). Isolators (ISOs, using two ports of circulators) are used to ensure power monitoring accuracy of PM and variable optical attenuator (VOA-)2 by avoiding facet reflection. The filters are bandpass DWDM filters at 1550.116 nm. The polarization of LO1 is managed by APC. After SHC detection, 4 parallel electrical signals from the integrated coherent receiver (ICR, NeoPhotonics Class 40) will be captured by 80-GSa/s operated digital sampling oscilloscope (DSO, LeCory LabMaster 10-36Zi-A) for offline processing. The 4×4 real-valued (RV) MIMO is used for frequency-dependent IQ impairments mitigation, as well as polarization demultiplexing and CD compensation. Its coefficients are initialized via training mode then updated in blind mode, with the direct decision least mean square algorithm (DDLMS). The DDLMS can correct the constant rotation phase of the constellation in SHC scheme as well. Due to the lack of >50-km duplex fibre or multi-core fibre, which has more stable relative propagation delay (RPD) as environment changes [18], a simple maximum likelihood (ML) phase recovery (PR) [19] is employed to compensate residual phase noise due to RPD fluctuations of the two SSMFs. To assess the performance, the powerful blind phase estimation (BPS) and 4×4 RV MIMO with radius decision constant modulus algorithm

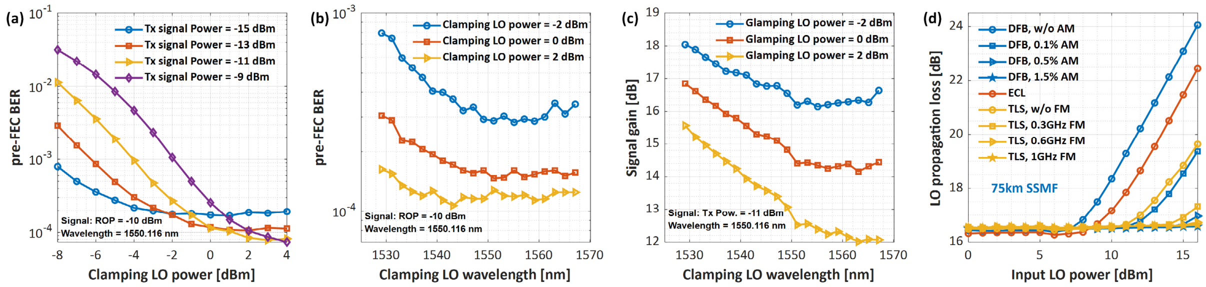

Fig. 3 OB2B results (a) pre-FEC BER vs LO power; (b) pre-FEC BER vs LO wavelength;(c) signal gain vs LO wavelength, and (d) LO propagation loss of 75km SSMF vs input LO power.

(RDCMA) applied in intradyne scheme will be used as comparison.

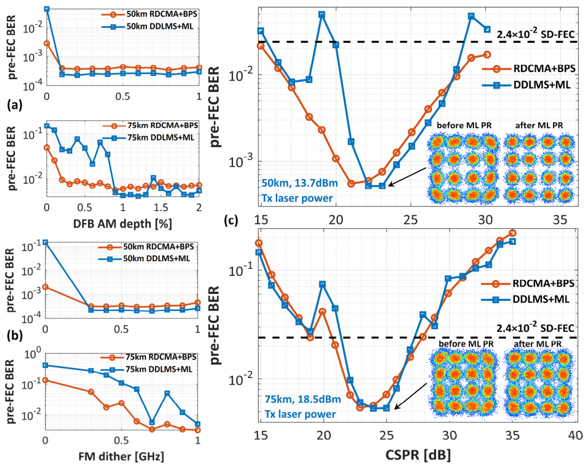

Fig. 4 50-km and 75-km results (a) pre-FEC BER vs clamping DFB AM depth;(b) pre-FEC BER vs TLS FM dither frequency;(c) pre-FEC BER vs CSPR.

We firstly investigate the optimal clamping power and wavelength under OB2B. Since the DFB wavelength is fixed, we replace it with an external cavity laser (ECL, coherent solutions). As illustrated in Fig. 3(a), the optimal clamping power varies from -4 dBm to 3 dBm as the signal power increases from -15 dBm to -9 dBm, indicating the necessity of CSPR optimization. It is noteworthy that the LO power should not continue to increase once the nonlinear distortions are suppressed, which will reduce the signal gain. Fig. 3(b) and (c) show the results of BER and signal gain versus clamping wavelength. In comparison with long wavelength, the short-wavelength clamping has larger signal gain but worse performance under the same received optical power (ROP) (due to the nonlinear distortions), revealing that short wavelength (<1550.116 nm) is relatively difficult to clamp SOA gain. On account of the unavoidability of short wavelength in the SHC-BiDi scheme, the wavelength of DFB will be fixed to 1547.715 nm to investigate the worst case. We next investigate the LO propagation loss, as shown in Fig. 3(d). In spite of considerable propagation loss caused by the SBS effect, the build-in frequency modulation (FM) dither of TLS and amplitude modulation (AM) dither of DFB can be used to increase the SBS-equivalent linewidth, thus suppressing the SBS effect and improving ROP of remote LO. Since only one TLS is available and the control strategy of APC is to minimize the power of unwanted polarization, which breaks down under DFB AM dither, we employ DFB as clamping light (LO2) and TLS for Sig.1 and LO1. Fig. 4(a) and (b) show the BER performance under different FM dithers and AM dither depths. By supressing the SBS effect utilizing AM or FM dithers, the remote LO can be effectively delivered to the end of SSMF for clamping and regeneration, thus improving transmission performance. Besides, note that the unfiltered EDFA noise or the insufficient LO ROP will degrade the quality of regenerated LO, which induces instable APC locking and additional phase through APC manipulation in some case. We finally validate the SOA capability to extend reach of SHC-BiDi scheme. As depicted in Fig. 4(c), the BER under the optimal CSPR is far below SD-FEC limit for 50-km and-75 km links, with the Tx laser power of 18.5 dBm and 13.7 dBm, respectively. Besides, the phase noise of the ~1MHz TLS can be greatly eliminated by SHC detection, according to the insert constellations. And instead of using the complex BPS(+RDCMA) algorithm, a simple ML phase recovery is enough to cope with the residual phase noise.

Conclusions

We propose a cost-efficient reach-extended SHC-BiDi scheme utilizing bidirectional-operated gain-clamped SOAs as both linear-booster signal amplifier and LO regenerator. Demonstrations of 400G DP-16QAM SHC transmissions indicate that the SOA is far enough to handle the link loss of 50-km and 75-km SSMFs with Tx laser power of 13.7 dBm and 18.5 dBm. DSP employing the simple ML phase recovery is validated to be feasible under ~1MHz laser linewidth. The proposed scheme provides a promising solution to extend reach of SHC-BiDi scheme for future inter-DCI applications.

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