DSP for Single-sideband Direct-detection Systems

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Abstract: We review signal-signal beat interference mitigation techniques for direct-detection systems. Simulation and experiments have been carried out for ≥ 100 Gb/s/λ WDM systems transmitting over up to 160 km single-span SSMF.

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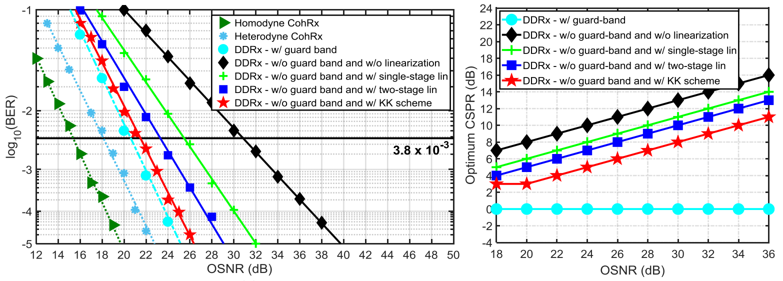
1. Introduction

In order to deal with unprecedented data traffic growth in data center interconnect (DCI) and metropolitan networks, optical transmission systems providing compact, low power and low-cost solution are required, whilst offering high speed, spectrally efficient transmission over ≥ 80 km of uncompensated SSMF. Single-polarization single-photodiode based single-sideband direct-detection (DD) transceivers may be favorable for such applications due to their simpler optical structures compared to the conventional polarization-multiplexed coherent transceivers. However, direct-detection introduces a severe nonlinearity, namely signal-signal beat interference (SSBI), causing significant degradation of the system performance. Thus, it is desirable to develop SSBI mitigation schemes to eliminate this impairment, enabling DD transceivers supporting high throughput transmission (at net rates ≥ 100 Gb/s/λ) [1]. In this work, we review the DSP-based SSBI mitigation techniques that have been implemented for single-sideband DD systems, describing both numerical simulations and experimental demonstrations.

2. Performance Assessment of Different 100 Gb/s/λ Transceiver Structures

A comparison of the performance of various coherent and direct-detection transceivers, operating at a gross bit rate of 112 Gb/s (28 GBd) and employing Nyquist pulse-shaped 16-QAM subcarrier modulated signal, was carried out through numerical simulations. Conventional homodyne and heterodyne coherent designs were modeled to provide benchmark performance, whilst single-photodiode receiver with sufficiently wide guard-band to avoid SSBI [2] and digital SSBI mitigation schemes, including single-stage [3] and two-stage [4] linearization filters and Kramers-Kronig (KK) scheme [5-7] were assessed for DD systems. Penalties due to the practical limitations were neglected, allowing to purely focus on performance differences between the SSBI mitigation schemes.

The back-to-back performance was assessed through ASE noise loading and the BER with respect to OSNR is plotted in Fig. 1(a). The case with sufficient guard-band was found to offer the best performance among the considered DD transceiver designs but at the expense of doubled optical and electrical bandwidth requirements and halved spectral efficiency. Considering the DSP-based SSBI mitigation techniques, the KK scheme offers a required OSNR 3.3 dB higher than of the heterodyne coherent receiver at the HD-FEC threshold, as shown in Fig.1(a). This is explained by the additional power of the optical carrier which is required in the DD system, and which is included in the calculation of the signal power. Carrier-to-signal power ratio (CSPR) optimization was performed, with the results plotted in Fig. 1(b). From this plot of optimum CSPR versus OSNR, it can be observed that the optimum CSPR increases with OSNR, i.e., increasing by approximately 1 dB with every 2 dB OSNR increase when no guard-band or linearization scheme is used. Due to their different capabilities in suppressing the SSBI, the optimum CSPR at a given OSNR was reduced by 2 dB, 3 dB and 5 dB for single-stage linearization filter, two-stage linearization filter and the KK scheme, respectively [8].



(a) **(b)**

Fig.1: (a) Theoretical BER vs OSNR. (b) Optimum CSPR vs OSNR [1].

3. Experimental Demonstration

The transmission performance of the DD systems was experimentally assessed using the setup in Fig. 2. Odd and even WDM channels were separately generated using a pair of IQ-modulators, driven by two 92 GSa/s DACs. 28 GBd (112 Gb/s SSB 16-QAM and 168 Gb/s SSB 64-QAM) 0.51-cycle subcarrier-modulated Nyquist signals were generated with RRC filters with a 1% roll-off, and multiplexed to form a 28 GHz-spaced 4-channel WDM signal. Transmission tests were performed over SSMF links, with span lengths of 80, 120 and 160 km without inline amplification, followed by an EDFA (5 dB noise figure). At the receiver, wavelength demultiplexing was carried out using an optical bandpass filter (OBPF), and the channel-under-test was detected using a 40 GHz PIN photodiode followed by an 80 GSa/s scope. Receiver-based digital dispersion compensation was performed.

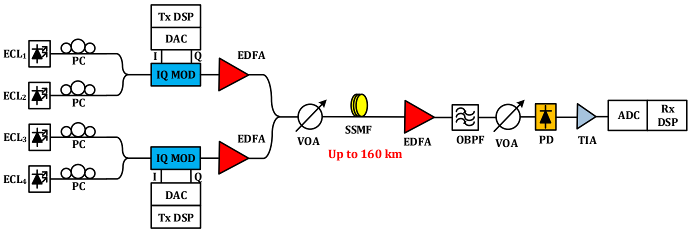


Fig. 2: WDM transmission experimental test-bed.

The WDM transmission performance for both 16-QAM and 64-QAM systems was evaluated as shown in Figs. 3(a) and 3(b), respectively. In Fig. 3(a), for 112 Gb/s/λ WDM 16-QAM signaling, the minimum BER values at the optimum launch power were reduced from 1.1×10^{-2} without linearization to 1.6×10^{-3} and 6.1×10^{-4} using the two-stage linearization filter and the KK scheme at 120 km. At 160 km transmission, the BER values were reduced from 5.4×10^{-2} without linearization to 1.3×10^{-2} and 5.4×10^{-3} with two-stage linearization filter and the KK scheme, respectively. Finally, the minimum BER values at 80 km were found to be 1.1×10^{-2} and 4.5×10^{-3} using two-stage linearization filter and the KK scheme, respectively for 168 Gb/s/λ WDM 64-QAM signal, as shown in Fig. 3(b). The achieved net optical spectral efficiencies (SE) obtained by considering the theoretical hard-decision decoding were found to be 4.61 (b/s)/Hz, 3.17 (b/s)/Hz and 3.05 (b/s)/Hz, respectively, for transmission over 80 km, 120 km and 160 km single-span SSMF (Fig. 3(c)).

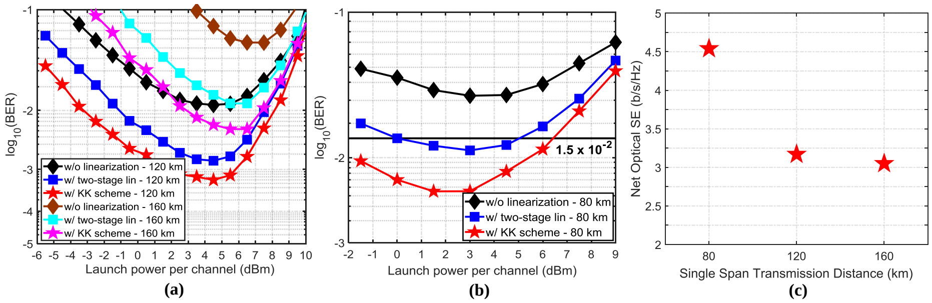


Fig. 3: BER vs optical launch power per channel for (a) 112 Gb/s/λ 16-QAM [1] and (b) 168 Gb/s/λ 64-QAM SSB transmission experiments [9]. (c) Achieved net optical spectral efficiency vs single-span transmission distance.

5. References

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