Enabling High Capacity Direct-Detection Optical OFDM Transmissions Using Beat Interference Cancellation Receiver

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Abstract *We demonstrate a simple beat interference cancellation approach enabling higher spectral efficiency and better sensitivity (> 2 dB) for DDO-OFDM. The associated benefits of enhanced phase noise and PMD tolerances, as well as the impacts of diverse filter parameters, are also discussed.*

Introduction

Optical OFDM has recently attracted lots of interest because of its simple equalizer for compensating the linear impairments throughout the link[1,2]. Compared with the coherent optical OFDM (CO-OFDM) [1], the lower-priced and less-complex direct-detection optical OFDM (DDO-OFDM) [2] would be a more suitable candidate for the medium and short distant transmissions, i.e. the metropolitan and local access networks.

In order to combat for the fibre chromatic dispersion (CD), linear field modulation is typically applied in DDO-OFDM transmissions. However, due to the square-law nature of the photodiode, the sideband-sideband beat interference (SSBI) would mix with the desired signal and thus severely degrade the system performance. A simple approach avoiding this problem is to insert a frequency gap with the same width as the data sideband[3], which will locate the signal and SSBI in different frequency bands after the photodiode. Nevertheless, the associated drawback in such a DDO-OFDM system is the low spectral efficiency resulted from that inserted gap which bears no data information. Hence, it would gain much benefit in spectral efficiency if the gap width could be reduced or this gap could be even discarded.

So far, there have been mainly two proposals targeting at the gap issue: 1) Carrier-boosting approach[2], in which the optical carrier is filtered out and amplified with an EDFA. In this method, a narrow-band optical filter and a careful polarization management are needed in the carrier path of the receiver, which complicates the optical front end and would possibly suffer unexpected obstacles from the view point of fabrication. 2) Signal processing approach[4], which estimates and removes the SSBI after the photodiode using a digital iterative equalizer. However, this approach requires a high computationally-efficient algorithm to relieve the heavy burden of the complex iterative equalizer, which is still under explored. Therefore, a laudable solution to this gap issue should involve the least complexity for both the optical front end and electrical post end, and therefore could offer a lower-cost and higher-throughput transmission.

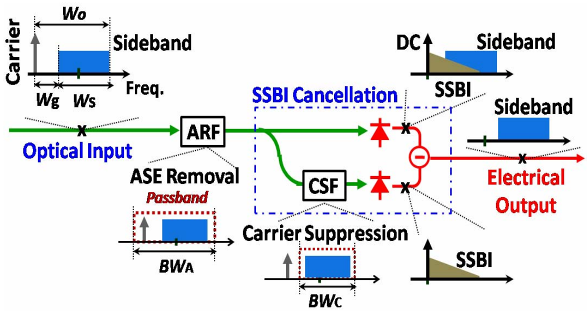

Fig. 1: Sideband-sideband beat interference (SSBI) cancellation receiver for DDO-OFDM. ARF: ASE-removing filter, CSF: carrier suppression filter.

In this paper, we demonstrate the SSBI cancellation receiver which can reduce the frequency gap and achieve a higher spectral efficiency. Since it requires only one optical filter and one balanced receiver in the optical front end without the need for a careful polarization management, the proposed receiver is relatively simple for design and fabrication when compared with the previous gap-reduction proposals[2,4]. In addition to the enhanced spectral efficiency, the receiving sensitivity, as well as the tolerances against both the phase noise and polarization mode dispersion (PMD), can also be improved with this proposal. In this paper, we firstly investigate the impacts of diverse design parameters of the utilized filter, including its order, bandwidth, and central frequency deviation, on the gap width and the system performance, and then we demonstrate the enhanced tolerances against both laser linewidth and PMD with the proposed receiver.

Beat Interference Cancellation Receiver

The proposed receiver architecture is shown in Fig. 1. After the ASE-removing filter (ARF), practically a WDM de-multiplexer, the received signal is then split into two branches via a 1x2 optical coupler: the upper branch is directly feed to the photodiode yielding both the desired data

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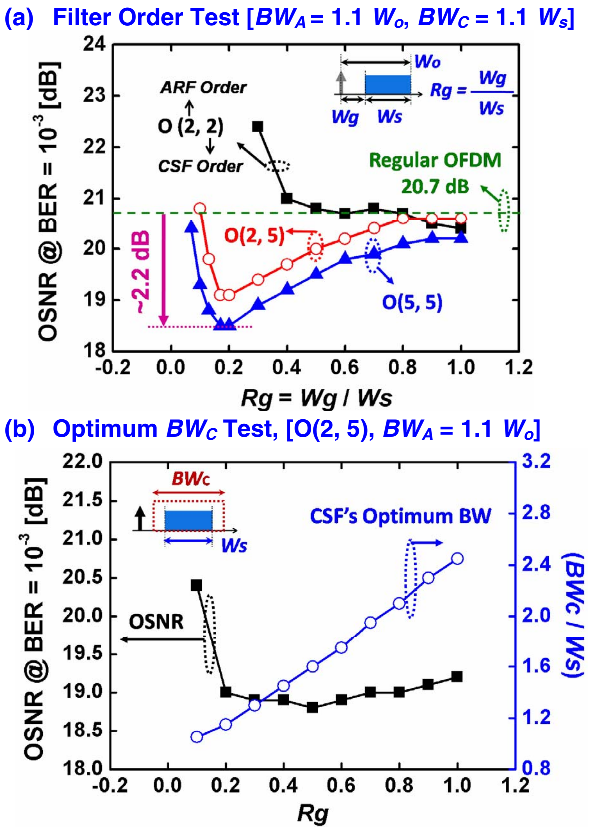

Fig. 2: (a) OSNR vs. gap width with fixed BW_A and BW_C. Different filter orders are tested. **(b)** Re-simulation results of O(2, 5) in (a) but now with the optimum CSF bandwidth, BW_C. System parameters: 16 QAM, 50 Gbps, CP = 20 %, Ws = 15.63 GHz.

sideband and SSBI; while the lower branch suppressing the optical carrier with a carrier suppression filter (CSF) results in only SSBI after the photodiode. After subtraction the desired signal without SSBI could be obtained at the output of the balanced detector, thus enabling a smaller-gap OFDM system possible. Actually, this balanced detector would cancel out not only the SSBI, but also part of the beat noise power, thus yielding an improved receiving sensitivity. Notably, because any relative polarization rotation between the two optical branches would not affect the output electrical waveforms, a careful polarization management is not needed in this receiver, which could greatly simplify its design and fabrication process.

Results and Discussions

Since the signal quality would strongly depend on the degree of the SSBI removal, the filter parameters of CSF, including its order, bandwidth, and central frequency deviation, could be critical to the system performance. Therefore, in this section we will firstly explore the impacts of CSF's diverse parameters on both the gap width and system performance, and then demonstrate the associated benefits in both the enhanced phase noise and PMD tolerances. In simulations we consider a 16-QAM and 50-Gbps single-polarization DDO-OFDM system. 160 data subcarriers are zero-padded to a FFT size of 256, and a 20% cyclic prefix is applied for the margin of inter-symbol interference, leading to a sideband bandwidth of Ws = ~15.63 GHz. The laser linewidth is particularly set at 2 MHz for Fig. 4(a) and at 0 MHz for the rest of this paper, and the noise bandwidth for OSNR is set at 0.1 nm throughout this paper.

Figure 2(a) depicts the required OSNR at BER = 10^{-3} as a function of the gap width, Rg (Rg = Wg / Ws) for different orders of both ARF and CSF. Herein the bandwidths of ARF and CSF are fixed at BW_A = 1.1 W_o and BW_C = 1.1 Ws, respectively, to focus on the filters' order study. The dash line representing the OSNR sensitivity of the regular DDO-OFDM[3] (~20.7 dB), which applies Rg = 1 without the CSF path, is also shown for comparison. First of all, for the lower-order sets , denoted as O(2, 2) where the 1st and 2nd entries respectively stand for the orders of ARF and CSF, the sensitivity has a negligible gain compared with the regular system when Rg > 0.6, and, however, it would

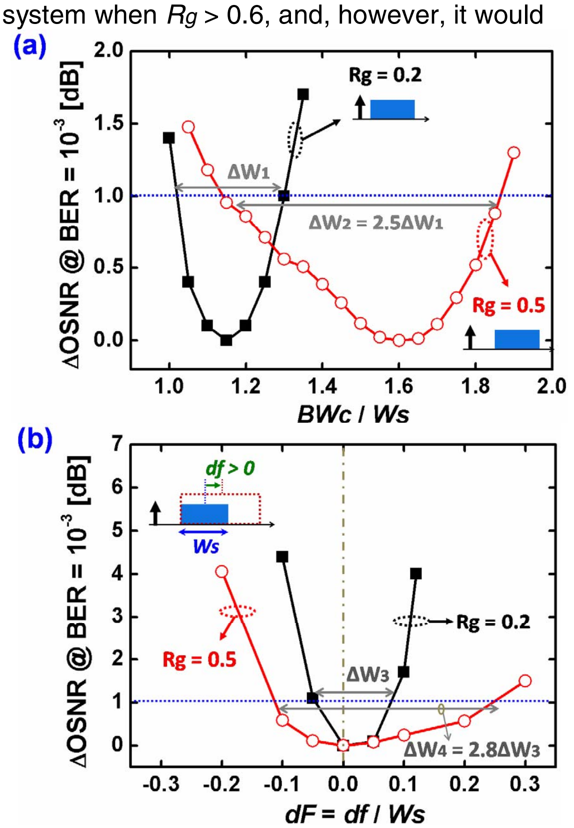

Fig. 3: OSNR penalties vs. **(a)** BW_C variations, and **(b)** CSF's central frequency deviation, with Rg = 0.2 and 0.5. Filter order O(2, 5) and BW_A = 1.1 W_o are used.

become even worse when $R_g \le 0.6$. The reason that a smaller gap results in a worse sensitivity with low-order filters is the slow frequency roll-off of CSF, which would fail to suppress the carrier power leading to some sideband cancellation right after the balanced detector. When a higher-order CSF is used, i.e. in both cases of O(2, 5) and O(5, 5), sensitivity gain can be continuously found with a decreasing gap width until $R_g = 0.2$, where O(5, 5) can even provide an ~2.2 dB improvement compared with the regular systems. Notably, with CSF order = 5, increasing the ARF order from 2 to 5 will not significantly affect the performance but only improve the sensitivity by ~0.5 dB, implying that the CSF is more critical than ARF to the system performance. Hence, we choose O(2, 5) and $BW_A = 1.1W_O$ for the following simulations.

In Fig. 2(b), we further explore the CSF's bandwidth effect. The O(2, 5) results in Fig. 2(a) are now re-simulated with their optimum CSF bandwidths (normalized to W_S), which is found to be larger for a greater gap. Interestingly, with the optimum CSF bandwidth, the sensitivities (~19 dB) become less sensitive to the gap width within the range of R_g = 0.2 ~1.0. In particular, when $R_g = 0.1$, more carrier power is involved in the CSF branch leading to a signal cancelation, and thus the sensitivity gain can not be sustained anymore. To simplify the following discussions, we will consider the two systems with R_g = 0.2 and 0.5 with their optimum BW_C of 1.15 W_S and 1.6 W_S, respectively.

In Fig. 3(a) we investigate the impact of CSF's bandwidth variation on the performance in terms of OSNR penalty. Although a greater gap would sacrifice the spectral efficiency, the system with $R_g = 0.5$ is found to behave more robust to the bandwidth variation: for 1-dB penalty, the bandwidth tolerance with $R_g = 0.5$ is ~2.5 times greater than that with $R_g = 0.2$. In Fig. 3(b) we also study the impact of the CSF's central frequency deviation. Note a positive deviation dF, normalized by the sideband bandwidth W_S, stands for the movement toward the other direction from the carrier. From Fig. 3(b), the system with $R_g = 0.5$ is ~2.8 times more robust than that with $R_g = 0.2$ against the frequency deviation, which could be attributed partly to the larger CSF bandwidth and partly to the greater frequency margin between the carrier and CSF passband in the system with $R_g = 0.5$. The greater penalty for the negative deviation ($dF < 0$) is caused by the higher residual power of the carrier in the CSF branch, which results in a sideband cancellation lowering the SNR. Fig. 3 clearly depicts the trade-off between a better spectral efficiency and a more robust system performance.

Shown in Fig. 4(a) and (b) are the phase noise and PMD (1st order) tolerances with R_g = 0.2 and 0.5. Note that for Fig. 4(a) the laser linewidth is particularly set at 2 MHz and the phase noise power will increase in proportion to the transmission length according to an recent resport[5]. The performance of the regular OFDM system[3] is also shown as an reference. Compared with the regular OFDM, both the phase noise and PMD tolerances are improved with the proposed method, especially for R_g = 0.2. Because in DDO-OFDM both the phase noise and PMD would affect strongly the signal components that are spectrally far from the optical carrier[5,6], a reduced signal bandwidth could naturally provide the better tolerances against both effects.

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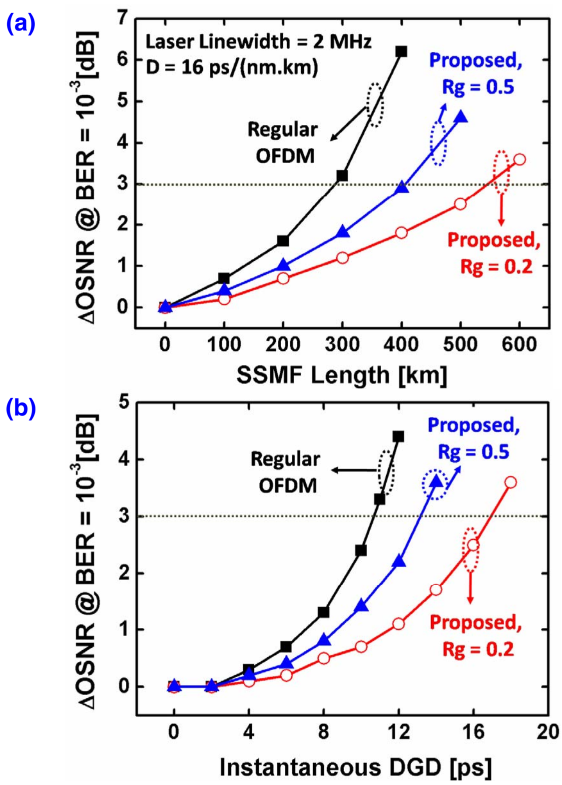

Fig. 4: (a) Phase noise and **(b)** PMD induced penalties with proposed (R_g = 0.2 and 0.5) and regular OFDM methods. Notably, in DDO-OFDM the phase noise will linearly increase with the fibre length.

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