Dual-SSB Modified Duobinary PAM4 Signal Transmission in a Direct Detection System without using Guard Band

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Abstract: We experimentally demonstrate a single-carrier dual-SSB signal generation without guard band based on a low-cost DDMZM. A 112-Gb/s dual-SSB modified duobinary PAM4 signal is transmitted over 80-km SMF by using a MIMO linear equalizer. © 2020 The Author(s)

1. Introduction

Recently, the emerging applications such as Internet of Things (IoT) and 4K/8K video have driven the increasing capacity demands in fifth generation (5G) mobile fronthaul and data center interconnections (DCI). Direct detection (DD) systems are attractive in such scenarios due to their low costs and simple implementations [1]. However, chromatic dispersion (CD)-induced power fading effect limits the transmission capacity and the distance in a conventional intensity modulation (IM)-DD system. An effective solution is to transmit a single sideband (SSB) signal. Furthermore, to fully utilize the electrical bandwidth of the transmitter, a dual-SSB format was firstly proposed in a multicarrier system [2]. In the dual-SSB discrete multitone (DMT) scheme, two independent DMT data streams are modulated on the left sideband (LSB) and right sideband (RSB) of the transmitted signal, respectively. However, for the reception of the conventional dual-SSB signal, the limited sharpness of the optical bandpass filter (OBPF) leads to mutual interferences between the two sidebands. Multiple-input multiple-output (MIMO) equalization and spectral guard band schemes are widely employed methods to mitigate the interferences [3,4]. Moreover, introducing guard band reduces the spectral efficiency (SE) and requires high-bandwidth electronic devices. In single-carrier systems, dual-SSB signal transmission over single mode fiber (SMF) without guard band has not been experimentally demonstrated.

In this paper, a single-carrier dual-SSB modified duobinary (MDB) PAM4 signal format without guard band is demonstrated. The low-frequency components of the MDB signal are weak, since its cosine spectral profile rolls off to zero at its carrier frequency [5]. If the dual-SSB MDB PAM4 signal is optically filtered and square-law detected at the receiver, the LSB and RSB suffer less residual interference from each other and thus the guard band between the two sidebands can be removed. The MDB PAM signal exhibits higher spectral efficiency, compared to a conventional PAM4 signal or a Nyquist PAM4 signal with a roll-off factor larger than zero. In order to generate the MDB signal, the modulator can be biased at the quadrature or null point. In a DD system with square-law detection, an optical carrier is required and therefore the modulator bias is set at its quadrature point. In this work we experimentally demonstrate a 112-Gb/s dual-SSB MDB PAM4 signal transmission over an 80-km SMF without using guard band. By using MIMO linear equalization, the dual-SSB MDB PAM4 signal achieves a BER below the 20% soft-decision forward error correction (SD-FEC) threshold of 2.4×10^{-2}.

2. Operation principle

The motivation for proposing the dual-SSB MDB PAM4 signal generation scheme is discussed in Fig. 1, which illustrates the reception of a dual-SSB Nyquist PAM4 and a dual-SSB MDB PAM4 signals, respectively. The non-ideal SSB spectrum after optical filtering is caused by the limited sharpness of the OBPF. As a result, the LSB and RSB signals are impaired by the interference from the opposite sideband after the square-law detection of the photodetector (PD). However, it can be observed that the dual-SSB Nyquist PAM4 signal has strong low-frequency components, whereas the spectrum of the dual-SSB MDB PAM4 signal rolls off to zero at the carrier frequency, i.e., the low-frequency components are weak. In this case, the filtered LSB and RSB MDB PAM4 signals suffer less crosstalk after detection compared to the Nyquist-shaped signals. Thus, the guard band between the two sidebands can be removed for the dual-SSB MDB PAM4 signal generation.

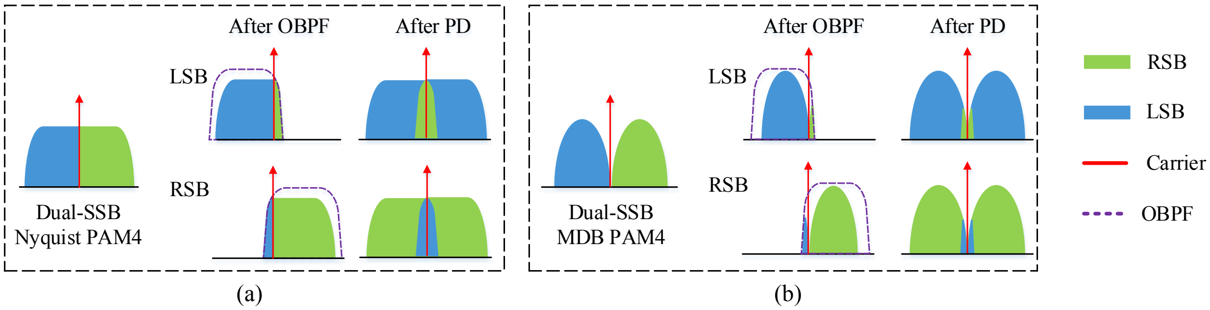

Fig. 1. Spectra at the receiver side for the dual-SSB Nyquist PAM4 signal (a) and the dual-SSB MDB PAM4 signal (b), respectively.

3. Experimental setup and results

Fig. 2(a) depicts the experimental setup of the dual-SSB MDB PAM4 system. At the transmitter, an arbitrary waveform generator (AWG) (Keysight M8195A) operating at 64 GSa/s is used to generate a dual-SSB MDB PAM4 signal. The output in-phase and quadrature (IQ) parts are first amplified by two electrical amplifiers (EAs) with 17-dB gains and then applied to drive a 22-GHz DDMZM biased at the quadrature point of its transmission curve. A distributed feedback (DFB) laser at ~1550.2 nm with a 14-dBm output power is employed as the light source, and the polarization state of the light is aligned by a polarization controller (PC). After the DDMZM, an optical signal with a 5-dBm power is launched into an 80-km SMF. No erbium doped fiber amplifier (EDFA) is employed before the transmission. At the receiver side, a variable optical attenuator (VOA) is utilized to adjust the received optical power (ROP), followed by an EDFA to amplify the signal. The LSB and DSB of the received optical signal are detected separately, by using a tunable OBPF (EXFO XTM-50) with a 3-dB bandwidth of ~30 GHz. Finally, the signal after a 40-GHz PD is captured by a digital storage oscilloscope (DSO) (LeCroy 36Zi-A) operating at 80 GSa/s. The digital signal processing (DSP) flow charts are presented in Fig. 2(b). In the transmitter DSP, the input binary data is mapped into a PAM4 symbol stream for each sideband, respectively. Then, a synchronization sequence is added, followed by the MDB coding. CD compensation (CDC) is performed to compensate the inter-symbol interference (ISI) induced by CD. After the phase alignment, the IQ parts are resampled to 64 GSa/s and loaded to the AWG. At the receiver, resampling and synchronization are firstly implemented for each sideband. After signal-signal beat interference (SSBI) cancellation, the MIMO linear equalization is used to equalize the LSB and RSB signals simultaneously. Finally, de-mapping and BER calculation are performed.

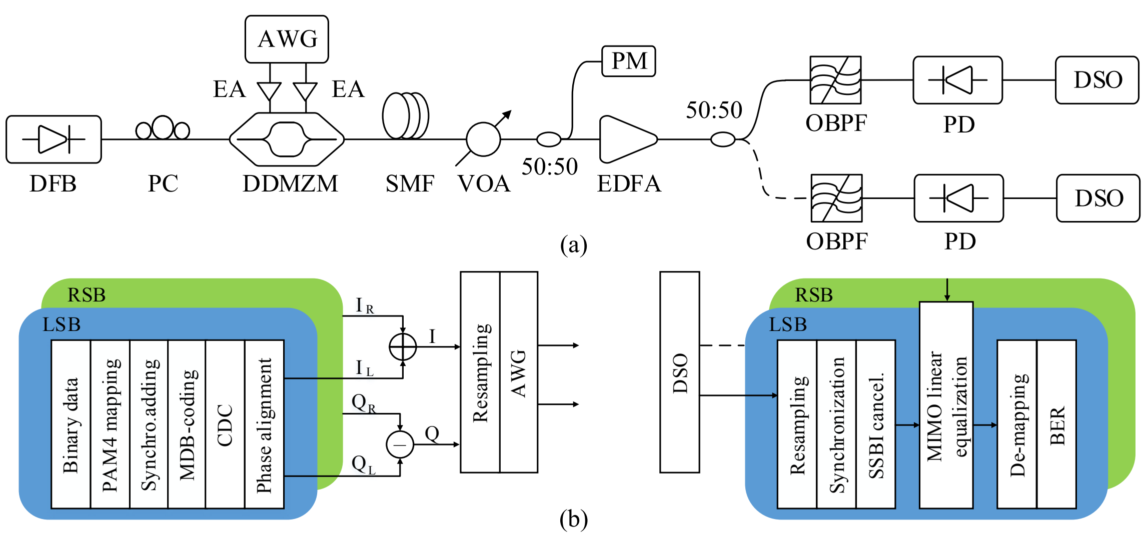

Fig. 2 (a) Experimental setup of the dual-SSB MDB PAM4 system. (b) DSP flow charts. PM: power meter

Fig. 3(a) plots the optical spectra of the dual-SSB MDB PAM4 signal in the optical back-to-back (OBTB) case and after transmission, respectively, measured after the OBPF by an optical spectrum analyzer (OSA) (APEX AP2040C) with a 1.12-pm resolution. The filtered LSB and RSB signals spectra are collected after the fiber transmission. Fig. 3(b) shows the BER versus the number of LMS taps in the MIMO linear equalization after the fiber transmission. A larger tap number reduces the BER effectively, whereas the extra taps beyond 116 do not further improve the system performance significantly. Considering the trade-off between the computational complexity and the system performance, 116 taps are used in the following measurements. Then, we optimize the signal amplitude output by the AWG in the transmission case, as provided in Fig. 3(c). A smaller signal amplitude leads to an improved BER performance, since small signals are needed for the dual-SSB signal generation based on DDMZM. Meanwhile, the signal to noise ratio (SNR) decreases, leading to an optimum signal amplitude of 100 mV. Fig. 3(d) shows the BER versus the ROP in different cases. The dashed curve representing feedforward equalizer (FFE) is used at the received side to recover the LSB and RSB signals in order. The MIMO linear equalization improves the BER performance. After the 80-km SMF transmission, the minimum ROP for the proposed dual-SSB MDB PAM4 signal to reach the 20% SD-FEC threshold is −14 dBm.

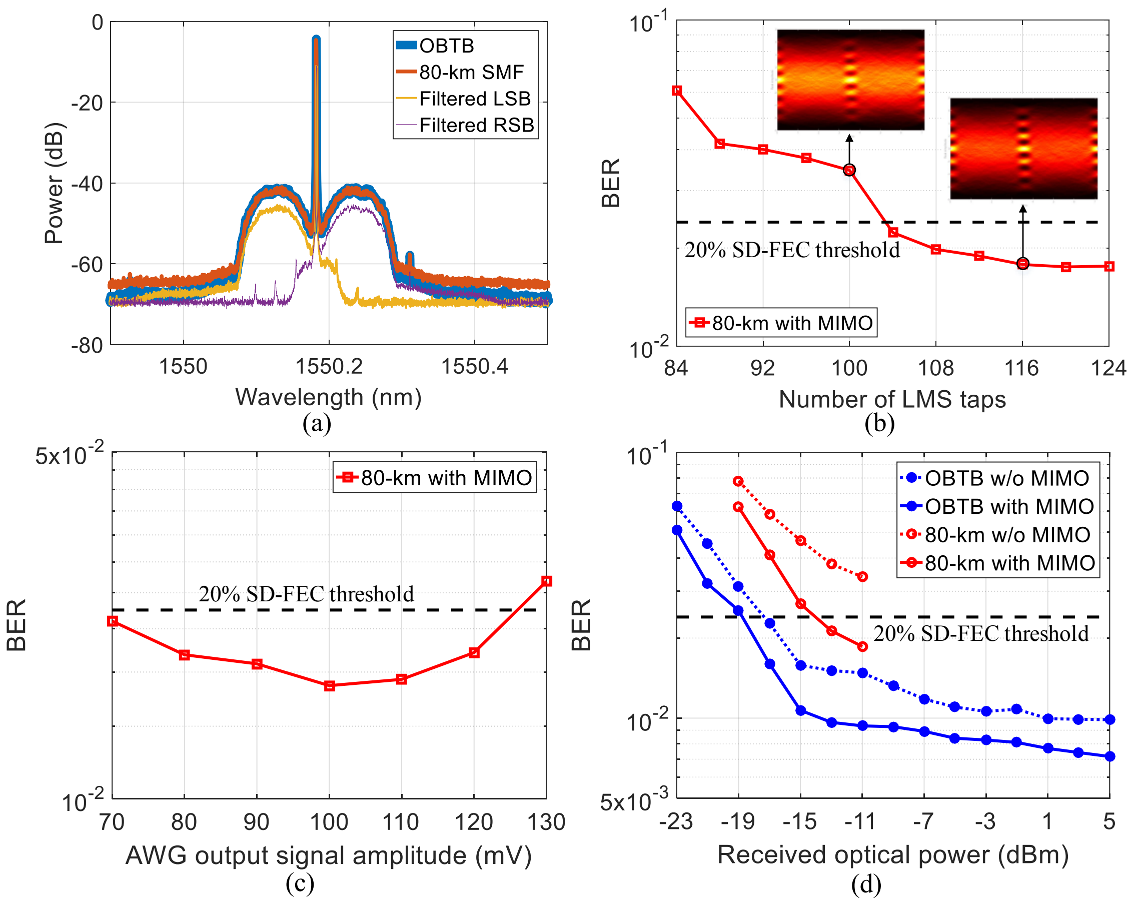

Fig. 3. (a) Optical spectra in the OBTB case and after transmission. (b) BER versus number of LMS taps in the MIMO linear equalization after the fiber transmission. (c) BER versus AWG output signal amplitude in the transmission case. (d) BER curves in the OBTB case and after the fiber transmission, respectively.

4. Conclusion

We proposed and experimentally demonstrated a 112-Gb/s dual-SSB MDB PAM4 signal transmission over 80-km SMF using a low-cost DDMZM in a DD system. Due to the weak spectral components at the carrier frequency of the signal, the guard band between the two sidebands was successfully removed.

5. References

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