Deep-learning Enabled Direct Detection of 42-GBaud Complex-valued DSB 16-QAM Signal

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Abstract: A 42-GBaud complex-valued double-sideband 16-QAM signal is transmitted over 80-km SMF using deep-learning enabled direct detection. We achieve the highest baud rate of 42 GBaud in the complex-valued double-sideband direct detection systems. © 2022 The Authors

1. Introduction

Direct detection (DD) of the complex-valued double-sideband (CV-DSB) signal has attracted much attention since the optical field of a CV-DSB signal can be recovered without using a narrow linewidth local oscillator laser, which greatly saves the implementation cost of the system. In [1], carrier-assisted differential detection (CADD) was proposed to recover the CV-DSB signal by introducing a delay interferometer-based receiver structure. The extended versions of CADD are also reported [2,3]. In [4], a carrier-less full-field reconstruction technique using DD was presented based on a Gerchberg-Saxton (GS) algorithm, but the required receiver electrical bandwidth is doubled compared to the coherent detection, and also hundreds of iterations are needed for algorithm convergence.

Recently, we have proposed and demonstrated a deep-learning enabled DD (DLEDD) scheme to reconstruct the full field of a 28-GBaud 16-ary quadrature amplitude modulation (16-QAM) signal [5]. However, the baud rate is limited to 28 GBaud, which may not satisfy the high-capacity transmission demand. In this paper, the baud rate is increased to 42-GBaud. The bandwidth limitation is compensated by transmitter-side pre-emphasis. We experimentally demonstrate the optical field reconstruction of a 42-GBaud 16-QAM signal after 80-km single-mode fiber (SMF) transmission based on DLEDD with a 5-dB optimum CSPR. Considering the frame redundancy and 25% forward error correction (FEC) overhead, a net data capacity of 133.73 Gb/s is obtained. To our best knowledge, 42-GBaud is the highest baud rate in the experimentally demonstrated CV-DSB DD systems.

2. Experimental setup

Fig. 1 shows the experimental setup of the 42-GBaud 16-QAM DLEDD transmission system. A 100-GSa/s digital-to-analog converter (DAC) (MICRAM DAC10002) with a 3-dB bandwidth of 35 GHz generates a 42-GBaud dual-single-sideband (SSB) 16-QAM signal, in which a 6-GHz guard band is inserted. After being amplified by two electrical amplifiers (EAs) (SHF S807 C), the dual-SSB 16-QAM signal drives a 35-GHz in-phase and quadrature modulator (IQM) (Fujitsu FTM7992HM) biased at the transmission null for field modulation. An external cavity laser (ECL) with ~15-kHz linewidth outputs a continuous wave light at 1550 nm, which is split into two branches. One path is modulated with the dual-SSB signal through IQM and the other provides a carrier. Then, the dual-SSB signal and the carrier form a CV-DSB signal. The states of polarization of both the dual-SSB signal and the carrier are aligned with the polarizer via two polarization controllers (PCs). The variable optical attenuator (VOA) is employed to vary the CSPR of the CV-DSB signal. After being boosted to 6-dBm by an erbium-doped fiber amplifier (EDFA), the CV-DSB signal is launched into an 80-km SMF.

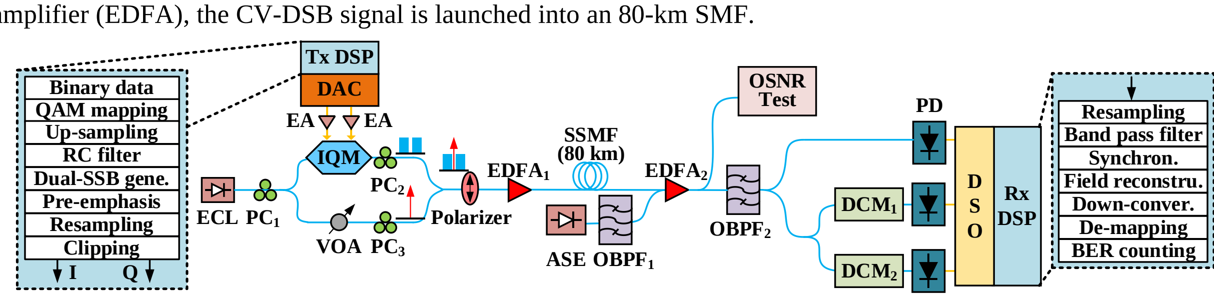


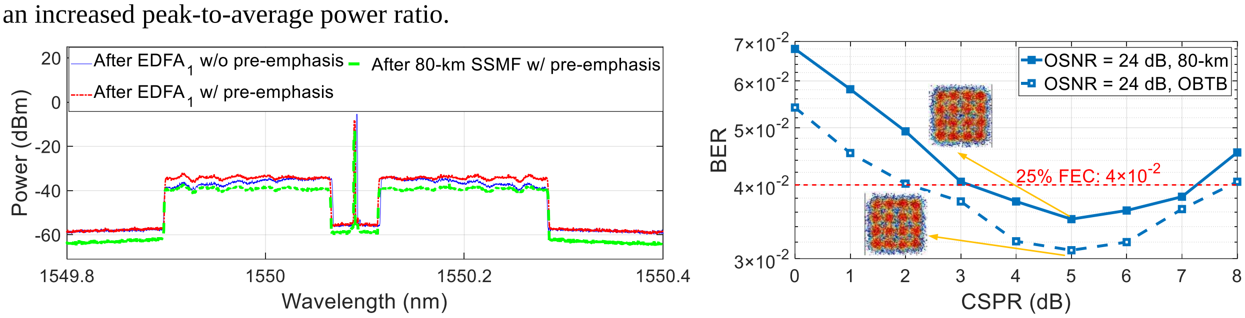
Fig. 1. Experimental setup of the 42-GBaud 16-QAM DLEDD transmission system.

At the receiver side, an amplified spontaneous emission (ASE) noise source is employed to adjust the optical signal-to-noise ratio (OSNR). Two optical band-pass filters (OBPFs) are used to suppress the out-of-band noise. The dispersion diversity receiver consists of two dispersion compensation modules (DCMs) and three 43-GHz photodiodes (PDs). The dispersion values of the two DCMs are –185 and –1008 ps/nm, respectively. Finally, the detected electrical signals are captured by an 80-GSa/s digital storage oscilloscope (DSO) (LeCroy 36Zi-A) with a 3-dB bandwidth of 36 GHz.

The DSP flow charts of the transmitter and the receiver are also presented in Fig. 1. A raised cosine (RC) filter with a roll-off factor of 0.01 is employed to generate a Nyquist-shaped 16-QAM signal. Moreover, the imperfect frequency response of the transmitter is compensated with the pre-emphasis technique. At the receiver side, a deep convolutional neural network is employed to reconstruct the signal and the bit error ratio (BER) is counted to evaluate the system performance.

3. Results and discussion

Fig. 2(a) shows the optical spectra in different scenarios, measured by an optical spectrum analyzer (APEX AP2040C) with a 1.12-pm resolution. The high-frequency attenuation in the spectrum is compensated using pre-emphasis. The frequency "ripples" are caused by the component imperfections such as DAC. The BER versus CSPR at 24-dB OSNR are shown in Fig. 2(b). The optimum CSPR is 5 dB for both optical back-to-back (OBTB) case and 80-km transmission. When the CSPR is lower than 5 dB, the signal suffers severe signal-signal beat interference (SSBI). Increasing the CSPR alleviates the SSBI distortion while higher CSPR than the optimum value sacrifices the effective OSNR leading to a worse BER performance. Compared to the OBTB case, the BER penalty after the 80-km transmission is mainly due to the higher quantization noise of DSO, since the signal after transmission imposes an increased peak-to-average power ratio.



(a) (b)

Fig. 2. (a) Optical spectra of various signals. (b) BER versus CSPR for OSNR = 24 dB and constellation.

Table 1 compares various CV-DSB DD schemes. All the results are based on experimental demonstration. It can be observed that we have achieved the highest baud rate in the CV-DSB DD systems.

Table 1. Comparison of CV-DSB DD schemes

Detection scheme	Baud rate (GBaud)	Required electrical bandwidth of the receiver	Optimum CSPR (dB)	Modulation format	Transmission distance (km)
PDD-CADD [3]	25	(Baud rate + Guard band)/2	14	16-QAM	80
CADD [6]	27	(Baud rate + Guard band)/2	7	QPSK	160
DLEDD [5]	28	(Baud rate + Guard band)/2	2	16-QAM	80
GS [4]	30	Baud rate	$-\infty$	QPSK	520
This work	42	(Baud rate + Guard band)/2	5	16-QAM	80

4. Conclusion

We experimentally demonstrated a 42-GBaud CV-DSB 16-QAM signal transmission over 80-km SMF employing DLEDD. Pre-emphasis is used for bandwidth limitation compensation and the optical field of the CV-DSB signal is reconstructed by the means of DLEDD. To the best of our knowledge, the highest baud rate of 42 GBaud is achieved in the experimentally demonstrated CV-DSB DD systems.

5. References

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