Demonstration of SOA-based IM/DD 1T (280Gbit/s×4) PS-PAM8 Transmission over 40km SSMF at O-band

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Abstract: We experimentally demonstrate a four-lane O-band IM/DD system. With the aid of semiconductor optical amplifiers and probabilistic shaping, a record bit rate of 1.12Tb/s (280Gbit/s×4) PS-PAM8 signal can be successfully transmitted over 40-km SSMF.

OCIS codes: (060.2330) Fiber optics communications, (060.2360) Fiber optics links and subsystems

1. Introduction

The explosive growth in data center traffic is driving the development of higher capacity short reach system. Recent years, some intensity modulation and direct-detection (IM/DD) systems which can support 400-Gbit/s transmission or beyond have been demonstrated [1,2]. For future network, the demand of 800G or even 1.6T data connection has come up. To support such high-speed data transmission, four-lane CWDM scheme is the most promising way, which can also reduce the system cost and power consumption [3]. Advanced modulation formats including PAM, DMT, CAP are attracting many attentions to help realize 200Gbit/s per lane or even higher. Considering the complexity, PAM is a suitable solution in IM/DD system and can effectively improve spectral efficiency. However, it requires a higher OSNR for high-order signal transmission. Probabilistic shaping (PS) technique has been proved effective to improve the system capacity, especially for high modulation formats under OSNR limited condition [4]. By changing the probability distribution, PS technique can reduce the average power of the transmitted signal and improve the receiver sensitivity.

When it comes to longer transmission distance, such as metro networks, the high-speed PAM signal suffers from the frequency dependent power fading induced by chromatic dispersion at C-band. From this perspective, O-band transmission may be a better solution for high-speed access networks. Compared with C-band, the large power attenuation during fiber transmission is the most important disadvantage for O-band. One feasible solution is using avalanche photodiode (APD) to improve the receiver sensitivity, but the dynamic range of APD based receiver would be a challenge, which needs more study [5,6]. Recently, semiconductor optical amplifier (SOA) has been given serious consideration to serve as amplifier in O-band PAM signal transmission due to its low cost, small physical footprint and high integratability. Up to now, C-band 300-Gbit/s PAM8 transmission over 1.2km in a single channel has been report [7]. For four-lane CWDM system, 600-Gbit/s PAM-4 transmission over 2-km distance has been achieved [8]. In Ref. 9, a single channel with entropy-loaded 554-Gb/s transmission over 22-km SMF is demonstrated. In Ref. 10, 1-Tb/s transmission system integrated with 5 lasers and 4 receivers (two single-end and two balanced PDs) is demonstrated. However, the complexity and cost of such system is relative high [10] or the transmission distance is short [9]. Moreover, few researches focus on the implementation of the CWDM PAM signal transmission over 800Gbit/s. It is meaningful to demonstrate an O-band four-lane IM/DD system with longer transmission distance, which can support future 800G data connections.

In this experiment, we demonstrate a four-lane CWDM IM/DD system at O-band. With the aid of SOA, PS technique and advanced DSPs, a record bit rate of 1.12Tb/s (280Gbit/s×4) PS-PAM-8 signal can be successfully transmitted over 40-km SSMF. As far as we know, it is the first time to realize over 1Tbit/s PAM signal transmission over 40km in a four-lane CWDM IM/DD system.

2. Experimental setup

The experimental setup of O-band four-lane CWDM IM/DD system is presented in Fig. 1. Four directly modulated lasers (DML) are used as O-band laser sources to generate CW light waves. The DMLs operate at 1304.8nm, 1308.5nm, 1312.5nm and 1316.0nm, respectively. With the aid of optical couplers (OC), the four optical carriers are simultaneously injected into two 40-GHz intensity modulators (IMs) for subsequent signal modulation. A digital-to-analog converter (DAC), whose sampling rate is 100GSa/s, generates the transmitted signals.

Fig.1 also shows the detailed DSP blocks. For each lane, the original binary data is firstly mapped into uniformly distributed or PS PAM symbols. In this experiment, PS-PAM8 signal follows the Maxwell-Boltzmann distribution

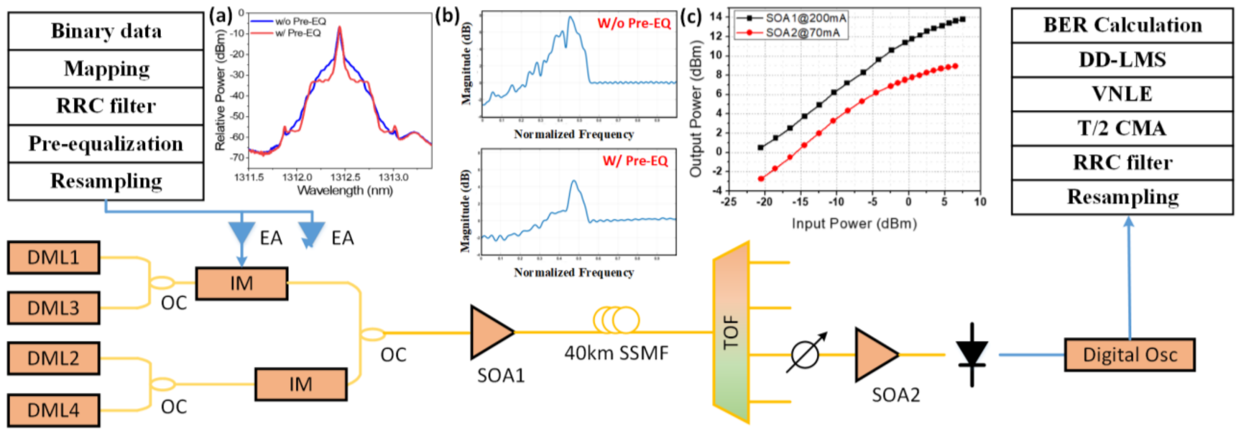

Fig. 1 The experimental setup (a) the spectra w/ and w/o pre-EQ, (b) The frequency response of CMA equalizer (c) The output power vs. input power of SOA1 and SOA2.

and the net entropy of PS-PAM8 signal is 2.8bit/symbol. After 2× up-sampling, the PAM signal is further shaped by a 128-tap square root raised cosine filter (RRCF) with 0.1 roll-off factor. To compensate the linear impairments induced by the electrical devices, a following pre-equalization (pre-EQ) filter based on T/2-spaced FIR is adopted. We use a 113-taps CMA equalizer to obtain the channel FIR at receiver side. Fig. 1(a) presents the spectra of the 100GBd PAM-4 signals in channel 3 (1312.5nm). Fig. 1(b) depicts the FIR with and without pre-EQ. Thanks to the bandwidth limitation, pre-EQ cannot compensate the frequency-dependent power loss completely. Finally, the digital PAM symbols are resampled to 1 Sa/symbol and converted into electrical ones at 100Gbaud. Amplifying by SOA1, the 100-Gbaud CWDM PAM signals are transmitted into the 40-km SSMF link with a launch power of 9.0dBm.

At the receiver, a 0.9-nm tunable optic filter (TOF) is used as a WDM de-multiplexing (DE-MUX) to separate four lanes. By changing the center frequency of the TOF, we can obtain the optical signal in each CWDM lane. The optical receiver consists of an SOA, a PIN-PD and a digital oscilloscope. The received optical signal is amplified by SOA2 and then directly detected by a photodiode (PD) with 70-GHz bandwidth. In this experiment, SOA1 and SOA2 work at bias current of 200mA and 70mA, respectively. The output optical power curves versus input power are presented in Fig. 1(b). Finally, the 100Gbdaud signal is sampled by a real-time digital storage oscilloscope (DSO) working at 160GSa/s with 62-GHz bandwidth. After resampling, a 128-tap 2×sampling RRCF with a roll-off factor of 0.1 is adopted as a matching filter. A 53-tap CMA equalizer and a 93-tap Volterra series based nonlinear equalizer are used to compensate for the linear and nonlinear impairments, respectively. Moreover, an additional decision-directly lease-mean-square (DD-LMS) processing further improve the BER performance.

3. Results and discussions

We firstly measure the BER performance for 200-Gbit/s/channel PAM4, 300-Gbit/s/channel PAM8 and 280-Gbit/s/channel PS-PAM8 transmission in channel 3. Based on the experimental results in Fig. 2(a), 100-Gbaud PAM4 signal can achieve a receiver sensitivity of -13.7dBm in BTB case when satisfy the 20% SD-FEC threshold at 2.4×10^{-2}. Here, the received power is the optical power into SOA2. For 100GBd PAM8 and PS-PAM8 signal, it is hard to satisfy the SD-FEC threshold of 2.4×10^{-2} after 40km SSMF transmission. Therefore, we consider 25% SD-FEC threshold of 4.0×10^{-2}. Even so, the BER of 300-Gbit/s/channel PAM8 signal transmission over 40-km is still too high. Adopting PS scheme, the 280-Gbit/s/channel PS-PAM8 signal can be successfully transmitted in BTB case with a sensitivity of -11.0dBm. Considering 25% FEC overhead, the net bit rate of 100-GBd PS-PAM8 signal is 224Gbit/s/channel. For a four-channel CWDM system in this experimental, the total transmission rate can achieve 896Gbit/s. Since the dispersion in O-band is minimal, the BER performance after 40-km SSMF transmission should be close to the BTB case, if the power loss is completely compensated by SOAs. The BER curves of PS-PAM8 transmission after 40-km SSMF is also presented in Fig 2(a), and the corresponding receiver sensitivity is -10.3dBm. There is a 0.7-dB receiver sensitivity penalty after 40km transmission, which is induced by the nonlinear effects and ASE noise accumulation in SOAs.

We also measure the BER curve of other channels. The other three channels show the similar BER performance. Fig 2(b) shows the measured BER as a function of the received optical power for PS-PAM8 transmission in channel 2 and 3. The BER of channel 2 and 3 are close. The receiver sensitivity of channel 2 and 3 are both -10.3dBm. Fig

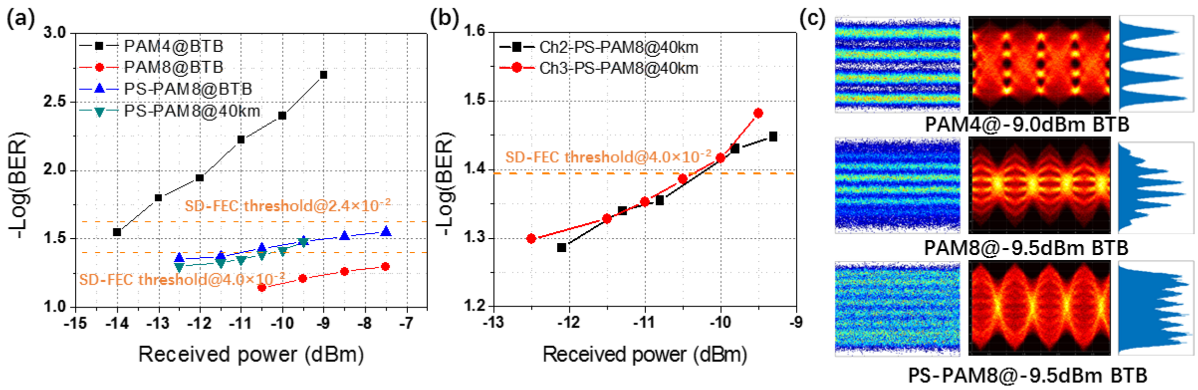

Fig. 2 The experimental results: (a) Measured BER as a function of the received optical power in channel 3; (b) BER performance after 40km transmission in ch2 and ch3, respectively; (c) the corresponding constellations, eye diagrams and probability distributions.

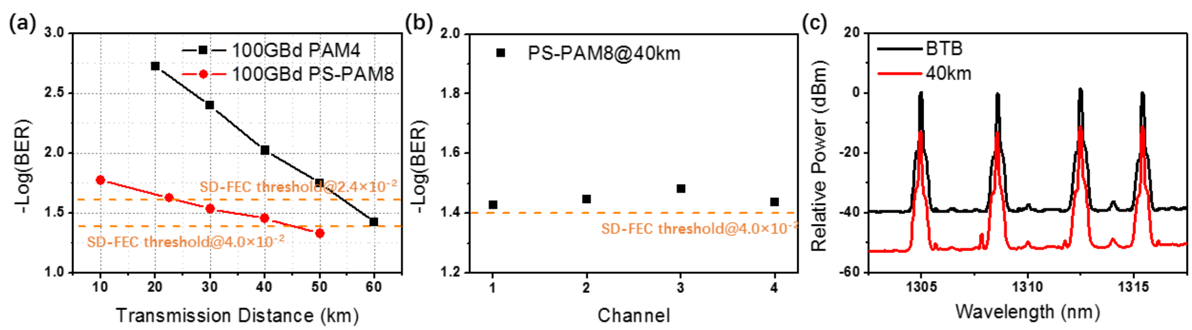

Fig. 3 The experimental results: (a) Measured BER as a function of the transmission distance (b) BER performance in different lanes (c) spectra of the CWDM PAM signals before and after 40km transmission.

2(c) depicts the constellations and eye diagrams of the received PAM4, PAM8, and PS-PAM8 signal at -10.0dBm, -9.5dBm and -9.5dBm received power. For PAM8 signals, the outside power levels are more scattered than the inner ones. Moreover, the outside power levels are compressed due to the saturation of SOA and other electrical devices. Adopting PS scheme, most symbols are converged on the inner power levels, the corresponding eye diagram is more distinct. This can be verified by the probability distributions in Fig. 2(c).

Fig. 3(a) depicts the BER performance of PAM4 and PS-PAM8 signals after different transmission distance. Satisfying the SD-FEC threshold (25% overhead) of 4.0×10^{-2}, PAM4 and PS-PAM8 signals can be reliably transmitted over 40 and 60km, respectively. When it comes to 20% FEC threshold, the transmission distance of 200-Gbit/s/channel PAM4 and 280-Gbit/s/channel PS-PAM8 are reduced to 22.5km and 50km, respectively. Fig. 3(b) presents the measured BER for different lanes after 40-km SSMF transmission at a received optical power of -10.0dBm. All the four lanes in such IM/DD system can ensure a BER lower than 4.0×10^{-2} after 40-km transmission. Fig. 3(c) is the spectra of the four-lane PAM signals before and after 40km transmission.

4. Conclusion

In this experiment, we demonstrate a four-channel IM/DD system at O-band. 1T (280Gbit/s×4) PS-PAM8 signals can be successfully transmitted over 40km. Considering 25% FEC overhead, the net bit rate is 896Gbit/s, which can meet the demand of 800G connection applications. We believe such SOA-based four-channel IM/DD transmission at O-band is a promising solution for the future high-speed access networks. *This work was partially supported in part by Chinese National key R&D projects under grant number 2018YFB1800900 and the NNSF of China under grants of 61935005，61922025, 61527801, 61675048, 61720106015, 61835002, 61875164, and 61805043.*

5. References

[1] Zhang, J., et al. OFC, 2017, Th4G.3.
[2] Zuo T., et al. OFC, 2014, M2E. 4.
[3] Dochhan A., et al. 2016,1-3.
[4] Chien, H., et al. Proc. ECOC, 2018, 1-3.
[5] Zhang J., et al. OFC, 2018, M1B. 4.
[6] Zhong K., et al. ECOC, 2016, 1-3.
[7] Lange S., et al. Journal of Lightwave Technology, 2018, 36(1): 97-102.
[8] Zhenping X., et al. ECOC, 2019, Tu.3.D.
[9] X. Chen, et al. OFC PDP 2019：Th4B.5.
[10] D. Che, et al. OFC PDP 2019: Th4B.7