Symmetrical 50-Gb/s/λ PAM-4 TDM-PON at O-band Supporting 26 dB+ Loss Budget using Low-bandwidth Optics and Semiconductor Optical Amplifier

Jiao Zhang[1], Kaihui Wang[1], Yiran Wei[1], Li Zhao[1], Wen Zhou[1], Jiangnan Xiao[1], Bo Liu[2], Xiangjun Xin[2], and Jianjun Yu[1*]

[1] Fudan University, Shanghai, 220 Handan Road, 200433, China
[2] Beijing University of Posts and Telecommunications, Beijing, China
*jianjun@fudan.edu.cn

Abstract: We experimentally demonstrated a symmetrical 50-Gb/s/λ PAM-4 TDM-PON in O-band to support over 26 dB link loss budget, with the using of simple DSP and SOA. The performances of DSP and dispersion tolerance are studied.

OCIS codes: (060.2360) Fiber optics links and subsystems; (060.4252) Networks, broadcast; (060.4080) Modulation.

1. Introduction

Rapid growth of cloud services, the burst of Internet of Things, interactive games and the need for 5G wireless backhaul are all driving operators to look for higher bandwidth solutions in the access network segment. Now, IEEE 802.3ca Task Force is finalizing 25/50G EPON standards by bonding two wavelength channels to reach its 50-Gb/s target [1], while ITU-T Q2/SG15 has started the standardization process of a series of higher-speed PON Recommendations including a single wavelength 50G-PON [2]. In symmetrical 50-Gb/s/λ PON systems, the adoption of legacy low-bandwidth optics has been investigated intensively [3-6] in order to reduce the CAPEX and OPEX for both the network provider and the customers. By using DSP and semiconductor optical amplifiers (SOAs), a symmetrical 50-Gb/s/λ PAM-4 TDM-PON solution in the O-band to support the 29 dB+ link loss budget with the BER threshold at 1×10^{-2} has been demonstrated using 18 GHz EML [3]. With SOA and commercial 10G-class optics including DML and PIN-TIA, symmetrical 50-Gb/s/λ PAM4 PON with a power budget up to 29 dB has been achieved under the BER threshold at 3.8×10^{-3} by using signal pre-equalization and Nyquist pulse shaping to compensate the bandwidth limitation [4]. However, in these works, the downlink and uplink for a symmetrical PON are separately researched with different fiber links, and complex DSP at OLT side or ONU side are used [5, 6].

In this paper, we experimentally demonstrated a symmetrical 50-Gb/s/λ PAM-4 TDM-PON over the same fiber link at O-band using 10G-class optics with SOA+PIN receivers and simple DSP for the first time. The downstream and upstream performances of 50-Gb/s/λ PAM-4 PON with different DSP equalization are studied. The dispersion tolerance of wavelength ranging from 1270 nm to 1390 nm is also evaluated. The results show that over 26 dB power budget can be achieved at the pre-FEC BER threshold of 3.8×10^{-3}.

2. Experimental setup

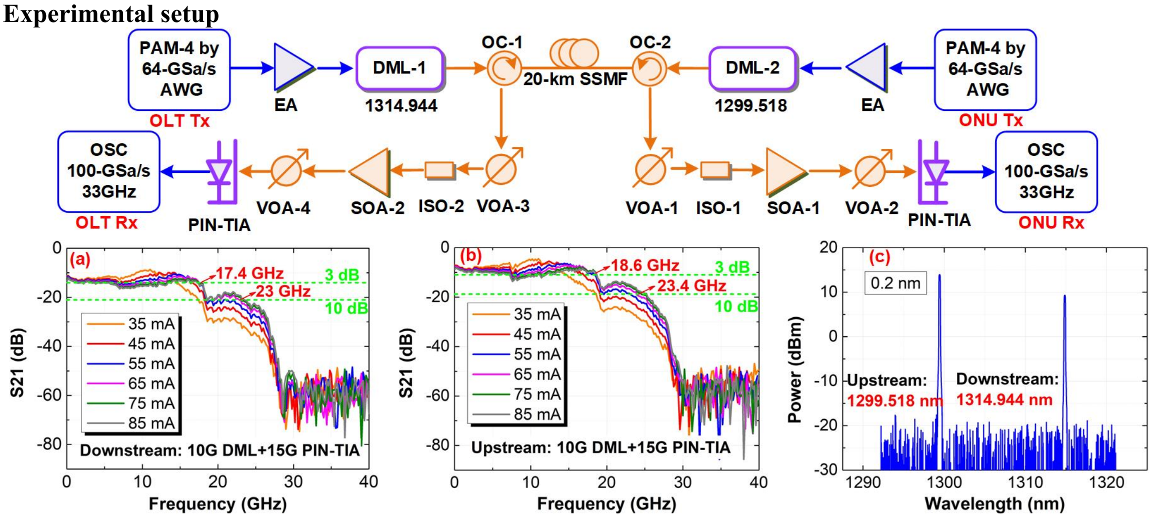


Fig.1. Experimental setup of symmetrical single-wavelength 50-Gb/s PAM4 PON system at O-band. Frequency response of the transceivers of 10G DML and 15G PIN-TIA for (a) downlink and (b) uplink. (c) Optical spectrum of downlink and uplink.

Figure 1 shows the experimental setup for the symmetrical transmission of a 50-Gb/s/λ PAM-4 PON at O-band with simple DSP and SOAs. The downlink and uplink signals are separated by optical circulators (OC-1 and OC-2) and transmitted over the same fiber link. For both downstream and upstream links, the arbitrary waveform generator (AWG) operating at 64 GSa/s is used as a DAC to generate 25 GBaud PAM-4 signal, and then amplified by a 25 GHz linear electrical amplifier (EA) before signal modulation. For the downlink, the output of the electrical driver is directly modulated by a commercial DML at the center wavelength of 1314.944 nm. The output power of the DML-1 is 8.7 dBm. Then, the 25 Gbaud PAM-4 optical signals are transmitted over 20 km standard single-mode fiber (SSMF) with an average loss of 0.33 dB/km at 1310 nm. As shown in Fig. 1, a variable optical attenuator (VOA-1) is applied to account for the splitter loss. In order to support larger link loss budget, an SOA pre-amplifier is used at the ONU before direct detection. An isolator (ISO-1) is placed between VOA-1 and SOA to avoid light reflection. The VOA-2 is deployed to adjust the received optical power (ROP) for sensitivity measurement. After PIN-TIA, the detected signal is captured by a 100 GSa/s oscilloscope with 33 GHz bandwidth and processed by offline DSP. The frequency response of the transceivers for downlink is shown in Fig. 1(a). The 3 and 10 dB bandwidth of the downstream transceivers are 17.4 and 23 GHz, respectively. For the uplink, another commercial DML at the center wavelength of 1299.518 nm is used, and the output power of the DML-2 is 9.1 dBm. As shown in Fig. 1(b), the 3 and 10 dB bandwidth of the upstream transceivers are 18.6 and 23.4 GHz, respectively. The optical spectrum of downlink and uplink is also given in Fig. 1(c).

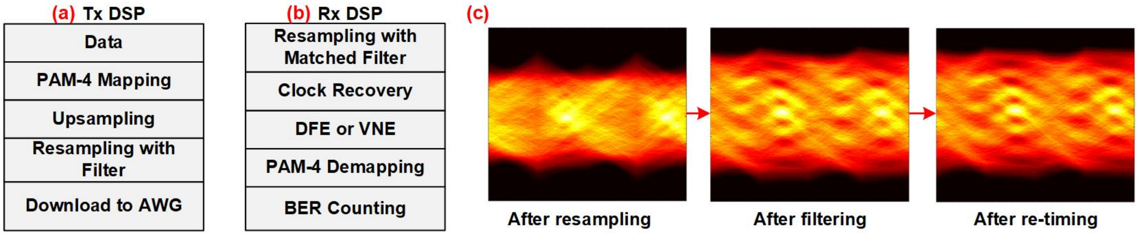


Fig. 2. (a) and (b) are the offline DSPs for PAM-4 signal generation and recovery, respectively. (c) Eye diagrams after different DSPs.

Figures 2 (a) and (b) show the offline DSPs for PAM-4 signal generation and recovery, respectively. At the Tx DSP, Gray-mapped PAM-4 symbols with a length of 2^{15} are generated. No digital pre-equalization and Nyquist pulse shaping are used to simplify the DSP process. At the Rx DSP, the captured offline data is firstly resampled to 2 samples per symbol with a matched filter, and then a squaring time recovery is applied to remove the timing offset and jitter from the data. Afterwards, 99-tap decision feedback equalizer (DFE) at 2-sps or 189-tap Volterra nonlinear equalization (VNE) at 2-sps is adopted to evaluate the system performance [7, 8]. Finally, the BER can be calculated based on the recovered PAM-4 signal. Fig. 2(c) shows that the eye diagrams are completely closed without DSP.

3. Results and discussion

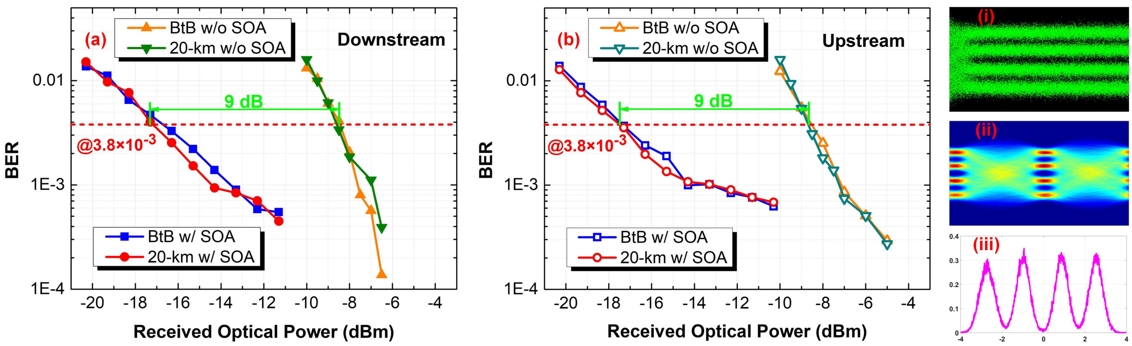


Fig. 3. BER performance versus received optical power (ROP) for 50-Gb/s PAM-4 PON with DFE in (a) downlink and (b) uplink. Insets (i)-(iii) are recovered symbols, eye diagram and histogram under the BER threshold at 3.8×10^{-3}.

The BER performance of 50-Gb/s PAM4 PON versus ROP for downlink and uplink with DFE only after 20 km fiber transmission are shown in Figs. 3(a) and (b), respectively. For downlink, the receiver sensitivity is -17.3 dBm at the HD-FEC threshold (3.8×10^{-3}), resulting in 26 dB power budget with 8.7 dBm DML output power. For uplink, 26.5 dB power budget can be achieved under HD-FEC limit. Around 9 dB power budget improvement can be achieved by using a SOA at HD-FEC threshold. Insets (i)-(iii) are recovered symbols, eye diagram and histogram at HD-FEC threshold, respectively. There is no obvious dispersion penalty after 20 km transmission. Moreover, we also evaluate downlink and uplink performances with VNE processing, as shown in Figs. 4(a) and (b). For both downlink and uplink, 28.7 dB and 29 dB is achieved at HD-FEC threshold, respectively. It can be observed that the receive sensitivity at HD-FEC threshold has about 2.5 dB improvement after employing VNE.

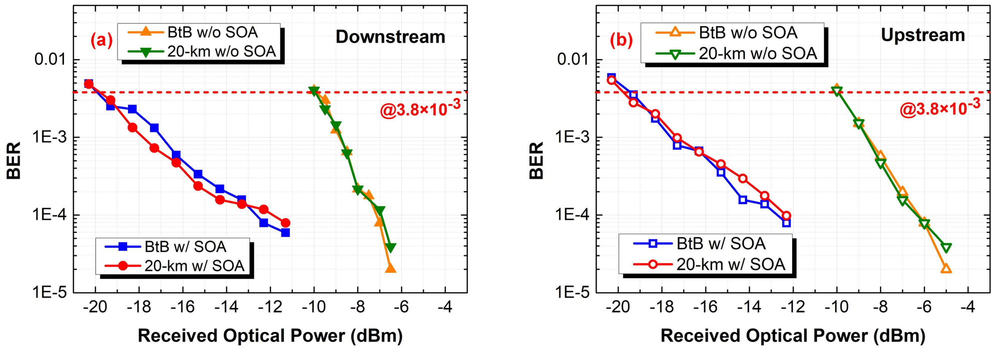
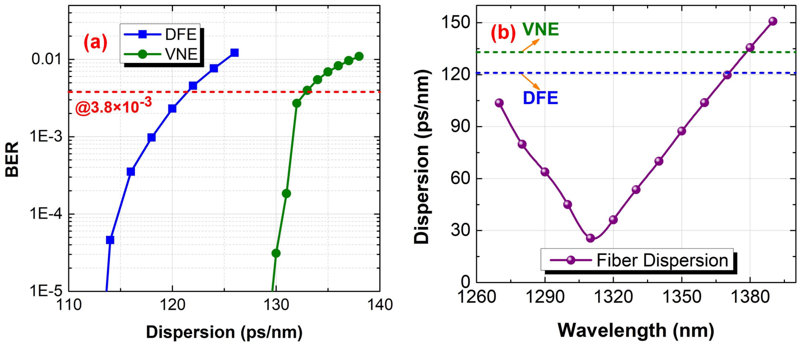


Fig. 4. BER performance versus received optical power for 50-Gb/s PAM-4 PON with VNE in (a) downlink and (b) uplink.

The dispersion tolerance at O-band is also investigated. We further simulate dispersion tolerance for 50-Gb/s PAM-4 signals over 20 km G.652 type fiber, as shown in Figs. 5(a) and (b). We consider two equalization conditions: DFE and VNE. The DFE with a small tap number is a weak equalization method. But VNE with non-linear equalization is a strong equalization. Fig. 5(a) shows the BER versus dispersion tolerance at O-band. The chromatic dispersion coefficient is specified for ITU-T G.652 type fibers [9]. Considering the HD-FEC threshold, the dispersion tolerance is about ± 133 ps/nm by using VNE. Fig. 5(b) shows the dispersion tolerance versus wavelength ranging from 1270 to 1390 nm [10]. Based on advanced DSP equalization algorithms, 50-Gb/s PAM-4 works well at least 1380 nm, and also be above 1270 nm. Fig. 5(c) summarizes both of the receiver sensitivity and power budget performance. We can observer that >29 dB link loss budget can be achieved for both downstream and upstream links assuming LDPC FEC at BER threshold of 1×10^{-2} [11].



(c)	DFE		VNE	
	DS	US	DS	US
Sensitivity @$3.8\text{x}10^{-3}$	-17.3	-17.4	-20	-19.9
Power Budget @$3.8\text{x}10^{-3}$	26	26.5	28.7	29
Sensitivity @$1\text{x}10^{-2}$	-19.3	-20	<-21	<-21
Power Budget @$1\text{x}10^{-2}$	28	29.1	>29	>30

Fig. 5. Dispersion tolerance for 50-Gb/s PAM-4 after 20 km G.652 type fibers. (a) BER vs. dispersion and (b) dispersion vs. wavelength ranging from 1270 nm to 1390 nm with different DSP equalization methods. (c) Summary of 50-Gb/s PAM-4 receiver sensitivity and power budget.

4. Conclusions

We have experimentally demonstrated a symmetrical transmission of 50-Gb/s PAM-4 PON at the single-wavelength using 10G-class optics in the O-band assisted by SOA and DSP to achieve over 26 dB power budget at the HD-FEC threshold. >29 dB link loss budget can also be achieved for both of downstream and upstream links assuming LDPC FEC at BER threshold of 1×10^{-2}. *This work was partially supported by National Key R&D Program of China (2018YFB1801703) and Natural National Science Foundation of China (61935005，61922025, 61527801, 61675048, 61720106015, 61835002, and 61805043).*

5. References

[1] IEEE 802.3ca Task Force, accessed on May 19, 2019. [Online]. Available: http://www.ieee802.org/3/ca/index.shtml.
[2] ITU-T Q2/SG15, accessed on May 19, 2019. [Online]. Available: https://www.itu.int/en/ITU-T/studygroups/2017-2020/15/Pages/q2.aspx.
[3] J. Zhang, et al. OFC, San Diego, CA, USA, 2018: M1B4
[4] K. Zhang, et al. Optics Express **26**.21 (2018): 27873-27884.
[5] C. Li, et al. Optics Express **27**.13 (2019): 18343-18350.
[6] C. Ye et al. ECOC, Rome, Italy, 2018: Mo4B.3
[7] W. Yan et al. ECOC, Amsterdam, Netherlands, 2012: Mo.1.B.2
[8] J. Zhang, et al. OFC, San Diego, CA, USA, 2019: Th4C.3
[9] Characteristics of a Single-Mode Optical Fibre and Cable, ITU-T Recommendation G.652, sec. 6.1, 2016.
[10] V. Houtsma and D. Van Veen, J. Light. Technol., **35**. 4 (2017): 1059-1066.
[11] M. Yang, et al. OFC, San Diego, CA, USA, 2019: W3H.2