50-Gb/s TDM-PON Based on 10G-Class Devices by Optics-simplified DSP

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Abstract: We demonstrate a 50-Gb/s PAM-4 TDM-PON over 25-km SSMF based on DML and APD with 6-GHz 3-dB bandwidth in O-band. Dispersion-supported optical equalization is used to reduce the complexity of FFE and Volterra algorithms. © 2018 The Author(s)

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

1. Introduction

Driven by newly emerging service such as cloud data center, virtual reality, 4k/8k HD television videos, the capacity of passive optical networks (PONs) system should be evolved to satisfy the increasing demand of users. Currently the IEEE 802.3ca Task Force is focusing on the standardization of low-cost 25-Gb/s/λ and by wavelength-division multiplexing it is flexible to support 100-Gb/s [1]. Increasing the capacity to 50-Gb/s/λ to take full advantage of limited available wavelength resource, a potential cost-effective way would be using high order modulation formats such as 4-ary pulse-amplitude modulation (PAM-4), discrete multi-tone (DMT), carrier-less amplitude and phase modulation (CAP) combined with digital signal processing (DSP) to compensate the fiber dispersion and optical/electronic bandwidth limitation [2, 3]. Recently several solutions for single wavelength 50G-PON have been proposed. Using PAM-4 and DMT, 50-Gb/s 20-km transmission employing a 10GHz DML and APD in O-band has been demonstrated, where signal pre-equalization, feed forward equalization (FFE) combined with maximum likelihood sequence estimator (MLSE) algorithms are used to compensate the bandwidth limitation, achieving a bit error ratio (BER) of 1×10^{-3} after 20-km standard single mode fibre (SSMF) transmission at -20 dBm/-18 dBm [4]. In [5], 50-Gb/s PAM-4 IM/DD PON transmission up to 20-km has been demonstrated using 10 GHz optics, neural network regression algorithms and MLSE are used for nonlinear equalization. The DSP algorithms used in these work are complicated which is difficult for real-time implementation. In our previous work, we have achieved symmetric 4×25-Gb/s TWDM-PON based on 10-GHz DMLs and APDs. Dispersion-supported equalization (DSE) technology instead of DSP is employed to compensate the bandwidth limitation in optical domain [6].

In this paper, we apply PAM-4 to experimentally demonstrate 50-Gb/s/λ TDM-PON over 25-km SSMF based on low-cost commercial available 10G-class DML and APD with only 6-GHz end-to-end 3-dB bandwidth. By employing DSE combined with simple FFE equalizer, we can achieve -16 dBm sensitivity at BER of 3.8×10^{-3}. We further use Volterra equalizer for nonlinearity compensation, -14 dBm sensitivity can be achieved after 25-km SSMF transmission in the O-band with Volterra kernels of (87, 35, 5). By performance comparison, DSE combined with simple FFE outperforms complex Volterra equalizer, therefore we consider this optics-simplified DSP (OsDSP) as a good option for high-speed and low-cost TDM-PON.

2. Principle

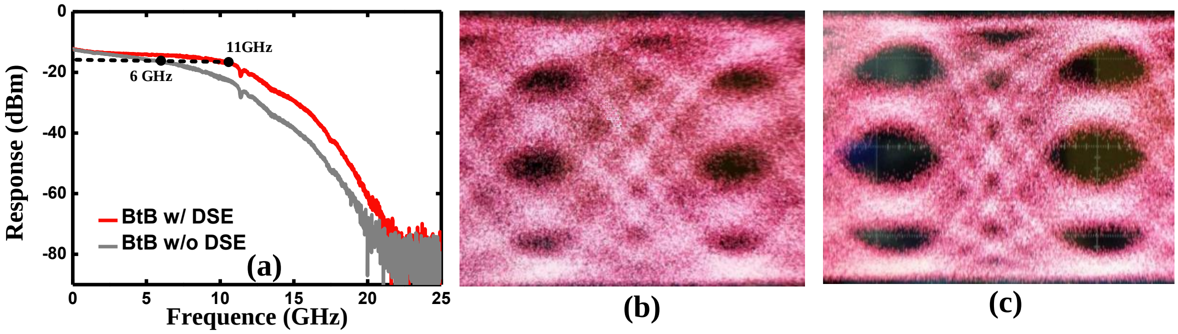
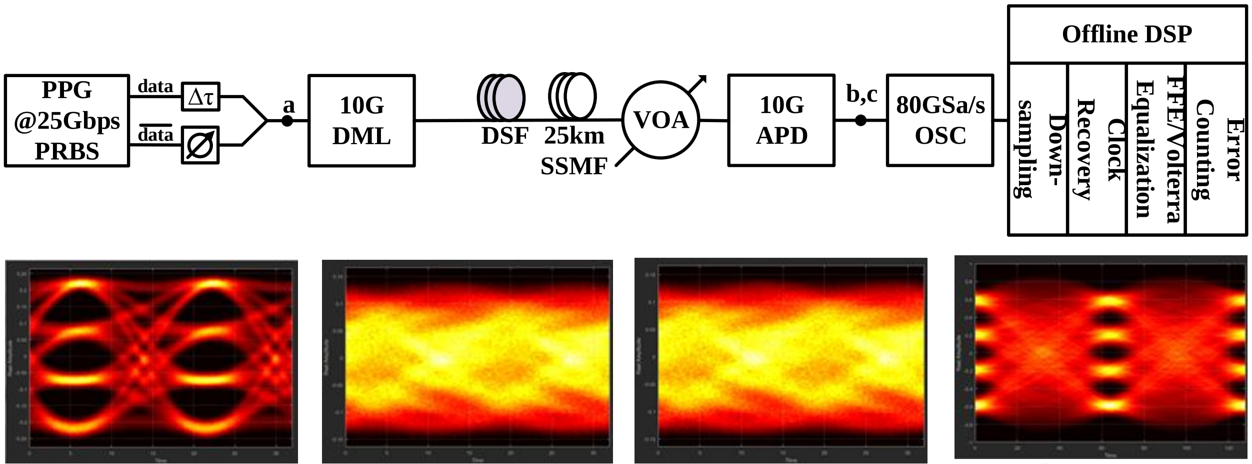


Fig. 1 Frequency response of the end-to-end system with and without DSE (a); 25-Gb/s PAM4 eye diagram at BtB without (b) and with DSE(c) respectively.

For bandwidth-limited direct modulation and direct detection (DM-DD) system, the high frequency components of the signal are degraded, resulting in the broadening of pulses therefore inducing inter symbol interference (ISI).

However, when transmitting in negative dispersion fiber, the pulse will be compressed for the positive chirp characteristics of directly-modulated signal, corresponding to the high-frequency enhancement. We use a roll of 10-km dispersion-shifted fiber (DSF) with around -150 ps/nm dispersion at 1310 nm to evaluate the frequency response of the system at BtB case shown in Fig. 1(a). The high frequency components are improved and the 3-dB end-to-end system bandwidth is improved from 6 GHz to 11 GHz due to DSE effect. To demonstrate the DSE technology also works efficiently under PAM-4 modulation format, we evaluate the eye diagram performance of 25-Gb/s PAM signal at back-to-back (BtB) case, the results are shown in Fig. 1(b) and (c). It can be observed that the eye diagram is not clear without DSE due to the bandwidth limitation. After employing the DSE for bandwidth improvement, the eye diagram become clearer. However, when the capacity is up to 50-Gb/s, DSE technology is not enough for bandwidth improvement and electrical equalization technology is also required at the same time.

3. Experimental setup



a(EBtB) b(OBtB) c(25 km) d(after RX DSP)

Fig. 2 Experimental setup of 50-Gb/s/λ TDM-PON using PAM-4. Insets (a-d): Normalized eye diagrams at different location in transmission link.

The experimental setup of the proposed 50-Gb/s/λ TDM-PON system is shown in Fig.2. At the transmitter side, 50-Gb/s PAM-4 signal is generated by pulse pattern generator (PPG, Keysight N4960A). By manipulating the magnitude and delay of two 25-Gb/s pseudo-random bit sequence (PRBS) signals with 2^{15}-1 in length, and then combined the two signals as an electrical PAM-4 signal and the peak-to-peak power is 1.5 V. A 10G-class DML operating at ~1310 nm with an output power of 7 dBm is used to convert electrical signal to optical domain. A roll of 10-km DSF with -150 ps/nm negative dispersion value is used for DSE function. After 25-km SMF transmission, a tunable optical attenuator emulates the optical splitter and for sensitivity measurement. At the receiver side, a 10G APD is used to directly detect the optical signal and convert it back to electrical signal. The received electrical signal is sampled by a Keysight real-time oscilloscope (DSOV334A) with the sampling rate of 80-GSa/s and then processed offline in Matlab. In the offline DSP part, the captured PAM-4 signal was firstly re-sampled, synchronization, and normalized. Then, FFE and Volterra filter are applied to mitigate the signal distortion due to the bandwidth limitation induced ISI. The Volterra kernels are updated by least mean square (LMS) algorithm. The measured 50-Gb/s PAM4 eye diagrams at different location in the transmission link are shown as insets in Fig. 2. As is shown, the eye diagram is completely closed at BtB and 25-km transmission even with DSE, so DSP should be employed to further equalize the signal.

4. **Results**

Figure 3 shows the measured BER performance as a function of the received optical power (ROP) for 50-Gb/s PAM-4 signal based on 10G devices. The BER cannot be measured without offline equalization due to the eye diagram is completely closed even with DSE. We first employ simple linear equalizer to recover the degraded signal shown in Fig. 3(a). The use of FFE filter with 17, 27, 57, 67, 87 taps improves BER gradually and brings it blow the FEC threshold of 1×10^{-3} when the FFE tap is more than 27. When the FFE tap is increased to 67, 3 dB receiver sensitivity improvement is obtained and higher numbers does not further improve the performance. The dependence of the BER on the ROP for BtB and 25-km transmission with and without DSE under 87 FFE tap have also been measured. As is shown in Fig. 3(b), the receive sensitivity at BER of 3.8×10^{-3} is -16 dBm and -12 dBm with and without DSE respectively, with about 4 dB improvement for the bandwidth improvement of DSE function.

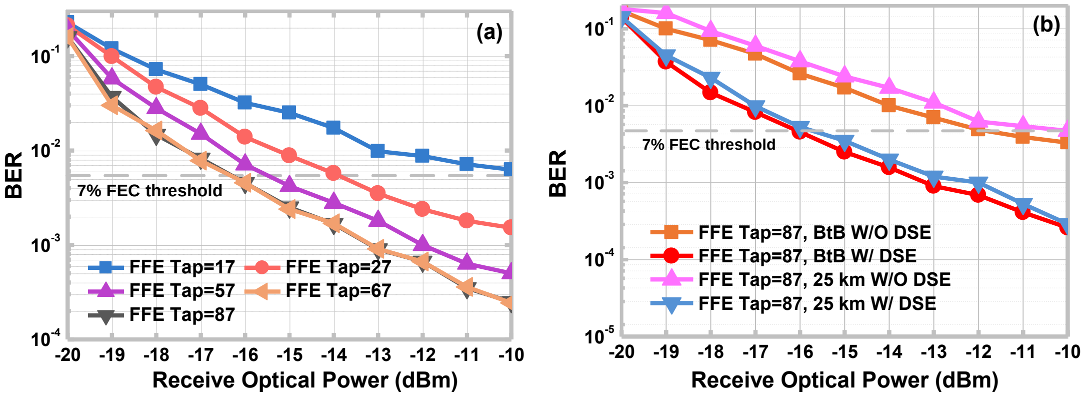


Fig. 3 Measured BER performance of 50-Gb/s PAM-4 signal. (a) Optimization of the FFE taps at BtB with DSE. (b) BtB and 25-km with and without DSE.

To further improve the receive sensitivity, we employ three kernels Volterra equalizer to combat the non-linear degradation in the system. Note that the memory length of the kernel is defined as Volterra (L_1, L_2, L_3) in Fig. 4. We compare four cases with different memory length of Volterra kernel at BtB with DSE. As we can see from Fig. 4(a), the receive sensitivity is improved from -16 dBm to -18 dBm at the BER threshold of 3.8×10^{-3} when the memory length of Volterra kernel changes from (87, 0, 0) to (87, 35, 5). Considering the optimal output power of DML of 7 dBm, a power budget of 25 dB can be obtained after 25-km SSMF transmission. We can also see that the Volterra equalizer with only first- and second-order kernel perform better than that with first- and third-order kernels, which means that the second-order nonlinearity is more severe than the third-order nonlinearity after 25-km SSMF transmission. In Fig. 4(b), the Volterra filer can also improve the BER performance at BtB case with DSE which means that the DSE also introduce nonlinear degradation to the signal. It can also be observed that the receive sensitivity at the BER threshold of 3.8×10^{-3} has 4 dB improvement after employing DSE technology. By comparing the results of Fig. 3 and Fig. 4, the receiver sensitivity of DSE combined with FFE is 2 dB better than Volterra-only equalizer, considering FFE is much simpler than Volterra equalizer and easy for real-time implementation, this is why we consider optics (DSE) can simplify DSP.

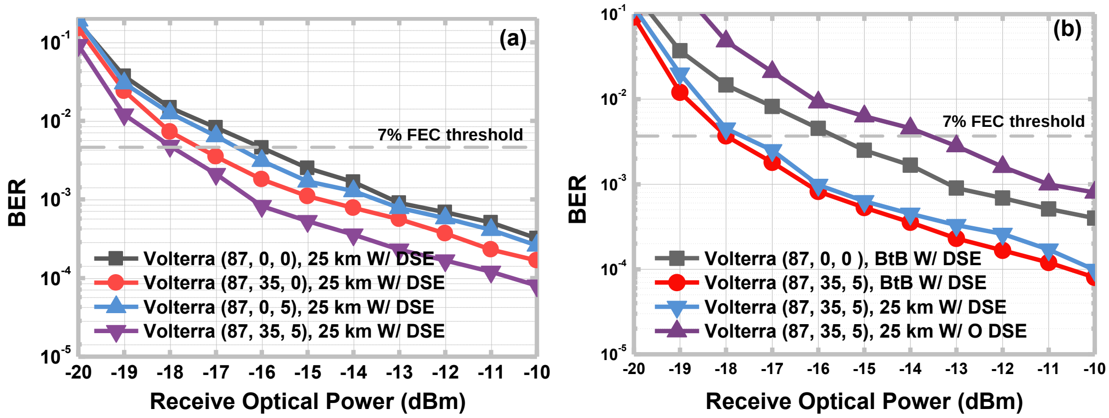


Fig. 4 Measured BER performance of 50-Gb/s PAM-4 signal. (a) Optimization of the memory length of Volterra filter after 25-km SMF transmission with DSE. (b) BtB and 25-km with and without DSE.

5. Conclusions

In this paper, we have experimentally demonstrated 50-Gb/s/λ TDM-PON by reusing 10G class devices. Dispersion-supported optical equalization combined with simple FFE are used to compensate the bandwidth limitation and -16 dBm receiver sensitivity has been achieved, which is 2 dB better than the Volterra equalizer case. Considering the simplicity of FFE compared with Volterra equalizer, we suppose this proposed optics-simplified DSP (OsDSP) is a promising solution for high-speed low-cost TDM-PON.

6. References

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