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SOA Pre-Amplified 200 Gb/s/λ PON Using High-Bandwidth TFLN Modulator

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Abstract *We experimentally demonstrate 200/240 Gb/s/λ PAM-4 PON downstream transmission based on high bandwidth thin film lithium niobate modulator and direct detection in O-band. By using SOA and Volterra equalizer at the receiver side, over 29/28 dB power budget is achieved after 20 km SSMF.*

Introduction

To accommodate the rapid growth of emerging applications such as HD video streaming, online games, cloud services, the transmission capacity of optical access network needs great expansion. The access data rate of about 1 Gb/s per wavelength has been upgraded to 10 Gb/s, 25 Gb/s in the past several years. Several organizations have dedicated to promoting the development of high-speed passive optical network (HS-PON) technology [1]. ITU-T Q2/SG15 has committed to the standardization of HS-PON. IEEE 802.3ca is working on the recommendations of 100 Gb/s for next generation Ethernet passive optical network (NG-EPON) [2].

Coherent detection is an effective way to increase the capacity due to its high receiver sensitivity. However, it requires expensive components and high power consumption, which is not suitable for PON applications. 4-level pulse amplitude modulation (PAM-4) and direct detection (DD) are usually considered in PON system due to the cost-effective and spectrum efficiency advantage. However, the fiber chromatic dispersion (CD), nonlinearity, and bandwidth limitation are main problems for high-speed DD transmission, and introduces challenge to achieve the high power budget requirement in PON system. There are several ways to cope with these problems. First, O-band can be used since it has lower dispersion penalties compared to the C and L bands [3]. However, O-band has high fiber attenuation loss, which greatly decreases the system power budget. Using semiconductor optical amplifier (SOA) at receiver side is a suitable method to improve the system loss budget [4]. Moreover, the additional cost to the system is small because photodetector (PD) can be easily integrated with SOA. Besides using O-band, digital signal processing (DSP) algorithms can also be employed to overcome linear/nonlinear distortions and other impairments in fiber links. Algorithms such as feed-forward equalization (FFE), decision feed-back equalization (DFE), Volterra equalization and maximum likelihood sequence estimation (MLSE) are investigated in recent research [5]. Furthermore, the high bandwidth devices such as modulator, amplifier and photodetector are continuously studied to expand system capacity. For example, the thin film lithium niobate (TFLN) electro-optic modulators have become a strong candidate for high-speed application in recent years [6].

In this paper, by using a high bandwidth thin film lithium niobate modulator with 3-dB bandwidth of 60 GHz, we experimentally demonstrate 200 Gb/s/λ and 240 Gb/s/λ PAM-4 PON downstream transmissions in O-band. A pre-amplified SOA and 2nd-order Volterra equalizer are utilized at the receiver side to deal with the fiber attenuation and nonlinearity. Over 29 dB and 28 dB power budgets are achieved respectively after 20 km standard single mode fiber (SSMF) considering the soft-decision FEC (SD-FEC) threshold (1×10^{-2}). To our knowledge, it is the first time the transmission capacity reaches up to 200 Gb/s with single-wavelength in direct detection PON system, where the power budget meets the IEEE PR-30 requirement.

Experimental Setup

Fig. 1 shows the experimental setup of our demonstrated PAM-4 PON with direct detection by single-PD in O-band. Both 200 Gb/s and 240 Gb/s downstream transmissions are realized. A packaged TFLN Modulator is used at Mach-Zehnder interferometer configuration. The MZM is based on LN-on-insulator platform with a single-crystal. Submicrometre-thick LN film is bonded on top of a low-index substrate (silicon dioxide, SiO_2). The frequency response of this modulator is shown in Fig. 1(a). The 3-dB bandwidth of the device is 60 GHz.

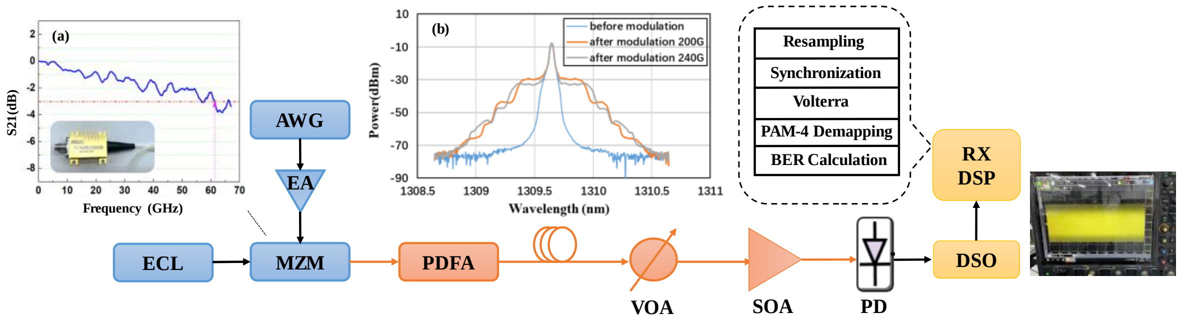

Fig. 1: The experimental setup of 200/240 Gb/s PAM-4 PON downtream transmission in the C-band; (a) The frequency response of MZM device; (b) the optical spectrum of signal before and after MZM;

At the OLT side, an external cavity laser (ECL) operating at 1310 nm with linewidth of 200 kHz is employed as optical source. The 100/120 Gbaud PAM-4 baseband signal is generated by an arbitrary waveform generator (AWG) (Keysight 8199A) with bandwidth of 60 GHz and sampling rate of 256 GSa/s. The electrical signal from AWG is then amplified by an electrical amplifier (EA) with 67 GHz bandwidth before loading onto the packaged TFLN MZM. The optical spectrum of signal before and after modulation is shown in Fig. 1(b). An O-band booster praseodymium-doped fiber amplifier (PDFA) is employed to increase the launching power, where a maximal launch power of 14 dBm is obtained. The modulated optical signal is then sent to the SSMF with an average loss of 0.33 dB/km at 1310 nm. After 20 km transmission, a variable optical attenuator (VOA) is used to account for the splitter loss in PON system. At the ONU side, An O-band SOA (Aeon SAOM) is applied in order to improve the system power budget. After that, a 70 GHz PIN-PD (FINISAR XPDV3320R) is used for photoelectric conversion. The output signal of PIN-PD is captured by a 256 GSa/s real-time digital storage oscilloscope (DSO) (Keysight UXR0704A), with bandwidth locked at 70 GHz, and finally processed offline in Matlab.

The offline DSP flow at the Rx is also shown in Fig. 1. The captured offline signal is firstly resampled to 2 samples/symbol with the matched filter. Then synchronization is conducted to extract the required data and remove the timing offset. After that, a 2nd-order Volterra equalizer is applied to compensate linear and nonlinear impairments before PAM-4 demodulation. Finally, the bit-error-ratio (BER) results are calculated based on the recovered signal.

Experimental Results

We firstly measure the BER performance versus received optical power in back-to-back (B2B) case for 200 Gb/s and 240 Gb/s downstream transmissions. With pre-amplied SOA and Volterra equalizer used at ONU side, the BER result can be greatly improved. We set the SOA bias current to 180 mA and Volterra equalizer length to 183 for getting the optimized system performance. To measure the receiver sensitivity, we vary the received power into the SOA by changing the attenuation of VOA. The receiver sensitivity of 200 Gb/s can achieve -16 dBm at the SD-FEC threshold of 1×10^{-2}. When the data rate is increased to 240 Gb/s, the BER performance degrade. the receiver sensitivity decline to about -15 dBm becasue that higher speed induce more inter-symbol interference (ISI). The results show that the sensitivity of 200 Gb/s has about 1 dBm priority compared to the 240 Gb/s, as shown in Fig. 2.

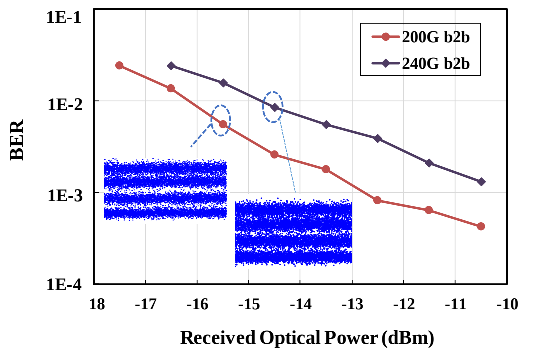

Fig. 2: BER versus ROF of 200 Gb/s and 240 Gb/s at back-to-back case.

The BER performance versus received optical power after 20 km SSFM are also measured for both 200 Gb/s and 240 Gb/s transmissions, as shown in Fig. 3. The sensitivities of 200 Gb/s and 240 Gb/s after 20 km fiber are about -15.5 dBm and -14.5 dBm respectively considering the SD-FEC threshold. Because of near zero-dispersion at O-band, the CD after short fiber transmission has little effect on the system performance. The 0.5 dBm penalty compared to B2B case is mainly due to the nonlinear distortions from the link. The BER floor after increasing the received power to -12.5 dBm are also because of the nonlinearity in the system.

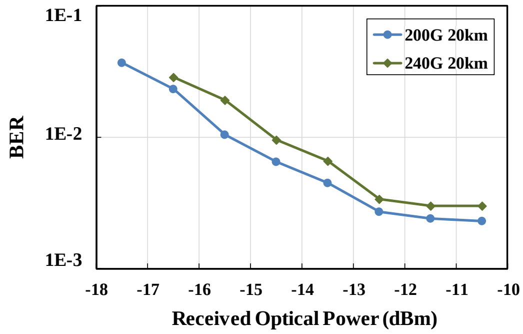

Fig. 3: BER versus ROF of 200 Gb/s and 240 Gb/s at 20 km SSMF case.

Next, we evaluate the power budget of the downlink system for both 200 Gb/s and 240 Gb/s transmissions. The launch power is varied from 8 dBm to 14 dBm by changing the gain of the PDFA. We firstly fix the receiver power to -15.5 dBm as a benchmark at data rate of 200 Gb/s. The BER fluctuation are small when increasing the launch power, and the results are mostly under the FEC threshold of 1×10^{-2}. The results show that the optimal launch power is 14 dBm in our experiment, and the corresponding power budget is 29.5 dB for 20 km SSMF transmission. This high power budget is mainly due to the broad bandwidth of the modulation, which enhance the tolerant of optical signal to fiber nonlinearity, and application of the pre-amplified SOA and Volterra equalizer. The results are depicted in Fig. 4. Then we fix the receiver power to -14.5 dBm as a benchmark to investigate the optimal launch power at data rate of 240 Gb/s. The results are identical as that of 200 Gb/s, the largest launch power is 14 dBm, which means the power budget can achieve 28.5 dB at data rate of 240 Gb/s.

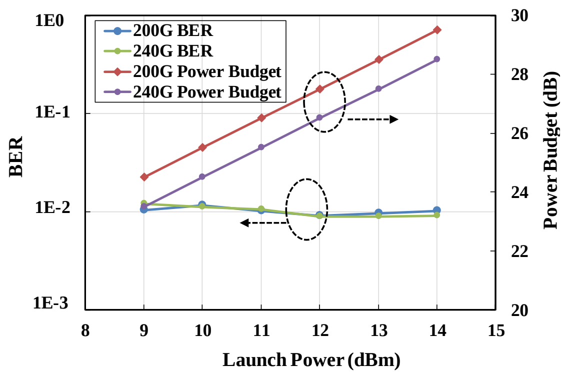

Fig. 4: BER and power budget versus launch power after 20 km SSMF.

Conclusions

We have experimentally demonstrated 200 Gb/s and 240 Gb/s/λ PAM-4 direct detection PON downstream transmission in O-band. With a high bandwidth TFLN MZM used, the receiver sensitivity can achieve -15.5 dBm and -14.5 dBm respectively considering SD-FEC threshold. The pre-amplified SOA and Volterra nonlinear equalizer are applied to improve the system performance. The power budgets of more than 29 dB at 200 Gb/s/λ and 28 dB at 240 Gb/s/λ are obtained after 20 km SSMF transmission. Tab. 1 summarizes our results.

Tab. 1: Summary of 200 Gb/s and 240 Gb/s PAM-4 PON downstream link

Data rate	Launch power	Sensitivity	Power Budget
200-Gb/s/λ	14 dBm	-15.5 dBm	29.5
240-Gb/s/λ	14 dBm	-14.5 dBm	28.5

Acknowledgements

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