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Amplifier-Less Transmission of 56Gbit/s PAM4 over 60km Using 25Gbps EML and APD

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Abstract: In this paper, we experimentally demonstrated 56Gbit/s PAM4 signal optical amplifier-less transmissions over a record distance 60km using 25Gbps EML and APD. Compared to PD-based receiver, improvements of 7dB and 50% in terms of receiver sensitivity and transmission distance were achieved.

OCIS codes: (060.2330) Fiber optics communications; (230.0250) Optoelectronics; (060.4080) Modulation

1. Introduction

The fast developing of bandwidth hungry data center and optical inter-connect applications desire high capacity short reach transmission system. Considering the form factor, power consumption and cost, intensity modulation with direct detection (IM/DD) is promising way for short reach transmission system. Recently, short reach transmission systems with high capacity have been widely demonstrated [1-3] employing low cost EML and IM/DD. In future client network systems, the transmission distance has to be increased up to 40km or more in order to cover long-reach optical inter-connect applications such as inter-data center connection. Low output power at transmitter, the sensitivity of receiver and dispersion of the fiber would shorten the achieved transmission distance. Long distance transmission can be realized with the help of optical amplifiers [4, 5]. However, it will increase the power consumption and cost. Avalanche photodiode (APD) is a promising component to achieve optical amplifier-less long reach IM/DD transmission system as it has much higher responsivity than conventional photodiodes. In [6-7], a 56Gbit/s 40km optical amplifier-less transmission with NRZ or PAM4 format employing high speed APD was experimentally demonstrated. However, there is no reports on 56Gbit/s transmission over 40km or more without any optical amplifier using commercial 25Gbps EML at O band.

In this paper, we experimentally demonstrated single-channel 56Gbit/s PAM4 signal transmission over 60km SSMF without any optical amplifier using commercial 25Gbps EML and APD at O band. PAM4 is employed in order to reduce the bandwidth requirement. Receiver sensitivities of -20dBm and -19.9dBm at 7% FEC threshold were achieved for back-to-back and 60km transmission. Compared to PD based receiver, improvements of 7dB and 50% in terms of receiver sensitivity and transmission distance were achieved with APD based receiver. To the best of our knowledge, this is the longest reported transmission distance at 56Gbit/s IM/DD system employing commercial 25Gbps EML without any optical amplifier at O band.

2. Experimental Setup

Figure 1 shows the experimental setup for 56Gbit/s PAM4 60km optical amplifier-less transmission system. A 2^{16} de Brujin bit sequence is used for bit to symbol mapping and generation of PAM-4 signal. In this experiment setup, a DAC with a 3dB bandwidth of 30GHz (Keysight M8196A) operated at 56GSa/s is used to generate the driving signal. The eye-diagram of generated 28Gbaud/s electrical PAM4 signal was shown in Fig. 1(a). We adjust the eye-opening of the middle eye in order to compensate for the nonlinearity of EML. Then, the electric signal is amplified to a peak-to-peak voltage of 1.78V by a linear EA (electric amplifier) and used to drive a 25Gbps EML (electric absorption modulated laser). The 3 dB bandwidth of the EML is 20GHz. The center wavelength is 1295.13nm. The bias voltage is optimized to be -1.49V. The power of output optical signal is 1dBm. The optical spectrum of signal after back-to-back transmission and after 60km transmission were shown in Fig. 1(b). A variable optical attenuator (VOA) is placed after SSMF to adjust the received optical power. The total loss of the 60km SSMF is 20.7dB at O band. At receiver side, the transmitted signal is detected by an ADP+TIA receiver (SiFotonics, RLNS200-200) with a 3dB bandwidth of 25GHz. The performance using a PIN+TIA receiver (Discovery Semiconductor DSC-R409, 3dB bandwidth of 30GHz) was also measured for comparison. The detected signal is sampled by a real-time scope

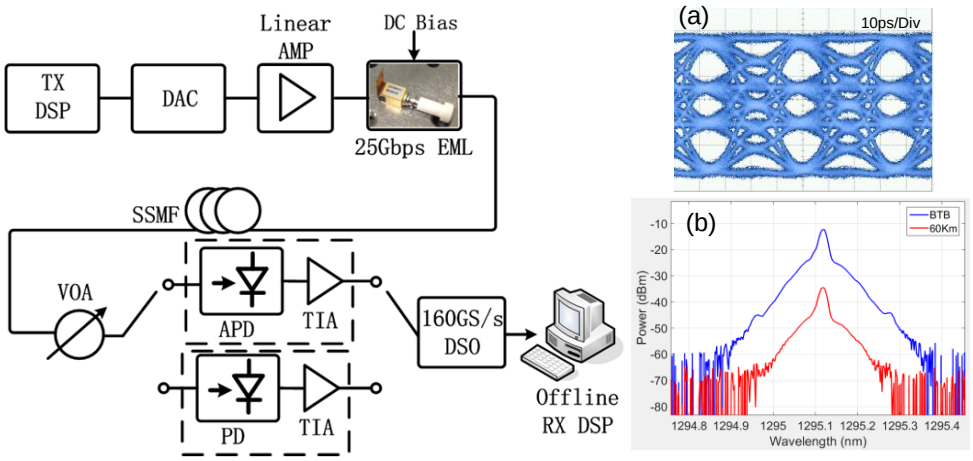

Fig. 1 Experimental setup for 56Gbit/s PAM4 60km optical amplifier-less transmission system. DAC: digital to analog converter; AMP: amplifier; EML: Electric-Absorption modulated laser; VOA: variable optical attenuator; APD: avalanche photodiodes; PD: photodiodes. TIA: trans-impedance amplifier; DSO: digital storage oscilloscope. (a) Eye-diagram of 28Gbaud/s electrical PAM4 signal; (b) Optical spectrum for back-to-back transmission and after 60km transmission.

with a sampling rate of 160GS/s and a bandwidth of 59GHz and processed offline. The signal is normalized and re-sampled to 2 samples per symbol. A training symbol aided least mean square (LMS) algorithm is first used to initialize the equalizer taps. After the taps are fully converged, the equalizer is switched to a decision directed mode. The number of taps of DD-LMS is optimized to be 35. The recovered signal goes into decision module and the bit error rate was calculated by error counting. A total number of 1M bits are used for bit error counting.

3. Experimental Results

Figure 2(a) shows the measured end-to-end frequency response of optical transmission link with APD (blue curve) and PD (red curve). A 3dB bandwidth and 10dB bandwidth were demonstrated to be 8GHz and 21GHz for APD based system. Similar frequency response can be found in PD based system. The roll off of frequency response of APD based system is sharper than that of PD based system. Therefore, it is fair Fig. 2(b) shows the measured BER as a function of received optical power for back-to-back transmission with APD (blue curve) and PD (red curve), respectively. Receiver sensitivity at the 7% over head forward error correction (FEC) limit of $3.8\text{x}10^{-3}$ is -20dBm for APD based system. A receiver sensitivity of -13dBm was demonstrated for PD based system at the 7% over head forward error correction (FEC) limit of $3.8\text{x}10^{-3}$. An improvement of 7dB in terms of receiver sensitivity was achieved using APD. Assuming the launch power of transmitter and fiber loss at O band are 1dBm and 0.35dB, respectively, a transmission distance of 40km can be achieved with PD. However, a transmission distance of 60km can be achieved with APD, which is 50% increase in terms of transmission distance compared to PD based system.

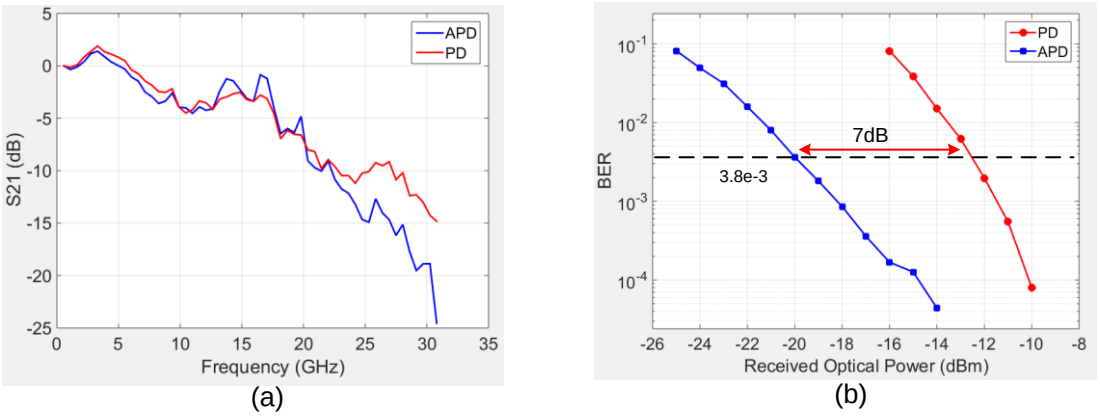

Fig. 2: (a) Measured frequency response for optical transmission link with APD (blue curve) and PD (red curve), respectively; (b) Measured bit error ratio as a function of received optical power for back to back transmission with APD (blue curve) and PD (red curve), respectively.

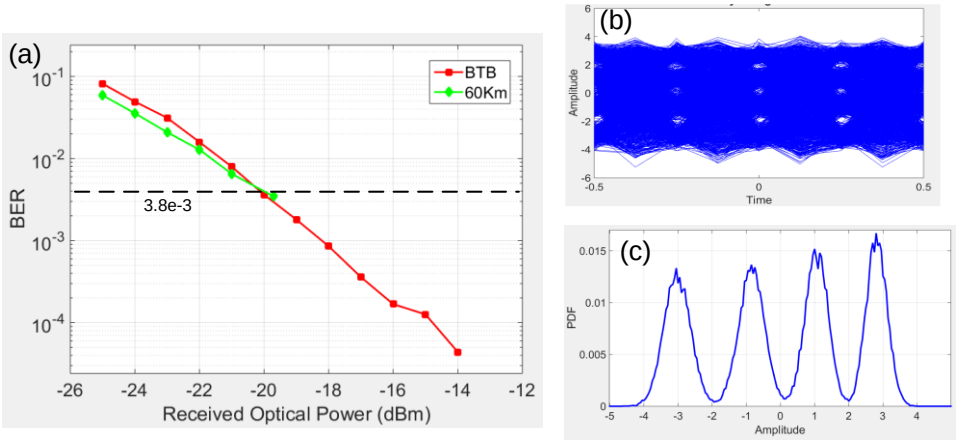

Fig. 3: (a) Measured bit error ratio as a function of received optical power for back to back, (b) eye-diagram of recovered signal. (b) amplitude histogram of recovered signal, the received optical power is -19.7dBm

Fig.3 (a) shows the measured bit error rate as a function of the received optical power for back-to-back transmission system and 60km transmission system with APD based receiver. Receiver sensitivity at 7% over head forward error correction (FEC) limit of $3.8\text{x}10^{-3}$ are -20dBm and -19.9dBm for back-to-back system and 60km transmission system, respectively. Fig. 3(b) shows the recovered eye-diagram after equalization with a received optical power of -19.7dBm. The corresponding amplitude histogram of recovered signal with 1 Sample/Symbol was shown in Fig. 3(c). The BER is $3.4\text{x}10^{-3}$.

4. Conclusions

In this paper, we experimentally demonstrated single-channel 56Gbit/s PAM4 signal transmission over 60km SSMF without any optical amplifier using 25Gbps EML and APD at O band. Receiver sensitivities of -20dBm and -19.9dBm at 7% FEC threshold were achieved for back-to-back and 60km transmission. Compared to PD based receiver, Improvements of 7dB and 50% in terms of receiver sensitivity and transmission distance were demonstrated with APD based receiver, respectively. To the best of our knowledge, this is the longest reported transmission distance at 56Gbit/s IM/DD system employing commercial 25Gbps EML without any optical amplifier at O band.

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