Experimental Demonstration of Amplifier-Less 82GBaud PAM4 Transmission over 40 km Using APD at O Band

Haiqiang Wei[1*], Kemo Ran[2], Kangping Zhong[1], Alan Pak Tao Lau[1], Changyuan Yu[1], Chao Lu[1]
[1] Department of Electrical and Electronic Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong SAR
[2] MACOM Technology Inc, Shenzhen, China
**Email: haiqiang.wei@polyu.edu.hk*

Abstract: We experimentally demonstrated an amplifier-less transmission of a record high 82Gbaud PAM4 signal over 40km using O-band APD with a receiver sensitivity of -15.8dBm.

1. Introduction

The demand for fast data transmission between data centers and users is growing due to the rise of 5G, cloud computing, Internet of Things, artificial intelligence applications. Future client network systems may require transmission distance exceeding 40 kilometers to facilitate long-distance optical interconnect applications, such as inter-data center connections, optical back-haul transmission etc. The ability to cover such distances is influenced by factors such as transmitter output power, receiver sensitivity, and fiber dispersion. In this connection, operating in the O-band eliminates dispersion effects. For long-distance transmission, optical amplifiers are typically necessary despite the associated increase in power consumption and cost. An alternative approach is to use avalanche photodiodes (APDs). APDs offer superior responsivity compared to conventional PIN photodiodes, making them particularly advantageous for the implementation of low-cost amplifier-less long reach intensity modulation/direct detection (IM/DD) transmission systems.

In recent studies, researchers have successfully demonstrated the feasibility of amplifier-less transmission at a rate up to 112Gbit/s over 40km using either NRZ or PAM4 format [1-4]. To meet the ever-increasing data transmission demand, optical interconnect with speed higher than 100Gbit/s is highly desired. In this paper, we successfully demonstrated the transmission of 82GBaud PAM4 signal over 40km without any optical amplification. This was achieved by utilizing commercially available 56G APD receiver optical sub-assembly (ROSA) in the O band. The receiver sensitivity is obtained to be -15.8dBm. To the best of the author's knowledge, this is the highest baud-rate of PAM4 signal transmission in a 40km amplifier-less IM/DD system.

2. Experiment Set-up

The experimental configuration for amplifier-less IM/DD transmission system using APD ROSA is shown in Figure 1 (a). At the transmitter side, a 2^{16} bit De Brujin sequence is employed for bits to symbols mapping. An arbitrary waveform generator (Keysight M8196) with a sampling rate of 119.7GSa/s and an analog bandwidth of 45GHz is employed to generate a PAM4 signal with a raised cosine pulse shaping and a roll off factor of 0.1. The output electrical PAM4 signal is amplified by a linear RF amplifier (SHF 807S) to a peak-to-peak voltage of 1.7V. Then, the electrical signal was used to drive an intensity modulator (Fujitsu, FTM7938EZ). Level optimization is employed to compensate for the nonlinearity of RF driver and modulator. The bias voltage of modulator is adjusted to quadrature point for optimal performance. A CW laser with a center wavelength of 1310 is launched into the modulator for modulation. The power of output optical signal is recorded to be 1.7dBm. The overall attenuation of 40km SSMF is measured to be 14dB at O-band. A variable optical attenuator (VOA) was placed before the APD ROSA to adjust the received optical power. An APD ROSA with a bandwidth of 35GHz was employed to detect the transmitted signal. Figure 1 (b) shows the picture of APD ROSA (MACOM MARP-BA56) used in this experiment. Figure 1 (c) shows the end-to-end system 3dB and 10 dB RF response is measured to be 22.3GHz and 37.3GHz, respectively, including the EVB and RF cables. It should be noted that the overall bandwidth can be improved by chip-on-board (COB) packaging method instead of TO-CAN used in this paper. The detected signal is captured by a real time scope operating at a sampling rate of 256GSa/s with a bandwidth of 65GHz. The captured data is processed using offline DSP. The offline DSP includes normalization, re-sampling, digital square and filtering based timing recovery, direct detection Faster-than-Nyquist (DD-FTN) algorithm [5] for equalization. DD-FTN algorithm consists of a decision-directed LMS, a 2-tap digital post filter and maximum likelihood sequence estimation (MLSE). Training symbols are used for the convergence of LMS based equalizer. After convergence, the equalizer is switched to a decision-directed mode. To obtain best performance, the number of taps in DD-LMS is optimized to be 201. The complexity of linear equalizer can be reduced by implement it in frequency domain. A two-tap digital

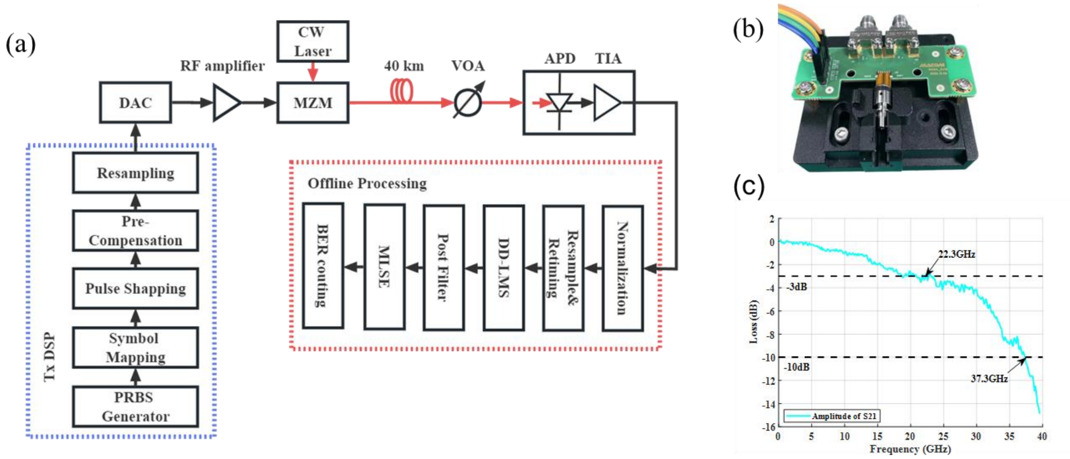

Fig. 1 (a) Experimental setup for amplifier-less IM/DD transmission system over 40 km using APD ROSA. DAC: digital to analog converter; Linear AMP: Linear electrical amplifier; EML: Electric-Absorption modulated laser; SSMF: standard single mode fiber; VOA: variable optical attenuator; APD: avalanche photodiodes; TIA: trans-impedance amplifier. (b) the APD ROSA EVB. (c) the frequency response of APD ROSA.

post filter is placed right after the DD-LMS to filter out the enhanced noise and improve the effective SNR of signal. The MLSE algorithm is then used to aid symbol decisions in presence of significant inter-symbol interference (ISI) caused by the post filter. This is followed by bit error ratio (BER) calculation from a dataset of 3M bits.

3. Results and Discussion

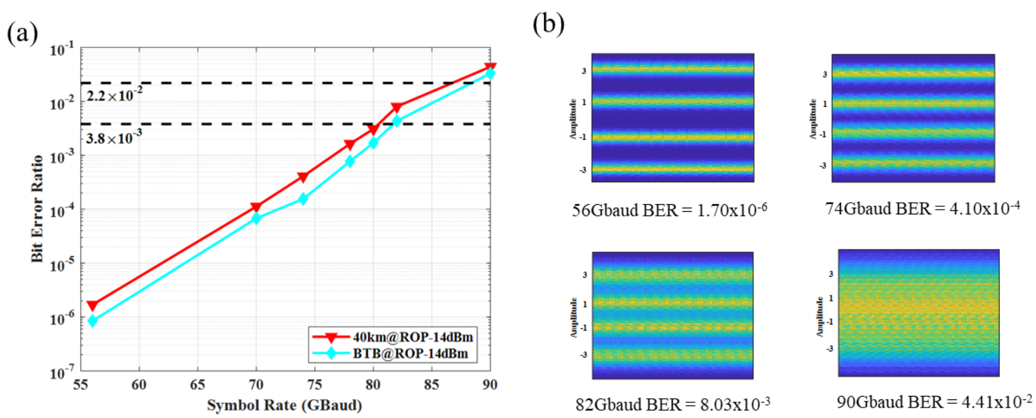

Fig.2 (a) Bit error ratio vs Baud rate after back-to-back and 40km transmission with a received optical power of -14dBm. (b)Equalized Signal at different baud rate with a receiver optical power of -14dBm.

Figure 2 (a) shows BER vs symbol rate for back-to-back and 40km transmission with a received optical power of -14dBm. At 7% FEC overhead limit of $3.8x10^{-3}$, the symbol rate can achieve 82Gbaud in a BTB configuration and 80Gbaud over 40km. If considering 20% soft-decision (SD)-FEC overhead limit of $2.2x10^{-2}$, the achievable symbol rate can exceed 82Gbaud for 40km. Figure 2 (b) shows the histogram of PAM4 signal after equalization at 56GBaud, 74Gbaud, 82Gbaud and 90Gbaud. The BER are $1.7x10^{-6}$, $4.1x10^{-4}$, $8.03x10^{-3}$, $4.41x10^{-2}$, respectively.

The BER as a function of received optical power of PAM4 signal with different baud rate investigated for back-to-back system and 40km transmission system are shown in Fig 3. Fig. 3(a) shows the BER vs received optical power for back-to-back system. At 7% FEC overhead limit of $3.8x10^{-3}$, receiver sensitivities for 56Gbaud, 64Gbaud, 70Gbaud, 74Gbaud, 78Gbaud, 80Gbaud and 82Gbaud are -21dBm, -19dBm, -18dBm, -17.5dBm, -16dBm, -15dBm and -14dBm, respectively. A BER below $3.8x10^{-3}$ for 90GBaud PAM4 cannot be reached. At 20% SD-FEC overhead limit of $2.2x10^{-2}$, receiver sensitivities for 56Gbaud, 64Gbaud, 70Gbaud, 74Gbaud, 78Gbaud, 80Gbaud, 82Gbaud and 90Gbaud are -22.5dBm, -20.8dBm, -19.7dBm, -19.2dBm, -17.8dBm, -17dBm, -16.2dBm and -

13.5dBm, respectively. Fig. 3(b) shows the BER vs received optical power for 40km SSMF system. At 7% FEC overhead limit of $3.8\text{x}10^{-3}$, receiver sensitivities for 56Gbaud, 64Gbaud, 70Gbaud 74Gbaud, 78Gbaud, and 80Gbaud are -20.9dBm, -18.5dBm, -17.4dBm, -16.1dBm, -15dBm and -14.3dBm, respectively. A BER below $3.8\text{x}10^{-3}$ for 82GBaud PAM4 signal cannot be reached. At 20% SD-FEC overhead limit of $2.2\text{x}10^{-2}$, receiver sensitivities for 56Gbaud, 64Gbaud, 70Gbaud 74Gbaud, 78Gbaud, 80Gbaud, 82Gbaud are -22.6dBm, -20.3dBm, -19dBm, -17.8dBm, -17.5dBm, -16.6dBm and -15.8dBm, respectively. A BER below $2.2\text{x}10^{-2}$ for PAM4 cannot be reached for 90GBaud and therefore the final achievable speed is 82GBaud PAM4 over 40 km.

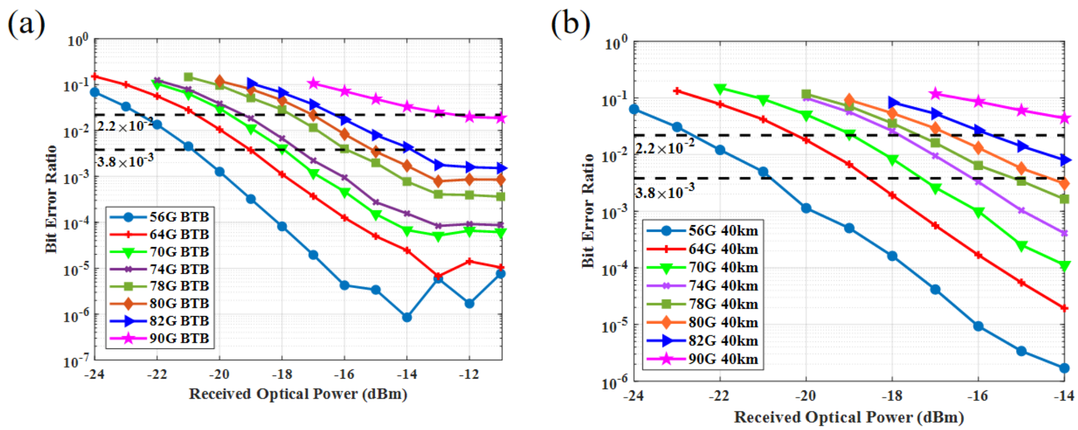

Fig.3 (a) BER vs ROP for different baud rates at BTB. (b) BER vs ROP for different baud rates at 40km.

4. Conclusions

In this paper, we experimentally demonstrated an amplifier-less PAM4 IM/DD transmission system with a record high baud-rate of 82GBaud over 40km SSMF fiber by using an APD ROSA at O band. A receiver sensitivity of -15.8dBm for 82Gbaud PAM4 signal transmission over 40km SSMF was achieved assuming the use of SD-FEC. To the best of the authors' knowledge, this is the highest report Baud-rate for an amplifier-less IM/DD system with a transmission distance of 40km at O-band.

5. Acknowledgement

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