300+ Gbps Short-Reach Optical Communications

Oskars Ozolins[1,2*] Lu Zhang[3], Aleksejs Udalcovs[1], Hadrien Louchet[4], Thomas Dippon[4], Markus Gruen[4], Xiaodan Pang[2,1,5], Richard Schatz[2], Urban Westergren[2], Shilin Xiao[6], Sergei Popov[2], Jiajia Chen[7]

[1]*RISE Research Institutes of Sweden AB, Kista, Sweden*
[2]*KTH Royal Institute of Technology, Kista, Sweden*
[3]*Zhejiang University, Hangzhou, China*
[4] *Keysight Technologies GmbH, Böblingen, Germany*
[5]*Infinera, Stockholm, Sweden*
[6] *Shanghai Jiao Tong University, Shanghai, China*
[7]*Chalmers University of Technology, Gothenburg, Sweden*
[*]*oskars.ozolins@ri.se, ozolins@kth.se*

Abstract: We review experimental intensity modulation and direct detection demonstrations for short reach optical communications. We also evaluate 8-level PAM and DMT transmitter to deliver 300 Gbps line rate and beyond per single lane in C-band.

1. Introduction

Exchange of information in fast, reliable and secure way with access anywhere is a must for a modern society. Emerging traffic in Data Centers is setting tight requirements for short-reach optical interconnects [1]. Research activities around 400-GbE interfaces employ wavelength division multiplexing (WDM) for short-reach optical communications [2]. Attractive solutions are proposed based on four optical lanes [3], two optical lanes [4]-[8] or even single lane [9]-[11] using high bandwidth components to overcome cost and energy crunch while reducing complexity of parallelism. C-band for intensity modulation direct detection (IMDD) short-reach optical communications is even more attractive thanks to the mature dense WDM (DWDM) technology. Building blocks for co-designed and co-integrated electronics and photonics are available: high-performance integrated circuits [12] and advanced digital to analogue converters (DACs) for generation [9]-[11]; high bandwidth modulators and photodetectors [3]-[13]; and analogue to digital converter (ADC) for reception [14].

In this paper we evaluate 300 Gbps line rate with 100 Gbaud 8-level pulse amplitude modulation (PAM8) [5] and 330-Gbps line rate with 128 quadrature amplitude modulation (QAM) discrete multitone (DMT) [8] IMDD transmission after 400 meters below pre-forward error correction (FEC) bit error rate (BER) of 2.7×10^{-2} [15] with a single packaged externally modulated laser (EML), a DAC and a packaged InP photo-detector (PD) in C-band.

2. Results

The experimental setup is shown in Fig 1. The PAM8 and DMT signals are generated offline. PAM8 signal with 2^{15}-1 long pseudorandom binary sequence is up-sampled and filtered with a root-raised-cosine filter having 0.15 roll-off factor then frequency domain pre-equalization up to 55 GHz is used. For DMT we use 816 subcarriers with 128 QAM having 47.8-GHz (816/2048×120-GSa/s) modulation bandwidth. The length of IFFT is set to 2048 with 58.6 MHz subcarrier spacing and 0.75 clipping ratio. Then signals are then loaded to 120 GSa/s 55 GHz arbitrary waveform generator (AWG, Keysight M8194A, see response in Fig.1(b)). Then signals are amplified in a 65 GHz electrical amplifier with 11 dB gain. Similar is used after PIN photodetector for PAM8 signal only. A distributed feedback laser-travelling wave electro-absorption modulator (DFB-TWEAM) is used to generate optical signals [15]. We obtain 0.5 dBm output power when DFB is driven with 120 mA current and TWEAM is biased at minus 1.83 volts. Operational temperature of the externally modulated laser (EML) package is ~ 20 °C. We use pre-amplifier (EDFA) with a variable optical attenuator (VOA) to adjust the power before the PIN photodetector. The signal is captured with a 256 GSa/s 110 GHz digital storage oscilloscope (DSO, Keysight UXR1102A).

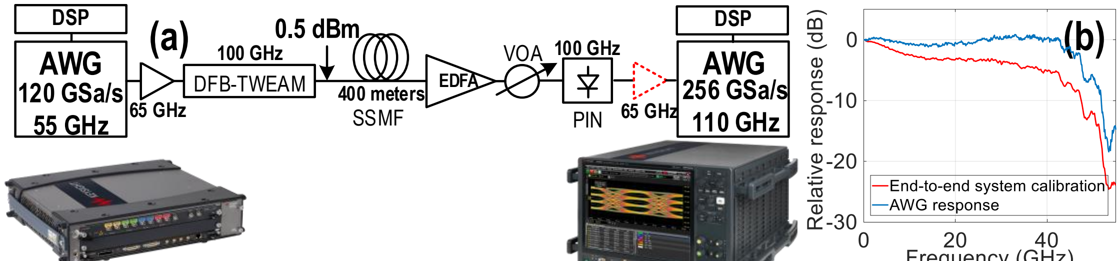

Fig. 1. (a) Experimental setup, (b) relative response for AWG and end-to-end system calibration.

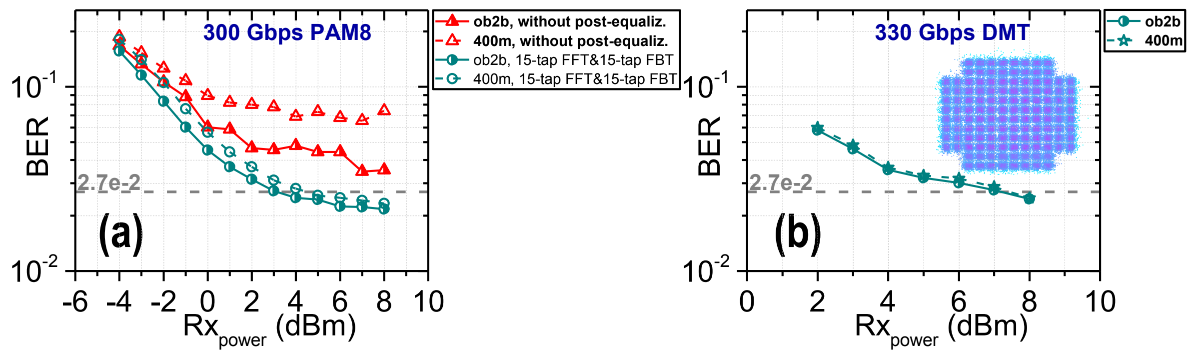

Fig. 2. BER versus received power (Rx_{power}) for PAM8 (a) and DMT (b)

Then we use offline digital signal processing (DSP) (see [5], [8] for details) for signal recovery and BER counting.

The transmission performance is shown in Fig. 2. For PAM8 we observe ~ 1 dB penalty and require ~ 4 dBm optical power at 2.7×10^{-2} pre-FEC BER limit with 15-tap feed forward & 15-tap feedback equalizer [5]. For DMT with lattice pilot-based channel equalization algorithm [8] optical back to back (ob2b) and 400 m fibre transmission reach the pre-FEC BER limit at ~ 7 dBm. The BER without any equalization is around 0.34 (not shown). One needs to consider the complexity of signal generation and processing when moving to PAM8 and DMT. Further improvements would be required in both to enable advanced intensity modulation direct detection systems but possibly at a cost of too high for short-reach optical communications.

3. Conclusions

We experimentally demonstrate 300 Gbps line rate for PAM8 and 330-Gbps line rate for 128QAM-DMT transmission with a single DAC, EML and PD for short-reach interconnections. The proposed solution may be efficient to enable next generation of Data Centre intra-connections.

4. Acknowledgements

The authors would thank Keysight Technologies GmbH for the loan of arbitrary waveform generator (AWG, Keysight M8194A) and digital storage oscilloscope (DSO, Keysight UXR1102A). We also wish to thank the Swedish Research Council (VR) within the PHASE (no. 2016-04510) and Go-iData (no. 2016-04489) projects, VINNOVA-funded Centre for Software-Defined Optical Networks project (no. 2017-01559), EU H2020 MSCA-IF Project NEWMAN (no. 752826), the SJTU State Key Laboratory of Advanced Optical Communication System and Networks Open Project 2018GZKF03001, and EU H2020 project TWILIGHT (no. 871741).

5. References

[1] Cisco Visual Networking Index: Forecast and Trends, 2017–2022.
[2] IEEE Standard, Media access control parameters, physical layers, and management parameters for 200 Gb/s and 400 Gb/s operation.
[3] K. Zhong, al., “400 Gbps PAM-4 Signal Transmission Using a Monolithic Laser Integrated Silicon Photonics Transmitter,” Proc. of OFC, San Diego, USA, 2019, paper Tu2I.4.
[4] S. Lange, et al., “100 GBd Intensity Modulation and Direct Detection with an InP-Based Monolithic DFB Laser Mach–Zehnder Modulator,” Journal of Lightwave Technology, 36(1), pp 97-102, (2018).
[5] O. Ozolins, et al., “100 Gbaud PAM4 Link without EDFA and Post-Equalization for Optical Interconnects,” in Proc. ECOC, Dublin, Ireland, 2019 paper Th.2.A.3.
[6] H. Mardoyan, et al., “222-Gbaud On-Off Keying Transmitter using Ultra-High-Speed 2:1-Selector and Plasmonic Modulator on Silicon Photonics,” in Proc. ECOC, Dublin, Ireland, 2019 paper PD2.3.
[7] S. Yamaoka, et al., “239.3-Gbit/S Net Rate Pam-4 Transmission using Directly Modulated Membrane Lasers on High-Thermal-Conductivity SiC,” in Proc. ECOC, Dublin, Ireland, 2019 paper PD2.1.
[8] L. Zhang, et al., “Lattice Pilot Aided DMT Transmission for Optical Interconnects achieving 5.82-Bits/Hz per Lane,” in Proc. ECOC, Dublin, Ireland, 2019 paper Tu.3.D.5.
[9] H. Yamazaki, et al., "Net-400-Gbps PS-PAM transmission using integrated AMUX-MZM," Opt. Express 27(18), 25544-25550 (2019).
[10] H. Yamazaki, et al., “Transmission of 400-Gbps Discrete Multi-Tone Signal Using >100-GHz-Bandwidth Analog Multiplexer and InP Mach-Zehnder Modulator,” Proc. ECOC, Rome, Italy, 2018, PDP.
[11] X. Chen, et al., "Single-Wavelength and Single-Photodiode Entropy-Loaded 554-Gb/s Transmission over 22-km SMF’. Proc. of OFC, San Diego, USA, 2019, paper Th4B.5.
[12] M. Nagatani, et al., “A 256-Gbps PAM-4 Signal Generator IC in 0.25μm InP DHBT Technology,” Proc. of IEEE BCICTS, San Diego, USA, October 2018, pp 28-31.
[13] U. Koch, et al., “Monolithic High-Speed Transmitter enabled by BiCMOS-Plasmonic Platform,” in Proc. ECOC, Dublin, Ireland, 2019 paper PD1.4.
[14] D. Che, et al., “Single-Channel Direct Detection Reception beyond 1 Tb/s,” in Proc. OFC, San Diego, USA, 2019, PDP, Th4B.7.
[15] D. Chang, et al., “LDPC convolutional codes using layered decoding algorithm for high speed coherent optical transmission,” Proc. of OFC, Los Angeles, USA, 2019 paper OW1H.4.
[16] M. Chacinski, et al., “ETDM Transmitter Module for 100-Gb/s Ethernet,” IEEE Photonics Technology Letters, 22(2), 70-72 (2010)