“Advancements in High Symbol Rate Optical Amplification-free IM/DD Systems”

Prof. Oskars OZOLIŅŠ, Dr.sc.ing., Docent (habilitation), LAS Academician

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MOPA seminar at OFC
March 25th, 2024

Outline

- About myself
- Motivation and introduction
- InP-based externally modulated laser
- Conclusions

Education and student supervision

- 17/06/2021 — **Docent (habilitation)** in physics with specialization in optical communications. VL-2020-0111. Department of Applied Physics. KTH Royal Institute of Technology. Completed pedagogical courses at KTH (15.0 ECTS).
- 2015 – 2017 — Postdoc at Swedish ICT Research AB (now RISE) and KTH Royal Institute of Technology under **Prof. Gunnar Jacobsen** and **Prof. Sergei Popov** supervision
- 2009 – 2013 — Ph.D. on optical communications at Riga Technical University, Latvia under **Prof. Ģirts Ivanovs** supervision. 3 months at Technical University of Denmark, Denmark **Prof. Christophe Peucheret** supervision.
- 2007 – 2009 — Master degree on Telecommunications with distinction at Riga Technical University under **Prof. Ģirts Ivanovs** supervision, Latvia.
- 2004 – 2007 — Bachelor degree at Riga Technical University under **Prof. Andris Ozols** supervision. Scholarship from Vītolu fonds supported by **Academician Pēteris Bolšaitis**.
- 2001 – 2004 — Gymnasium of Krāslava, Latvia.
- 1992 – 2001 — Krišjāņu elementary school, Latvia.

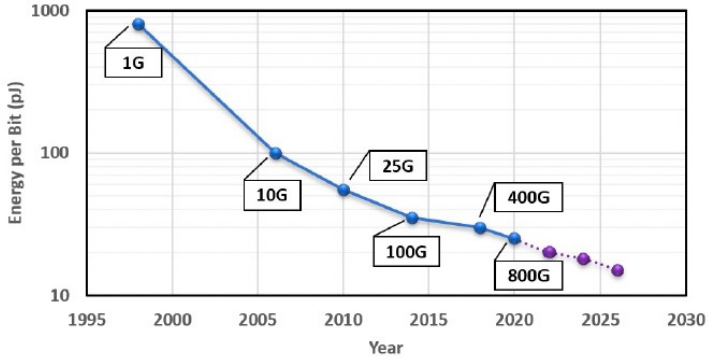
36 bachelor students, 24 master students,
9 (4 graduated) Ph.D. students,
and 3 postdocs

External stays

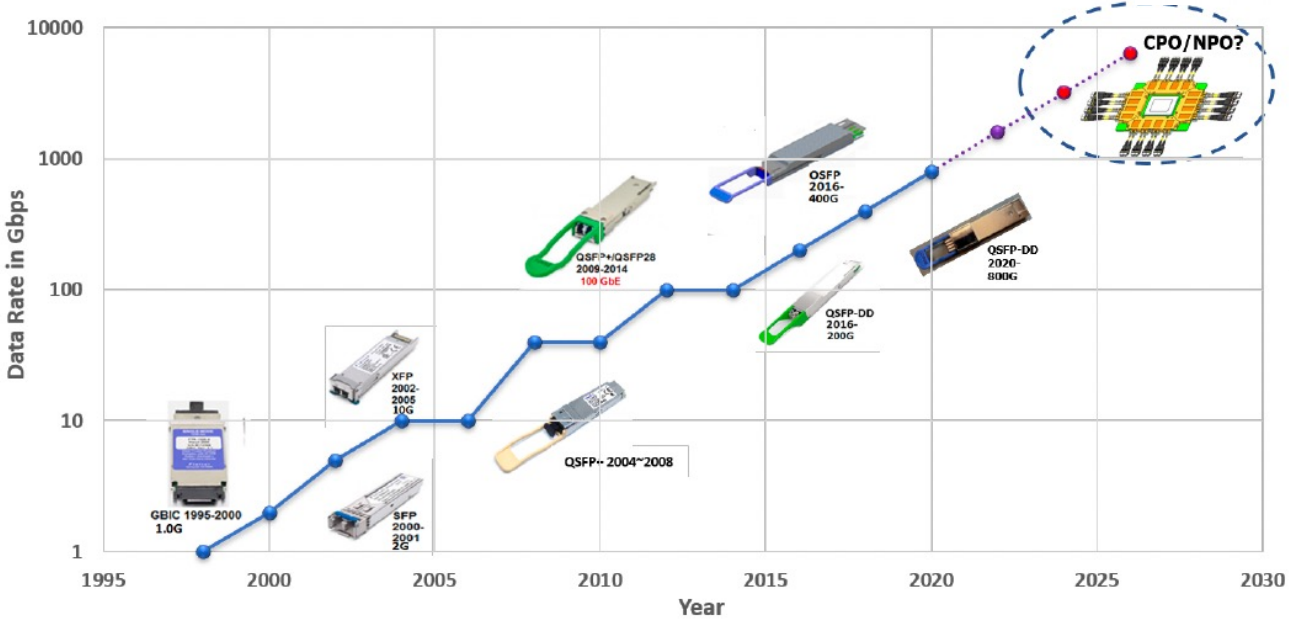
- 2024.01.16-2024.01.19 (4 days) **Keysight Tecnologies**, Germany
- 2022.09.25-2022.10.01 (7 days) **Keysight Tecnologies**, Germany
- 2021.10.24-2021.10.30 (7 days) **Keysight Tecnologies**, Germany
- 2018.12.09-2018.12.13 (5 days) **Keysight Tecnologies**, Germany
- 2018.06.11-2018.06.25 (15 days) **FOTON Institut**, **ENSSAT**, France
- 2018.06.04-2018.06.08 (5 days) **DTU Fotonik**, Denmark
- 2018.01.29-2018.02.08 (11 days) **III-V Lab**, **Nokia Bell Labs,** France
- 2017.08.21-2017.08.30 (10 days) **Ghent University - imec – iMinds**, Belgium
- 2016.08.22-2016.08.28 (7 days) and 2016.06.14-2016.06.24 (10 days) **Ghent University - imec – iMinds**, Belgium
- 2016.05.01-2016.06.13 and 2016.09.05-2016.09.16 (44 days) **DTU Fotonik**, Denmark
- 2015.05.01-2015.05.30 (30 days) **KTH Royal Institute of Technology**, Sweden
- 2014.06.30-2014.07.31 (31 days) **FOTON Institut**, **ENSSAT**, France
- 2012.01.15-2012.04.15 (90 days) **DTU Fotonik**, Denmark

In total 276 days

Motivation



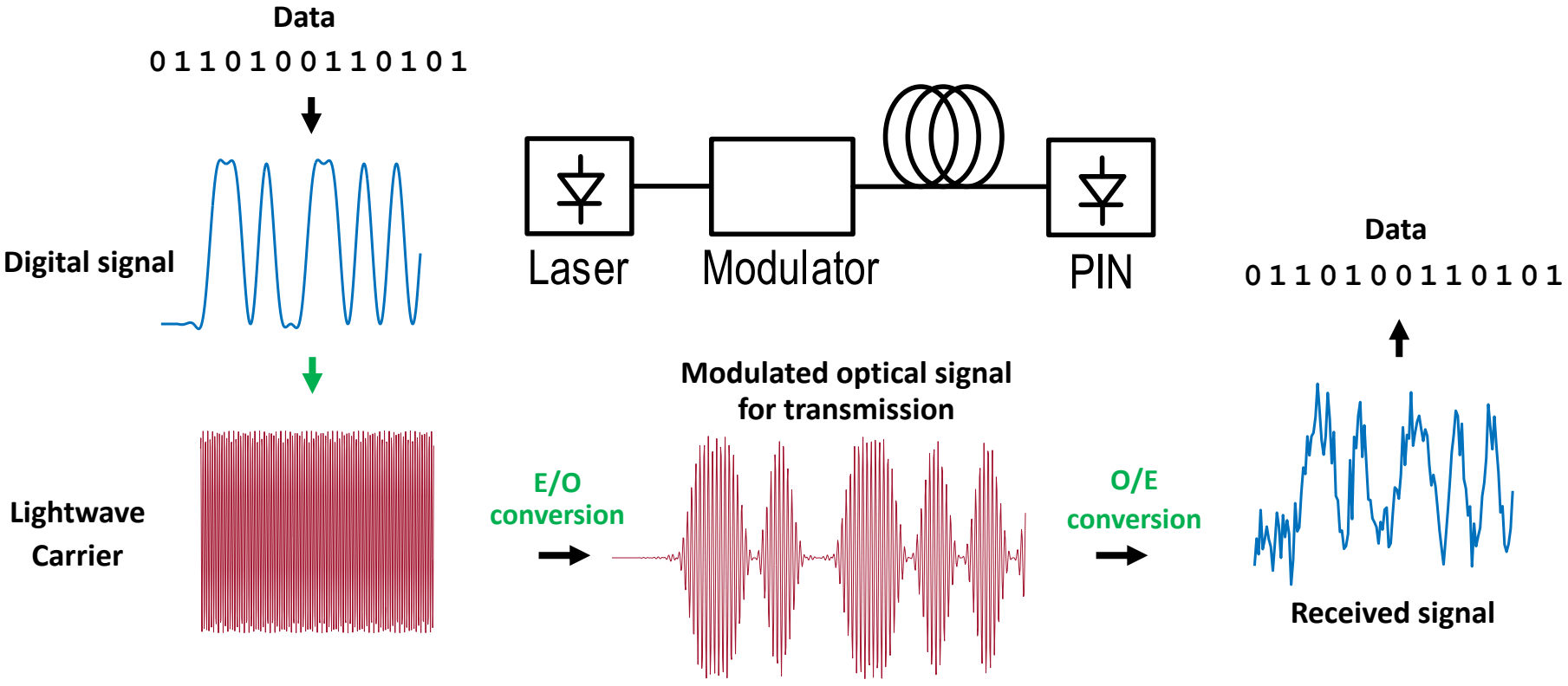
From 1G to 800G in about 25 years
From 800 pJ in 1G to 25 pJ for 800G



Co-packaged optics (CPO)
Near packaged optics (NPO)

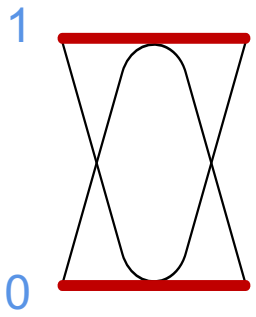
Po Dong, et al., OFC2022, p. M4H.1.

Intensity modulation direct detection (IM/DD) system

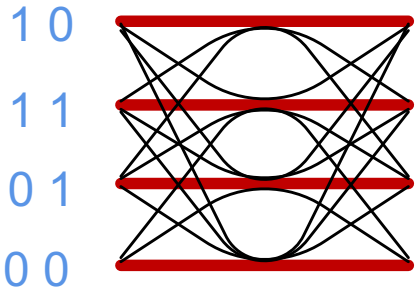


Modulation formats

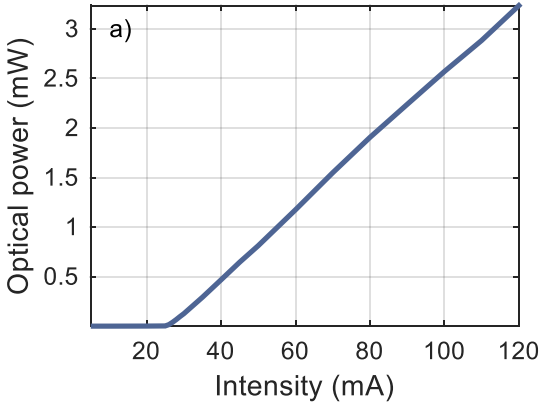
On-off keying (OOK)

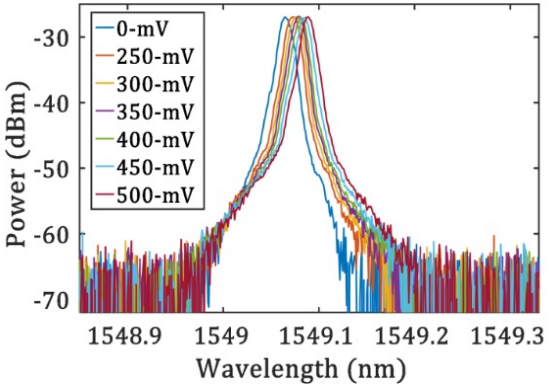


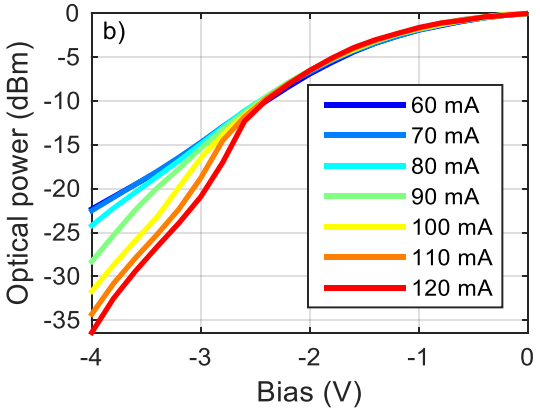
4 level pulse amplitude modulation (PAM4)

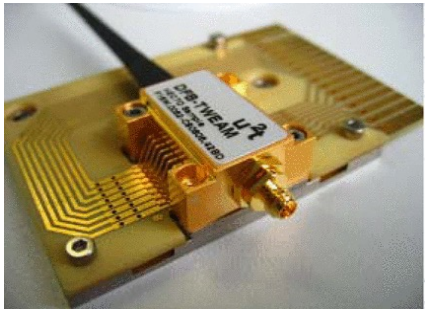


Externally Modulated Laser (EML)





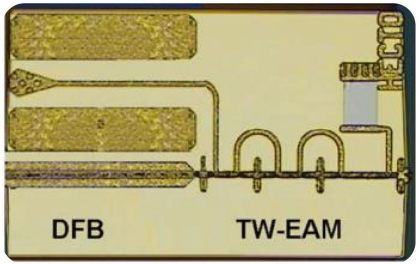




Monolithically integrated distributed feedback laser with travelling wave electoabsorption modulator (DFB-TWEAM)

with 1mm connector

Designed by **KTH** and manufactured by **KTH** and **Syntune**, packaged by **U²T**



M. Chaciński, et al., IEEE/OSA J. Lightwave Technol. 27(16), 3410-3415 (2009).
O. Ozoliņš, et al., IEEE/OSA J. Lightwave Technol., invited paper, 35(6), 1174-1179, (2017).

Digital Signal Processing (DSP) at TX and RX

Random Bit Generation
(Mersenne Twister gen.)

PAM Symbol Generation
(level correction)

Digital Upsampling
(4 samples per symbol)

Pulse Shaping
(Root Raised Cosine)

Resampling
(to match 256 Gsa/s)

- We train **the equalizer** with training sequences to converge into the **global minimum.**
- Then we apply it to cross validation sequences.

Matched Filter
(Root Raised Cosine)

Digital Upsampling
(16 samples per symbol)

Clock Recovery
(Maximum Variance)

Decision Feedback Equalizer

BER counting
(compare to TX data)

We use own developed DSP routines in MATLAB

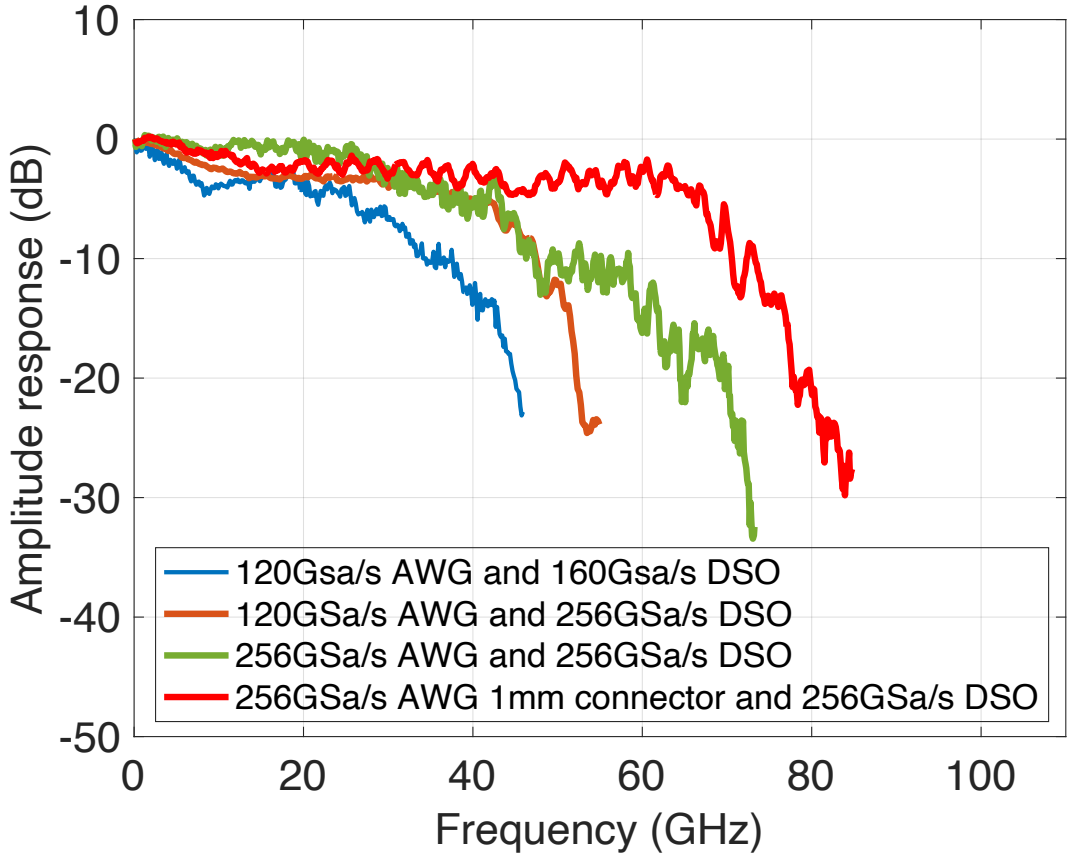
EML with different Keysight AWGs and DSOs

CLEO 2018
With EDFA,
Amps Tx = 11 dB, Rx = 11 dB

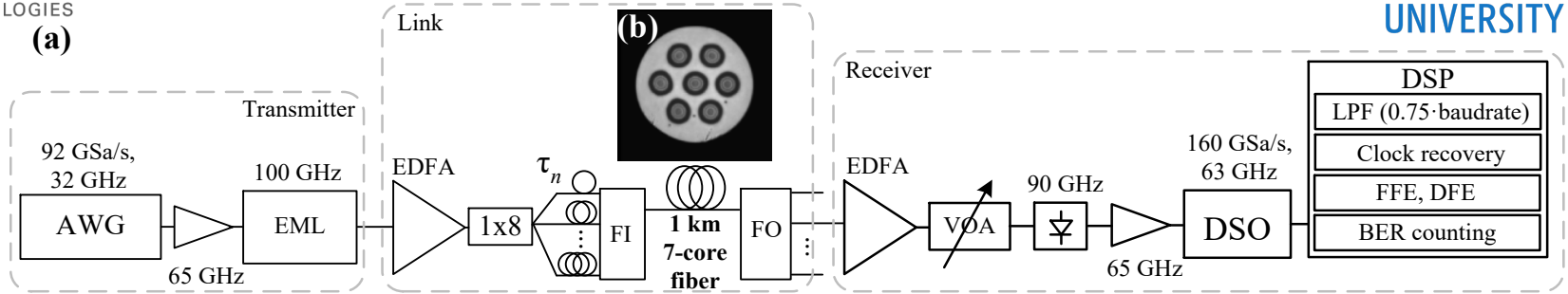
ECOC 2019
With and without EDFA,
Amps Tx = 11 dB, Rx = 11 dB

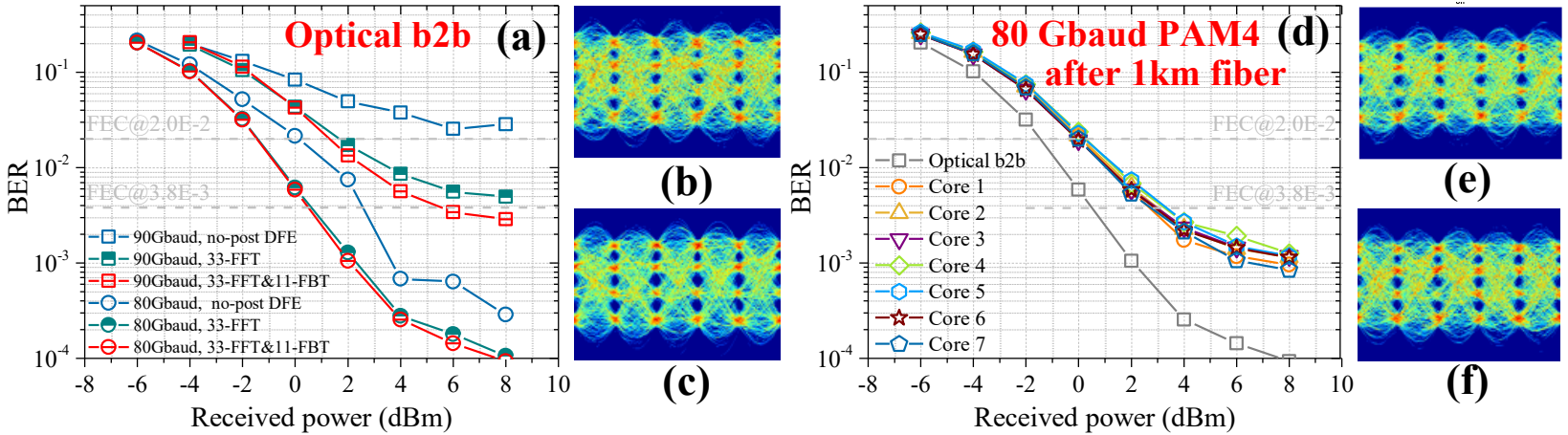
OFC pdp 2022
Without EDFA,
Amps Tx = 22 dB, Rx = 22 dB

OFC pdp 2023
Without EDFA,
Amps Tx = built in, Rx = 11 dB



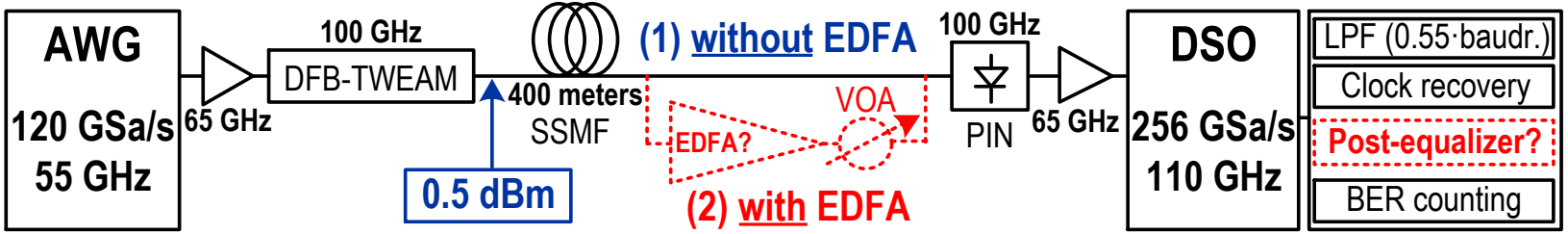
CLEO 2018

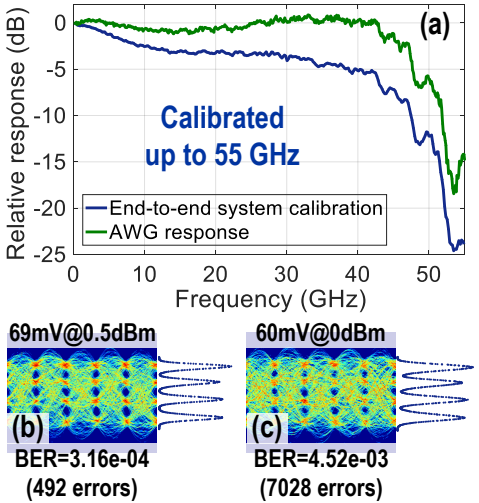


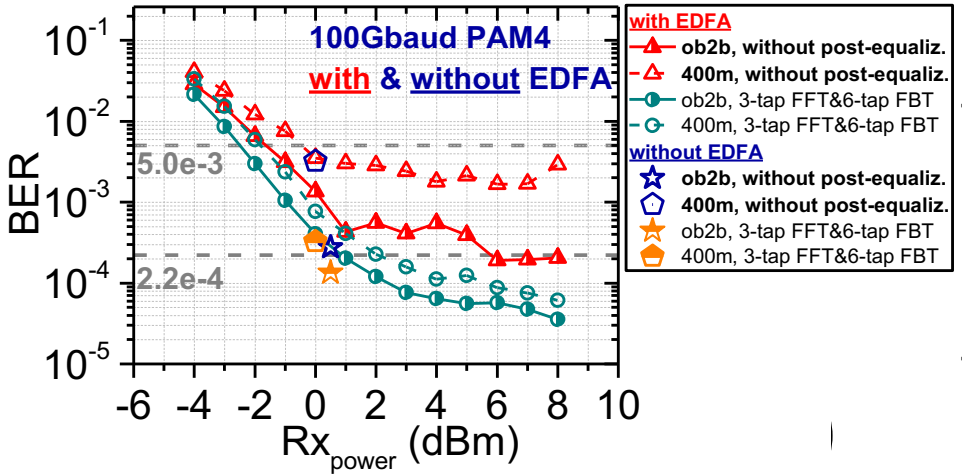


O. Ozoliņš et al., CLEO 2018, paper SM4C.4.

ECOC 2019

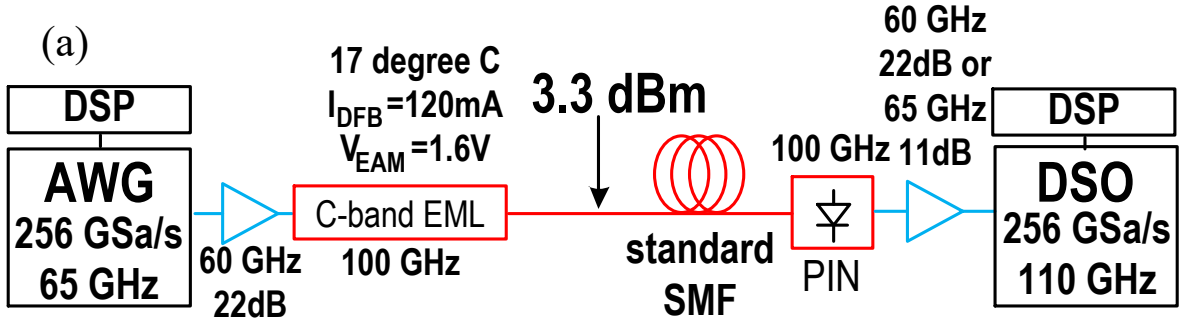


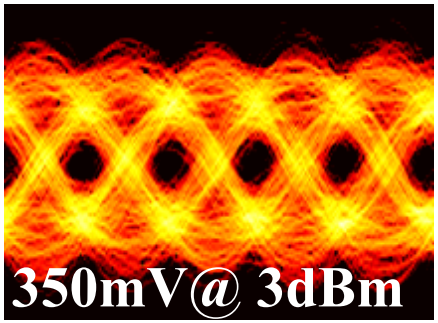


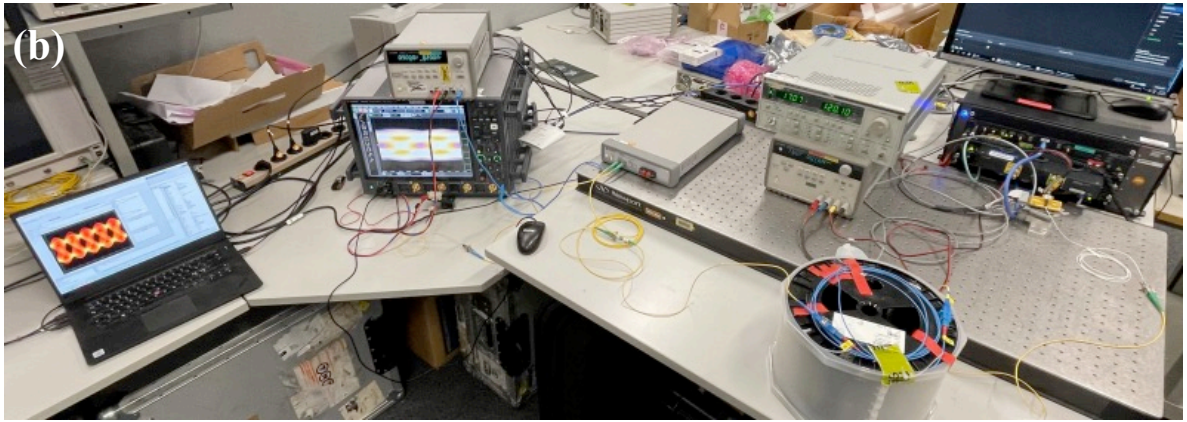


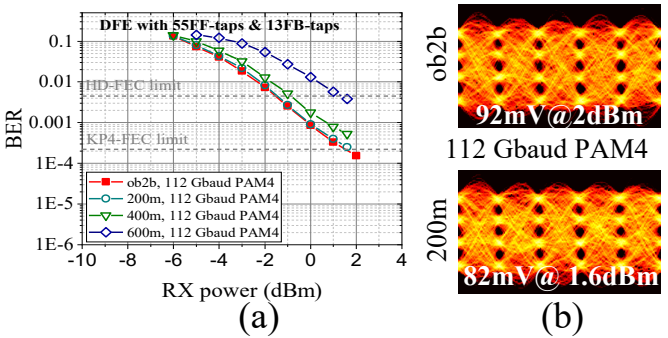
O. Ozoliņš et al., ECOC 2019, pp. 1-4

OFC 2022 pdp



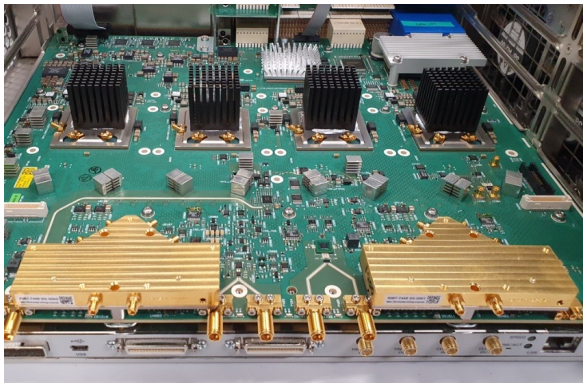






O. Ozoliņš et al., OFC 2022, pdp paper Th4A.6.

Improved AWG



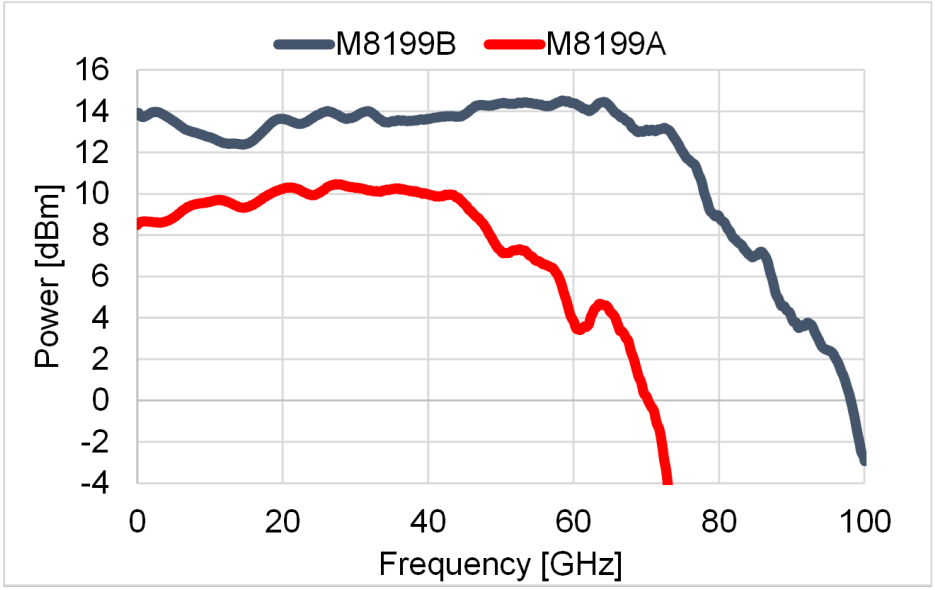
Sample rate range: **200 – 256 GSa/s**

Bandwidth (-3 dB, incl. sinc roll-off): **>75 GHz**

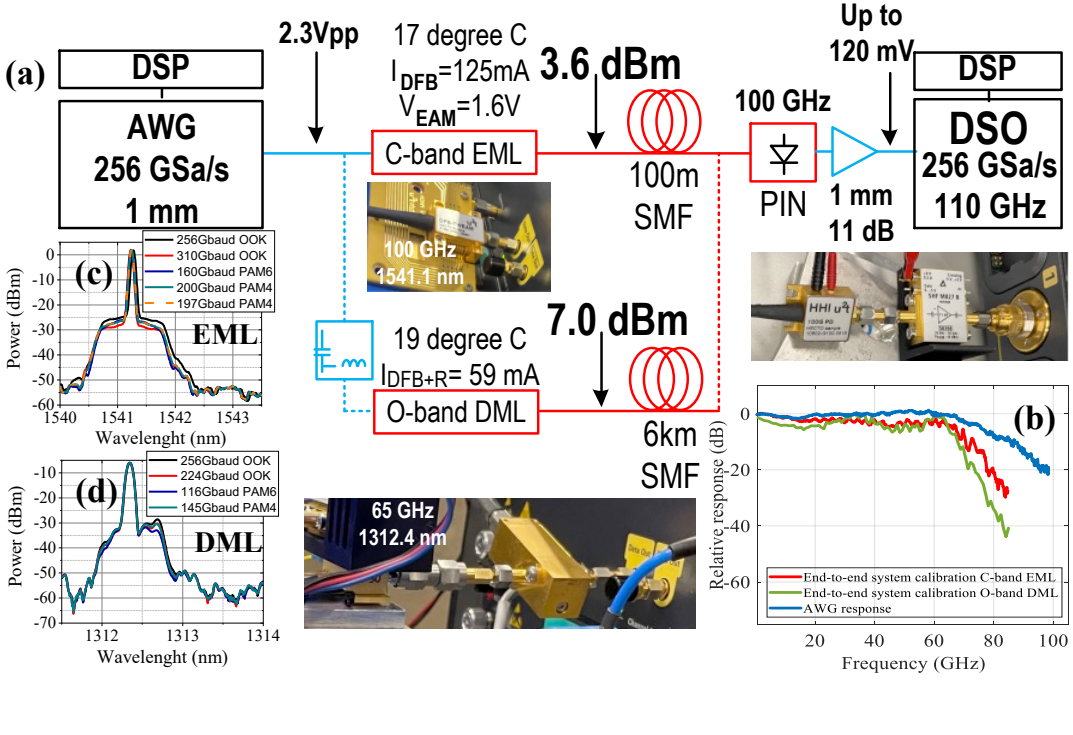
Differential output amplitude: **5 Vpp**

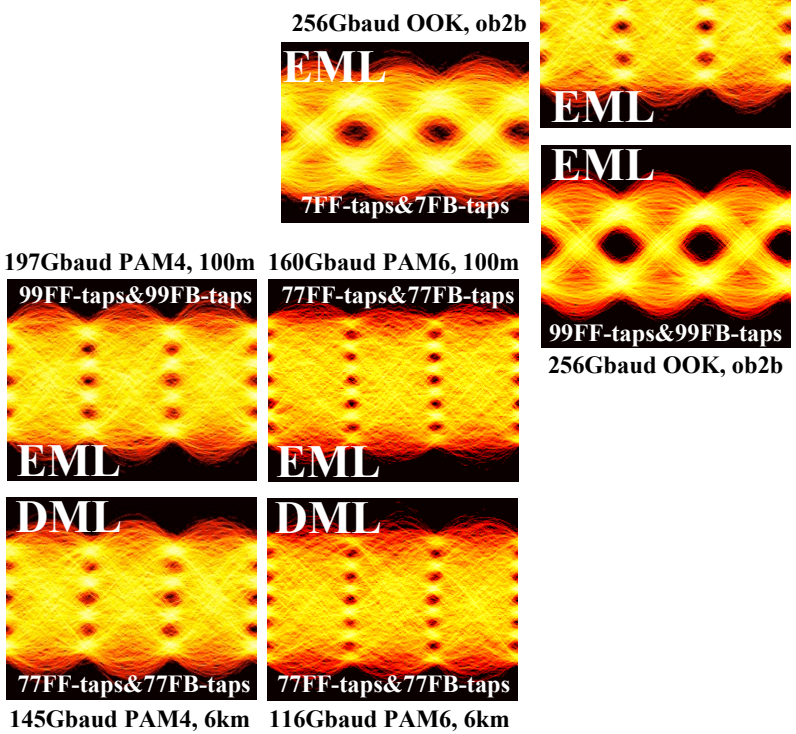
RF Characteristics

Bandwidth (including sin(x)/x roll-off, measured single-ended output, smoothed graph)	
3 dB	75 GHz (typ)
6 dB	80 GHz (typ)
10 dB	90 GHz (typ)
Rise/fall time (20/80)	3 ps (meas)
Achievable output amplitudes with digital correction enabled	
128 GBd	3.0 Vpp, diff (meas)
144 GBd	2.5 Vpp, diff (meas)
160 GBd	2.0 Vpp, diff (meas)



OFC 2023 pdp





O. Ozoliņš et al., OFC 2023, pdp paper Th4B.2.

EML with different Keysight AWGs and DSOs

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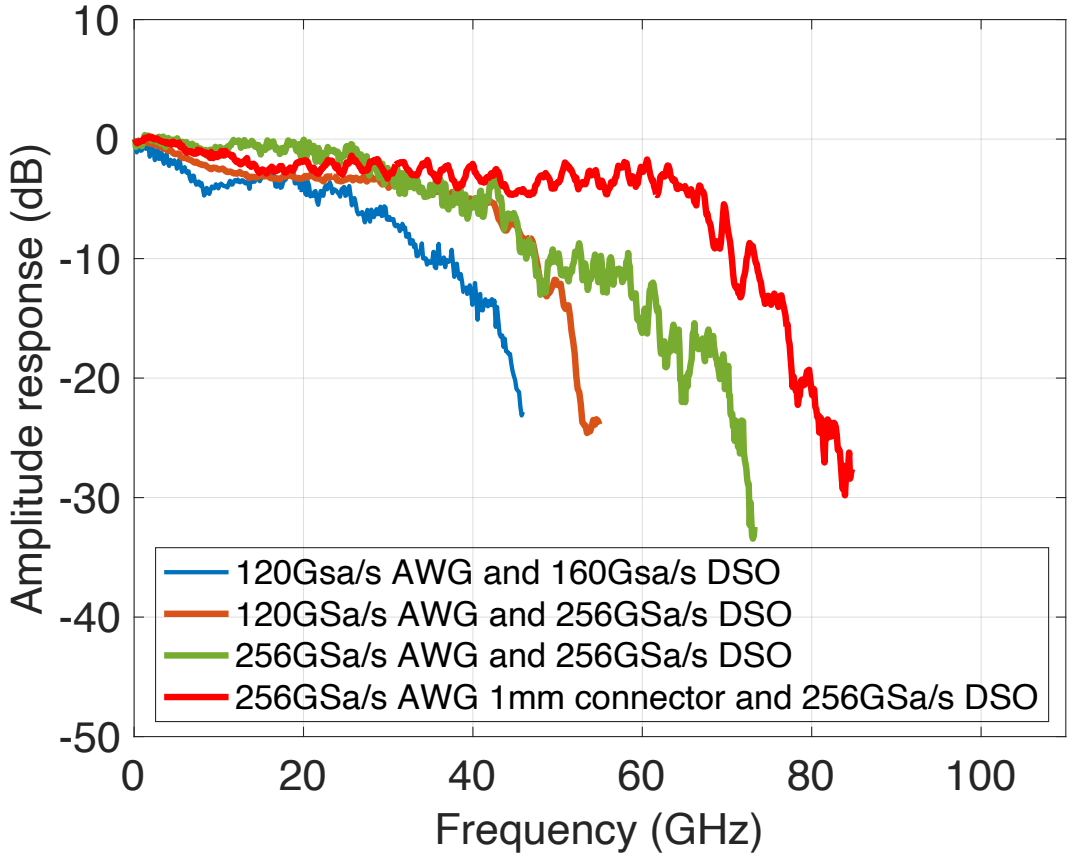
With EDFA,
Amps Tx = 11 dB, Rx = 11 dB

ECOC 2019
With and without EDFA,
Amps Tx = 11 dB, Rx = 11 dB

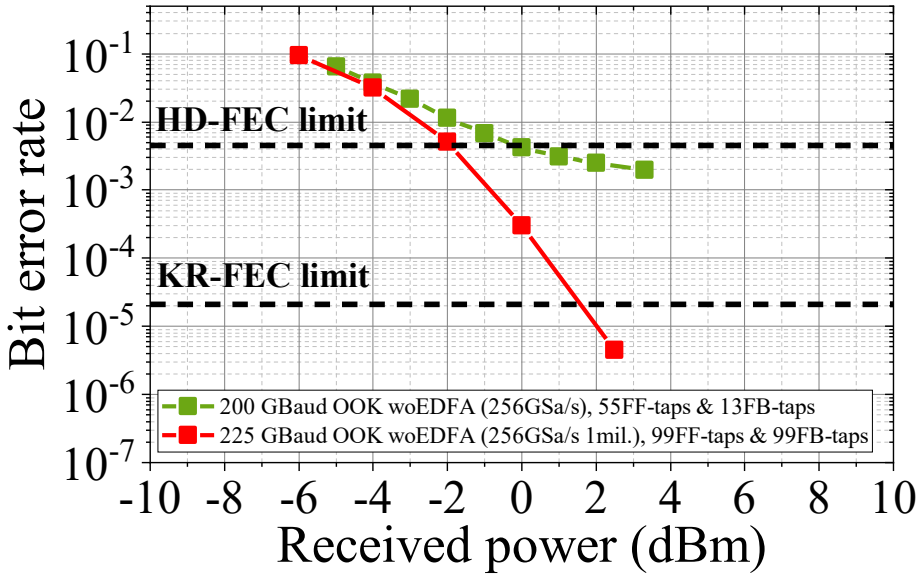
OFC pdp 2022
Without EDFA,
Amps Tx = 22 dB, Rx = 22 dB

OFC pdp 2023
Without EDFA,
Amps Tx = built in, Rx = 11 dB

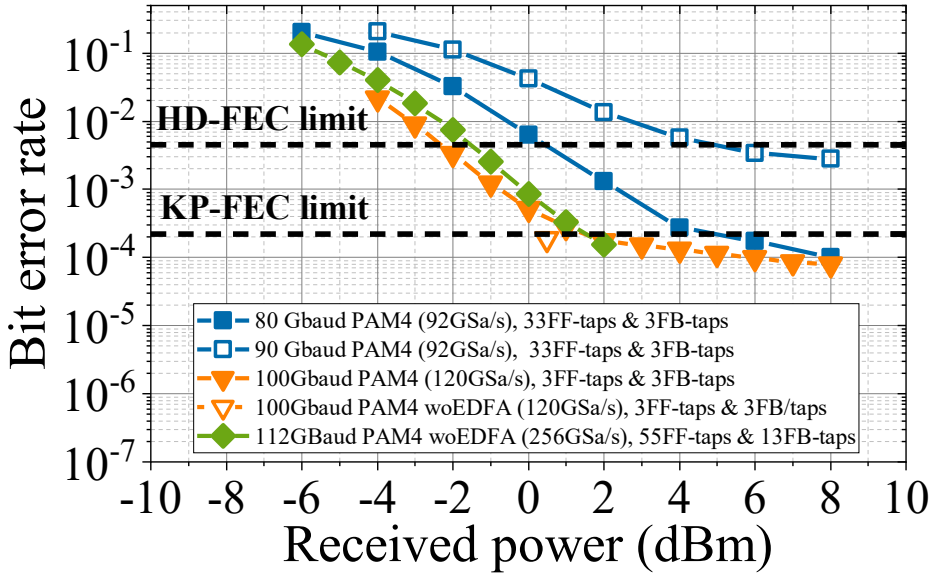


Performance over the years toward 200 Gbps

On-off keying (OOK)



4 level pulse amplitude modulation (PAM4)



Conclusions

- We demonstrate optical amplification-free EML-based optical links.
- This paves the way for low lane count solutions towards 1.6 Tbps.

We thank Ghen University for hostin first experiment. We also thank **Keysight Technologies** in Böblingen, Germany for hosting last three experiments and for loaning the **Arbitrary Waveform Generator prototypes** and the **Infiniium UXR-Series Oscilloscopes**

Thank you!

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