

Advanced solutions for inter- and intra-data center connectivity

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Advanced Communications Technology Symposium

Date & Time : 28th April, 2016, 13:00-17:00

Venue : Osaka University, Nakanoshima Center 7th floor, 702 class room

Program :

12:30 Registration desk open

13:00 Welcome Remarks

13:15 (1) Recent Trends of North American optical network

Hiroshi Onaka (Fujitsu)

13:25 (2) Optical fibers for long-haul and large-capacity optical communication systems

Yoshinori Yamamoto (Sumitomo Electric)

13:45 (3) Optical performance monitoring for dynamic and flexible photonic networks

Shoichiro Oda (Fujitsu Laboratories)

14:05 (4) A practical application of fixed microwave transceiver

using radio over fiber (RoF) technology

Kensuke Ikeda (Central Research Institute of Electric Power Industry)

14:25 (5) Underdetermined linear systems and problems in communications

Kazunori Hayashi (Kyoto University)

14:45 Break

15:15 (6) On-Demand Wireless Networks exploiting Wake-up Receiver

Hiroyuki Yomo (Kansai University)

15:35 (7) Coherent convergence of optical and wireless systems

Toshihiko Hirooka (Tohoku University)

15:55 (8) Nyquist OTDM scheme using correlation detection

and receiver bandwidth limitations.

Yuji Miyoshi, Hirokazu Kubota, Masaharu Ohashi (Osaka Prefecture University)

16:15 (9) Optical transceivers for next generation optical access systems

Satoshi Yoshima (Mitsubishi Electric)

16:35 (10) Advanced solutions for inter- and intra-data center connectivity

Juan Jose Vegas Olmos (Technical University of Denmark)

16:55 Closing Remarks

17:00 End of the symposium

18:00-21:00 Party@Diamond Room in Rihga Royal Hotel

Advanced solutions for inter- and intra-data center connectivity

J.J. Vegas Olmos, PD2008

DTU Fotonik, Technical University of Denmark (DTU), 2800 Kgs. Lyngby, Denmark,

Before we start



**Thank you Prof. Kitayama for your
leadership within the field**

Good luck in your new endeavor

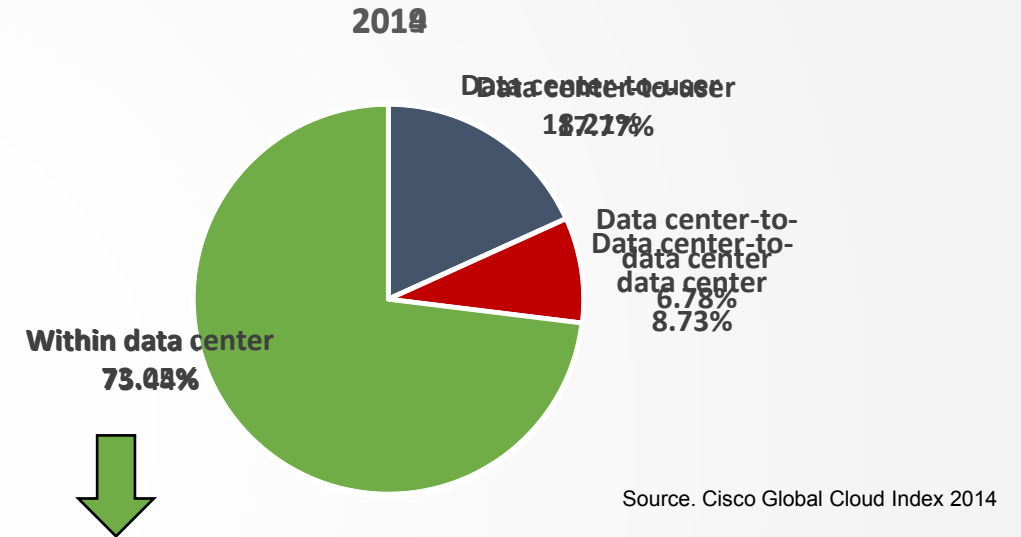
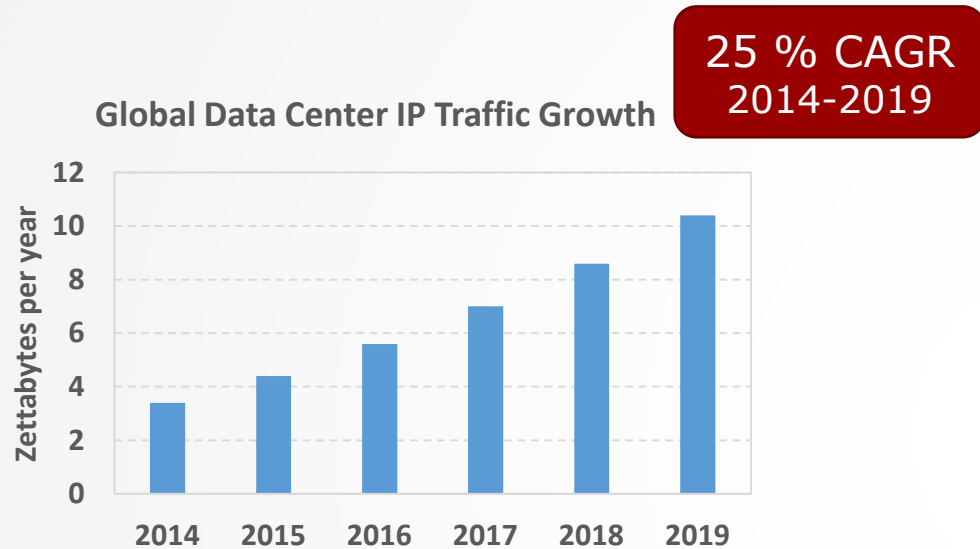
Motivation



By 2016, 90% of the global internet/
IP WAN traffic passes through data centers.
Cisco Global Cloud Index

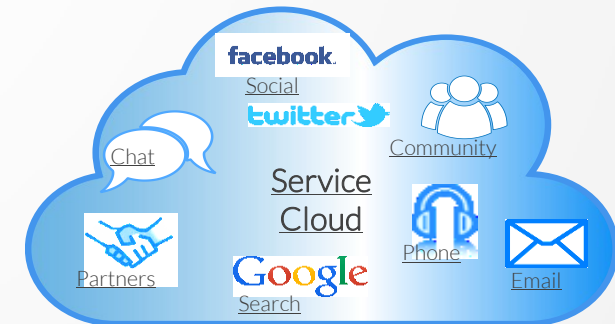
Motivation

DWDM Inter-Connection and Intra-Connections



PAM-4 currently being standardized by IEEE P802.3bs 400GbE task force

- » **Inter data center**
 - » Not standardized
 - » Requirements are very different from short reach
- » **Intra data center**
 - » Standardized
 - » Constant increase opens up for non-standardized solutions (proprietary)



Remember: we will need even more than now! 4

Outline of the talk

» **Inter data center (SMF)**

- » PAM-4

- » DMT

» **Intra data center (SMF and MMF)**

- » DMT

- » PAM-4

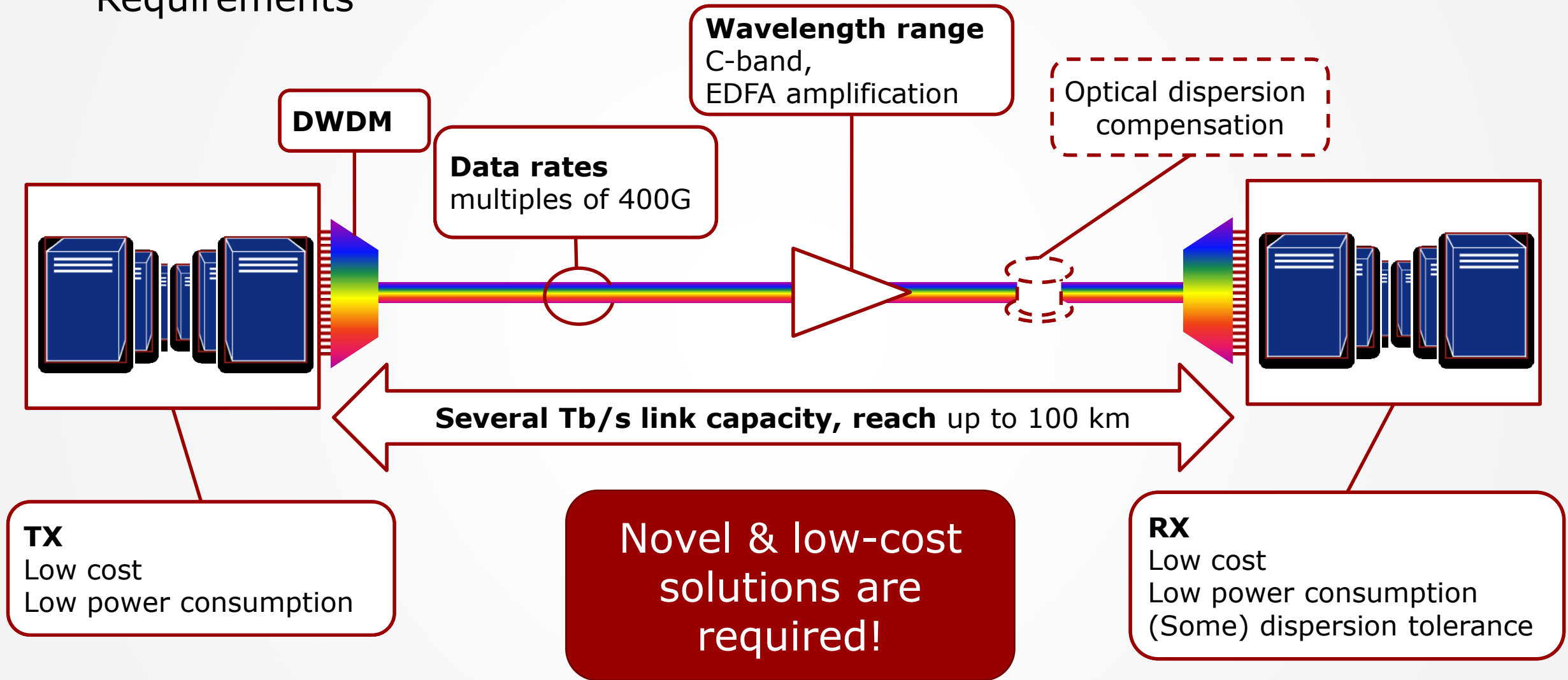
- » Polybinary

- » Multi-CAP

Inter-DC

Data center-to-data center

Requirements



DWDM Inter-Connections

Why direct detection?

Cost & Power Consumption

Spectral Efficiency

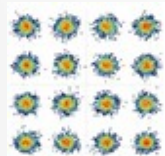
Long Haul

Scale up or scale down?

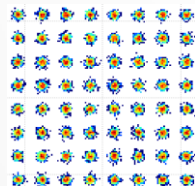
Short Reach

- » 400G coherent
- » 2 x 200G DWDM/ single λ 400G

16QAM

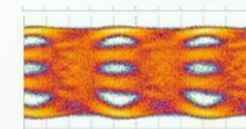


64QAM



- » 400G direct detect
- » 8x50G DWDM/ 4x100G WDM

PAM-4



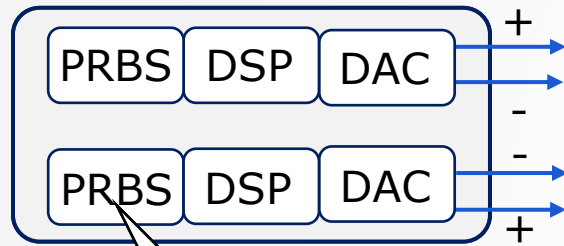
Similarities to IEEE P802.3bs 400GbE task force: 2km/10km over SSMF

PAM-4 for Inter-DC

400G DWDM

TX

2 x 25.78125 GBaud PAM-4



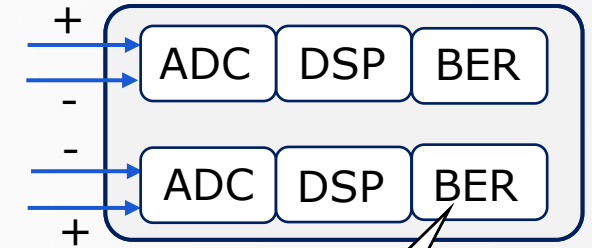
PRBS 31

PAM-4 Eval Board
Real-time Generation &
Detection
100G



RX

2 x 25.78125 GBaud PAM-4



PRBS 31

Experimental Setup

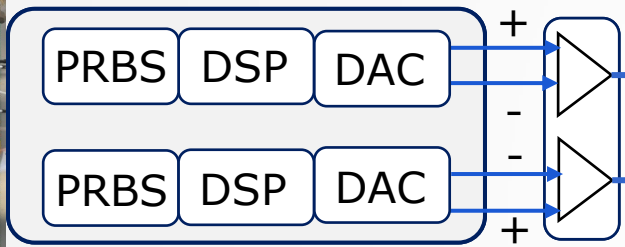
400G DWDM

Odd channels

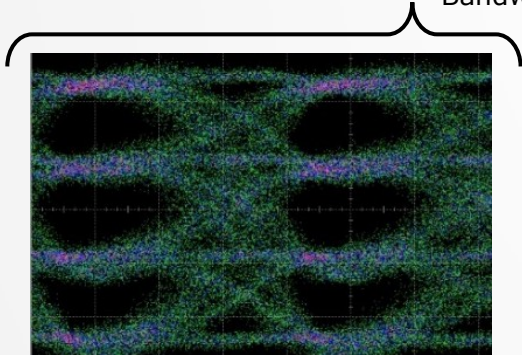


TX

2 x 25.78125 GBaud PAM-4



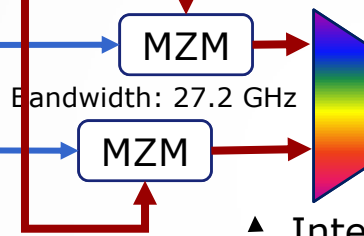
El. Driver,
Bandwidth: 30 GHz



w/CPPEEQ



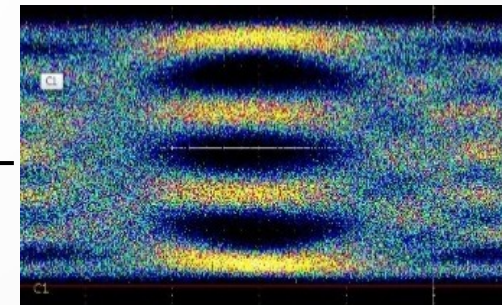
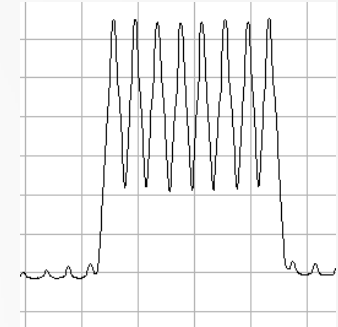
Even channels



Bandwidth: 27.2 GHz

Interleaver,
Bandwidth: 40 GHz

DWDM 400G spectrum

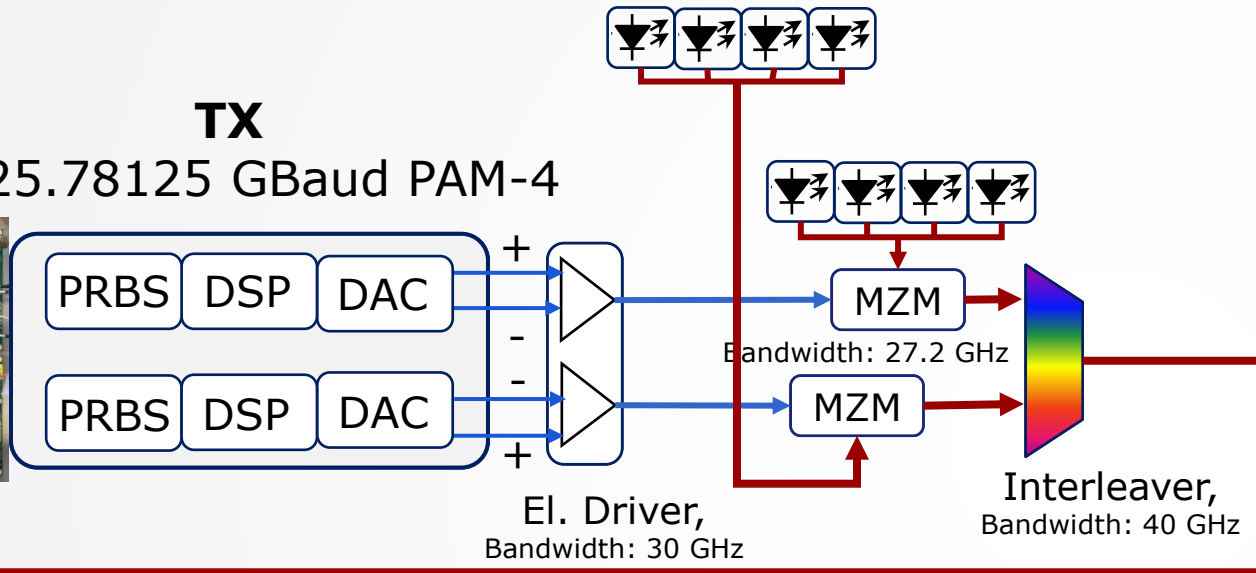


Experimental Setup

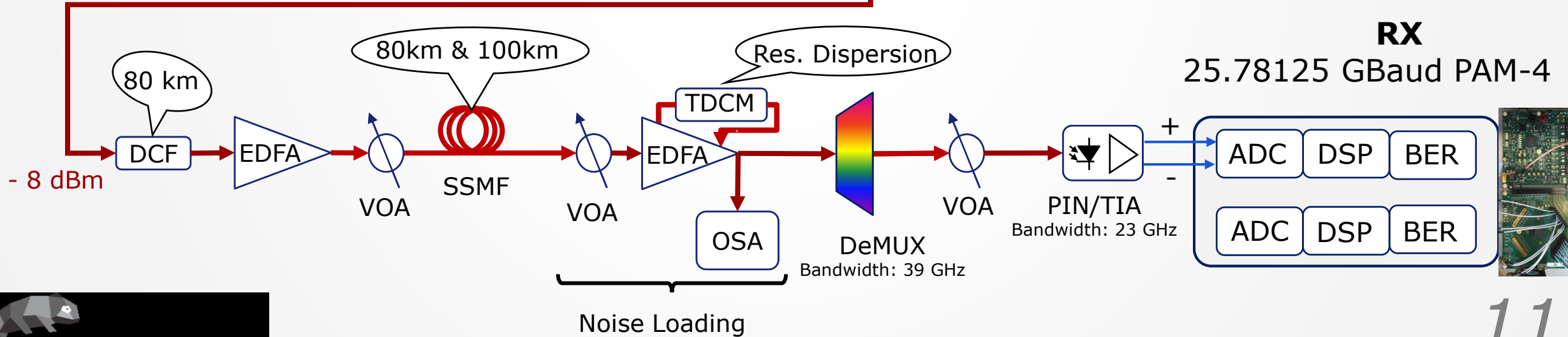
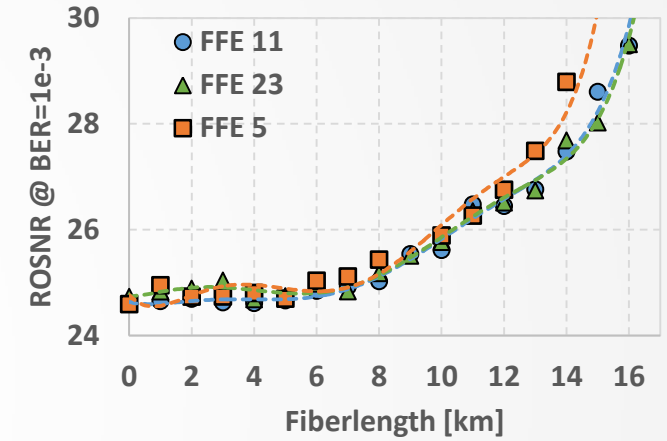
400G DWDM

TX

2 x 25.78125 GBaud PAM-4



CD-Tolerance of PAM-4 @ 25.78 GBd (Simulation)



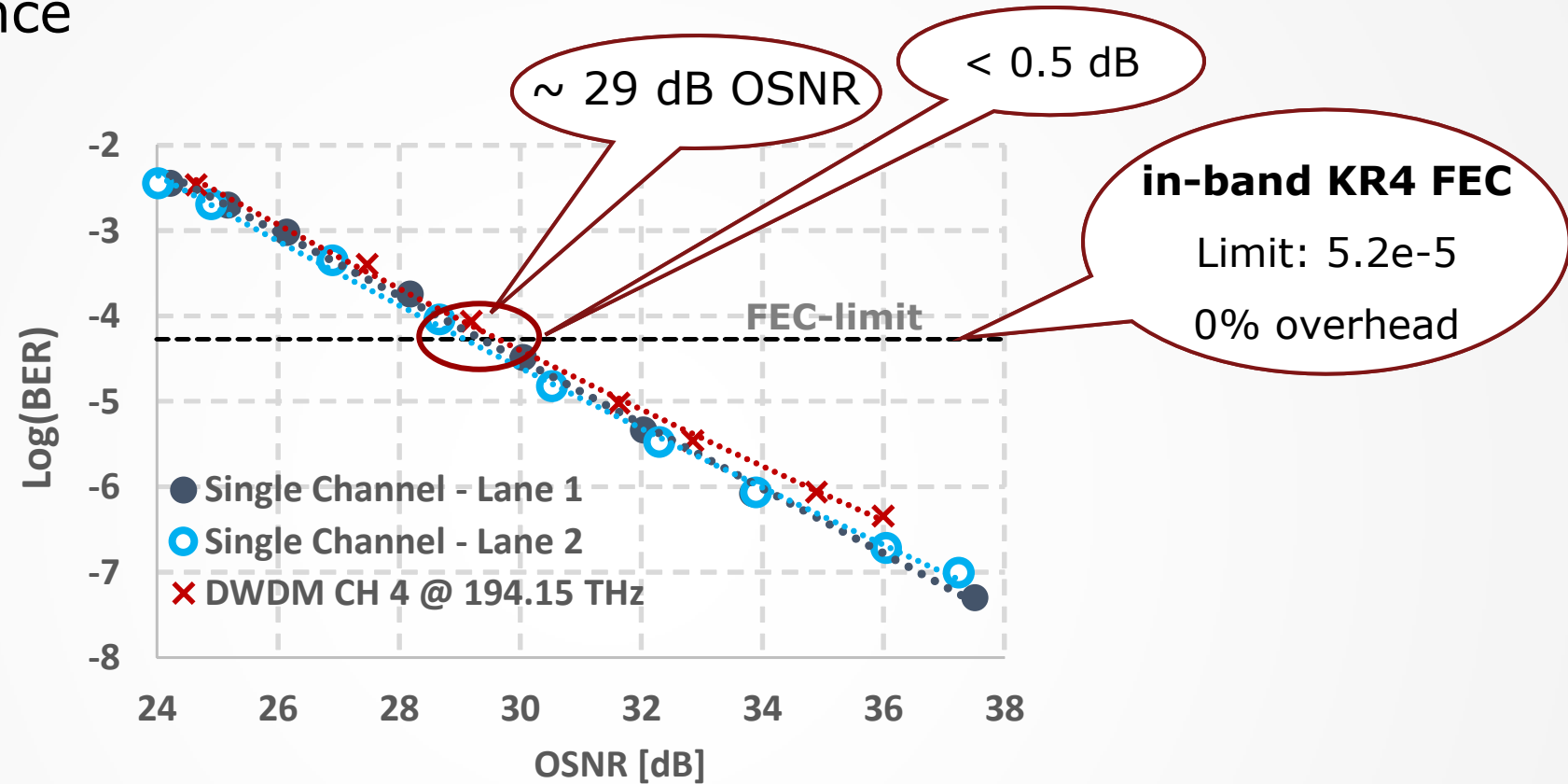
RX

25.78125 GBaud PAM-4



Experimental Results

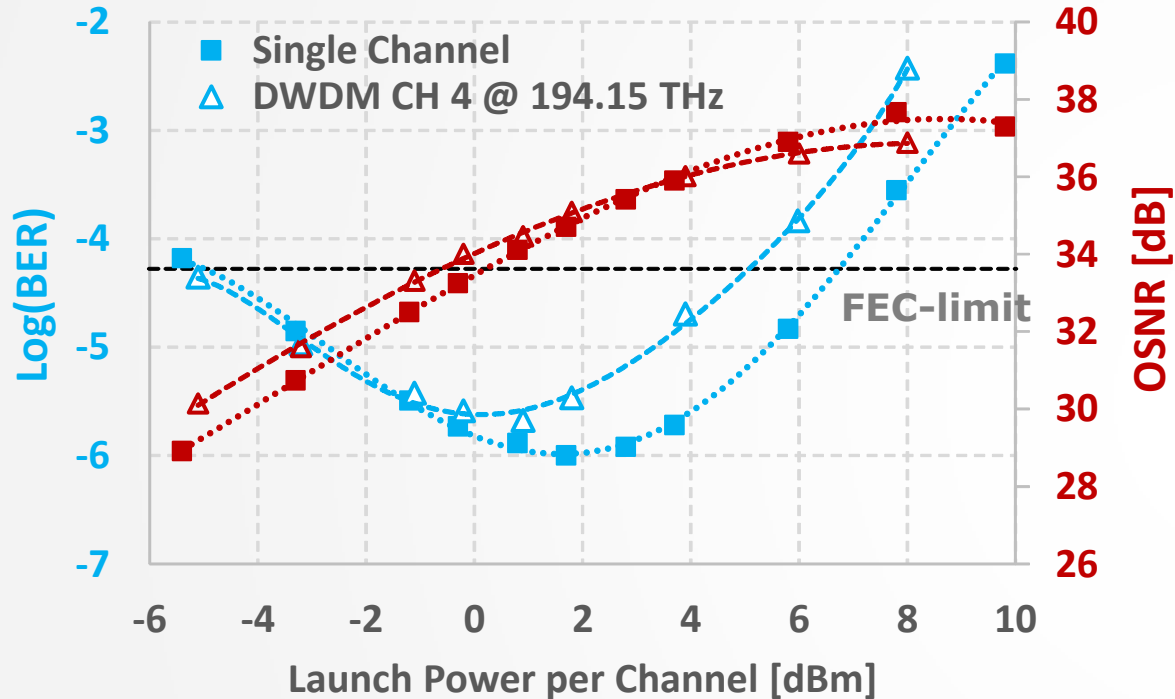
B2B Performance



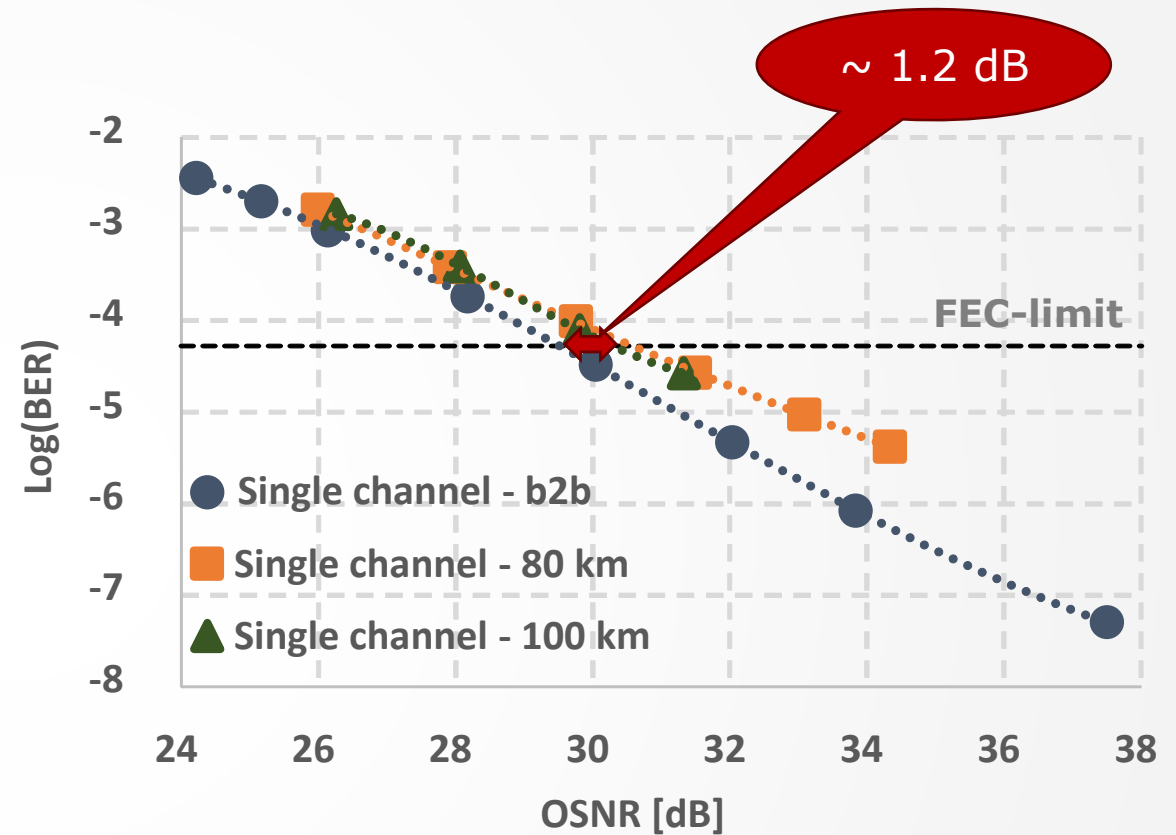
- » Similar performance of both channels from the eval board
- » No significant influence of linear crosstalk

Experimental Results

Launch Power – 80 km



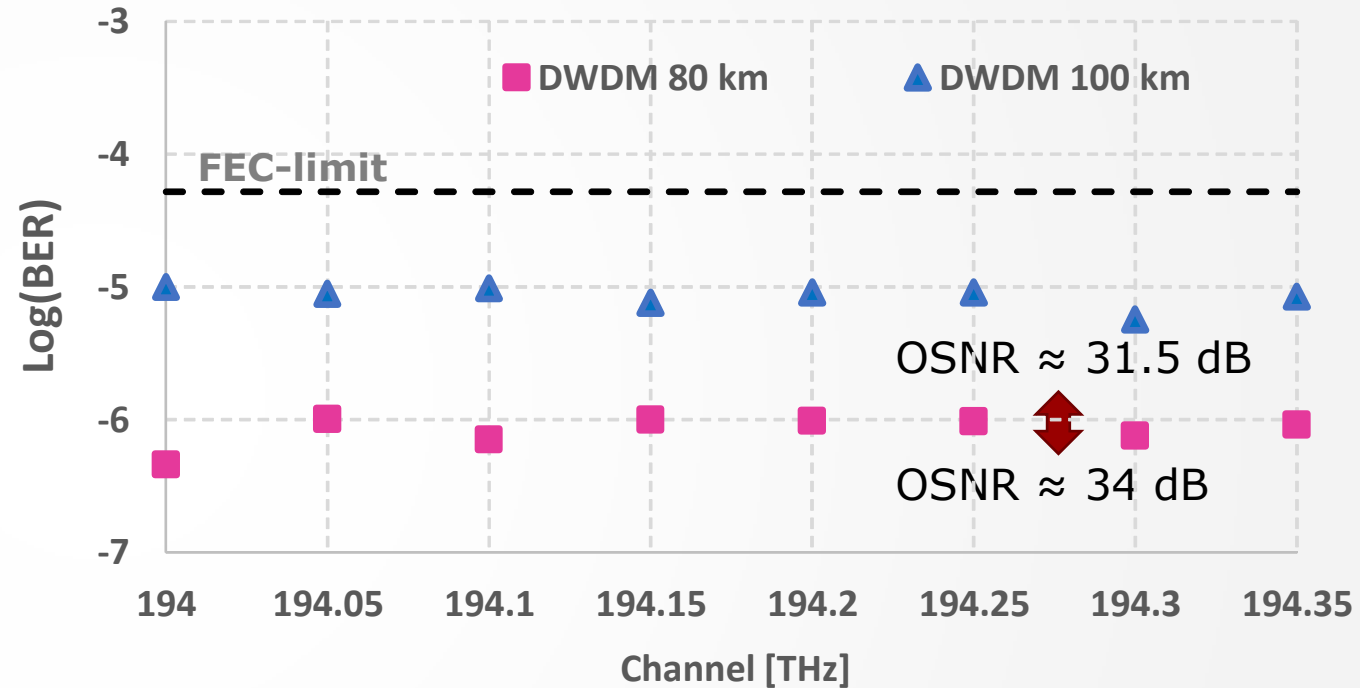
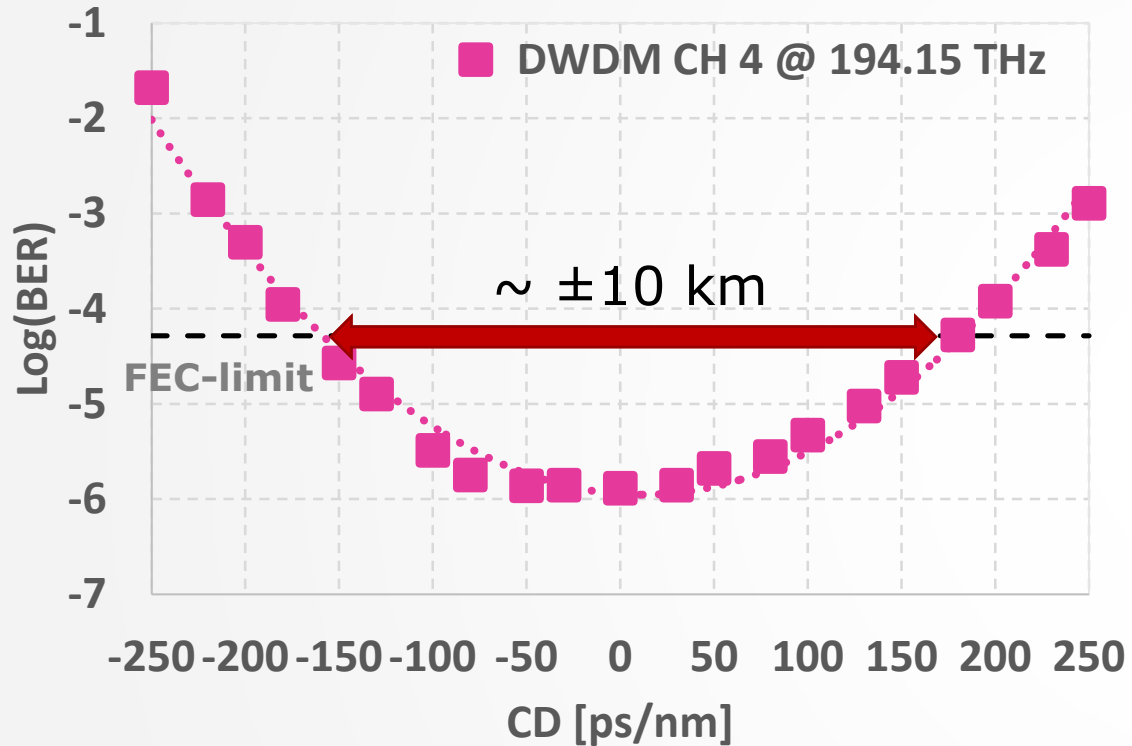
- » Optimum launch power:
 - » Single channel: ~ 2 dBm
 - » DWDM transmission: ~ 1 dBm



- » ~ 1.2 dB OSNR-penalty between b2b and 80 km at FEC-limit
- » No penalty between 80 km and 100 km at the FEC-limit

Experimental Results

PAM-4 over DWDM – Residual Dispersion and multichannel performance

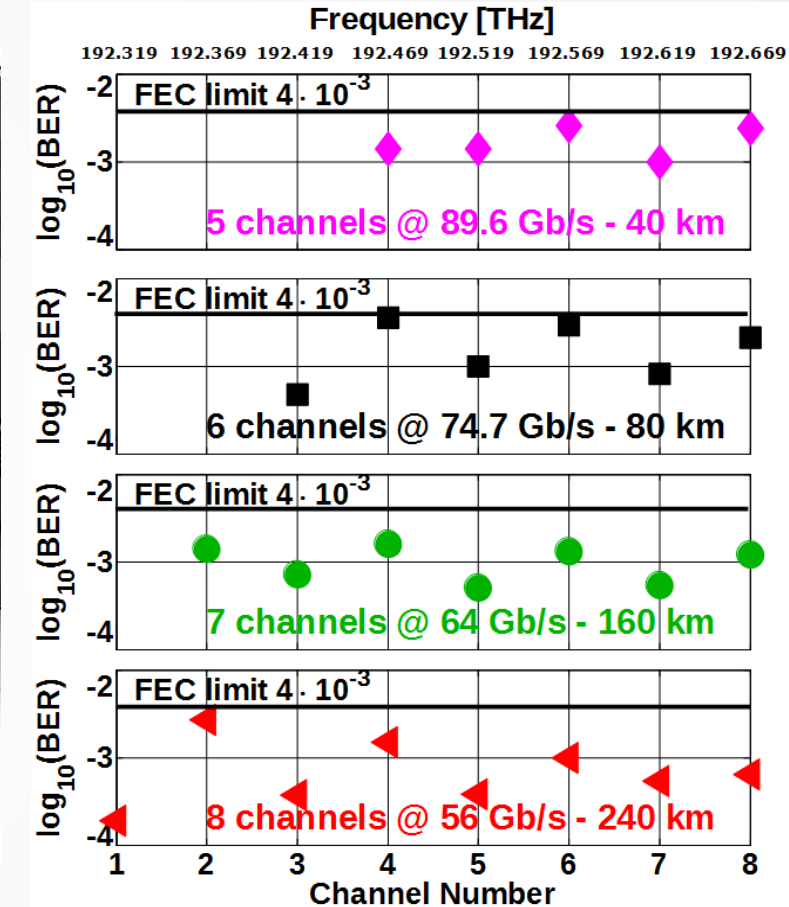
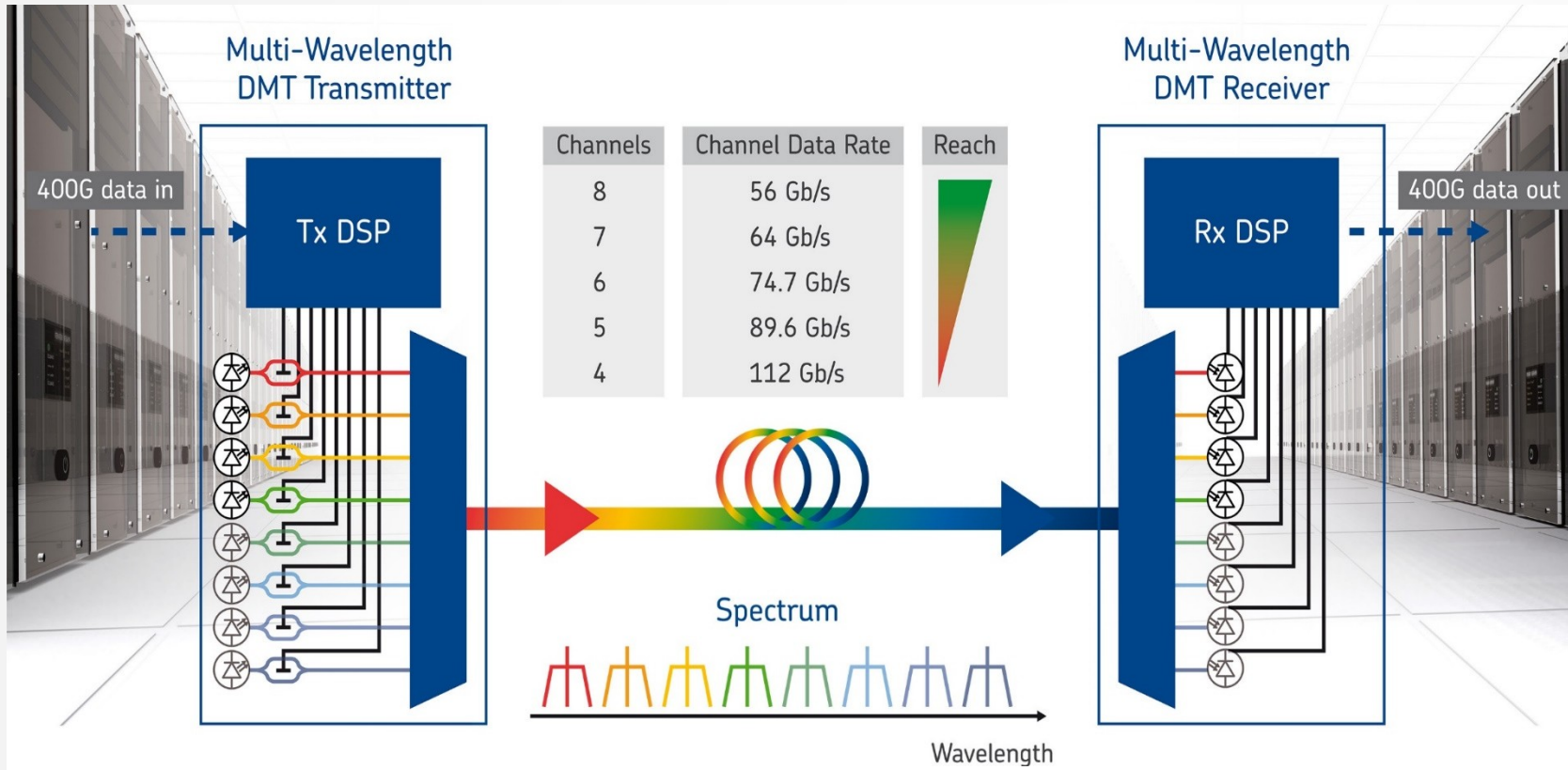


» Residual Dispersion of approx. ± 170 ps tolerable

» All channels stay below the FEC-limit

DMT as future technology

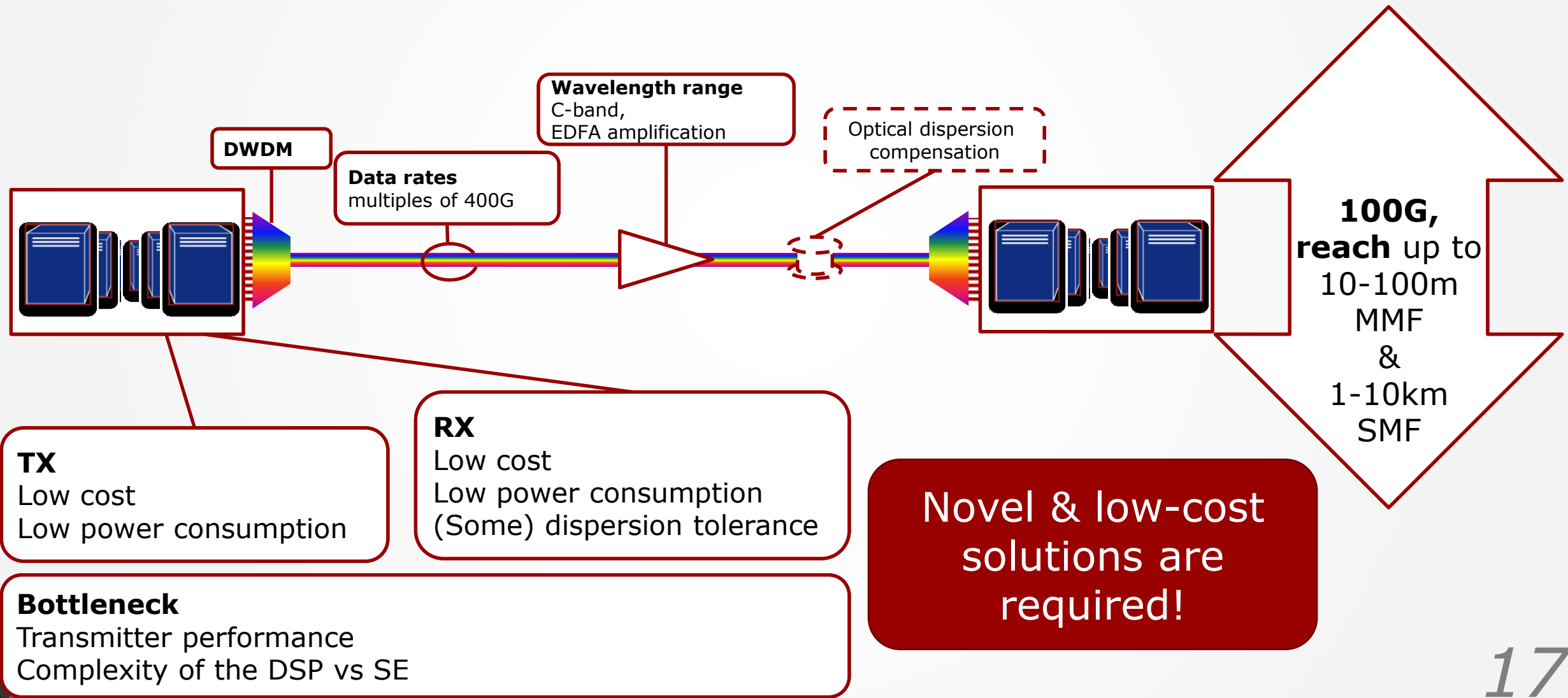
More growth – yet electronics need to catch up



» The challenge with DMT is the same we will point out in the intra-data connectivity section: is DSP and electronics mature enough?

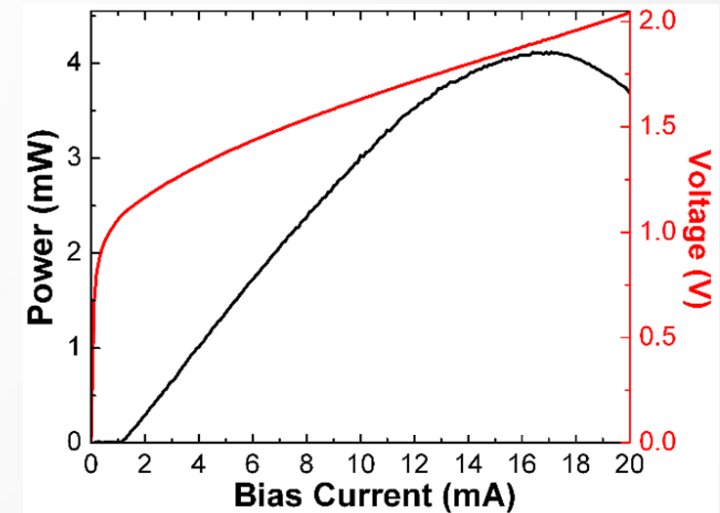
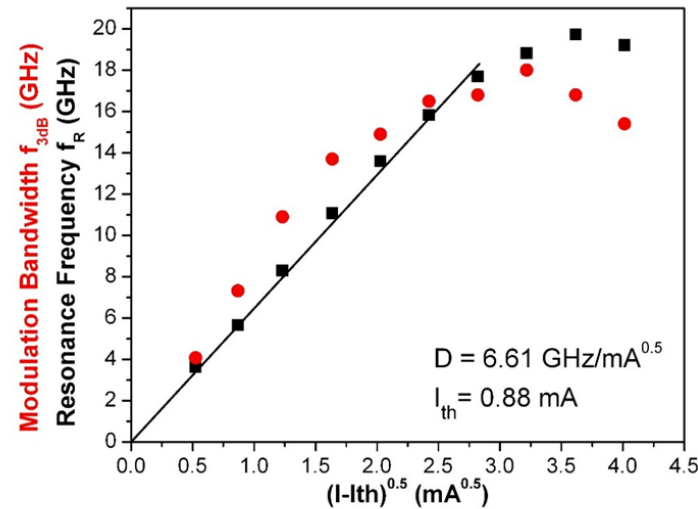
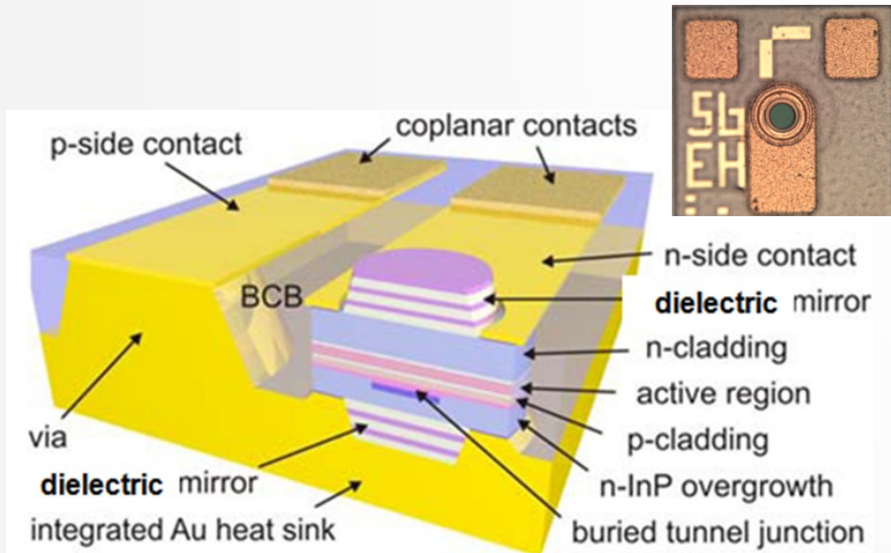
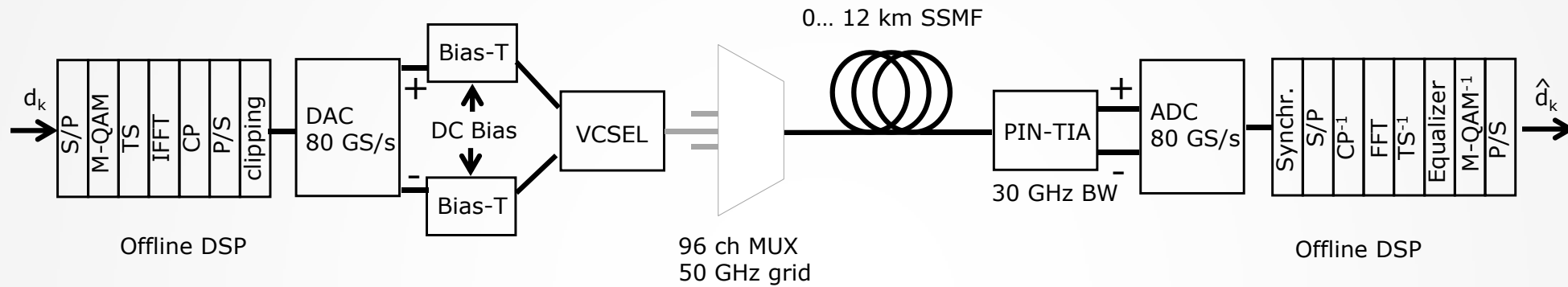
Intra-DC

Intra Data Center



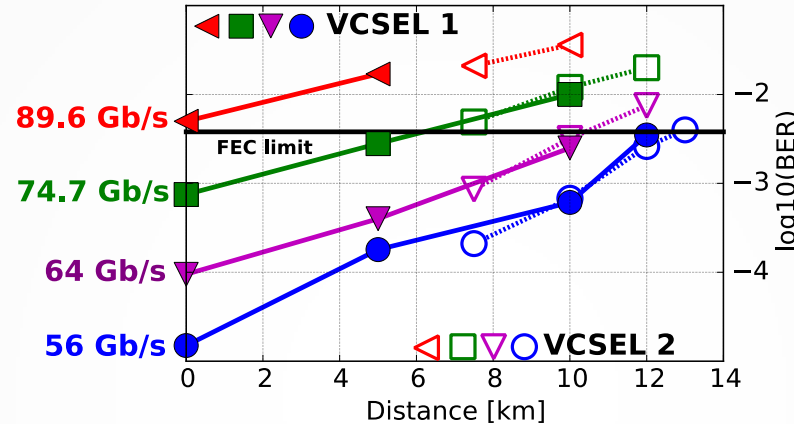
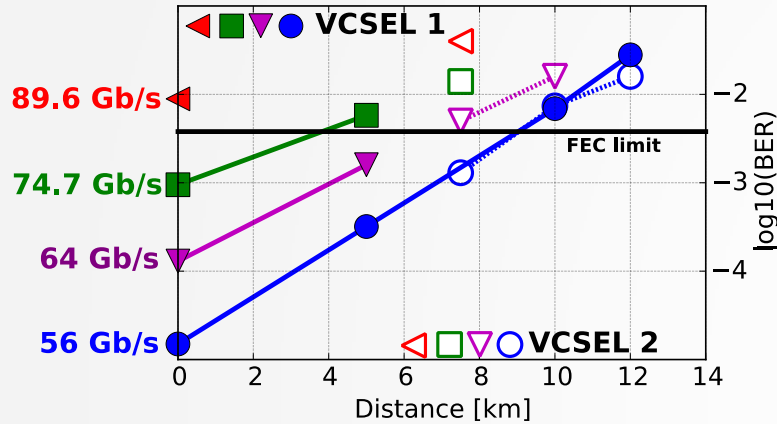
DMT Intra-DC

DMT as scalable technology using VCSELs

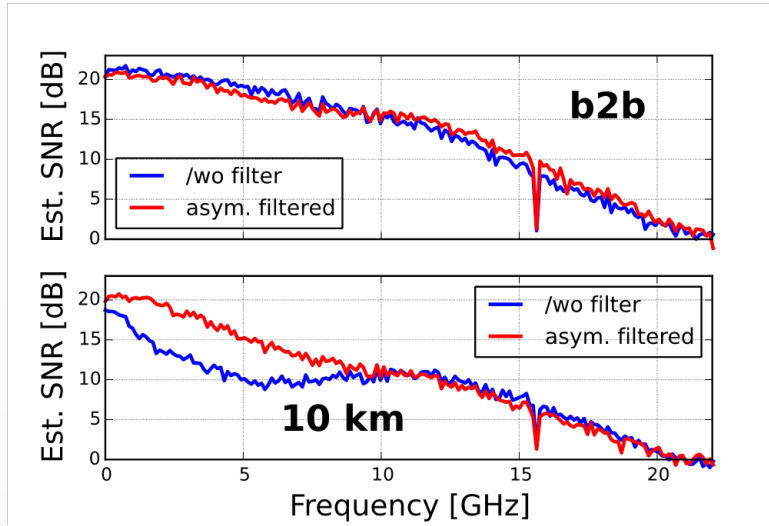
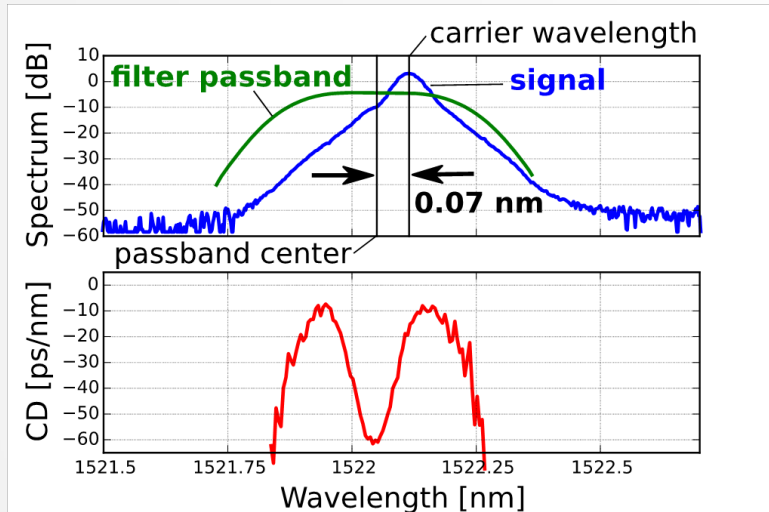


DMT Intra-DC

Performance evaluation

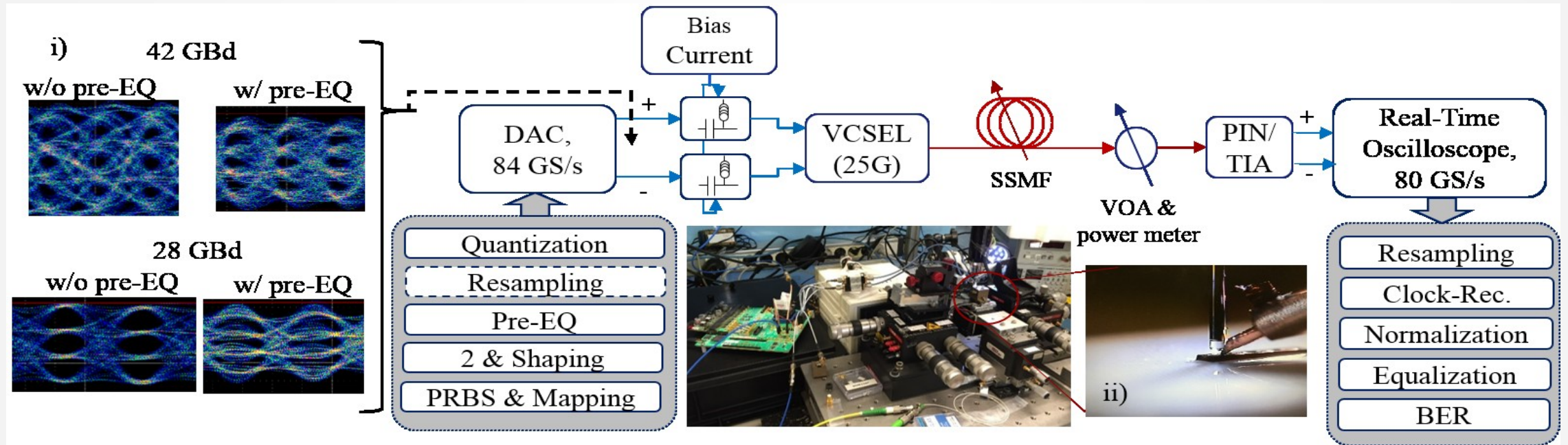


- » 56 Gbit/s in 1.5 μm over 12km SMF
 - » Without dispersion compen.
- » 400G achievable for 8 channels
- » VCSEL technology
 - » Low energy consump.
 - » Low cost



PAM-4 Intra-DC

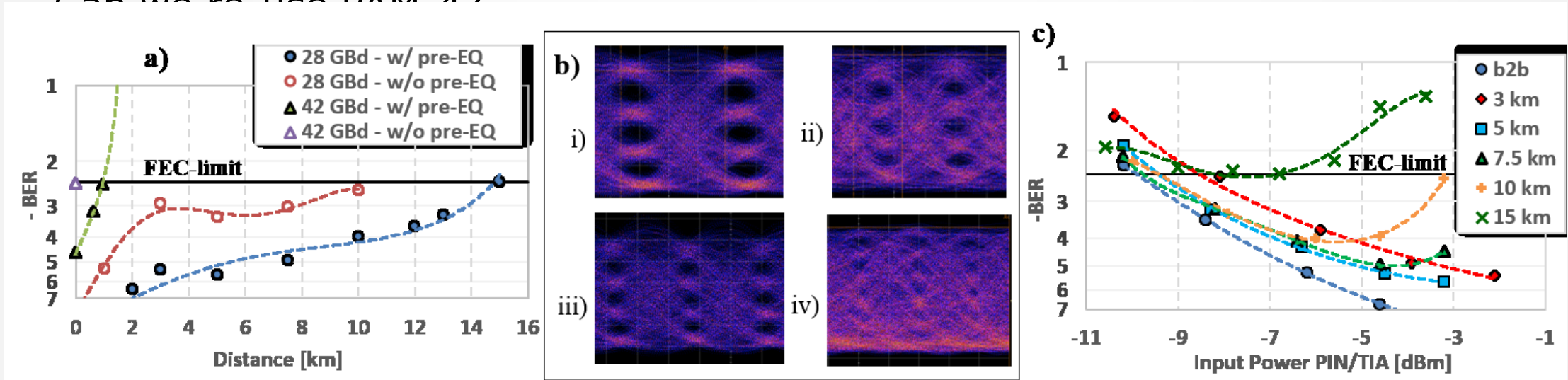
Can we re-use PAM-4?



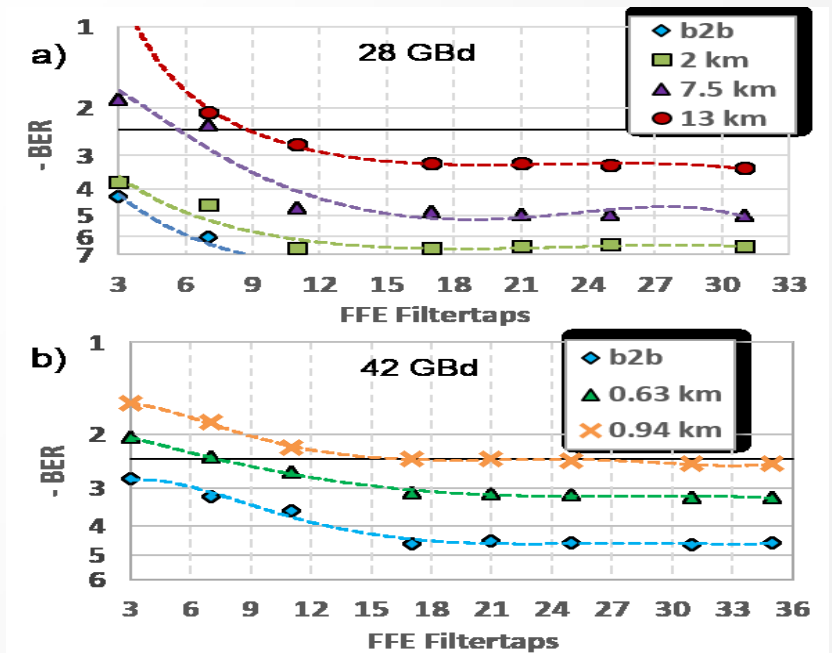
- » 25GHz bandwidth VCSELs being currently produced
- » PAM-4 is the "logical" next step after PAM-4
 - » Which means, although the SE is good... You still need large bandwidth

PAM-4 Intra-DC

Can we use PAM-4?

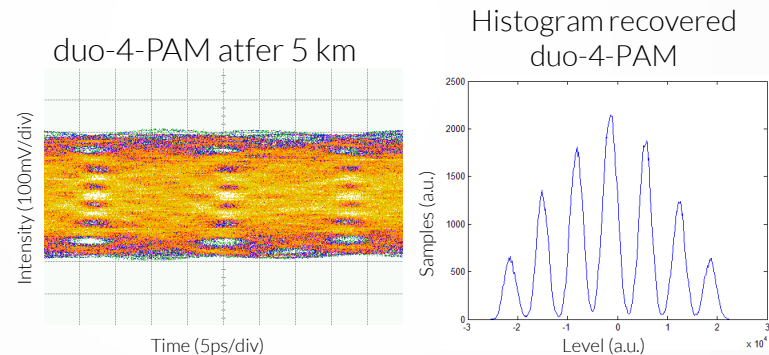
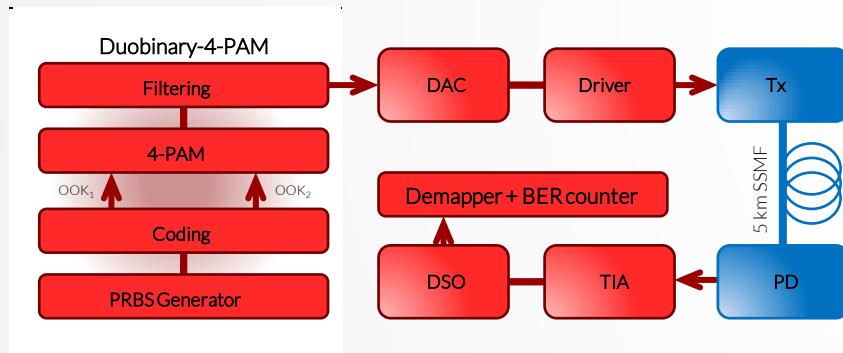
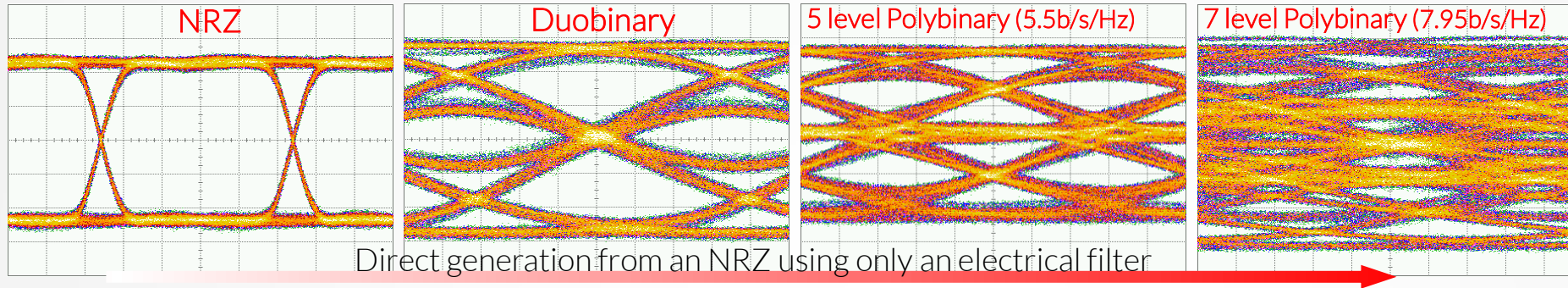


- » 100G solution with 25G class VCSELS
 - » 0.5km attainable
- » 50G solution doable
 - » 13km attainable
- » Low-latency PAM-4 Tx/Rx
 - » "Almost" commodity electronics



Polybinary Intra-DC

Polybinary – forgotten technology



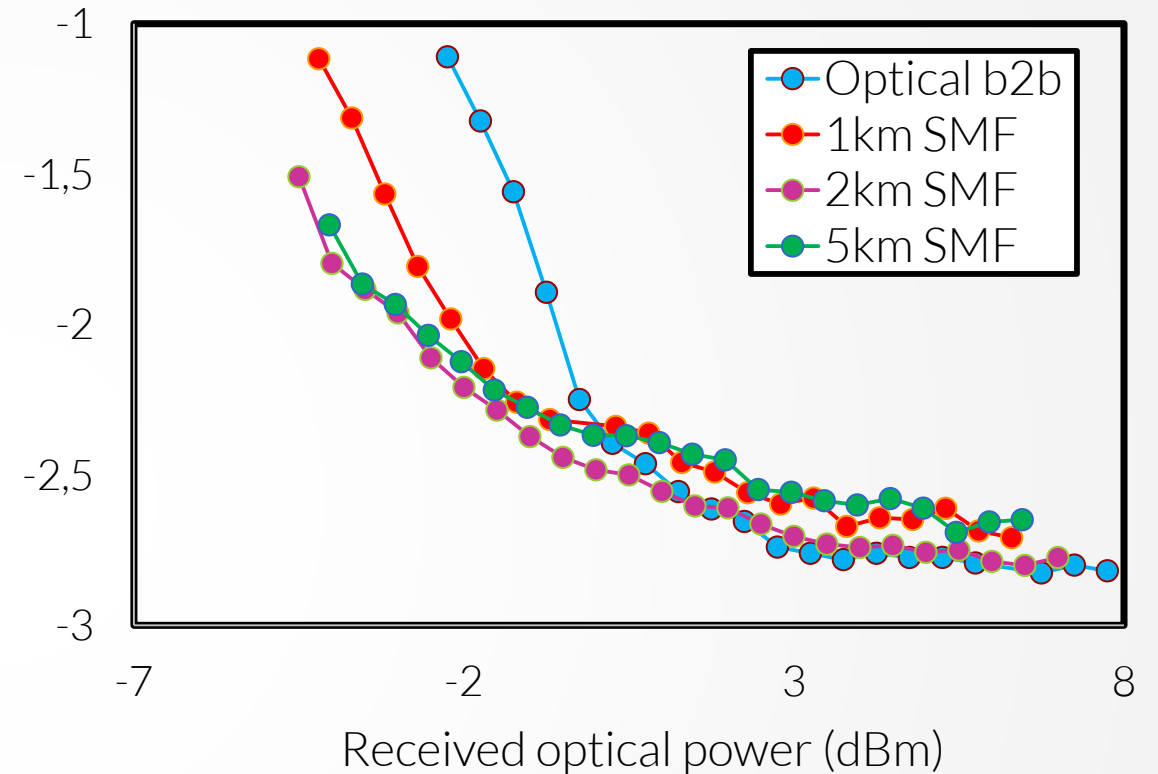
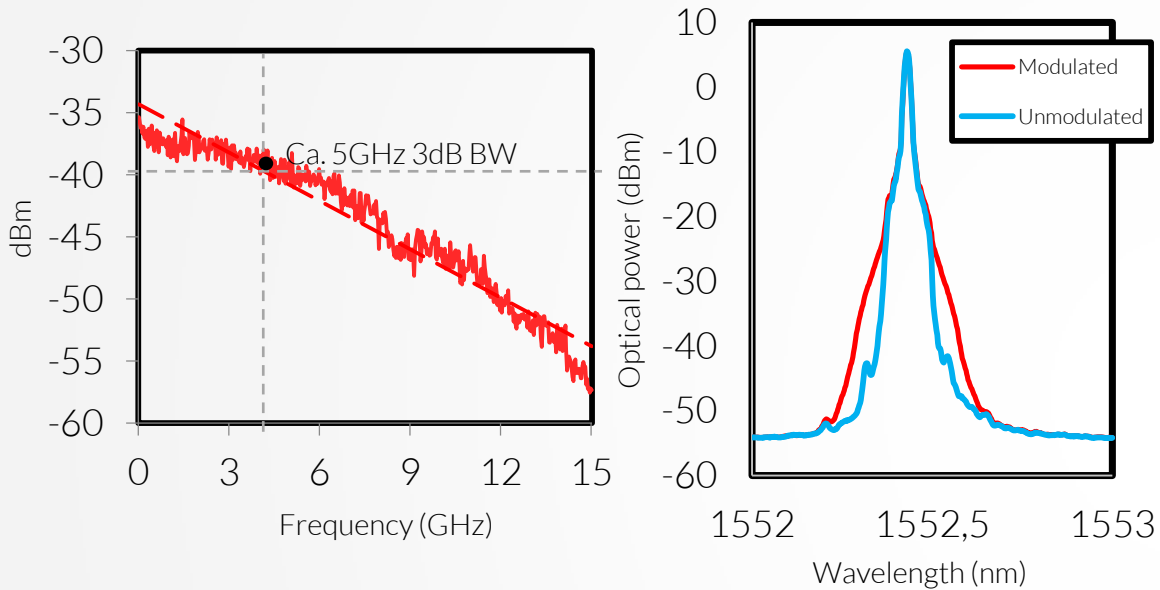
- » Duobinary
 - » NRZ as seed
- » Polybinary
 - » PAM as seed
 - » Increased SE

» Polybinary enables 100G operation in barely 5-6 GHz

» It is however DSP intensive

Polybinary Intra-DC

Performance – 112Gbit/s



» Consistent power penalty up to 5km

» No dispersion management – straight SMF fiber

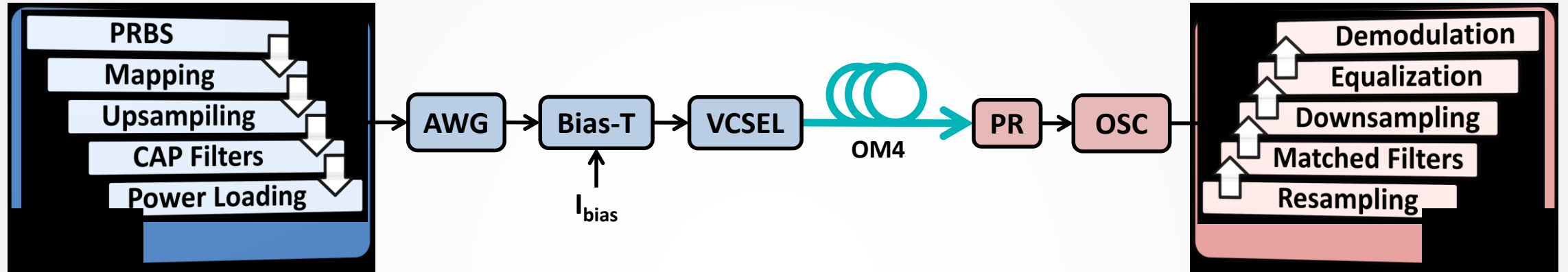
» Single point and measure recovery algorithm

» If dispersion kicks-in in you need complex DSP – dispersion is key bottleneck

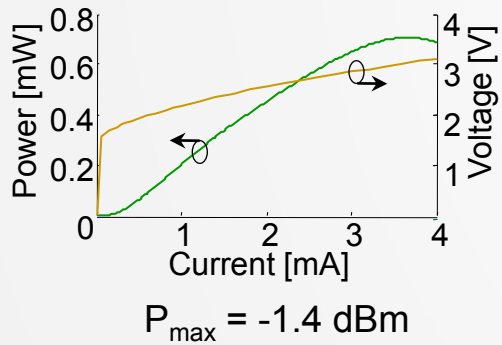
» experiments at 56Gbit/s using VCSEL

MultiCAP Intra-DC

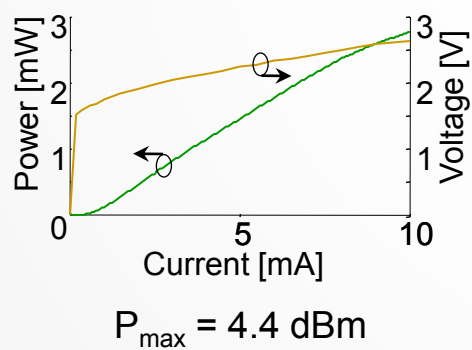
Move down to 850nm and hit 100G



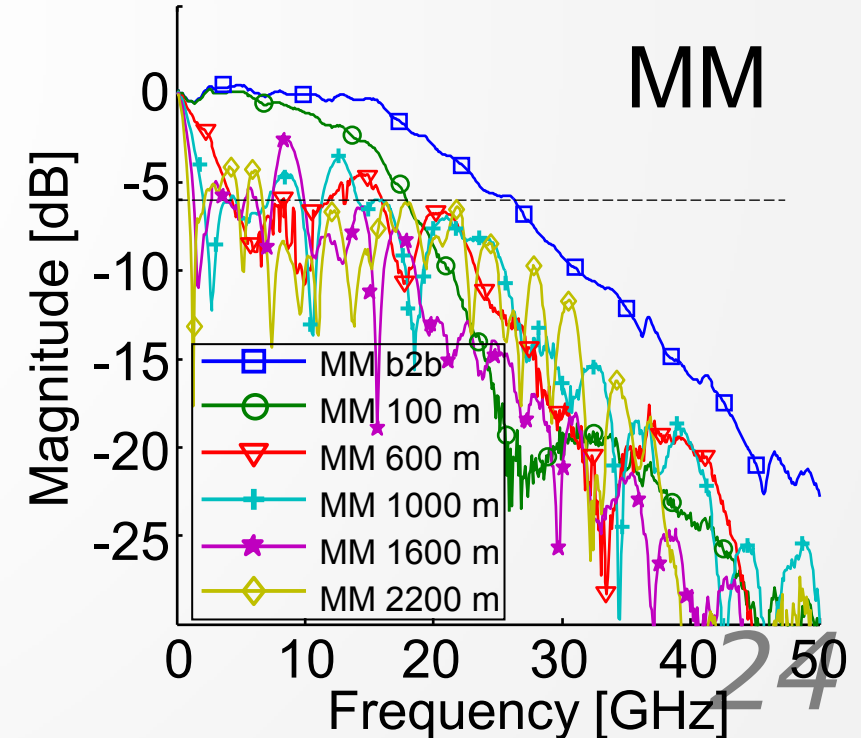
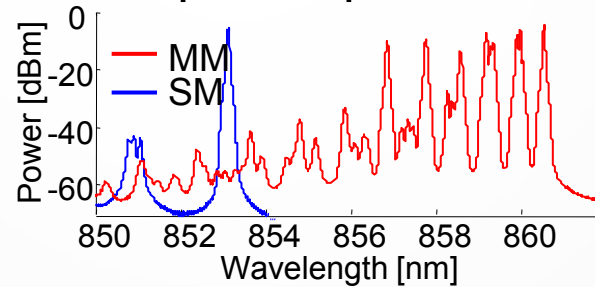
SM VCSEL LIV



MM VCSEL LIV



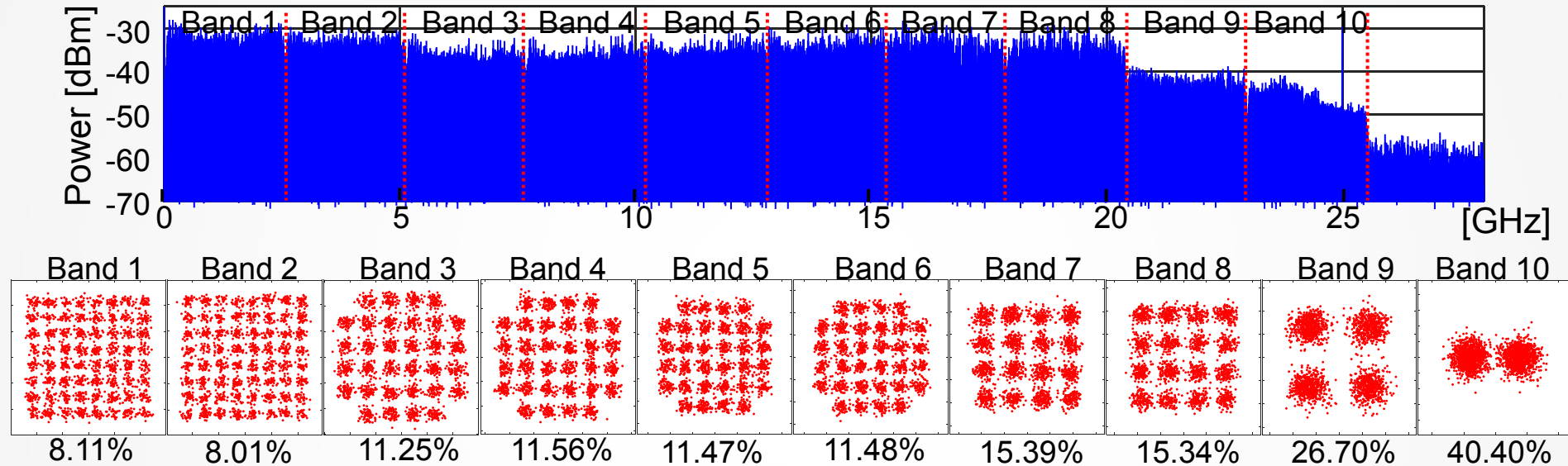
Optical spectra



MultiCAP Intra-DC

107.5 Gbit/s MMF 10m

Received electrical spectrum and constellation diagrams

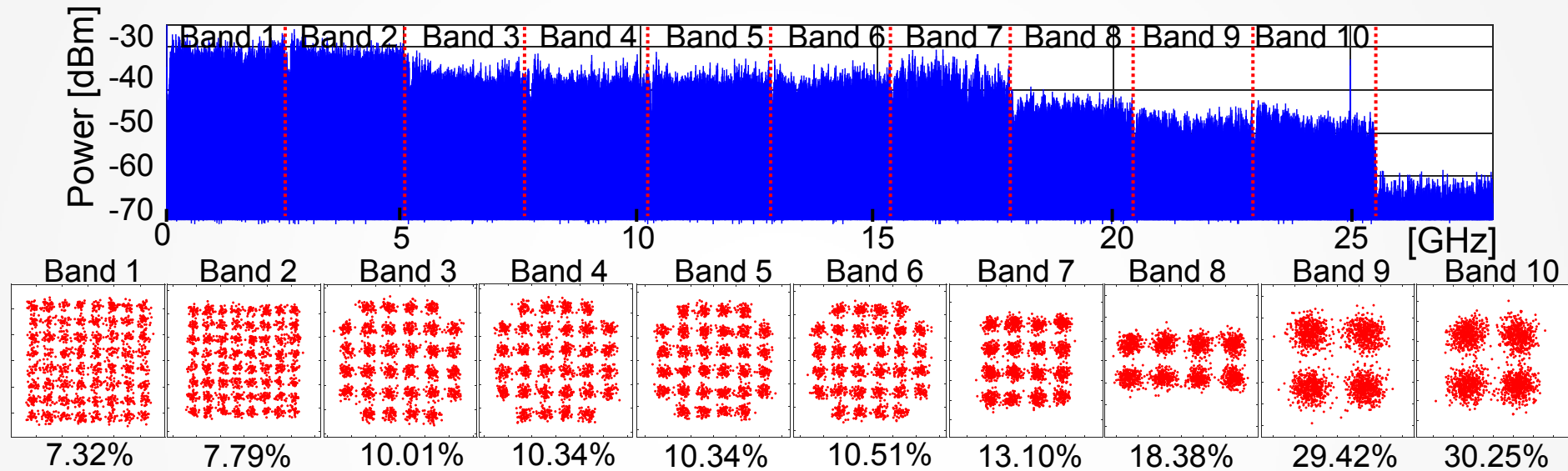


BER and main parameters of MM-VCSEL 107.5 Gb/s transmission

Band	1	2	3	4	5	6	7	8	9	10
Baud rate [Gbaud/s]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Modulation	64-QAM	64-QAM	32-QAM	32-QAM	32-QAM	32-QAM	16-QAM	16-QAM	QPSK	BPSK
Bitrate [Gb/s]	15	15	12.5	12.5	12.5	12.5	10	10	5	2.5
Power Loading [dB]	2	1	0.3	0.6	1	2.1	1.2	2.6	0.4	2
Transmitted Bits	2174976	2174976	1812480	1812480	1812480	1812480	1449984	1449984	724992	362496
BER	3.12e-03	2.58e-03	2.36e-03	2.53e-03	3.76e-03	3.33e-03	2.63e-03	2.77e-03	7.89e-04	3.56e-03

MultiCAP Intra-DC

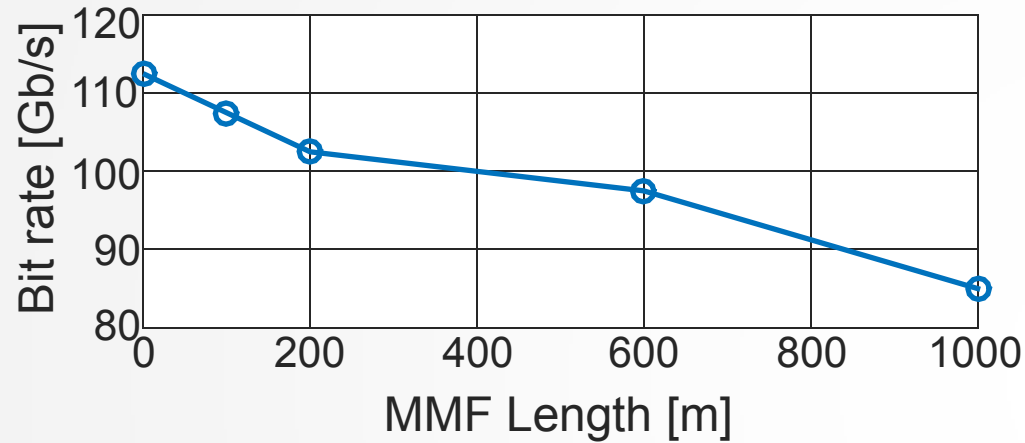
107.5 Gbit/s MMF 100m



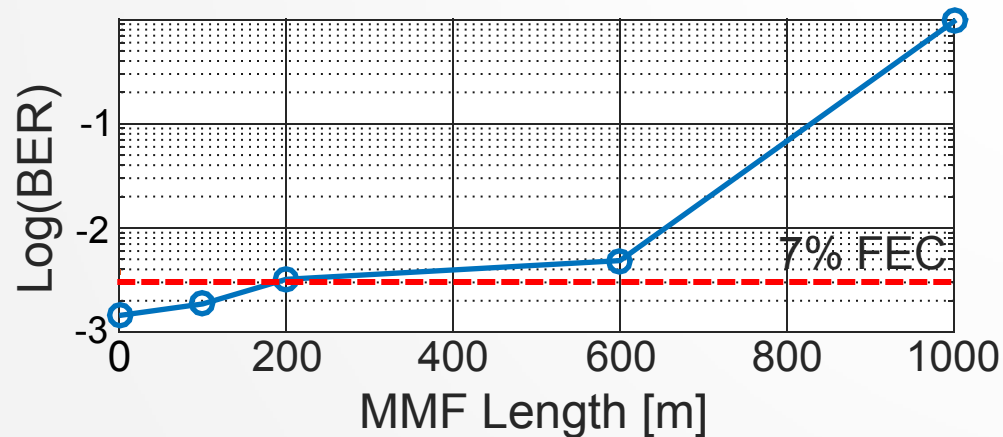
BER and main parameters of SM-VCSEL 107.5 Gb/s transmission

Band	1	2	3	4	5	6	7	8	9	10
Baud rate [Gbaud/s]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Modulation	64-QAM	64-QAM	32-QAM	32-QAM	32-QAM	32-QAM	16-QAM	8-QAM	QPSK	QPSK
Bitrate [Gb/s]	15	15	12.5	12.5	12.5	12.5	10	7.5	5	5
Power Loading [dB]	2	2.1	-0.2	0.7	1.7	2.6	2	1.1	-1	2.1
Transmitted Bits	1449984	1449984	1208320	1208320	1208320	1208320	966656	724992	483328	483328
BER	1.80e-03	2.94e-03	1.33e-03	1.58e-03	1.26e-03	1.89e-03	1.11e-03	1.66e-03	1.69e-03	2.08e-03

MultiCAP performance



- » Maximum bit rate below 7% FEC limit versus MMF length
- » 1km possible with 85 Gb/s

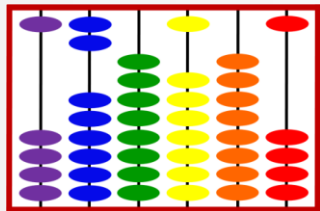


- » Application of more advanced FEC can extend the transmission distance
 - » Do we add latency?

Conclusion

...or rather "open issues"

- » Inter-data center
 - » Right now – upscaling NRZ/PAM seems the right way
 - » Coherent around the corner – "cheap" PICs will define the segment
- » Intra-data center
 - » Multiple ad-hoc technologies to boost SE
 - » Can electronics cope with the DAC/ADC requirements?
 - » SMF vs MMF vs 850 vs 1310 vs 1550



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