Symmetric 100G EPON proposals based on 10G-class optical components

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2016-3-16

Outline

- **100Gb/s downstream**
  - ✓ Transmitter options
  - ✓ Modulation format options
- **100Gb/s upstream**
  - ✓ Transmitter options
  - ✓ Modulation format options
- **Conclusions and proposals**

Key requirement in PON

Low Cost

With High Performance

Transmitter options

EML (Electro-absorption Modulated Laser)

- Integrated laser, EAM and SOA;
- **Higher cost**

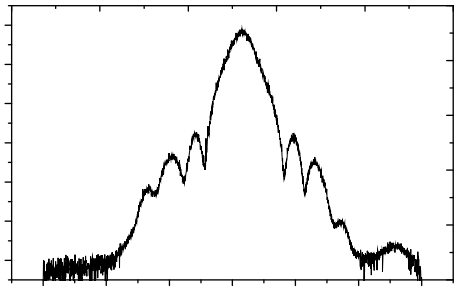
DML (Directly Modulated Laser)**: DFB/DBR**

- Thermal tuning 3-4 nm (λ changes with ΔT) / Grating Current 8 nm(λ changes with ΔI at grating)
- **Lower cost**

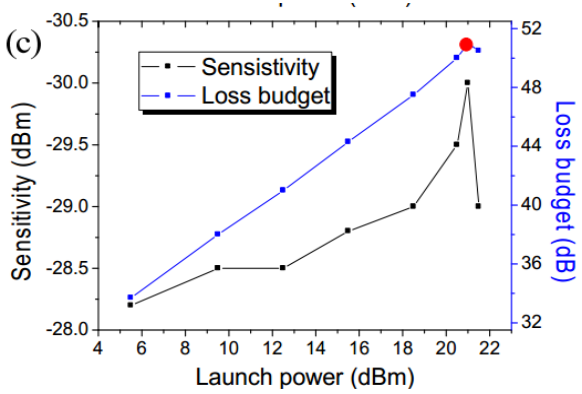
Why DML?

DML-Strong Chirp

- **Broad** spectrum——**Low** carrier density



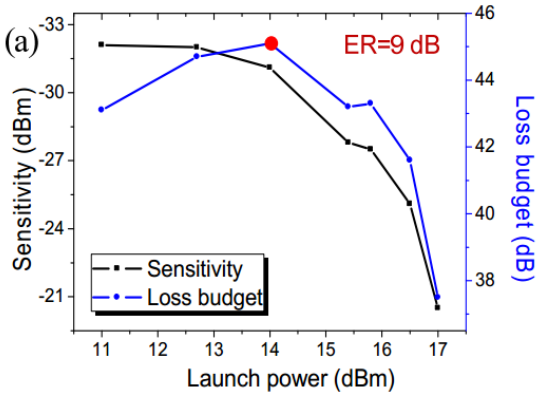
- **Higher** tolerance to fiber nonlinearity



EML-Low chirp

- **Narrow** spectrum——**Strong** carrier density

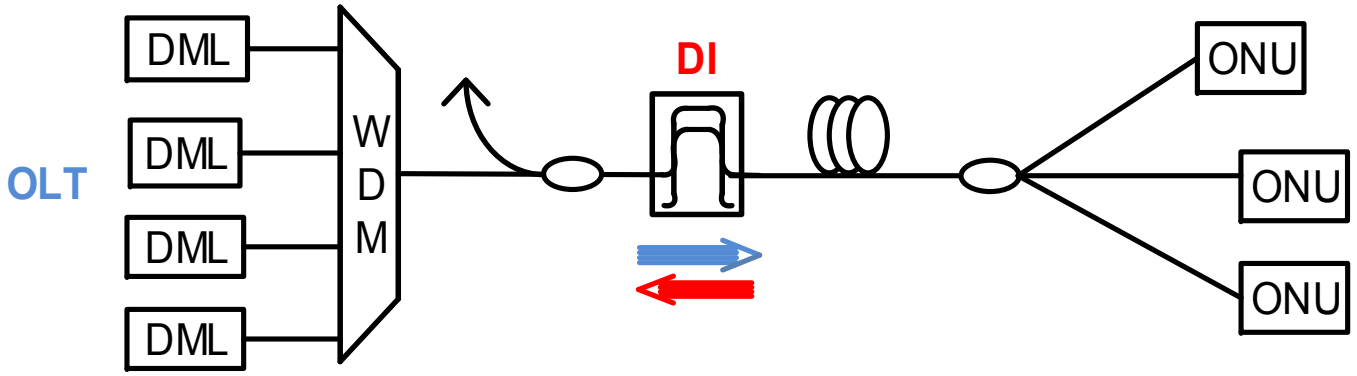
- **Lower** tolerance to fiber nonlinearity

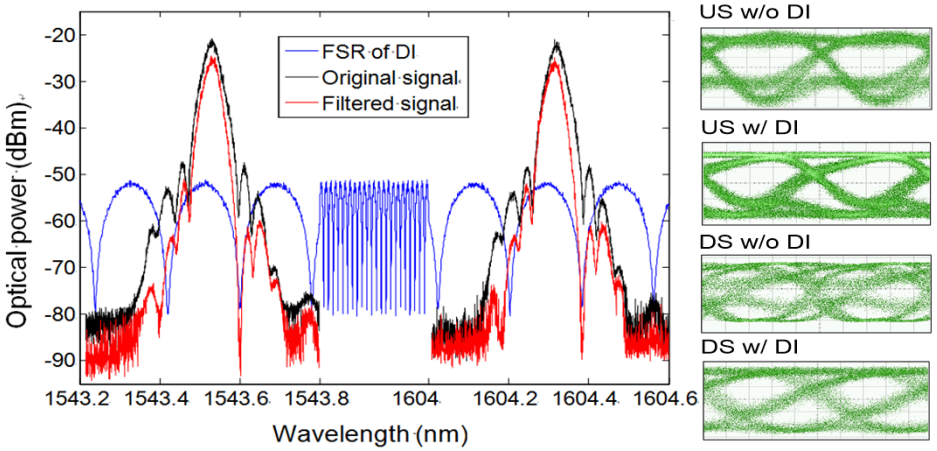


- *Zhengxuan Li, Lilin Yi, et al in OFC/NFOEC 2014, Paper Tu2C.4.*

DML- chirp management

◆Optical filtering for Multi-channel chirp management



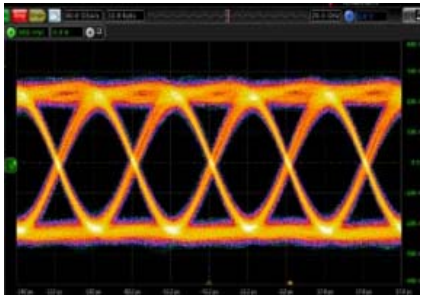


- DI: delay interferometer
- Solution on 10Gb/s OOK format
- Also applicable to advanced formats (duobinary, PAM-4…)

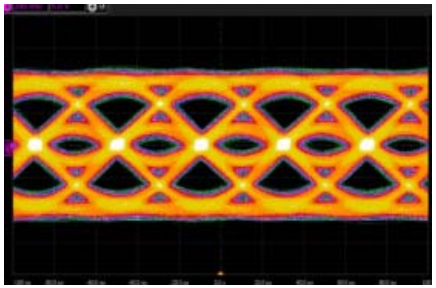
- *Zhengxuan Li, Lilin Yi, et al. IEEE JLT **32**(21), pp. 3389-3396 (2014).*
- *Lilin Yi, Zhengxuan Li, et al. ACP 2013 paper PDP AF2C.3*

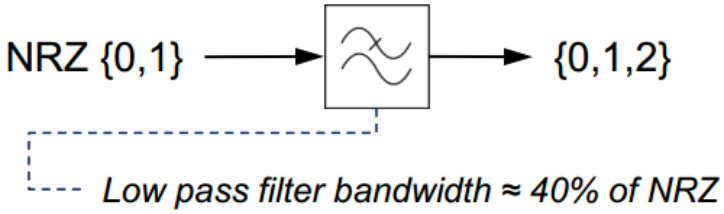
Modulation formats

◆NRZ-OOK

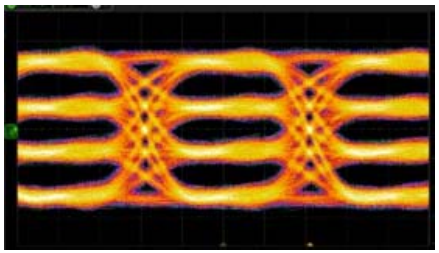


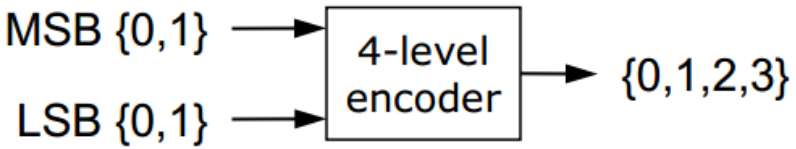
◆Duobinary





◆PAM-4



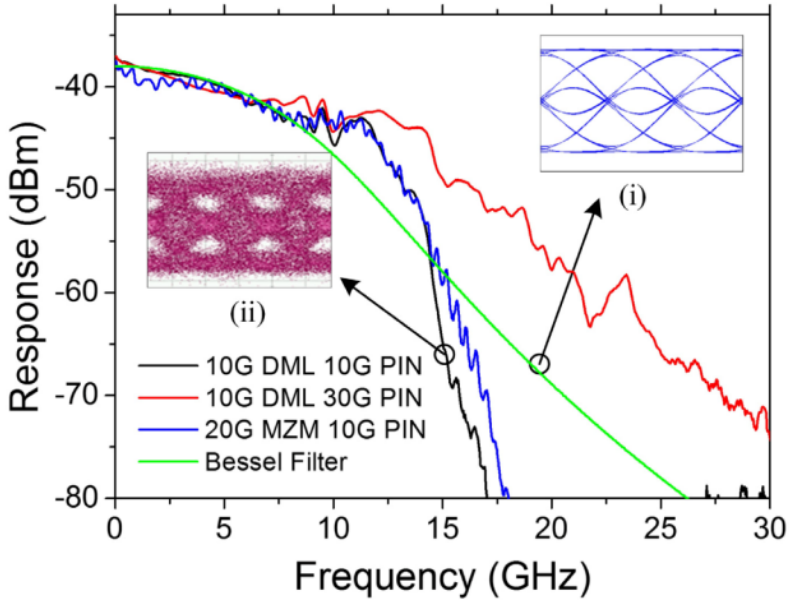


Decision Difficulty / Modulator Linearity

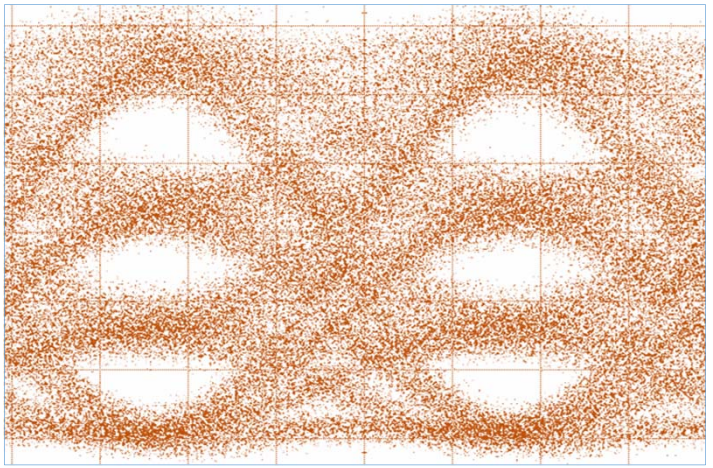
- *Ed Harstead, Dora van Veen, Vincent Houtsma, and Peter Vetter, 25G TDM PON overview, September 2015*

10G devices enabled 25Gb/s modulation -Duobinary and PAM4

◇ Duobinary



□ PAM-4



Bandwidth = 1/2× Bit Rate

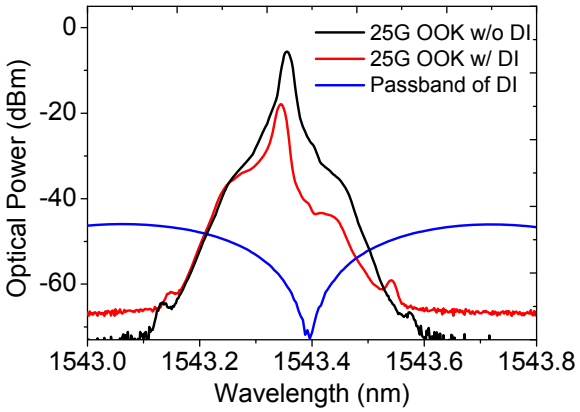
Limited Bandwidth →Low-pass filtering → Duobinary format

PAM-4 can reuse 10G optical devices

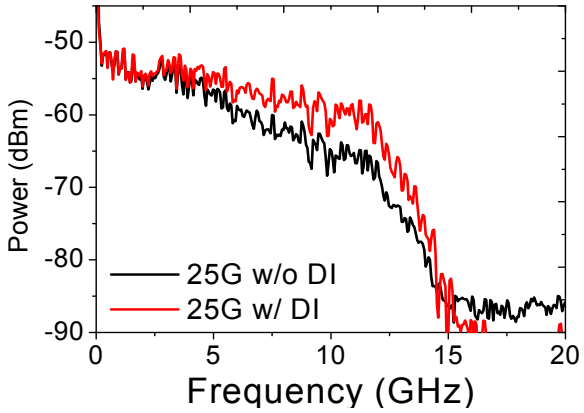
- *Zhengxuan Li, Lilin Yi, et al. Optics Express 23(16), pp. 20249-20256, (2015).*

10G devices enabled 25Gb/s modulation - NRZ-OEQ

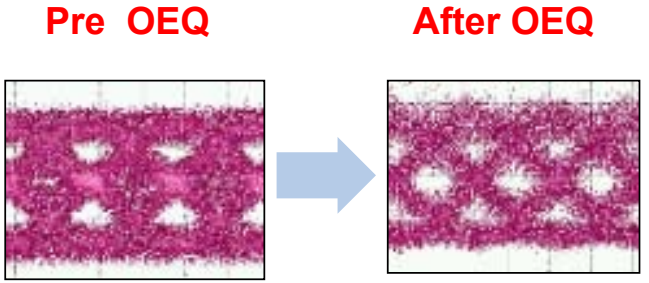
◆ NRZ based on Optical Equalization (NRZ-OEQ)

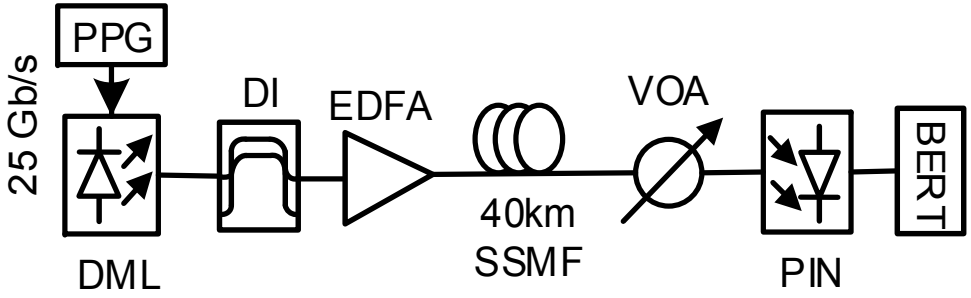


Optical spectrum



Electrical spectrum





- ✓ **Detuning of DI converts Dobinary into NRZ**
- ✓ **A Single DI for Simultaneous Multi-channel equalization and chirp management**

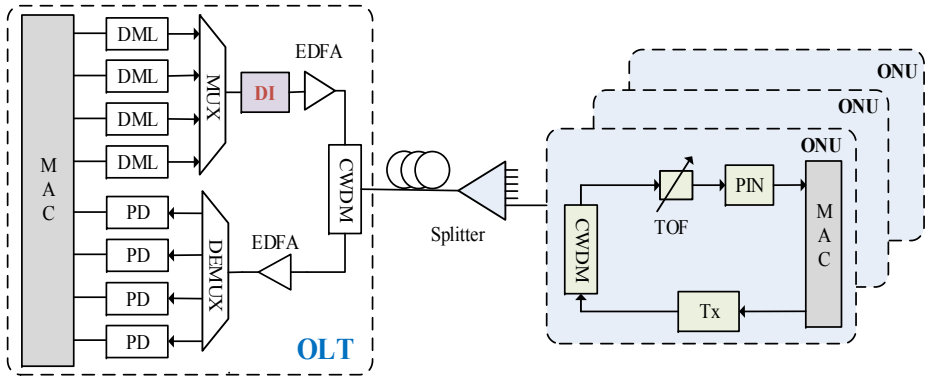
Formats comparison

Similarity：

◆System architecture

- ✓ 4×25 Gb/s TWDM
- ✓ Tx： DMLs and DI
- ✓ Rx: PIN or APD

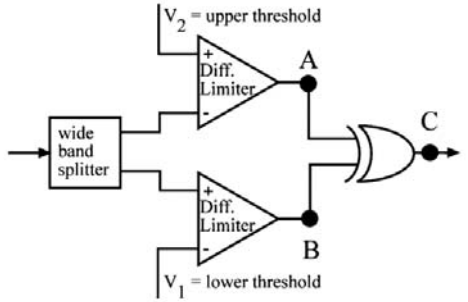
◆Tx and Rx — 10 GHz



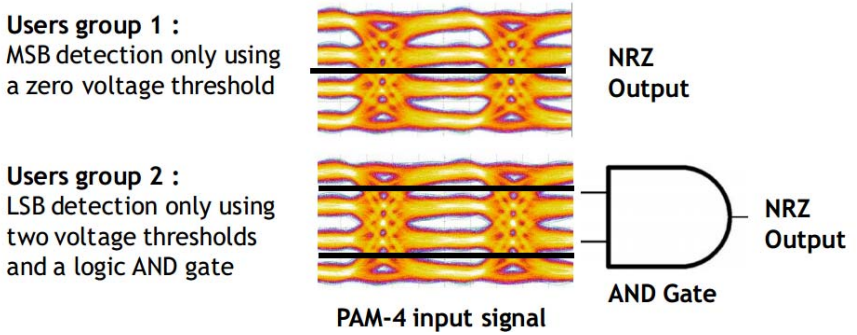
Differences:

☐**Complexity**

- ✓ Pulse generator
- ✓ Decision circuit in Rx



Real-time Duobinary Decision circuit



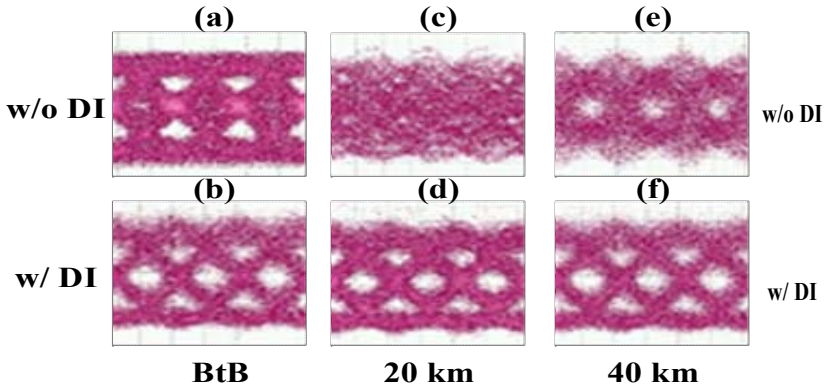
Real-time PAM-4 Decision circuit

☐ **Performance**

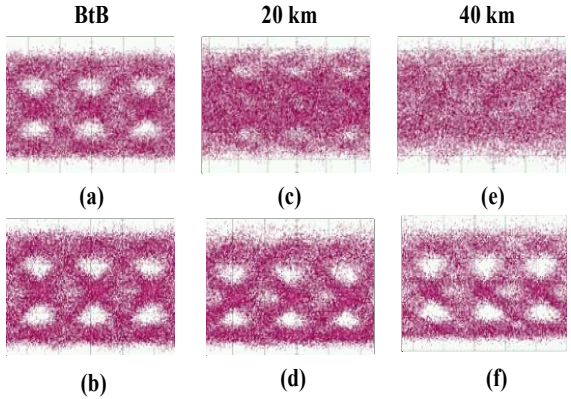
- ☐ **Launch power**
- ☐ **Sensitivity**

Formats comparison

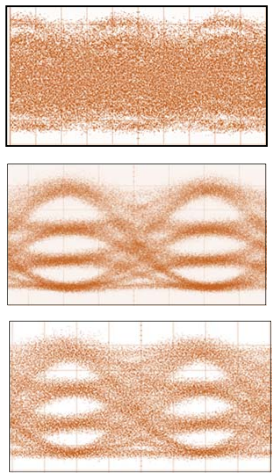
◆ Chirp management performance



NRZ-OEQ



Duobinary



20km w/o DI

20km w/ DI

40km w/ DI

PAM-4

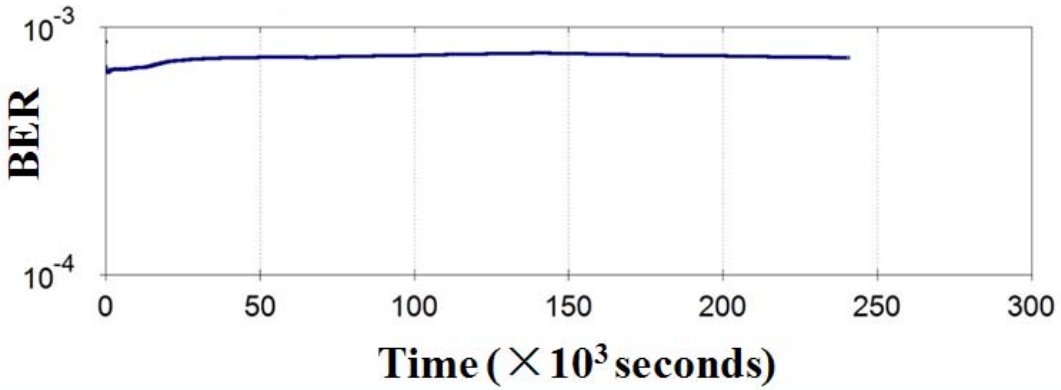
◆ Launch power & Sensitivity

Modulation format	Bit rate (Gb/s)	Reach (km)	Launch power (dBm)	Sensitivity (dBm)	Loss budget (dB)	Complexity
NRZ-OEQ	25	40	18.5	-17.5	36	Low
Duobinary	28	40	16	-15	31	
PAM-4	25	40	15	-11	26	High

Sensitivity is calculated using off-line processing

System stability evaluation

—real-time BER measurement for NRZ-OEQ



Rate	Timer	TX/RX Pattern	BER Count	Error Count	BER
25.59 Gb/s	240578s	PN31	6.16×10^{15}	4.6×10^{12}	7.5×10^{-4}

- A commercial 25Gb/s CDR is used for real-time BER measurement
- BER keeps stable over 67 hours with 40km reach and -19dBm input power

Proposal for 100Gb/s downstream solution

- **Launch power**
  - DML > EML
- **Sensitivity**
  - NRZ(2-level) > Duobinary(3-level) > PAM4(4-level)
- **Cost**
  - DML < EML
  - NRZ < Duobinary <PAM4
- **Proposal**
  - DML based NRZ supporting by DI based optical equalization

100Gb/s upstream solution

◆DML+DI based 25Gb/s NZR-OEQ for upstream?

- ✓ Cost: DI in OLT for multiple upstream channels equalization
- ✓ Performance: Same with downstream
- ✕ Stability: Wavelength drift in ONU is unavoidable

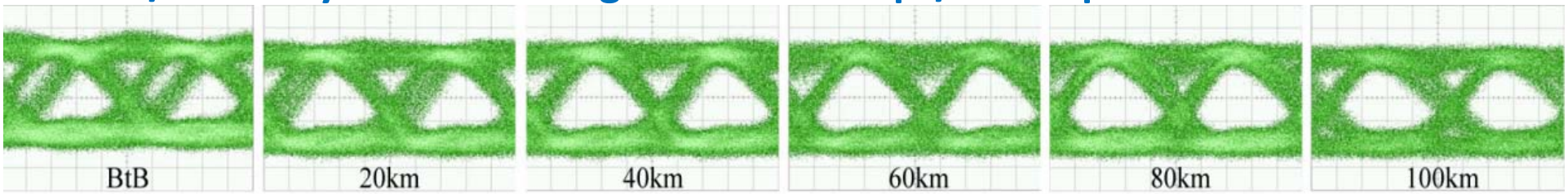
◆DML based Duobinary

- ➢ How to compensate chirp-induced dispersion for upstream?

Fixed negative dispersion at OLT

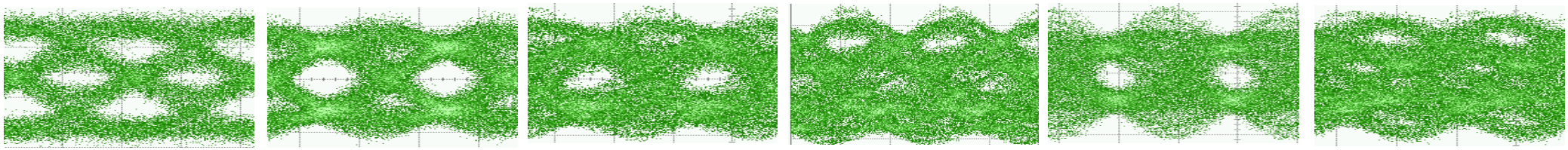
◆Directly-modulated signal is tolerated to negative dispersion

➢10Gb/s directly-modulated signal with -2100ps/nm dispersion value at OLT



Lilin Yi, et al. Optics Express 23(6), pp. 7971-7977, (2015).

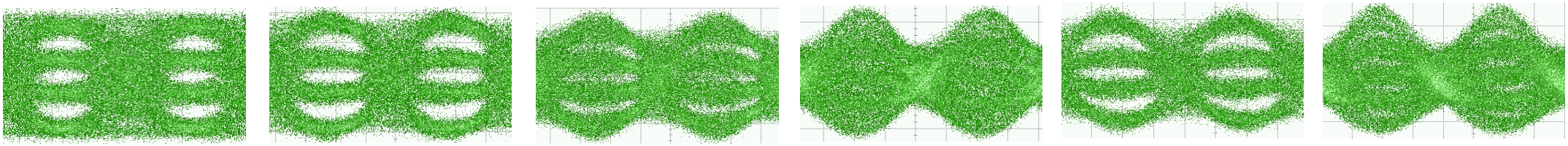
◆25Gb/s Duobinary based on 10G-class DML?



Difficult to find an optimal negative dispersion value to compensate CD from 0-40km differential reach

DML based PAM4?

◆25Gb/s PAM4 based on 10G-class DML?



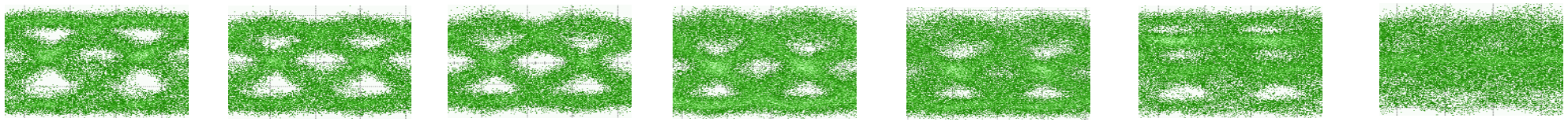
BtB | with -100ps/nm | with -300ps/nm | with -400ps/nm | with 20km SMF | with 40km SMF

Difficult to find an optimal negative dispersion value to compensate CD for 0-40km differential reach

◆For multi-level modulation formats (Duobinary and PAM4), chirp-induced dispersion significantly distort the signal performance, BM-EDC is necessary used in OLT

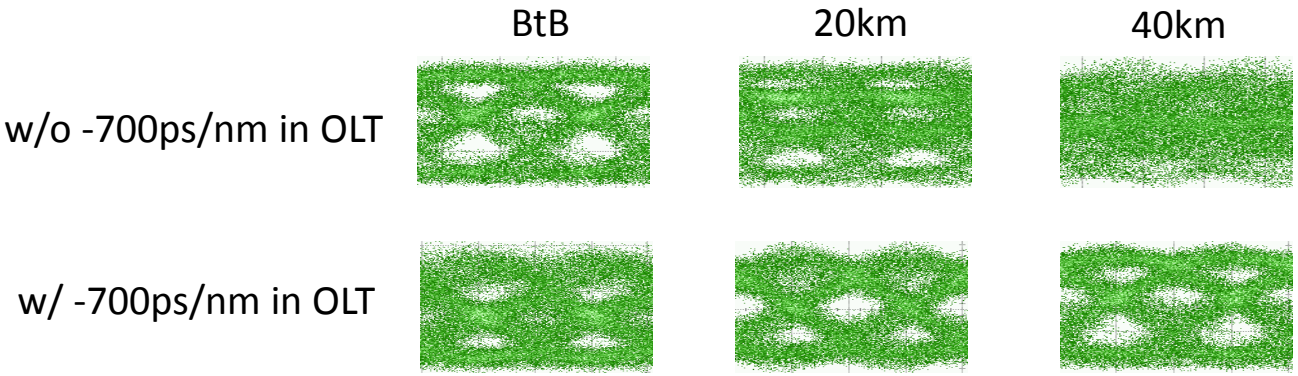
EML based Duobinary?

◆25Gb/s Duobinary based on 10G-class EML?



BtB -100ps/nm -300ps/nm -500ps/nm -700ps/nm 20km SMF 40km SMF

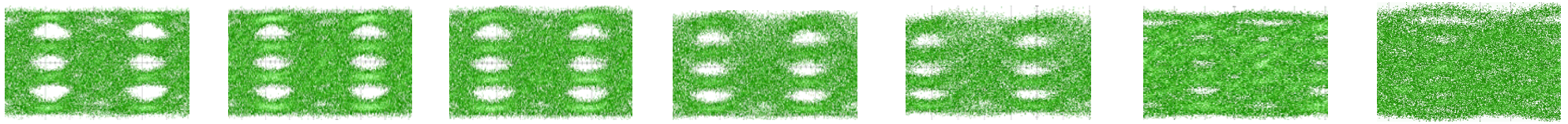
-700ps/nm would be a good negative dispersion value to compensate CD from 0-40km differential reach



It is possible to compensate the CD of 0-40km differential reach by using ODC with fixed negative dispersion in OLT for EML based Duobinary signal

EML based PAM4?

◆25Gb/s PAM4 based on 10G-class EML?



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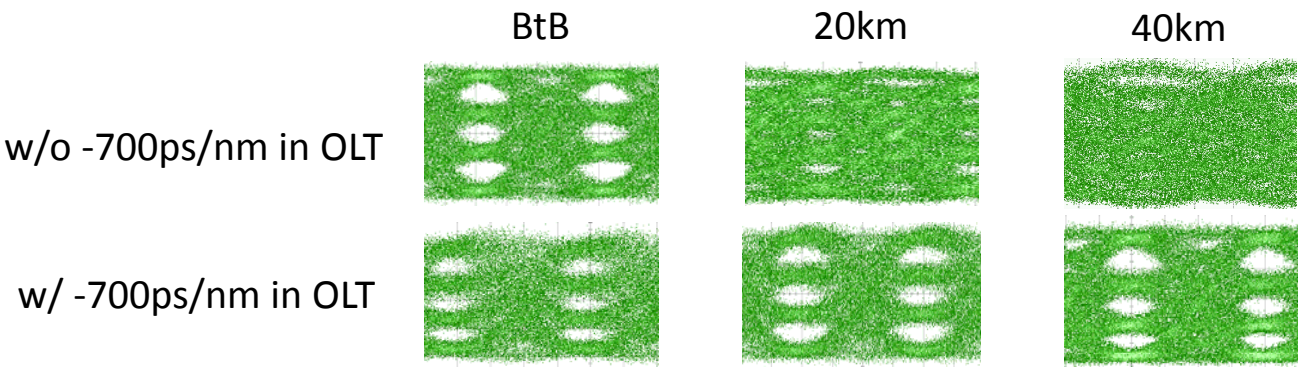

EML based PAM4 is more tolerated to negative dispersion than EML based duobinary due to lower baud rate

Proposal for 100Gb/s upstream solution

- For US, dispersion compensation is a serious problem
- BM-EDC is not mature yet, ODC is an option
- The strong chirp induced dispersion for DML based Duobinary/PAM4 is difficult to be compensated by ODC
- Fixed ODC in OLT is a good option for EML based Duobinary/PAM4
- Proposal
  - EML based PAM4/Duobinary supporting by ODC based CD compensation

Proposal for symmetric 100Gb/s NG-EPON

- **Downstream**
  - DML based NRZ supporting by DI based optical equalization
  - DSP is not required in ONU
- **Upstream**
  - EML based Duobinary/PAM4 supporting by ODC based CD compensation
  - BM-EDC is not required in OLT
- **Principle**
  - All equalization/compensation functions in OLT
  - Keep ONU as simple as possible
  - Use simple optics to relax the requirement on complex electronics

+THANKS!+

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