50Gb/s technical feasibility analysis

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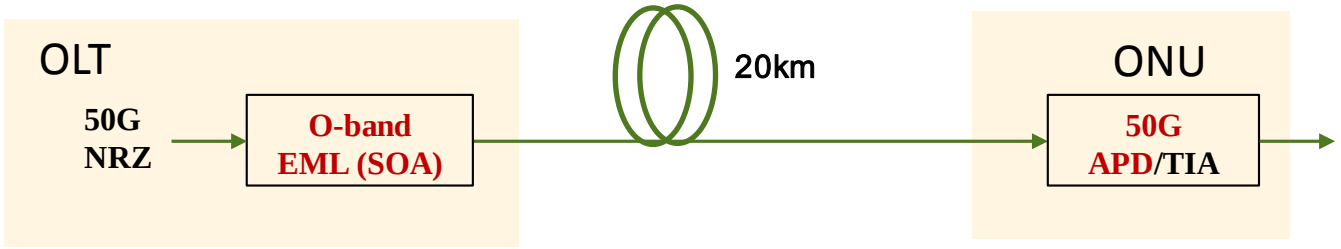
Sep, 2017

Background

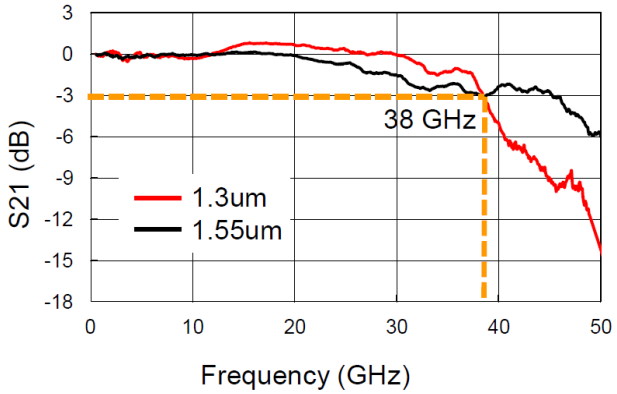
- In last Berlin meeting, the task force called for contributions on 50G PON solutions analysis.

- This contribution analyzes the different candidate technologies for 50Gb/s per wavelength, and their advantages and challenges .

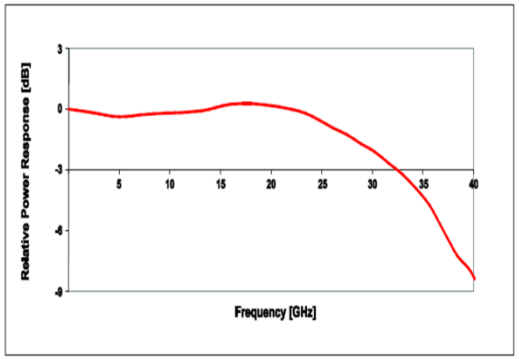
50Gb/s NRZ modulation



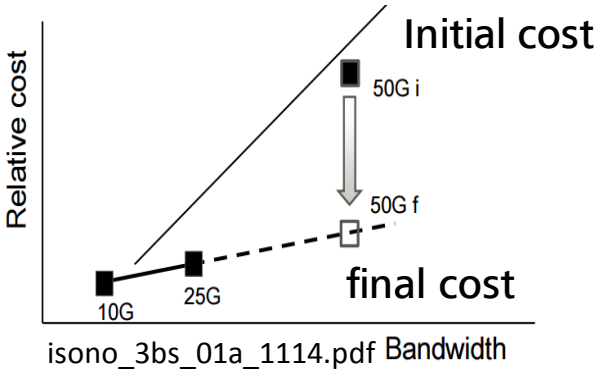
50G EML frequency response



50G PIN frequency response



50G optics cost curve trend



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- 50G NRZ requires very high bandwidth for optics
- There are only few 50Gb/s Tx optics with very high cost in industry, and no 50G APD by far. Feasibility of 50G APD is still not clear.
- The initial cost of 50G will be very high due to lack of application in other industry chain. (Datacenter adopts 25G Baud rate for high bit rates)

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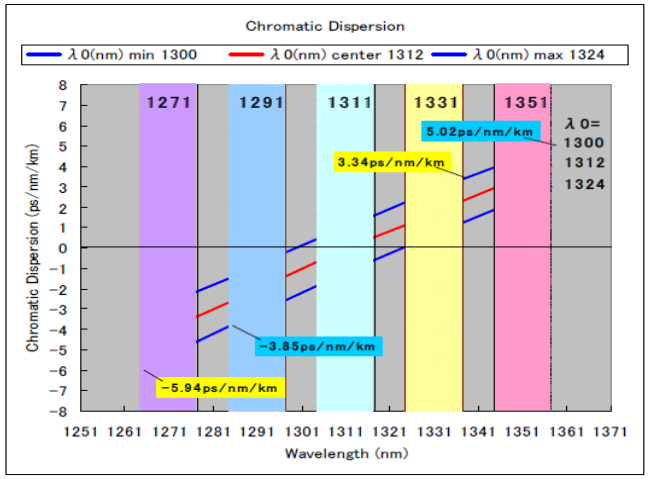
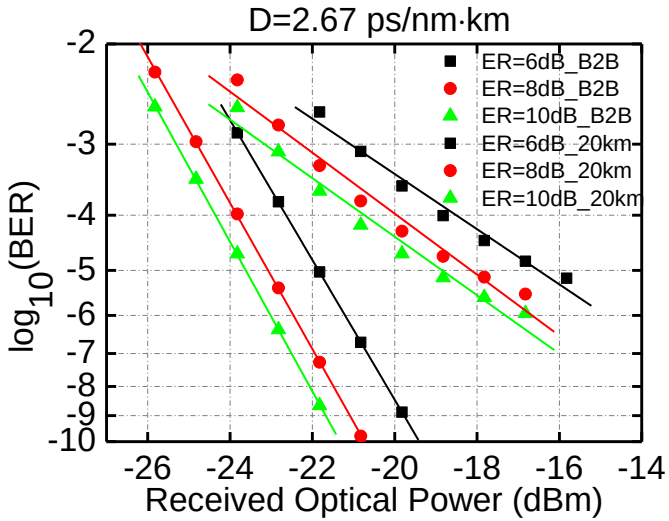
50Gb/s NRZ dispersion analysis

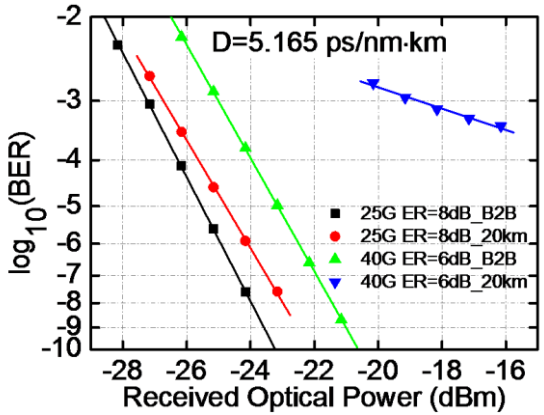
O+ fiber dispersion coefficient



50G NRZ dispersion penalty @1330nm (simulation)



25G/40G EML dispersion penalty comparison in O+ band 1358nm



50G NRZ (50G EML + 50G APD)	ER (dB)		
	6	8	10
ROF @ (B2B) BER = E-3/dBm	-23.7	-24.7	-25.2
CD penalty* after 20 km SMF@1330nm	~2.6	~2.4	~2.2

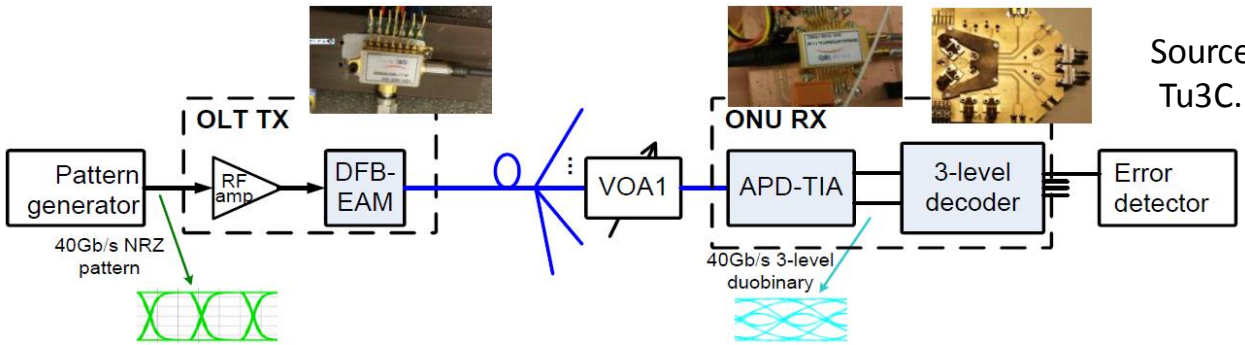
* 50G NRZ after 20km can't reach 1E-3 BER

50G NRZ power budget analysis

	Solution	Tx Power (dBm)	Rx Sen. (dBm), @BER 1e-2	Dispersion penalty (dB) @20km, 1330nm	TDP (dB)	**Power budget gap to 29dB**	**Power budget gap to 33dB**
25G NRZ	25G EML +25G APD	+4.5	-26.2	0.2	1.5	**-0.2 dB**	**3.8 dB**
50G NRZ	50G EML +50G APD	+4.5	-22.2	2.5	3.5	**5.8 dB**	**9.8dB**
	50G EML +50G PIN	+4.5	-17	2.5	3.5	**11 dB**	**15 dB**

Due to high dispersion penalty and low sensitivity of 50G, there is a big gap to meet the 29dB and 33dB power budget without amplifier.

50G EDB



Source：
Tu3C.1 OFC 2016

40G EDB based on 25G APD

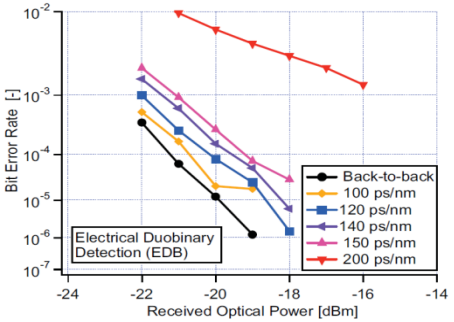


Figure 5 : Measured performance for electrical duobinary detection (EDB) at different positive dispersion values.

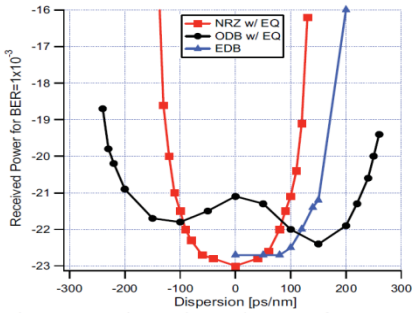


Figure 6 : Dispersion tolerance for EDB detection, equalized ODB and equalized NRZ at 0 dBm optical launched power.

Source：
Th4H.1 OFC 2015

- 50G EDB still requires transmitter with 50G bandwidth , which is in very high cost and far from mature in industry.
- Dispersion penalty of 50G EDB may be still noticeable in O+ band., which will make the power budget issue more challenging.

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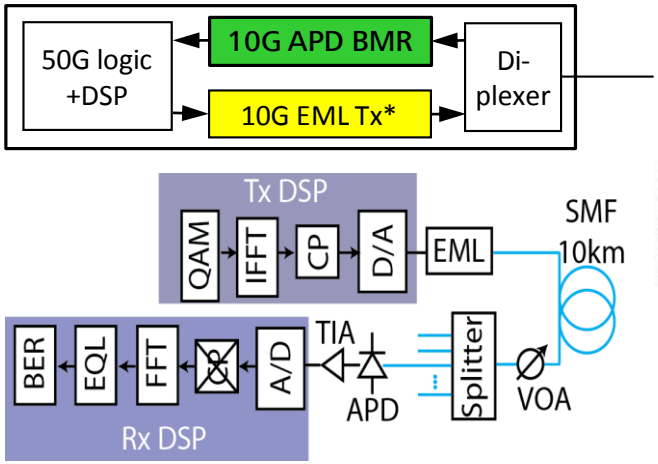
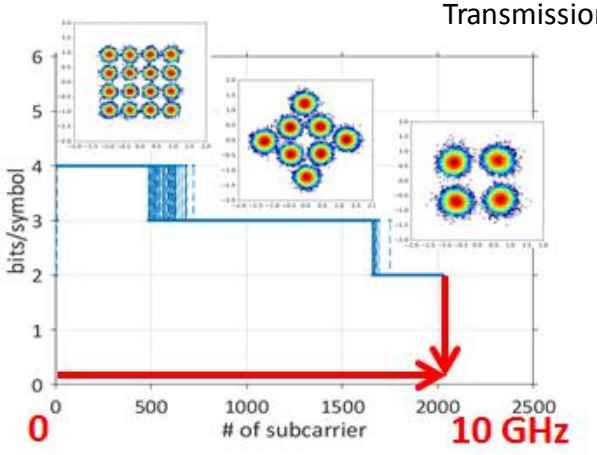
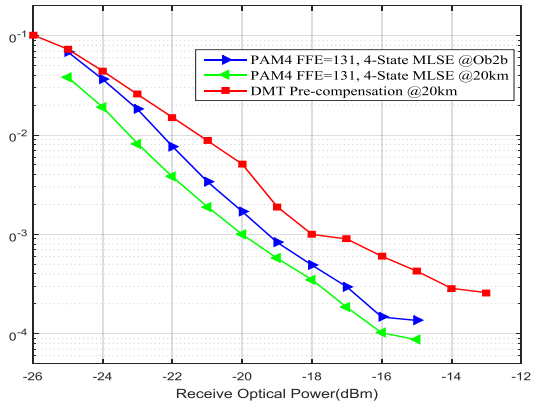
50Gb/s DMT modulation

50G Discrete Multitone Modulation using 10G optics

"50-Gb/s/λ TDM-PON Based on 10G DML and 10G APD Supporting PR10 Link Loss Budget after 20-km Downstream Transmission in the O-band", OFC. 2017.

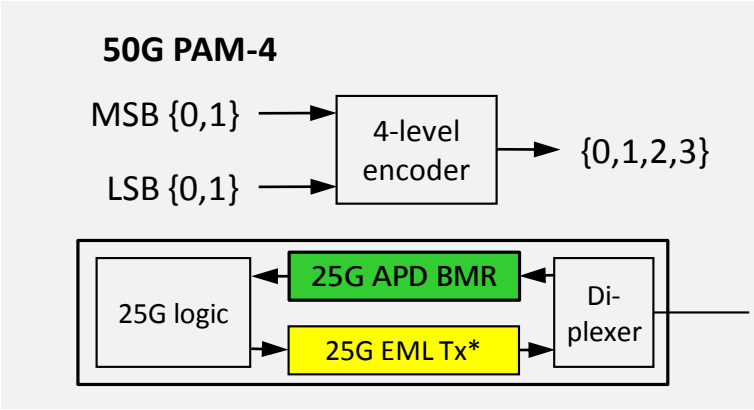


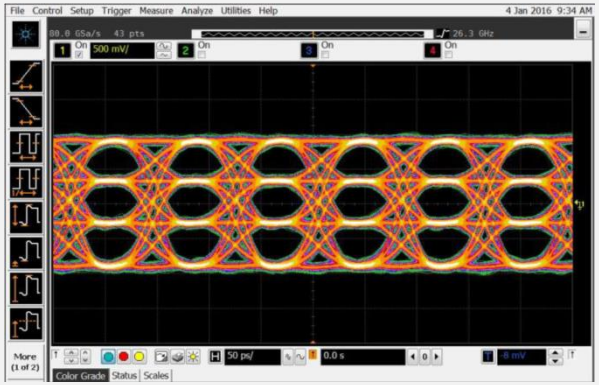




- DMT requires high linearity on the optics and complex DSP, cost is very high
- After long period debating and comparison, DMT has been beaten by PAM4 in Datacenter.

25GBaud PAM4

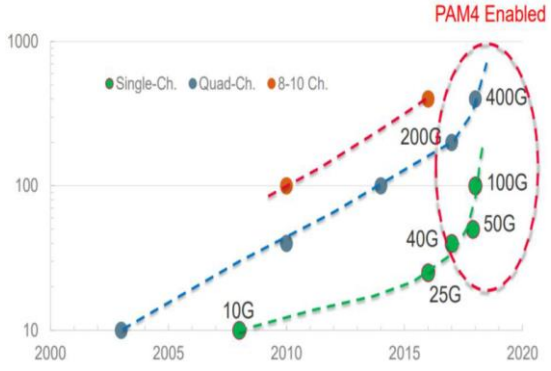




PAM4 application in Ethernet network for data center

		10GbE	25GbE	40GbE	50GbE	100GbE	200GbE	400GbE
500m	10G	-	-	-	-	-	-	-
	25G	-	-	-	-	-	-	-
	50G	-	-	-	-	-	4X50G	-
	100G	-	-	-	-	1X100G	-	4X100G
2km	10G	-	-	-	-	-	-	-
	25G	-	-	-	-	-	-	-
	40G	-	-	1X40G	-	-	-	-
	50G	-	-	-	1X50G	-	4X50G	8X50G
	100G	-	-	-	-	-		
10km	10G	1X10G	-	4X10G	-	-	-	-
	25G	-	1X25G	-	-	4X25G	-	-
	50G	-	-	-	1X50G	-	4X50G	8X50G
	100G	-	-	-	-	-	-	-
40km	10G	1X10G	-	4X10G	-	-	-	-
	25G	-	1X25G	-	-	4X25G	-	-
	50G	-	-	-	-	-	-	-
	100G	-	-	-	-	-	-	-

	Distance	Standard	Solution	Modulation
400G	100m	400GBASE-SR16 100m parallel MMF (16x25G NRZ)	16*25G	NRZ
	500m	400GBASE-DR8 500m parallel SMF (4x100G PAM4)	4*100G	PAM4
	2km	400GBASE-FR8 2km duplex SMF (8x50G PAM4 WDM)	8*56G	PAM4
	10km	400GBASE-LR8 10km duplex SMF (8x50G PAM4 WDM)	8*56G	PAM4



- PAM4 based on 25G optics , which is widely used in Ethernet network for datacenter, is the most mature technology for 50Gb/s per wavelength in industry

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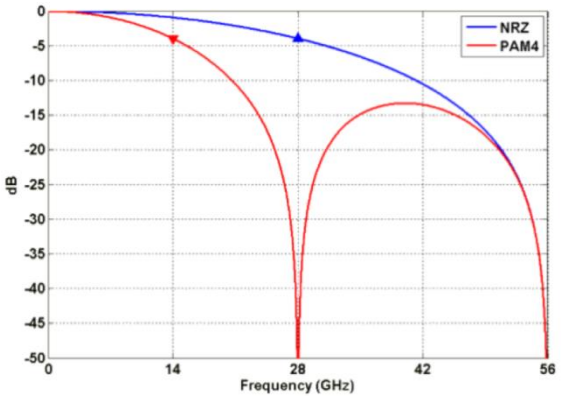
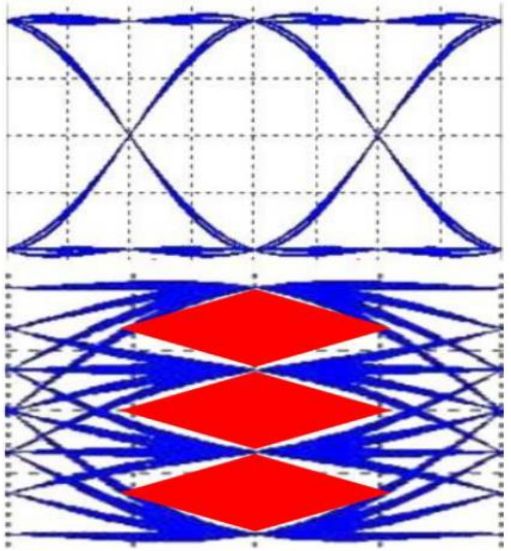
PAM4 band width requirement on optics

- **PAM4 eye width is not twice of NRZ**
  - The symbol duration of PAM4 is twice of that of NRZ
  - The achievable PAM4 eye width is only between 1/2 to 2/3 of the nominal eye width at the TX output
  - PAM4 needs 10~20% extra bandwidth than half of NRZ bandwidth in practical



- **The three vertical eyes are asymmetrical**
  - Even for a linear system, top and bottom eyes are not the same as the middle eye
  - Transitions are comprised of symmetrical and nonsymmetrical transitions
  - Impairments impact on the three eye is also different



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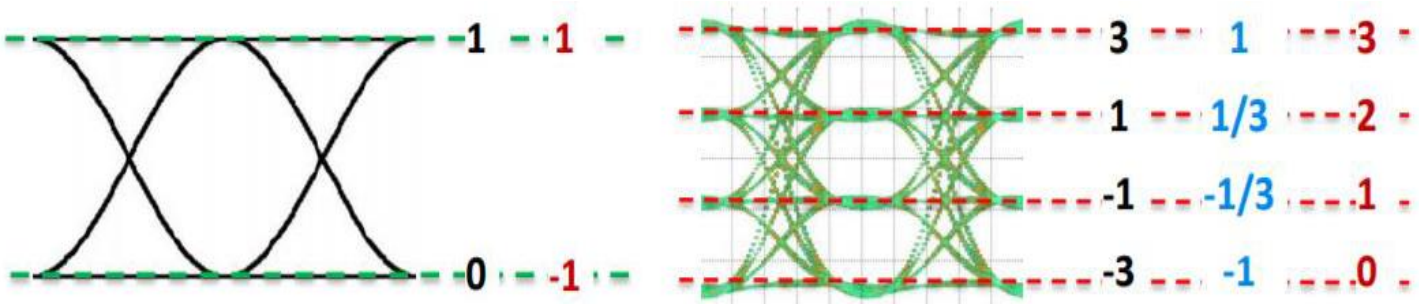
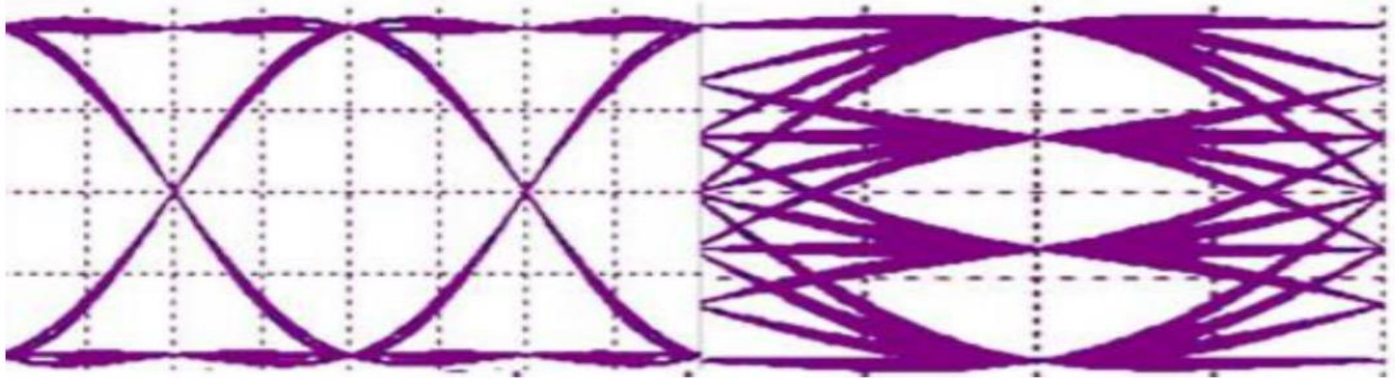
PAM4/NRZ sensitivity impact

- The eye height is 1/3 (4.8dB) of that of NRZ in theory



- In practice, the eye height degradation is more than 1/3 due to the nonlinearity



- There will be at least 6dB sensitivity degeneration from NRZ to PAM4 modulation.

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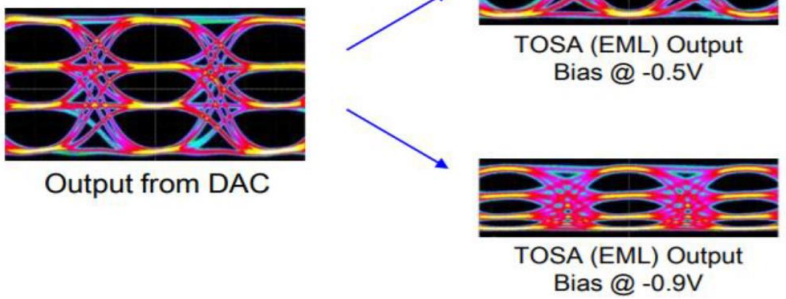
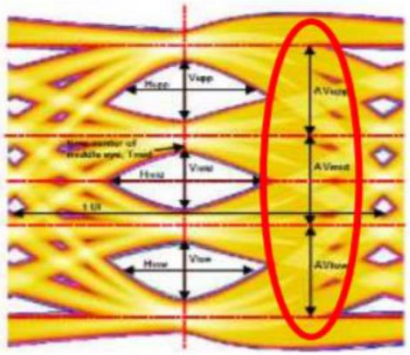
PAM4 Linearity requirement

- With the same output performance from the DAC, the optical performance will be subject to working conditions (e.g. bias etc) of components.
- Nonlinearity plays a much bigger role in PAM4; performance depends on the worst eye
- Nonlinearity starts right at TX output and each active block could add more
- The larger the signal, the more the nonlinearity becomes
- Adopting nonsymmetrical data and error slicers can help, but only to a certain extent



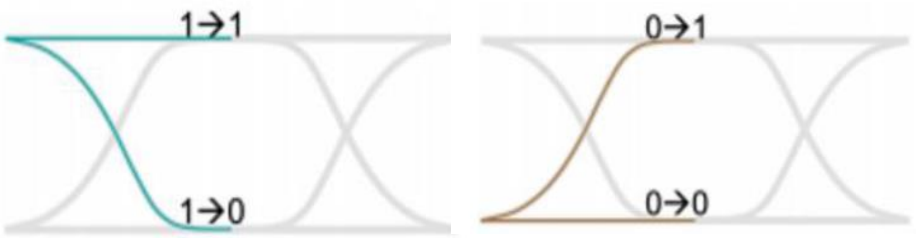


$$\text{Eye linearity} = \frac{\min(AVupp, AVmid, AVlow)}{\max(AVupp, AVmid, AVlow)}$$

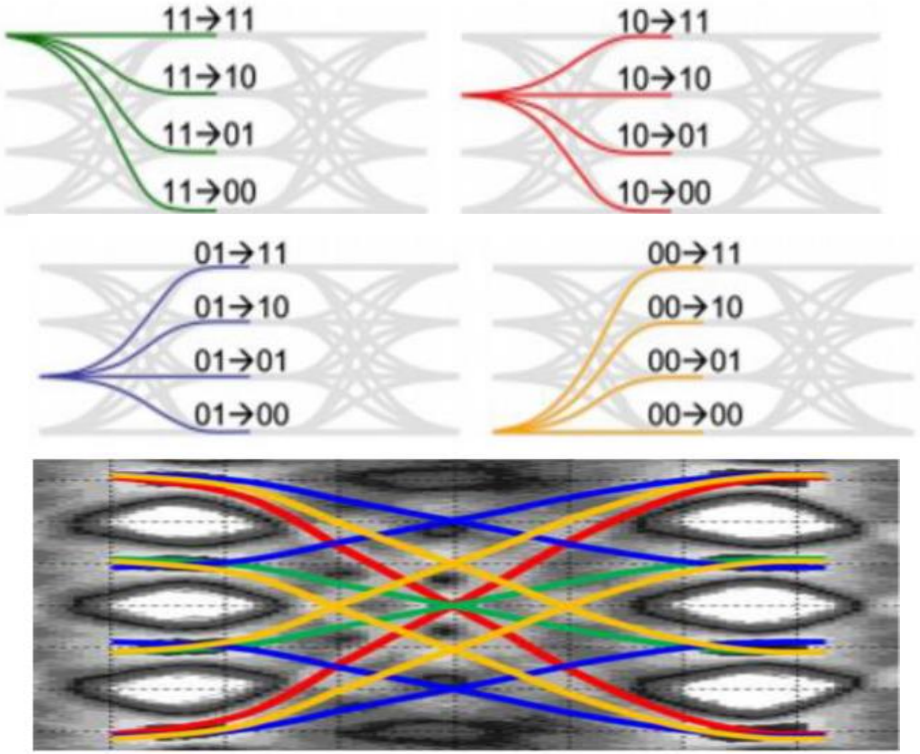
- DSP technology is required to compensate the nonlinearity of optics and decode the PAM4 signal

PAM4 CDR recovery

- NRZ signal transition is very simple



- PAM4 - Three groups of transitions
  - Major transitions: +3 ↔ -3
  - Minor transitions: +3 ↔ +1, -3 ↔ -1, +1 ↔ -1
  - Intermediate transitions: +3 ↔ -1, -3 ↔ +1
- PAM4 needs more time to recover the signal, longer burst overhead for upstream



50Gb/s PAM4 power budget analysis

ONU receiver sensitivity and OLT launch power specs.

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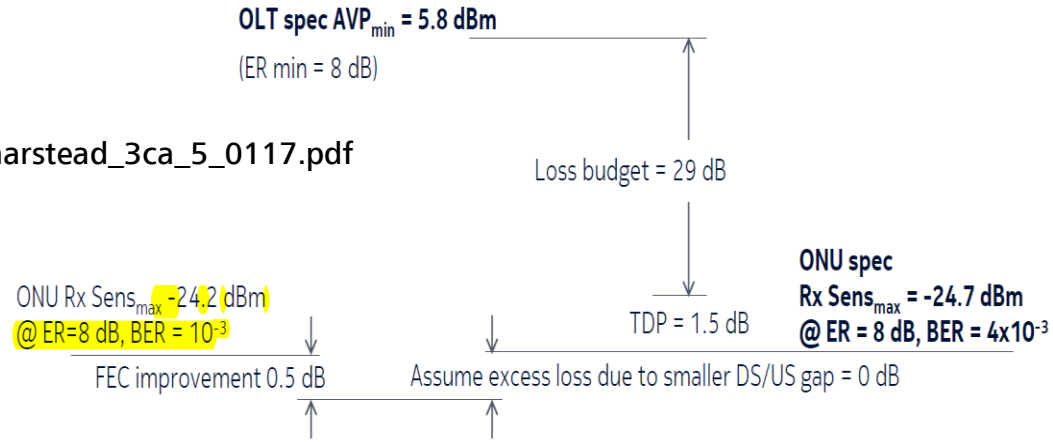
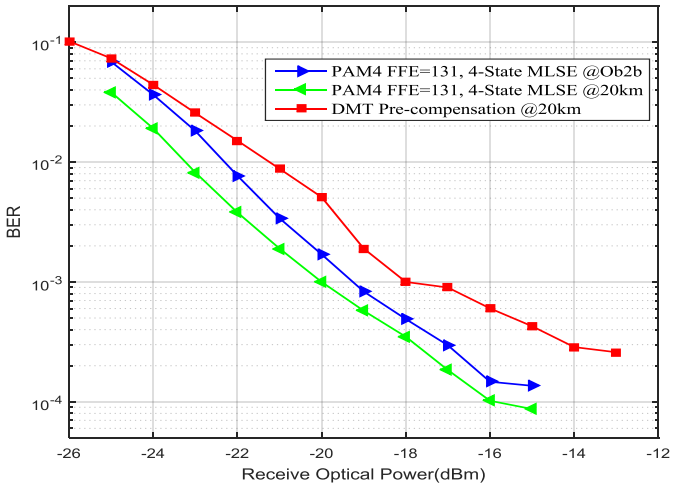


25G NRZ-> 50G PAM4: 5~6dB penalty
FEC 1E-3 ->1E-2 : 1.5~2 dB Gain

"50-Gb/s/λ TDM-PON Based on 10G DML and 10G APD Supporting PR10 Link Loss Budget after 20-km Downstream Transmission in the O-band", OFC. 2017.



- Take -20.7dBm@1E-2 as a starting point for 50G PAM4 analysis in continuous mode

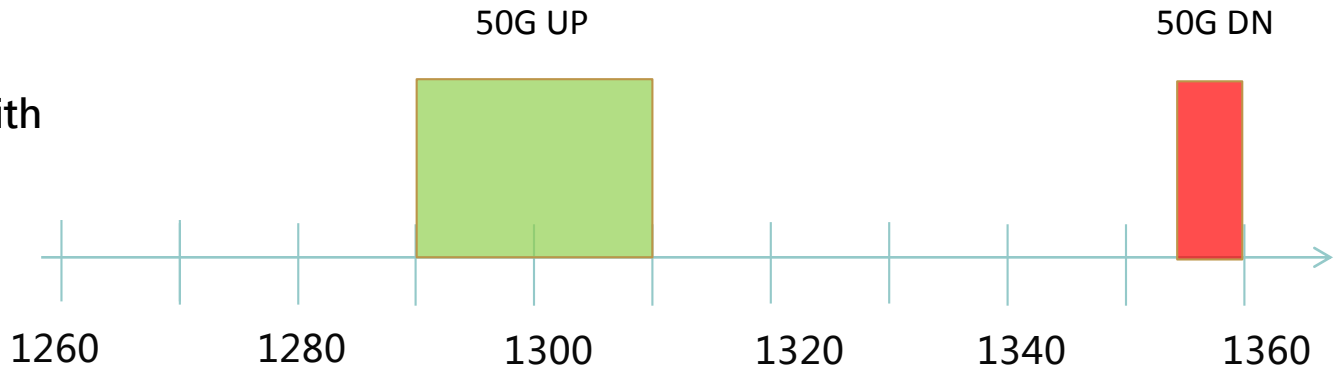
50Gb/s PAM4 power budget analysis

	Downstream	upstream
Bit rate	50Gb/s	50Gb/s
Modulation	PAM4	PAM4
Wavelength	1336nm	1270nm
Laser type	**25G EML**	**25G DML**
Launch power	**+9.8dBm (needs optical amplifier)**	**+12.3dBm (very difficult)**
Distance	20km	20km
TDP	1.5dB	2.5 dB
sensitivity	-20.7dBm@1E-2	-19.2dBm @1E-2 (burst mode)
Power budget	29dB	29dB

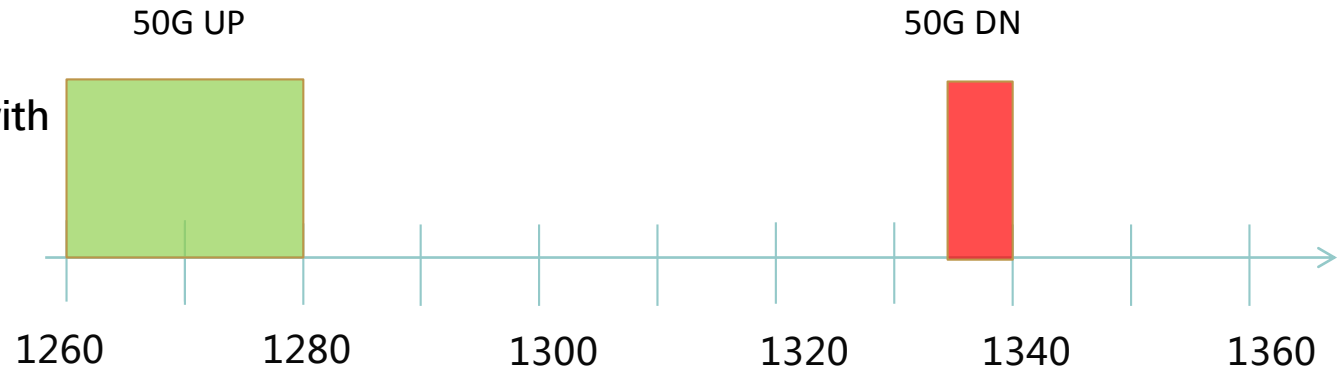
- 50Gb/s PAM4 still faces a high challenge to meet 29dB power budget
- The downstream is still possible to meet the power budget with an amplifier in OLT, but the upstream seems very very challenging!

50G wavelength plan example

Option 1:
WDM coexistence with XG(S)-PON basic wavelength set



Option 2:
WDM coexistence with XG(S)-PON optional wavelength set and GPON



Summary

- Several solutions for 50Gb/s per wavelength are analyzed, 50Gb/s per wavelength is a possible technical solution which could be used for PON application.
- 50G NRZ modulation suffers high dispersion penalty even in O-band, very high initial cost.
- PAM4 based on existing 25G optics seems one most promising technology for 50Gb/s which is adopted by Ethernet standard for datacenter, but more detail study are still needed for PON application :
  - Such as optics linearity requirement , burst mode recovery time
- Power budget issue will be the key challenge for 50Gb/s per wavelength , especially for the upstream power budget.

Thank you