DGD_{max} specification for 10km Ethernet

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800G LR4 DGD specification recap

- In the baseline of rodes_3dj_01_2307 DGD specifications have been recapped that were previously assumed in several contributions:
    - kuschnerov_3df_01b_221012 verified the DGD penalty for FFE and FFE+MLSE receivers and discussed PMD statistics in fibers
    - kuschnerov_3df_01a_2211 analyzed combined CD+PMD penalty and discussed cable segmentation
- Contrary to the several comments at the July 2023 plenary, at no point in time it was proposed to relax the DGD specifications, which stand at DGD_{max} = 5ps, DGD_{mean} = 1.33ps as per anslow_3cu_01_0519 derived on 802.3cu
- This penalty assumption leads to a 0.7dB penalty, which is part of the latest 800G LR4 link budget based on the FFE+MLSE receiver

DGD disconnect at July 2023 plenary discussion

- A disconnect between transmitter compliance specifications and channel specifications was brought up during the discussion, but wasn't resolved in the session
- The difference between the max DGD_{mean} spec of 0.8ps and DGD_{max} specification of e.g. 4ps for 400G LR4-6 or 5ps for 800G LR4 had to be explained

Table 151–12—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
400GBASE-FR4	$0.046 \times \lambda \times [1 - (1324 / \lambda)^4]$	$0.046 \times \lambda \times [1 - (1300 / \lambda)^4]$	Minimum	17.1 dB	0.8 ps
400GBASE-LR4-6	$0.138 \times \lambda \times [1 - (1324 / \lambda)^4]$	$0.138 \times \lambda \times [1 - (1300 / \lambda)^4]$	Minimum	15.6 dB	0.8 ps

[a] The dispersion is measured for the wavelength of the transmitter lane under test (λ in nm). The coefficient assumes 2 km for 400GBASE-FR4 and 6 km for 400GBASE-LR4-6.
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.
[c] The optical return loss is applied at TP2.

Table 151–13—Fiber optic cabling (channel) characteristics

Description	400GBASE-FR4	400GBASE-LR4-6	Unit
Operating distance (max)	2	6	km
Channel insertion loss[a, b](max)	4	6.3	dB
Channel insertion loss (min)	0	0	dB
Positive dispersion[b] (max)	6.6	19.9	ps/nm
Negative dispersion[b] (min)	−11.7	−35.2	ps/nm
DGD_max[c]	2.3	4	ps
Optical return loss (min)	25	22	dB

[a] These channel insertion loss values include cable, connectors, and splices.
[b] Over the wavelength range 1264.5 nm to 1337.5 nm for 400GBASE-FR4 and 400GBASE-LR4-6.
[c] Differential Group Delay (DGD) is the time difference at reception between the fractions of a pulse that were transmitted in the two principal states of polarization of an optical signal. DGD_max is the maximum differential group delay that the system is required to tolerate.

Clarification on DGD testing methodology

Clarification

- The 0.8ps max DGD_{mean} specification goes way back to at least Clause 88 for 100GBASE-LR4, where it was introduced for the compliance channel for TDP
- The Tx compliance channel specifies the DGD_{mean} to be minimized to 0.8ps max to avoid failing Tx's due to DGD which is a fibre impairment – not a Tx impairment.
- The actual channel (deployed in the field) needs to have the actual DGD specified which is 5ps for the LR4. The penalty from DGD is then added to the link budget.
- This is similar to MPI where the Tx is not screened against MPI but the link budget has an MPI penalty as it is a channel impairment.

Conclusions

1. 800G LR4 can adopt DGD=0.8ps for transmitter compliance testing regardless of the actual DGD_{max} specification
2. A linear FFE reference equalizer becomes feasible (see stojanovic_3dj_01_2307 , liu_3dj_01_2307 for added input on CD penalty)

10km Ethernet – the case for modeling link segmentation

- ITU-T defines PMD_Q, which is the PMD coefficient that will be exceeded by less than 0.01% of links made up of M=20 cable sections in series
- kuschnerov_3df_01a_2211 discussed the impact of link segmentation on the DGD_{max} parameter
- liu_3dj_01_2307 applied this principle to propose a CD_Q parameter
- July 2023 straw poll showed strong support for CD_Q methodology based on link segmentation motions_3cwdfdj_2307

➔ DGD_{max} could be also adapted for 10km Ethernet assuming link segmentation

kuschnerov_3df_01a_2211

Operator fiber deployment statistics

- Initial survey of tier 1 operators indicates following design rules:
  - Operator 1: **≤3km** cable length
  - Operator 2: **≤5km** cable length (see figure)
  - Operator 3:
    - **≤2.4km** cable length in access networks
    - **≤4.8km** cable length in backbone networks
  - Operator 4: **~6km** cable length (Backbone LEAF, deployment in 2000)
  - Operator 5: **≤3km** cable length
  - Operator 6: **≤2km** cable length
  - Operator 7: **≤6km** cable length in metro core (2-3km typ)
- **Assumption**: A 10km single section cable assumption might be an unrealistic scenario for access/LR links

➔ The initial data suggests a further study on access vs. backbone networks and information gathering from more operators

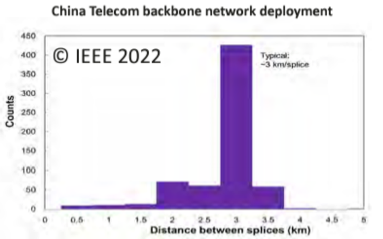


Figure taken from:
Chengliang Zhang et al., "Optical Layer Impairments and Their Mitigation in C+L+S+E+O Multi-Band Optical Networks With G.652 and Loss-Minimized G.654 Fibers", Journal of Lightwave Technology, Vol. 40, No. 11, June 1, 2022, page 3415 ff
https://ieeexplore.ieee.org/document/9756341

motions_3cwdfdj_2307

I support the use of the CD_Q methodology (with values TBD) as described in johnson_3dj_01a_2307 and liu_3dj_01_2307 to specify chromatic dispersion (CD) for initial baseline specifications for 200G per lane PAM4 PMDs

A: Yes

B: No, wait for more accurate CD_Q values from ITU-T

C: No, continue to use traditional worst case CD values

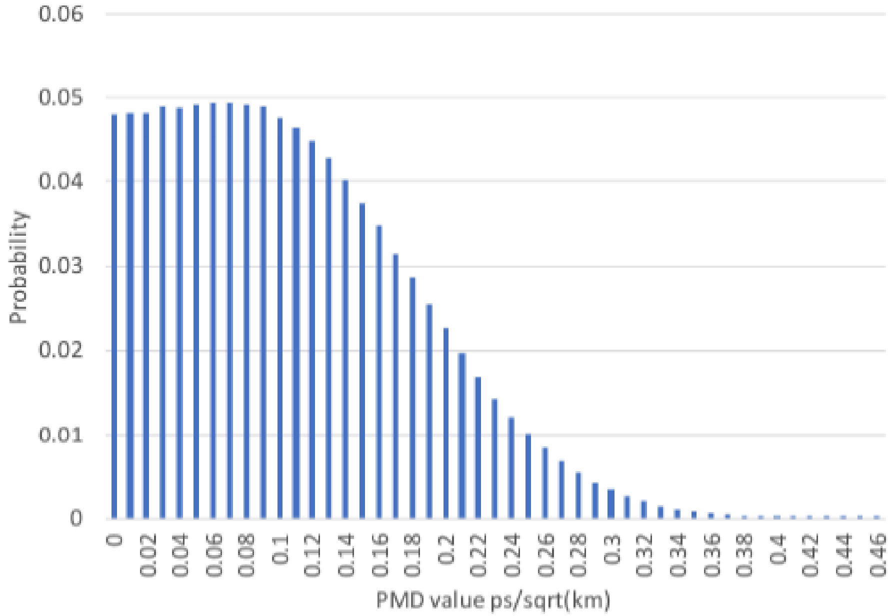
D: Abstain

Results (all): A: 72, B: 8, C: 1, D: 33

Fiber PMD coefficient recap

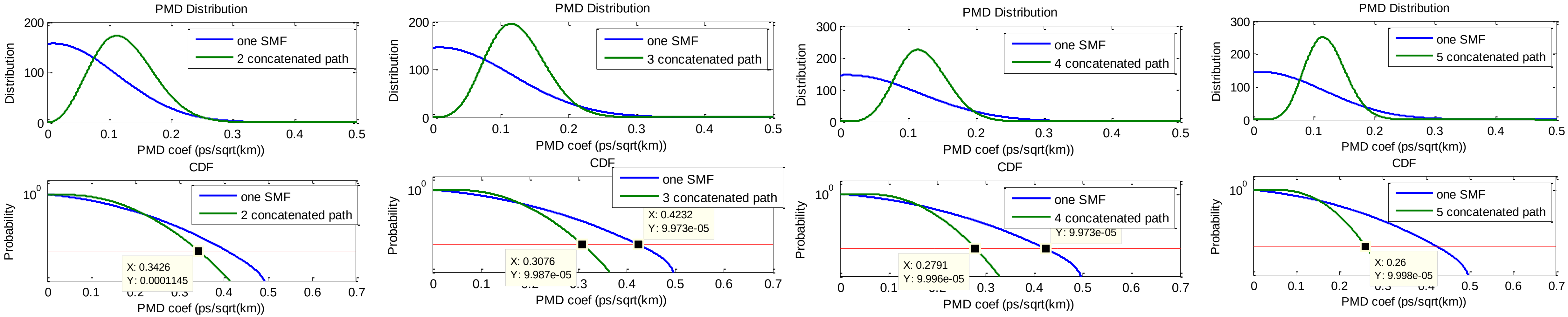
- kuschnerov_3df_01a_2211 showed an overview of max PMD coefficients for individual fibers, which were all ≤ 0.2ps/√km for uncabled fiber
- anslow_3cu_01_0519 proposed a hypothetical distribution for a single segment PMD for cabled fiber, which was derived from ITU-T PMD_Q
- The derived individual fiber "PMD_Q" at Q=1e-4 was 0.43ps/√km → @10km corresponding to a DGD_{mean} ≈ 1.33ps, DGD_{max} = 5ps
- There is no comprehensive analysis on cabled fibers available, which would allow us to assume lower PMD values than 0.43ps/√km for now

anslow_3cu_01_0519



DGD_{max} for 10km & different cable sections

- Since cabled fibers are typically manufactured with length of 2~3km, we calculate DGD_{max} for 10km when the link is composed of different number of cable sections **M**.
- Single segment PMD distribution is modelled after anslow_3cu_01_0519 with Q=1e-4



S=3.75*	M=1	M=2	M=3	M=4	M=5	M=6	M=7
PMD_{max} [ps/√km]	~0.43	0.34	0.3076	0.279	0.26	0.246	0.235
DGD_{max} [ps]	5	4	3.65	3.3	3.08	2.9	2.8

Note:

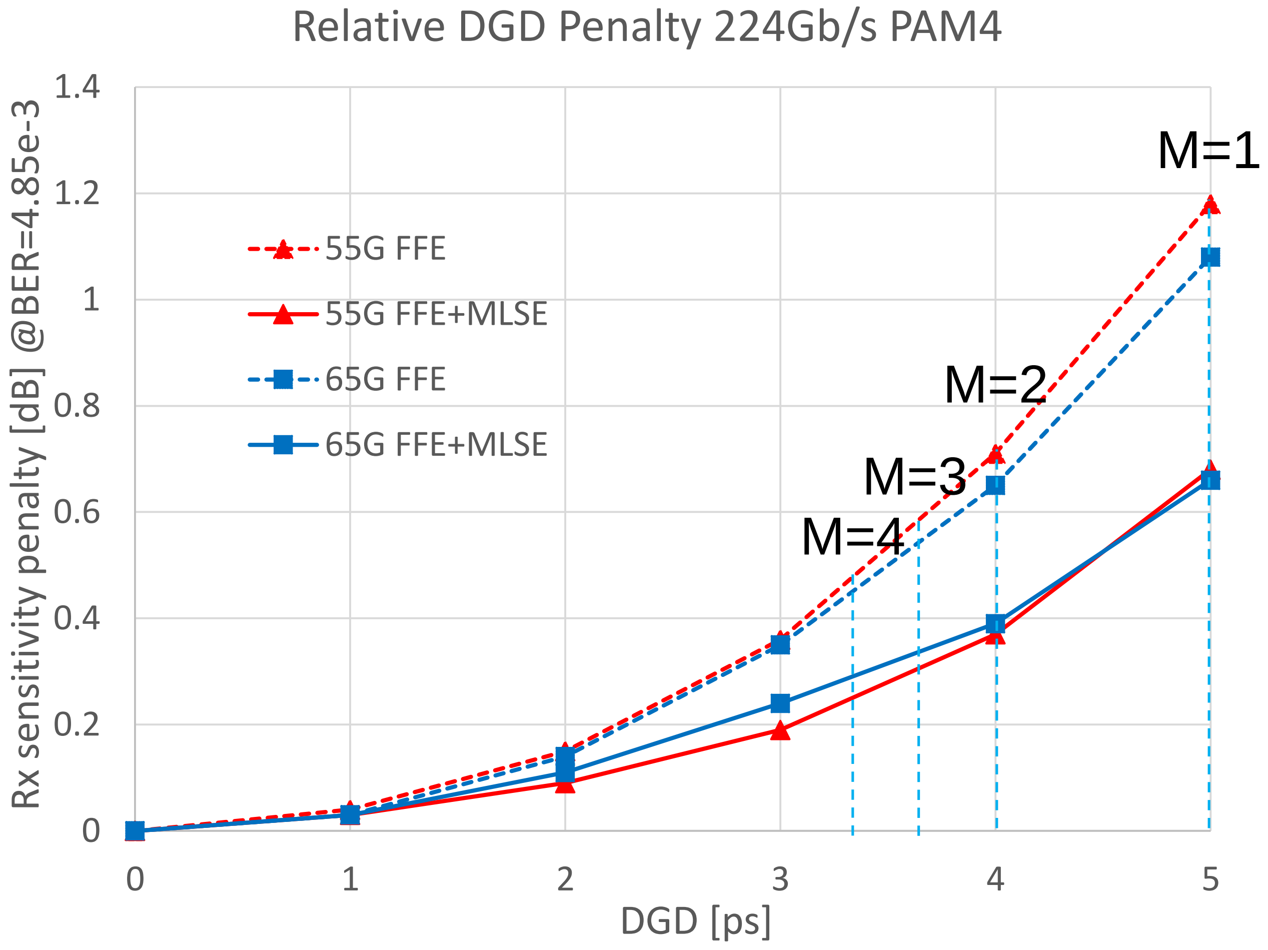
S: he ratio of DGD_{max} to DGD_{mean}. Set to S=3.75 according to anslow_01_0308, which corresponds to an outage probability of 8.21e-8

DGD_{max} = DGD_{mean} * S = PMD_{max} * sqrt(10km) * S

DGD penalty for varying number of segments M

- The original single segment (M=1) PMD penalty was based on a FFE+MLSE receiver (0.7dB)
- Assuming multiple segments, a linear equalizer would be sufficient to achieve acceptable performance
- Given the available data and pending further discussion by the industry M=4 seems to be a reasonable assumption
- M=4 can achieve a penalty of ≤0.5dB with an linear FFE equalizer

kuschnerov_3df_01b_221012



Conclusions

Proposal for 800G LR4

1. Adopt a Max DGD_{mean}= 0.8ps (or lower) for transmitter compliance testing
2. Adopt a DGD_{max} = 3.3ps for 10km Ethernet around the growing consensus of M=4 and Q=1e-4
3. Update PMD penalty in 800G LR4 baseline to 0.5dB based on a FFE linear filter

Further discussion

- Discuss FFE-only reference equalizer for 800G LR4 pending tap number (to be verified on real hardware; see rodes_3dj_02b_2305)

Thank you.