800G LR4 DGD penalty and fiber specifications

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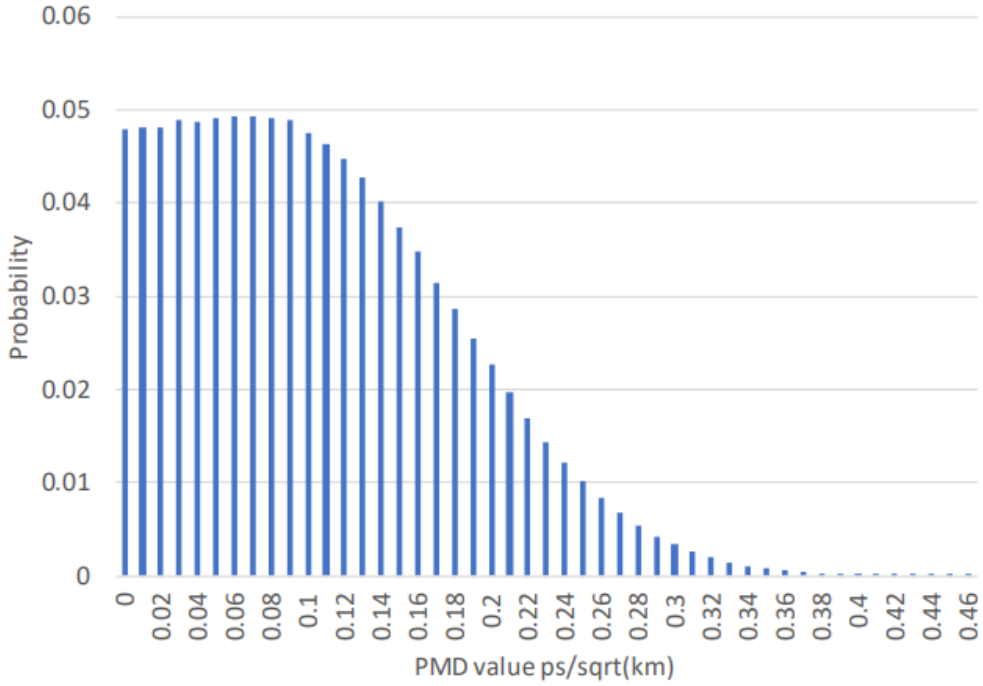
Historical evolution of LR DGD specifications

- 802.3ba (100G-LR4), 802.3bs (200G-LR4, 400G LR8), 802.3cd (50G-LR) specified **DGD_{max} = 8ps**
- In shuai_3cu_adhoc_050119 100G PAM4 DGD penalty at 8ps was analyzed to be 0.6dB, potentially requiring additional penalty allocation.
- In anslow_3cu_01_0519 it was argued that G.652.B and G.652.D fibers with a maximum PMD_Q of 0.2 ps/√km represent the bulk of the deployments and a new specification **DGD_{max} = 5ps** was derived (DGD_{mean} = 1.33ps) for 802.3cu (100G-LR1) with a penalty of <0.25dB
- In zhang_3df_01b_2207 the impact of first and second order DGD on 200G PAM4 was analyzed with the conclusion that maximum first order PMD leads to the largest system penalty
- This contribution targets a further analysis of 200G PAM4 DGD penalties

Current LR DGD specification derivation

- anslow_3cu_01_0519 derives the latest DGD specification from ITU-T's PMD_Q = 0.2ps/√km for G.652.B/D
  - PMD_Q serves as a statistical upper bound for the PMD coefficient of M=20 concatenated optical fiber cables and can be exceeded in 0.01% percent of all fibers
  - In ITU-T it is noted that PMD_Q should not be applied to short cables
  - For 1 cable section the PMD coefficient is derived as 0.43ps/√km (probability of 0.012% to exceed that)
- 100G-LR1 DGD specification
  - Assumes a certain distribution to match PMD_Q = 0.2ps/√km to derive a PMD coefficient for 10km
  - A single cable section 10km link was taken as the basis (worst case assumption for PMD coefficient)
  - Information on actual fiber DGD statistics was not available

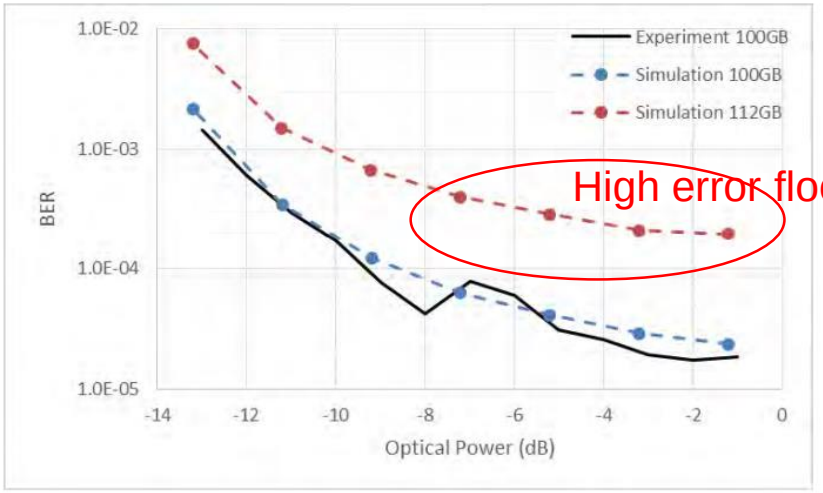


Anslow_3cu_01_0519 (slide 8)

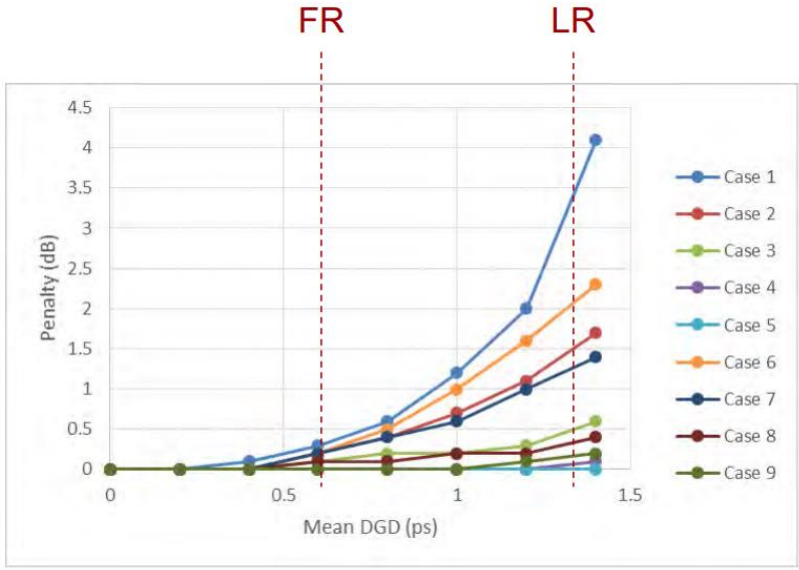
DGD_{mean} (LR-10km) = 0.43ps/√km * √10km = 1.36ps
DGD_{max} / DGD_{mean} ≈ 3.75
DGD_{max} (LR-10km) = 1.36ps *3.75 ≈ 5ps
DGD_{max} (LR-6km) ≈ 4ps

Previous analysis on 200G PAM4 DGD penalty

- zhang_3df_01b_2207 made a first attempt to analyze PMD penalty for 200G PAM4
- For DGD_{max} = 5ps the Rx sensitivity penalty at was deduced to be ~3.4dB
  - ❑ 2e-3 FEC threshold
  - ❑ FFE-only equalization was used
- However, the results shown raise doubt
  - ❑ 112Gbaud Rx sensitivity has a high error floor > 1e-4, likely caused by limited bandwidth
  - ❑ Penalty estimation on top of a high error floor usually leads to larger penalties
  - ❑ The absolute Rx sensitivity doesn't resemble technical evidence on optical 224Gb/s PAM4 presented so far in IEEE since a PDFA was used instead of an TIA



Zhang_3df_01b_2207 (slide 9)



Zhang_3df_01b_2207 (slide 10)

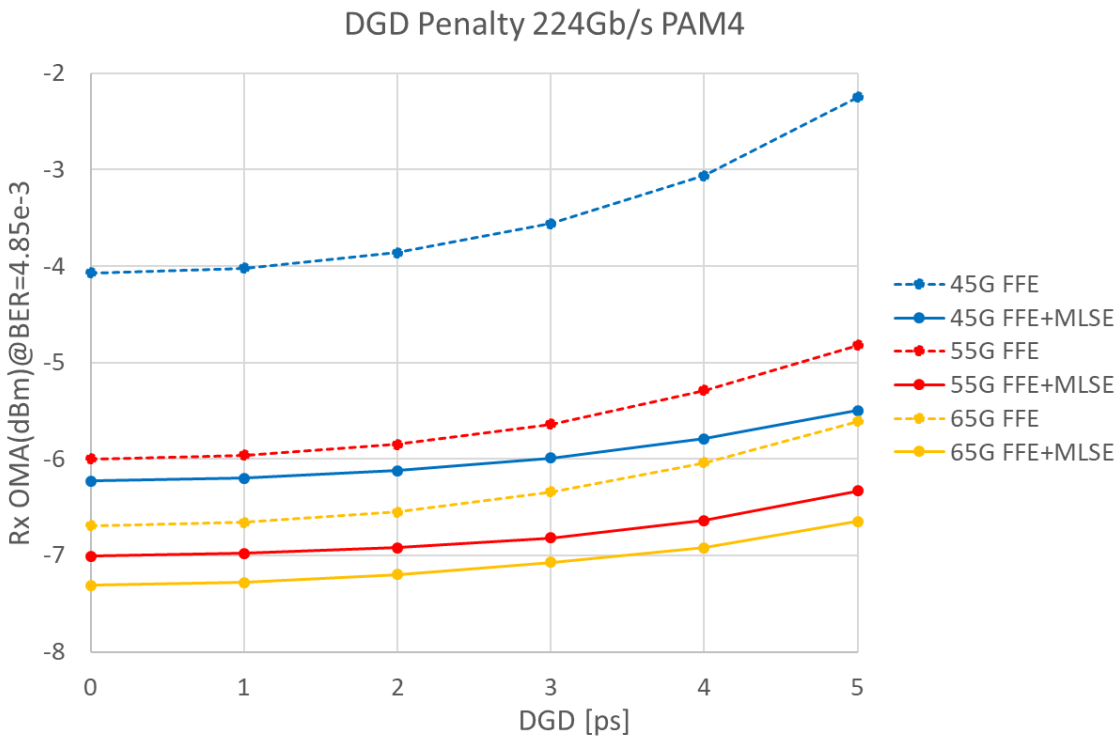
200G PAM4 DGD penalty simulation

Component parameters

- ❑ DAC / driver / EML / PIN / ADC – 4th order Bessel filter with 3dB bandwidth of 45GHz, 55GHz, 65GHz.
- ❑ DAC/ADC ENOB = 5
- ❑ EML ER = 5dB
- ❑ PIN Responsivity = 0.75 A/W
- ❑ PIN Dark current = 20nA
- ❑ PIN thermal noise density = 15 pA/√ Hz
- ❑ Signal aligned with 45deg vs. fast and slow DGD axis (worst case)

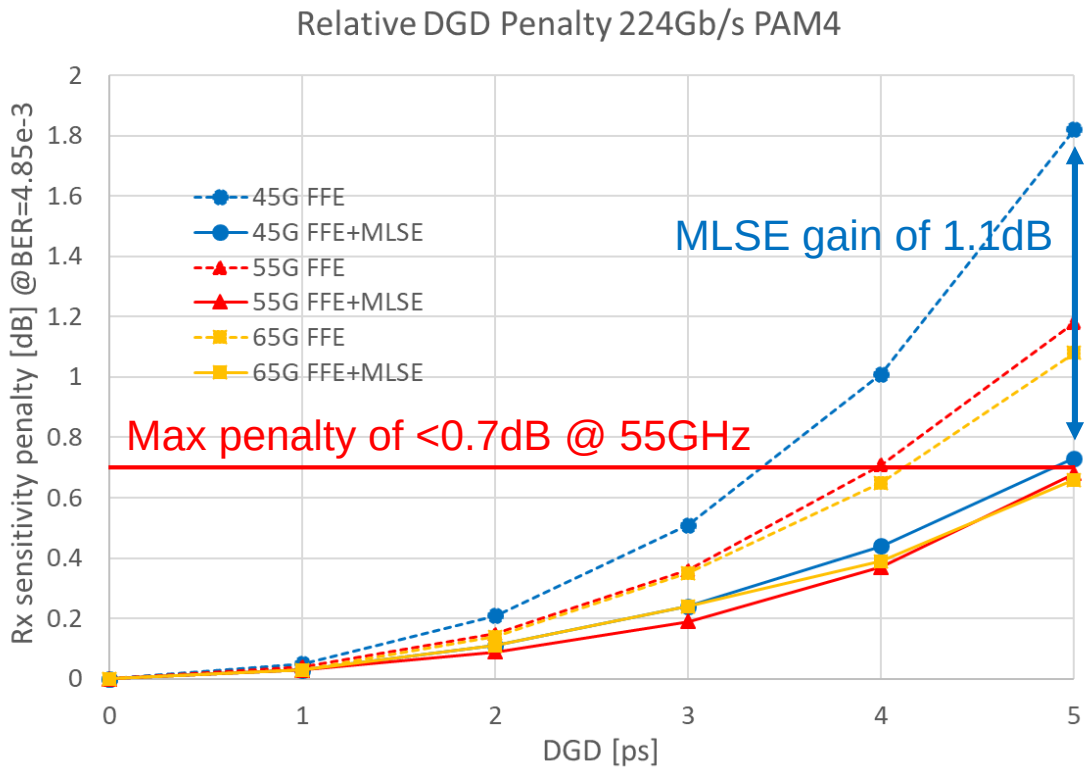
Rx DSP

- ❑ FFE + partial response filter + MLSE w/ blind training
- ❑ FEC threshold: 4.85E-3 assuming RS(544,514)+ Hamming (128,120) as in patra_3df_01a_2207



200G PAM4 DGD penalty

- For low bandwidth, MLSE brings a big improvement vs. FFE-only Rx at DGD=5ps (see zhang_3df_01b_2207)
- For realistic component 3dB bandwidth of 55GHz, penalty for FFE+MLSE is <0.7dB at DGD = 5ps
- If a DGD penalty of around **0.7 dB** is reconfirmed, we need to address how to take account of it, by either improving the power budget to maintain a channel loss of 6.3 dB or alternatively reduce the target distance
- Further work is needed to analyze how much penalty should be allocated in 800G-LR4 link budget



PMD coefficient spooled fiber

- Current DGD LR specifications assume an individual fiber PMD_Q = 0.43ps/√km
- Many popular spooled fibers have maximum PMD coefficients for individual fibers of 0.1ps/√km (see figure below)
- Most specs indicate that PMD values may change when the fiber is cabled (e.g. see reference in Corning SMF-28 ULL Optical fiber (G.652B/C))

Supplier	Country	Representative Fiber	Design PMDq (ps/sqrt (km)	Max_PMDq Individual Fiber (ps/sqrt (km)
Corning	US	SMF28 Ultra	0.04	0.1
YOFC	China	FullBand Ultra LL	0.06	0.1
OFS (Furukawa)	Japan	AllWave Low Loss	0.04	0.1
HTGD	China	BoneCom LL G652.D	0.06	0.1
Fiber Home	China	FiberHome ULL	0.04	0.1
Prysmian	Italy	BendBright-XS	0.06	0.1
Fujikura	Japan	FutureGuide	0.04	0.1

Source: Rangchen Yu, SiFotonics

Effect of fiber cabling on PMD coefficient

- Historically the PMD value measured on the shipping spool has often been referred to as the fiber PMD
- Spooling of fiber influences the PMD value: bending, rewind tension, pressure and crossing of windings [1]
- PMD level in spooled fibers can be lower or higher than in cabled fibers [1]
- Figure on the right shows a measured statistical relation between spooled and cable fiber [1]
- A decrease of maximum overall PMD values is observed

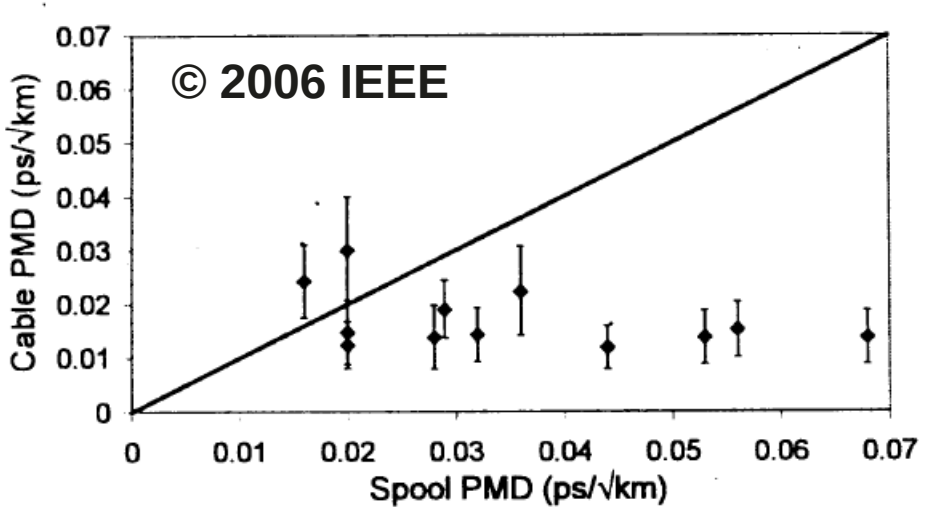


Figure 4. Corresponding spool and cable PMD measurements on 12 spun low PMD fibres. The cable PMD is the averages of 21 measurements on each fibre during a temperature cycling test from –40°C to 75°C.

[1] Tommy Geisler, "Low PMD Transmission Fibers", European Conference on Optical Communications (ECOC) Cannes, France, Sep 2006.

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Maximum Individual Fiber PMD coefficient – cabled fiber

Information provided from [1]

- Analysis of fiber PMD and cabled fiber PMD
- AllWave fiber is G.652D with 12 km loose tube cables (single section)
- Distribution shape is different as assumed in the 100G LR1 DGD specification derivation (see page 3)
- Overall statistics show that the distributions of spooled and cabled fibers are very similar

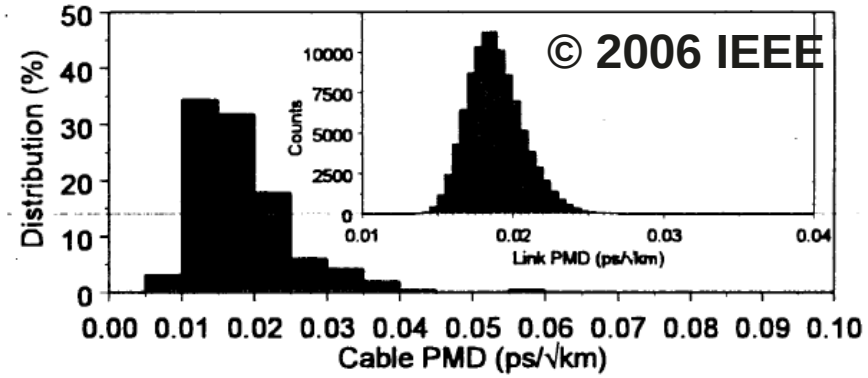

Figure 7. The PMD coefficient distribution for 264 AllWave® fibres in 12 km loose tube cable. The inset shows the PMD link distribution. The resulting LDV is 0.028 ps/√km.

[1] Tommy Geisler, "Low PMD Transmission Fibers", European Conference on Optical Communications (ECOC) Cannes, France, Sep 2006.

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Conclusions

- DGD penalty for 200G PAM4 at 10km was analyzed
- Using a stronger FEC, FFE+MLSE receiver and larger bandwidth components, the previously stated DGD penalty of 3.4dB can be significantly decreased
- KP4 + soft Hamming FEC improve the margins and require a soft output MLSE
- 0.7dB additional link budget would have to be considered for the reference 802.3cu DGD spec of DGD_{max} = 5ps
- Analyzing actual fiber data (primarily for G.652B/D) shows that the effective DGD penalty at 10km should be lower in practice

Thank you.