Reassement of FR4/LR4-6 Reach Specs, Are We on the Right Track?

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P802.3cu 100 Gb/s and 400 Gb/s over SMF at 100 Gb/s per Wavelength Task Force

31 March 2020

400G-FR4/LR4-6 Overview

FR4/LR4-6 status

- Current 400G-FR4 & LR4-6 appear in QSFP-DD market
- Supports 2km & 6km reach applications
  - 4 wavelengths CWDM EML and PIN
  - 400GAUI-8 electrical interface
  - QSFP-DD type 2 housing
  - Typically non-hermetic COB technology

Is it viable to extend for 400G-LR4 at 10km?

- For uncooled CWDM grid preferred by users at 53GBd PAM4, the debate of chromatic dispersion penalties represent a significant issue for reaches of 10 km
- The market seems to require full 10km interoperable solutions with margin.
- This presentation look into real field transceivers, and explore the possibility for extension to 10km.

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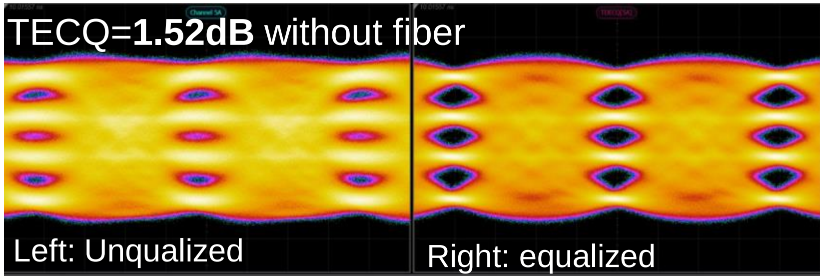
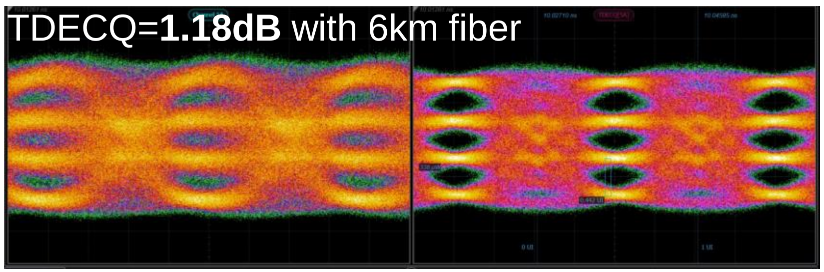
400G LR4-6 TX TDECQ Performance (SSPRQ)

L0=1273.88nm

TECQ=**1.52dB** without fiber

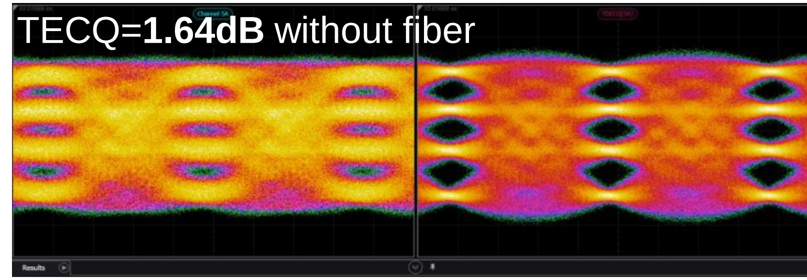


TDECQ=**1.18dB** with 6km fiber

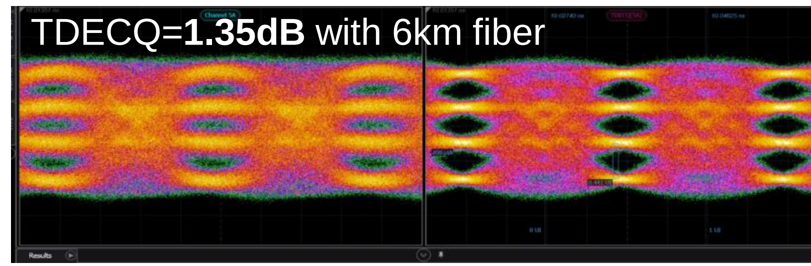


L1=1291.69nm

TECQ=**1.64dB** without fiber

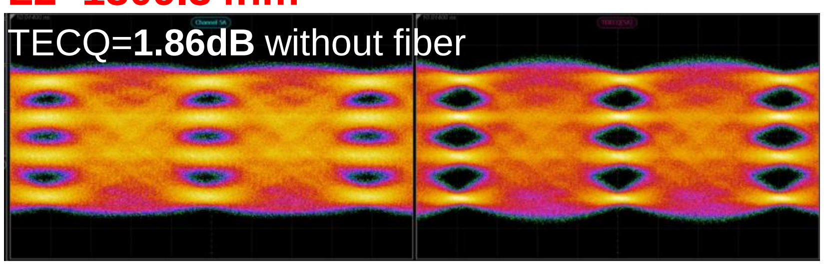


TDECQ=**1.35dB** with 6km fiber

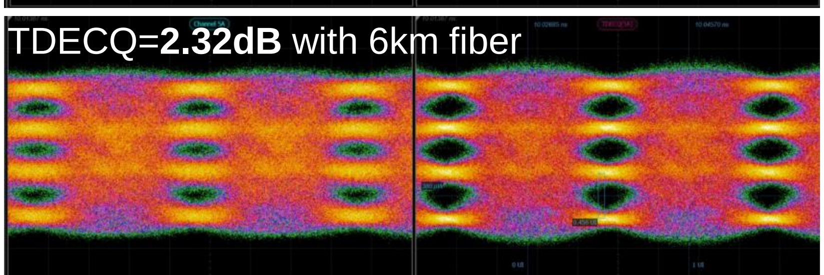


L2=1309.34nm

TECQ=**1.86dB** without fiber

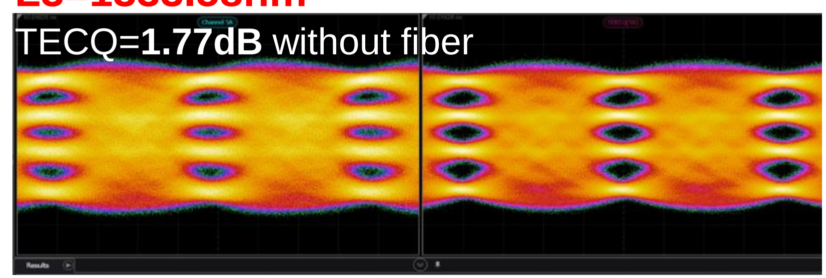


TDECQ=**2.32dB** with 6km fiber

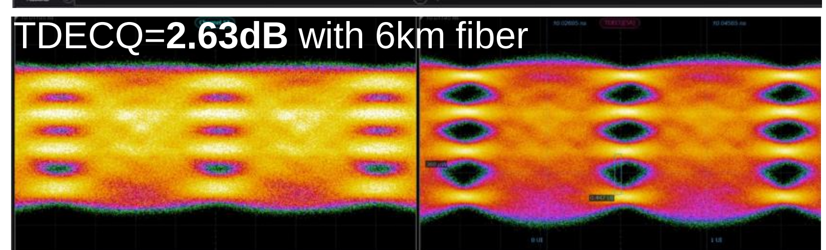


L3=1333.58nm

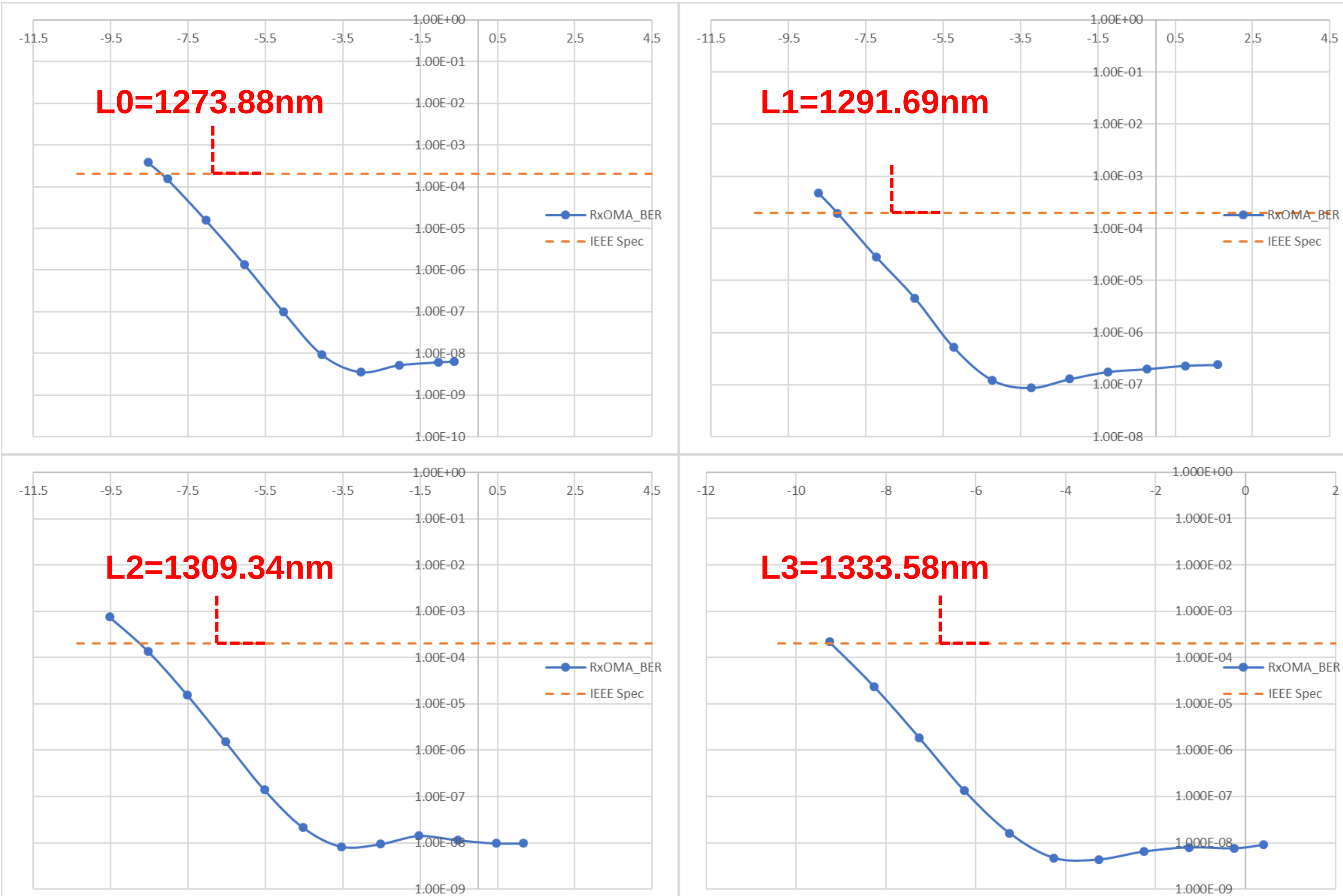
TECQ=**1.77dB** without fiber



TDECQ=**2.63dB** with 6km fiber



400G LR4-6 Rx OMA Performance



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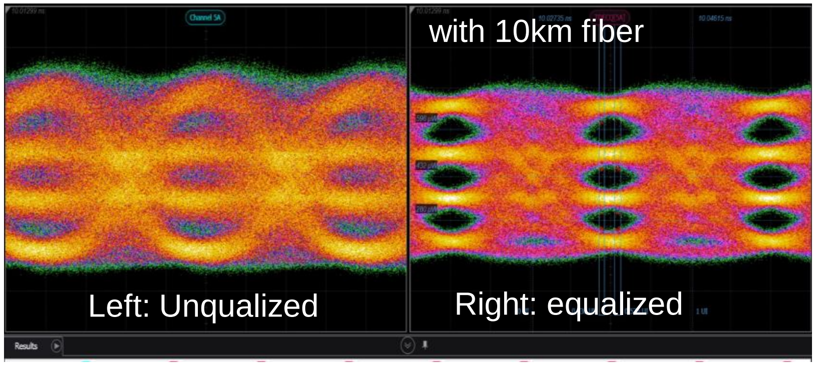
400G LR4-10 TDECQ Results

L0=1273.88nm

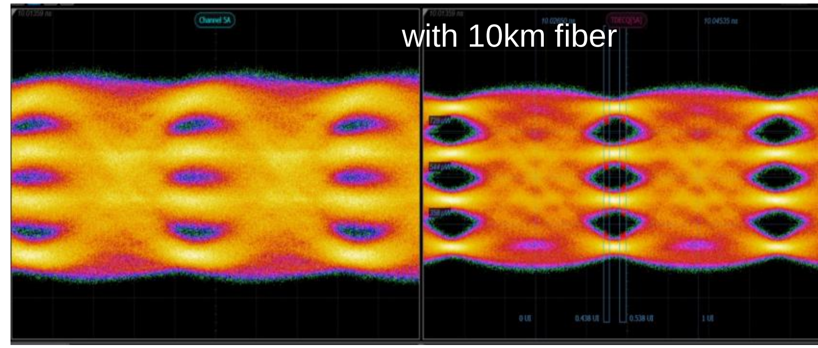
TDECQ=1.23dB (negative dispersion)



(Note: TECQ=**1.52dB)**

L1=1291.69nm

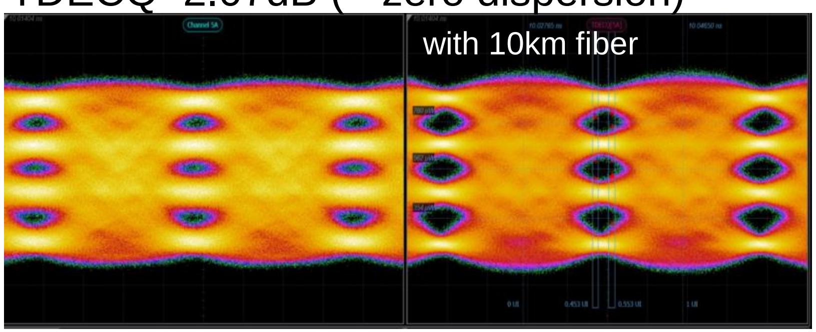
TDECQ=0.87dB (negative dispersion)



(note: TECQ=**1.64dB**)

L2=1309.34nm

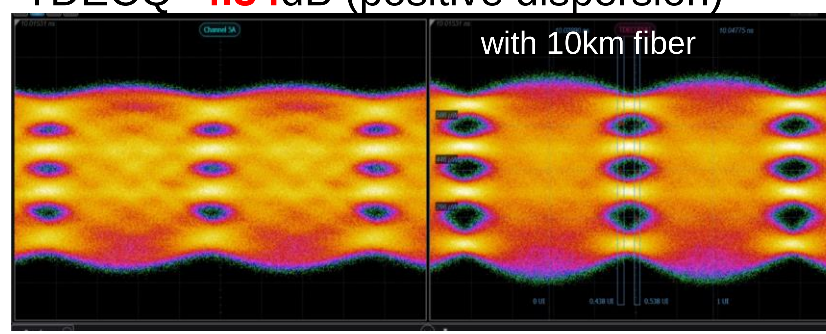
TDECQ=2.07dB (~ zero dispersion)



(Note: TECQ=**1.86dB)**

L3=1333.58nm

TDECQ=**4.34**dB (positive dispersion)



(Note: TECQ=**1.77dB)**

L3 fails TDECQ specs of <3.9dB for 10km due to positive dispersion!

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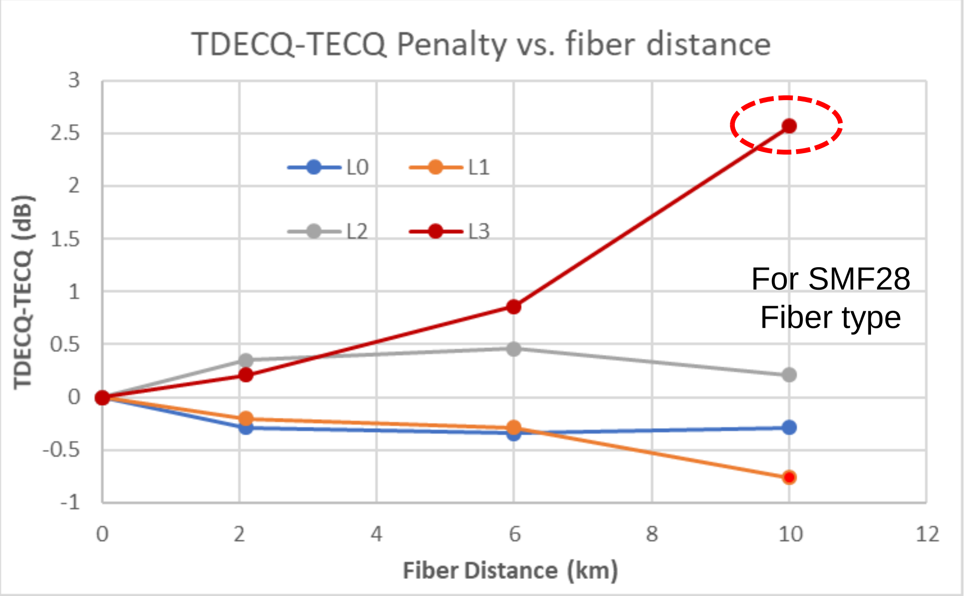
400G LR4 10km Challenges

Key consideration for challenges

- 400G LR4 6/10km has worst case CWDM dispersion window from **-35.6/-59.4 to +20.1/33.4ps/nm**.
- EMLs typically show positive chirp by nature, so L3 run into largest CD penalty.
  - SiPho MZ implmentation is normally close to zero chirp, so L0 could show worst case CD penalty.



TDECQ-TECQ varies with SMF28 dispersion

Dispersion	TDECQ	TDECQ-TECQ
Corning 10km (CD ~ 25.7ps/nm)	3.5dB	1.73dB
Corning 10.5km (CD ~ 28.0ps/nm)	4.34	2.57
Corning 10.6km (CD ~ 28.3ps/nm)	4.31	2.54
OFS 12.3km (CD~25.2ps/nm)	3.64	1.87

L3 CD penalty across various ~10km fibers

400G LR4 10km Challenges

- IEEE P802.3cu specifications look right for 6km reach.
  - There could exist interop challenge for 10km.
  - Primarily problem due to weaker Rx equalizer of **5 FFE** taps

L3 CD penalty across various ~10km fibers

Dispersion	TDECQ	TECQ	TDECQ-TECQ	10*log10(Ceq)	TDECQ-10*log10(Ceq)
Corning 10km (CD ~ 25.7ps/nm)	3.5dB	1.77	1.73dB	0.28	3.22
Corning 10.5km (CD ~ 28.0ps/nm)	4.34	1.77	2.57	0.48	3.86
Corning 10.6km (CD ~ 28.3ps/nm)	4.31	1.77	2.54	0.5	3.81
OFS 12.3km (CD~25.2ps/nm)	3.64	1.77	1.87	0.37	3.27

- Practically 10km link can be closed using real chip implementation of **≥10 FFE** taps. Actual BER test results normally show smaller CD penalty, e.g.
  - CIG (lewis_cu_adhoc_041719) with 0.85dB for L3 +chip EML
  - Intel (schube_3cu_01_0519) with L0 0.7dB for L0 –chirp SiPho

Recap 400G LR4 10km Results so far

- As reviewed in anslow_3cu_02a_0519, the TDECQ-TECQ is more than 2.5dB for 10km transmission with CWDM grid.
- Dispersion penalty can be too large to support 10km over CWDM wavelength.
- In Draft 2.0 of 400GBASE-LR4-6, the |TDECQ-TECQ| penalty is defined within 2.5dB for 6km.

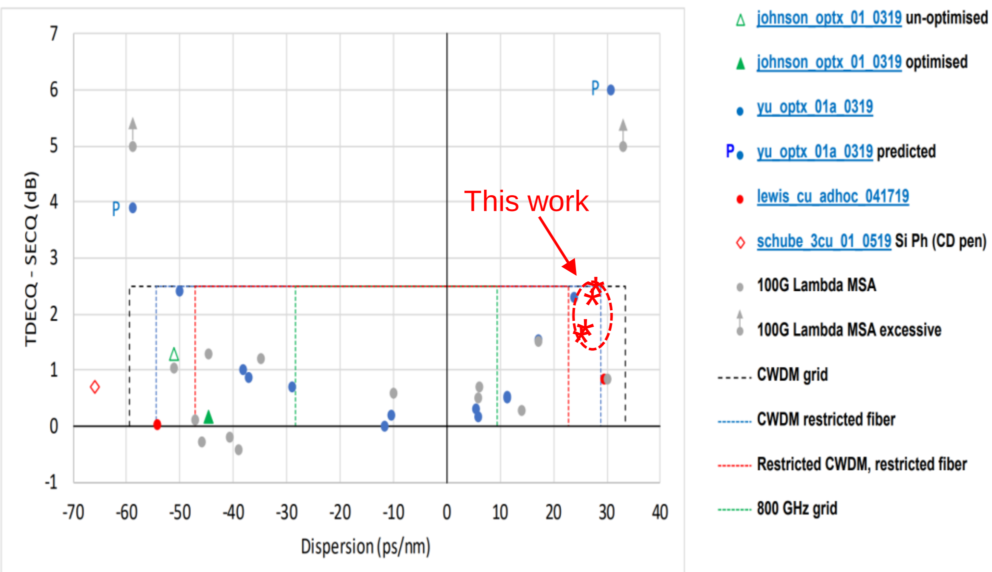


Table 151–7—400GBASE-FR4 and 400GBASE-LR4-6 transmit characteristics

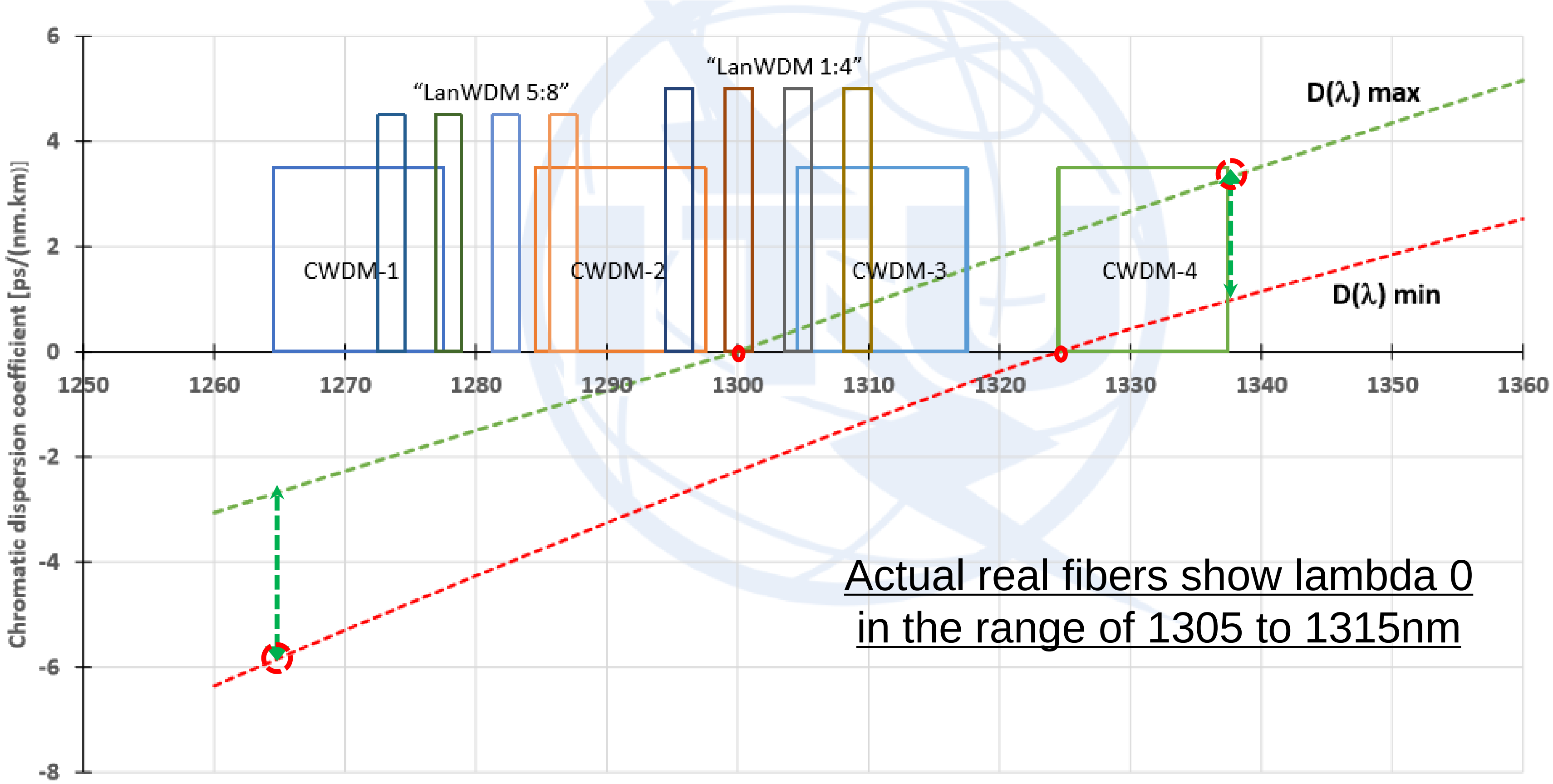
Description	400GBASE-FR4	400GBASE-LR4-6	Unit
Signaling rate, each lane (range)	53.125 ± 100 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5		nm
Side-mode suppression ratio (SMSR), (min)	30		dB
Total average launch power (max)	9.5	11.6	dBm
Average launch power, each lane (max)	3.5	5.6	dBm
Average launch power, each lane[a] (min)	−3.3	−2.8	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	3.7	4.4	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min)[b]	−0.3	0.2	dBm
Difference in launch power between any two lanes (OMA_{outer}) (max)	4	4	dB
Launch power in OMAouter minus TDECQ, each lane (min): for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 −1.7 −1.6	 −1.2 −1.1	 dBm dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	3.4	3.5	dB
Transmitter eye closure for PAM4 (TECQ), each lane (max)	3.4	3.5	dB
| TDECQ – TECQ | (max)	2.5	2.5	dB

Explore 400G LR4 10km options by 802.3?

- LR4 10km can be practically viable with following improvements:
  - Chirp managed EMLs (johnson_optx_01_0319)
    - Excessive CD penalties for L0 at cold (-chirp) or L3 at hot (+chirp)
    - Could be feasible in principle for future, but non-exist today
  - Increase the Ref Rx taps beyond >5 taps (chang_3cd_01a_0917; tamura_01a_1017_smf; way_3bs_01a_0717); .
    - Is it still possible to happen after long debate in the past?
  - Adopt new low dispersion fibers by Lewis ITU talk.
    - Tighten the worst case G.652 dispersion range.
  - Mitigate dispersion with bottom compression for Sipho Tx (welch_3cu_01_0719; mazzini_3cu_adhoc_082119)
    - Chromatic dispersion tends to impact PAM4 levels with upper eye(s) seeing most of the penalty, so forced bottom compression to alleviate.
    - Hard to interop with EML based Tx.
  - Stronger DSP algorithm like MLSE method
    - No taps change but use nonlinear equalization for extra 2-3dB.

What can we do for 400G LR4 at 10km?

- Suggestion to adopt subset of G.652 for use in the O-Band
  - Actual real fibers has lambda 0 [1305,1315nm]



CWDM Dispersion range for worst-case G.652 fiber (refer to Lewis ITU talk)

Summary and Comments

- Test data from existing FR4/LR4-6 modules shows IEEE P802.3cu specifications look right for defining 6km reach.
  - 6km can be fully interoperable for multi-vendors at worst-case G652 fiber deployments.
  - 10km might show marginal under real field fibers.
- There exist strong demand for LR4 at “real” 10km and can be practically viable using existing DSP IC implementation.
- Suggest add 10km option on the condition of following, e.g.
  - Increase the Ref Rx taps beyond >5 taps.
  - Adopt low dispersion fibers
- Hyperscale application is not likely necessary to require operation with deployed legacy fiber
  - Recommend to specify new low dispersion fiber for deploying 10km.

THANK YOU!

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