Considering Technical Feasibility Study of Various 200G/L PMDs - November 2023 update

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Acknowledgment:

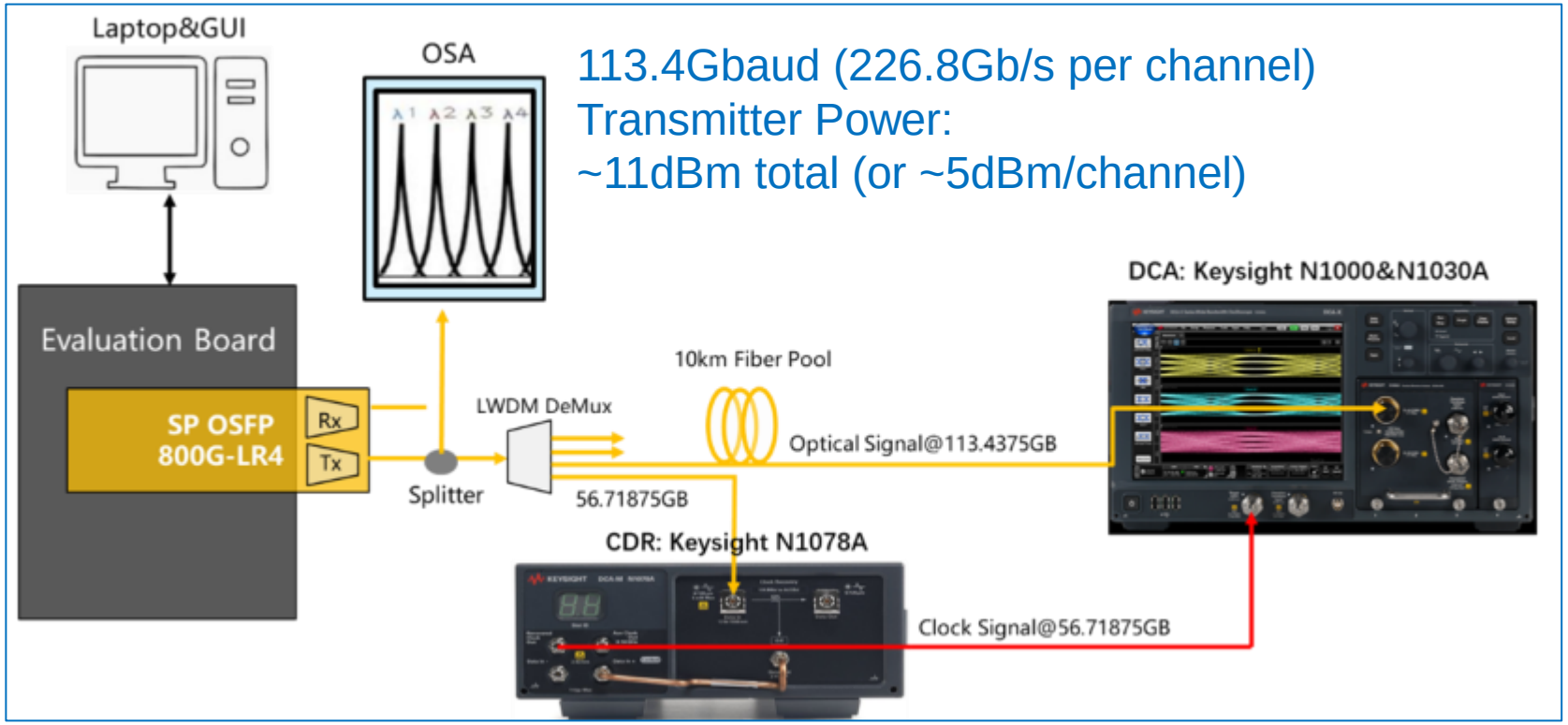
We wish to thank Charlie Sun and Eric Mak (Source), Paul Brooks (Viavi), Fred Tang and Vasu Parthasarathy (Broadcom) for help on TDECQ, and RX measurements

Introduction

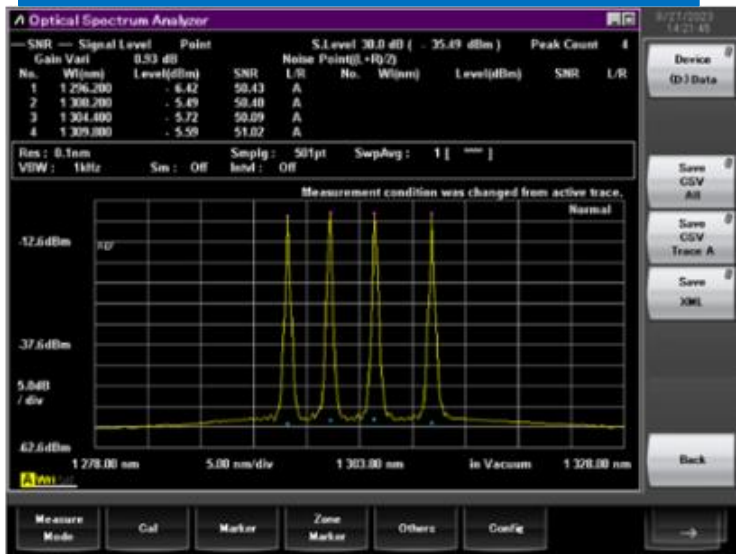
- This presentation aims to establish technical feasibility for 200G/L IMDD at 2km and 10km
  - Conduct various test validation based on real 800G pluggable modules implementing 200G/L EML optics
  - In particular, this set of test results validate support the 800G-LR4 baseline described in rodes_3dj_01_2309 and the DGD tolerance reported in kuschnerov_3dj_optx_01_230829 and Liu_3bj_optx_01a_231019.
- This presentation recaps the ECOC demo results with Liu_3bj_optx_01a_231019, and updates on the progress since the last meeting
  - Recap ECOC demo results with more TECQ/TDECQ and more fiber tests
    - Fiber dispersion tests with various fiber spools covering nominal 2km, 10.5km, 12.3km
  - Test validations of DGD tolerance using
  - Exploring FEC modes & linear reference equalizer
- We propose to support specifications baseline for 800GBASE-FR4 2km and 800GBASE-LR4 10km with further refinements based on contributions from the Task Force

800G-LR4 OSFP Transceivers at ECOC 2023

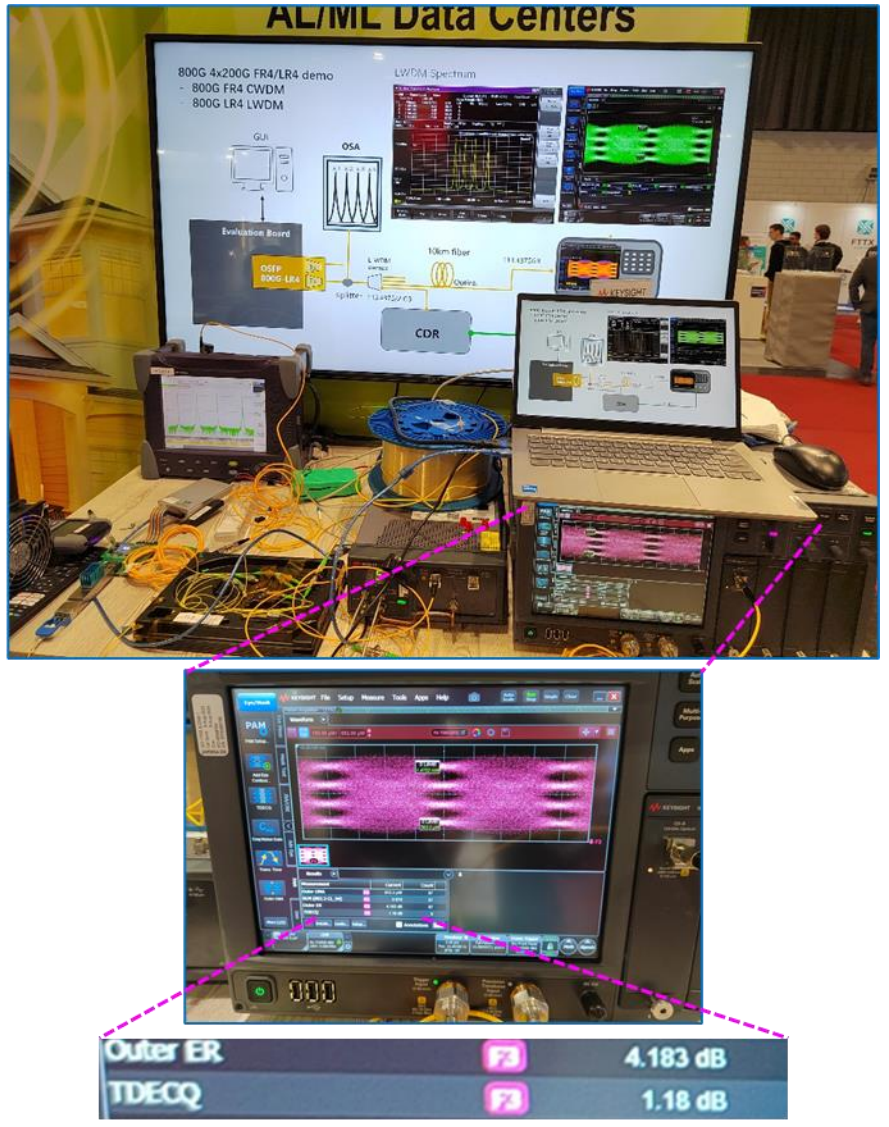
800G-LR4 OSFP on-site demo test platform



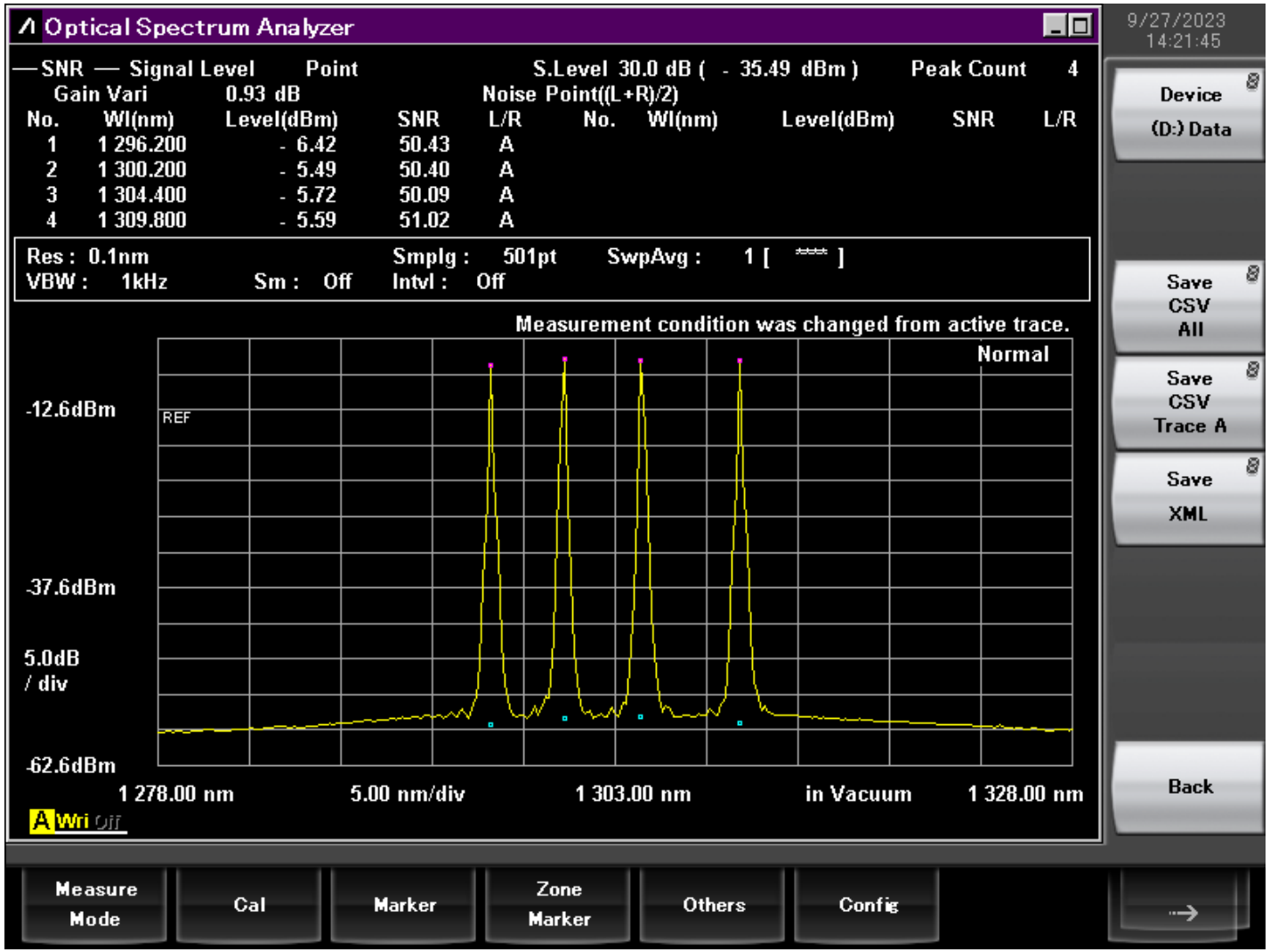
800G-LR4 Optical Spectrum



800G-LR4 Test Setup at ECOC 2023



800G OSFP LR4 LWDM Optical Spectra



800G LR4 LWDM

Lane	Center wavelength	Wavelength range
L_0	1295.56 nm	1294.53 to 1296.59 nm
L_1	1300.05 nm	1299.02 to 1301.09 nm
L_2	1304.58 nm	1303.54 to 1305.63 nm
L_3	1309.14 nm	1308.09 to 1310.19 nm

800G FR4 CWDM

Lane	Center wavelength	Wavelength range
L_0	1271 nm	1264.5 to 1277.5 nm
L_1	1291 nm	1284.5 to 1297.5 nm
L_2	1311 nm	1304.5 to 1317.5 nm
L_3	1331 nm	1324.5 to 1337.5 nm

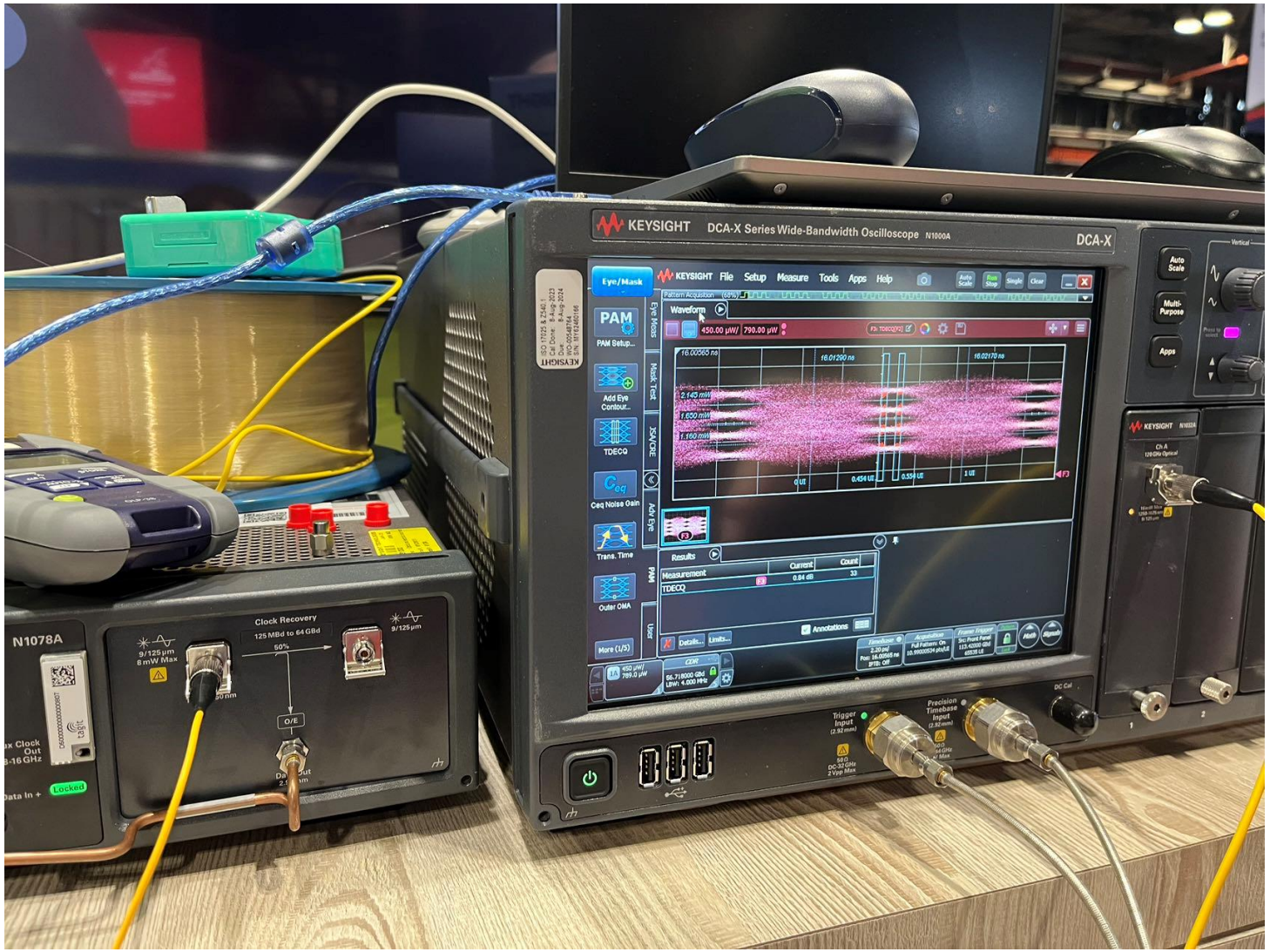
ECOC Live Demo (L3) @ ECOC 2023

Pattern: SSPRQ

TDECQ = 0.84dB

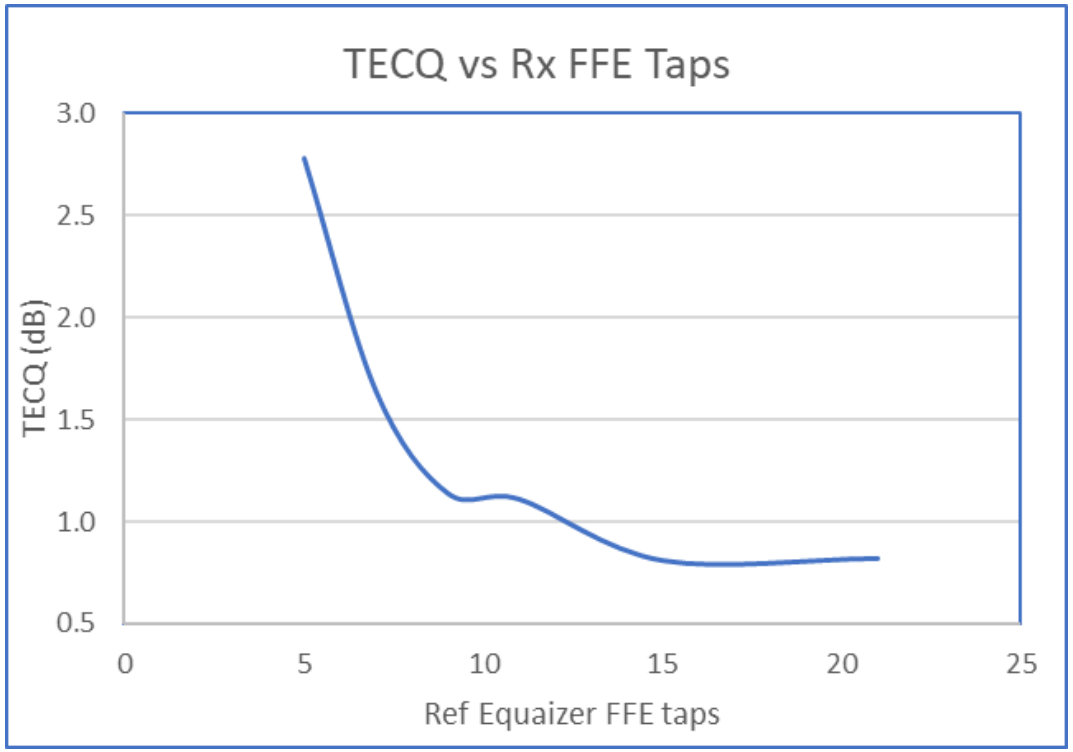
FFE: 11 taps

SER: 9.7E-3

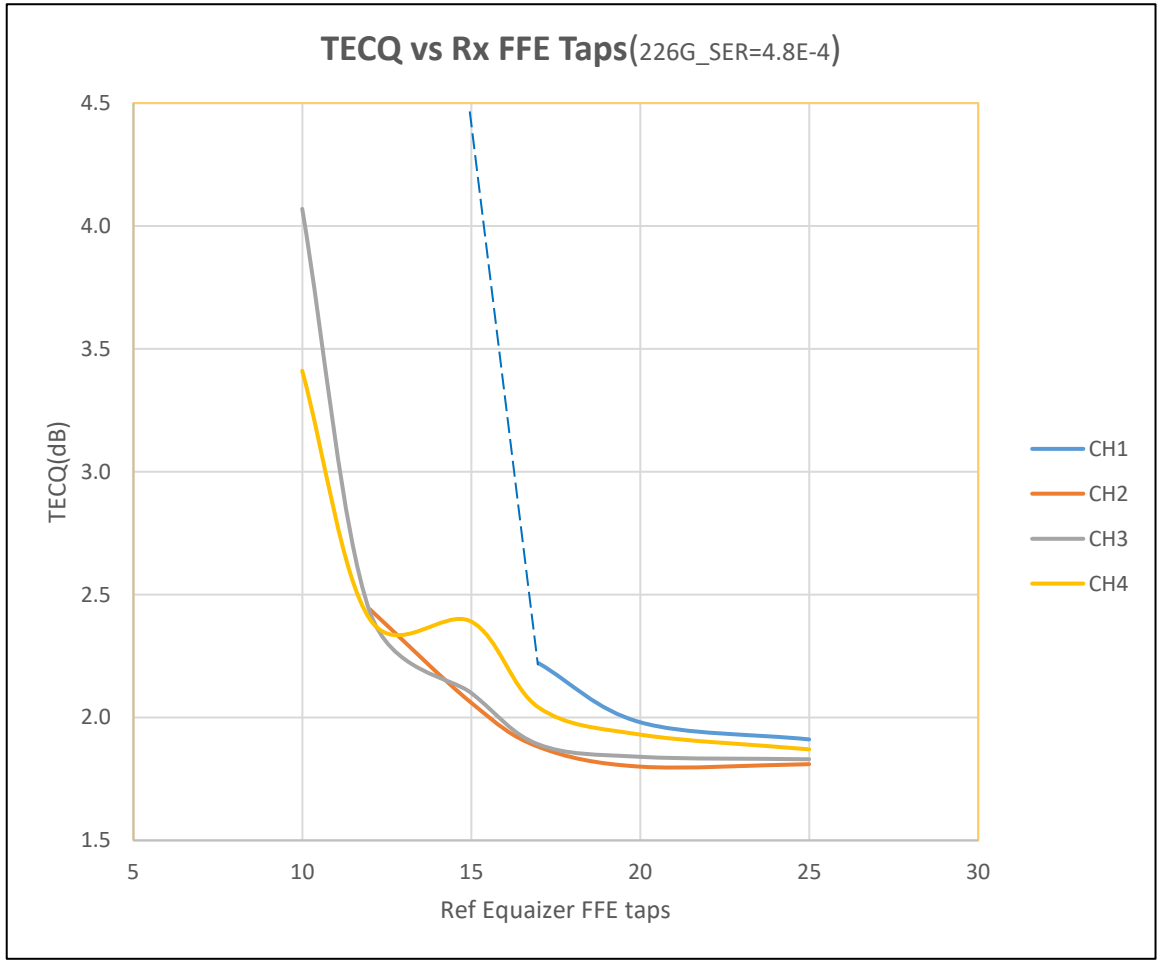


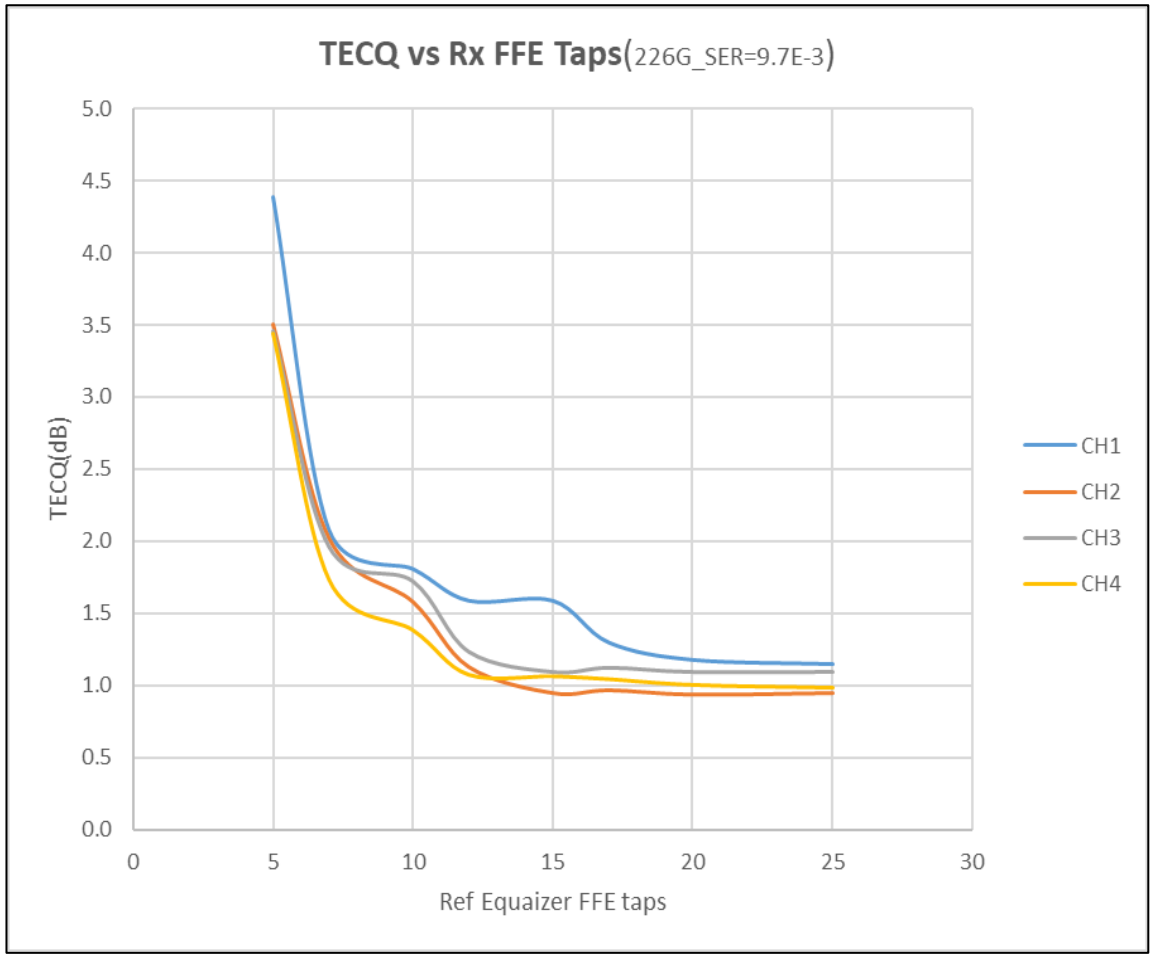
800G OSFP TECQ vs Ref Rx Equalizers at ECOC 2023

Measured TECQ on EML-based 800G-LR4 module @ 113.4GBd and BER = 4.85e-3



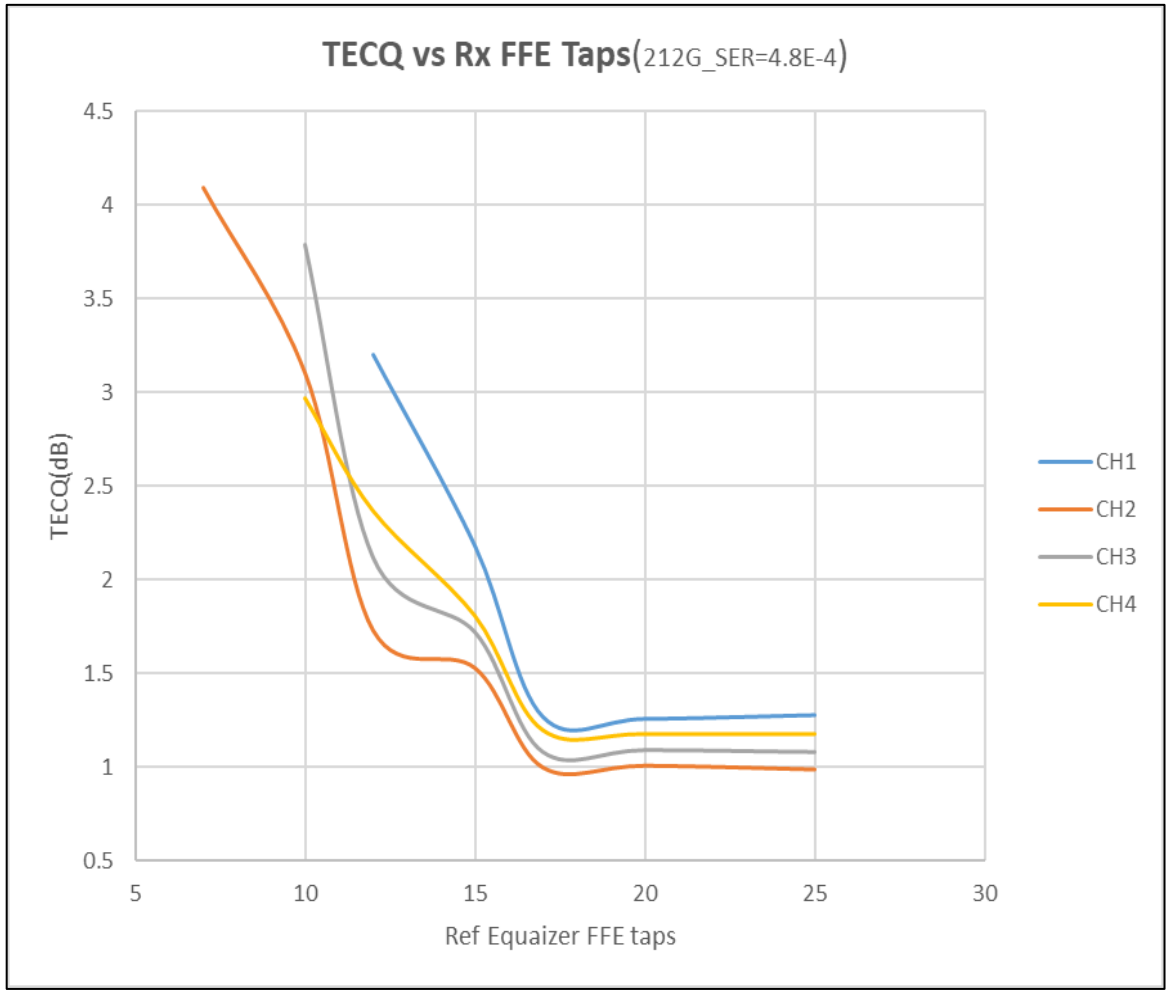
800G TECQ vs Ref Rx Equalizers @ 113.4GBd

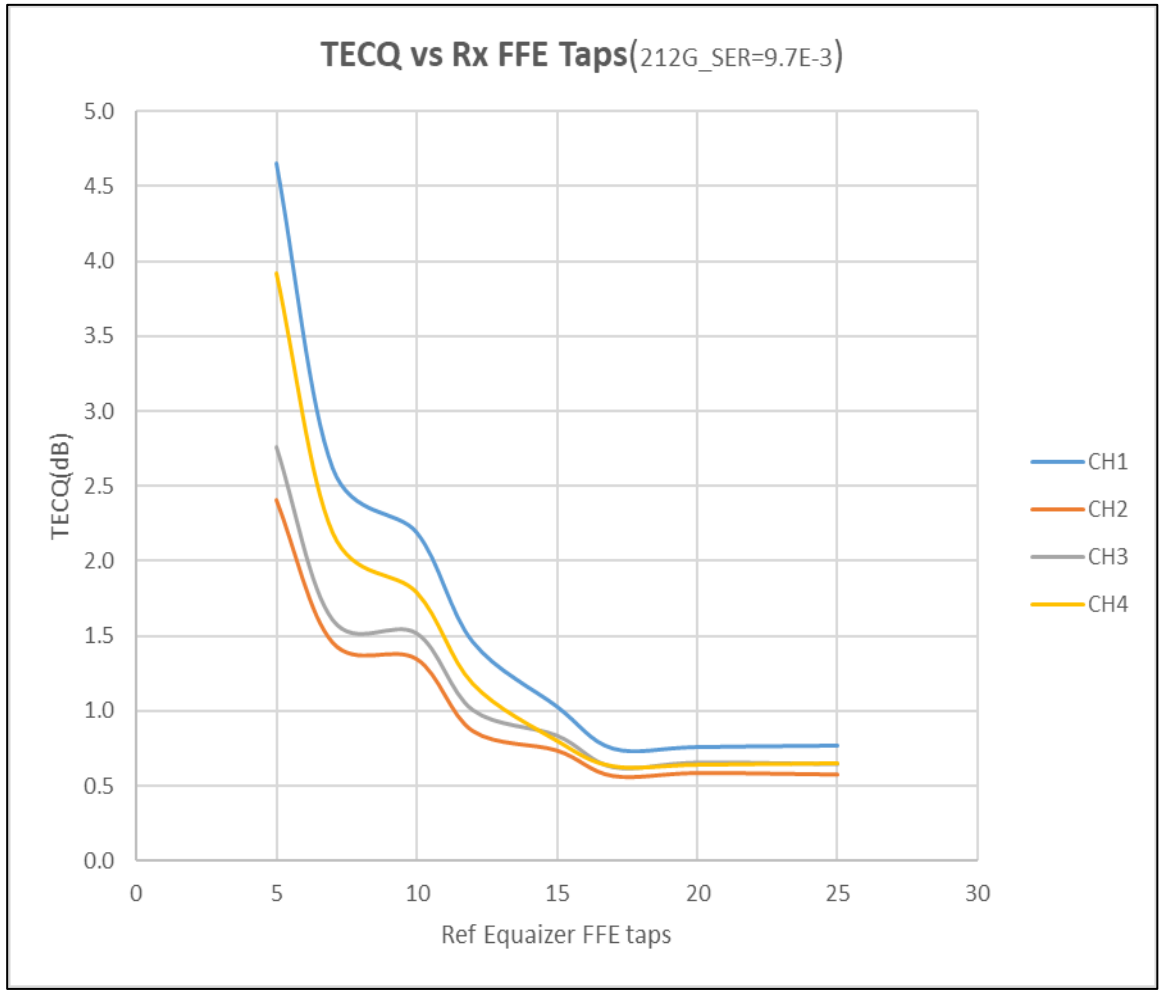




Note: FlexDCA FW V7.5 LSNR setting used for new LSNR (low signal to noise) feature in the advanced session of the TDECQ reference Rx.

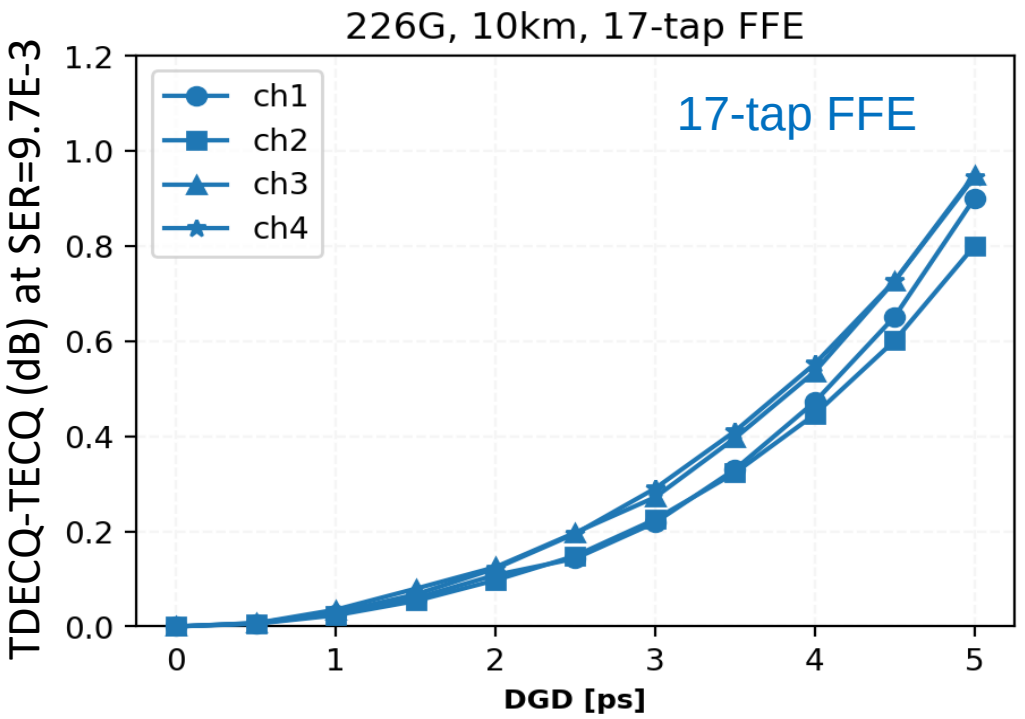
800G TECQ vs Ref Rx Equalizers @ 106.25GBd



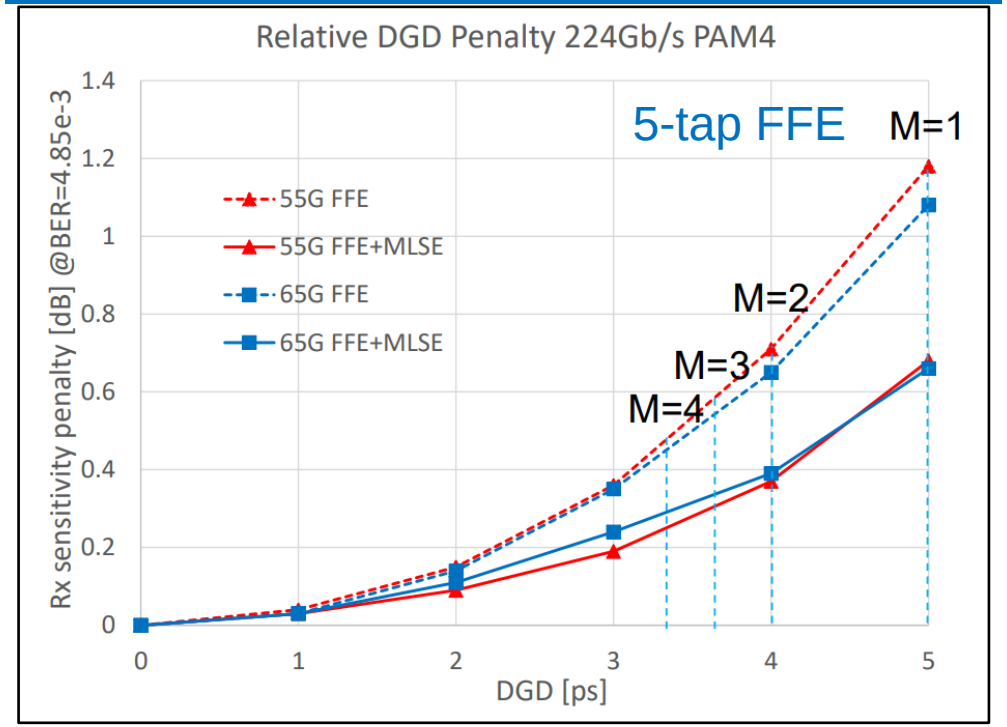


800G-LR4 “TDECQ-TECQ” as a Function of DGD @ 113GBd

Measured with the 800G-LR4 pluggable

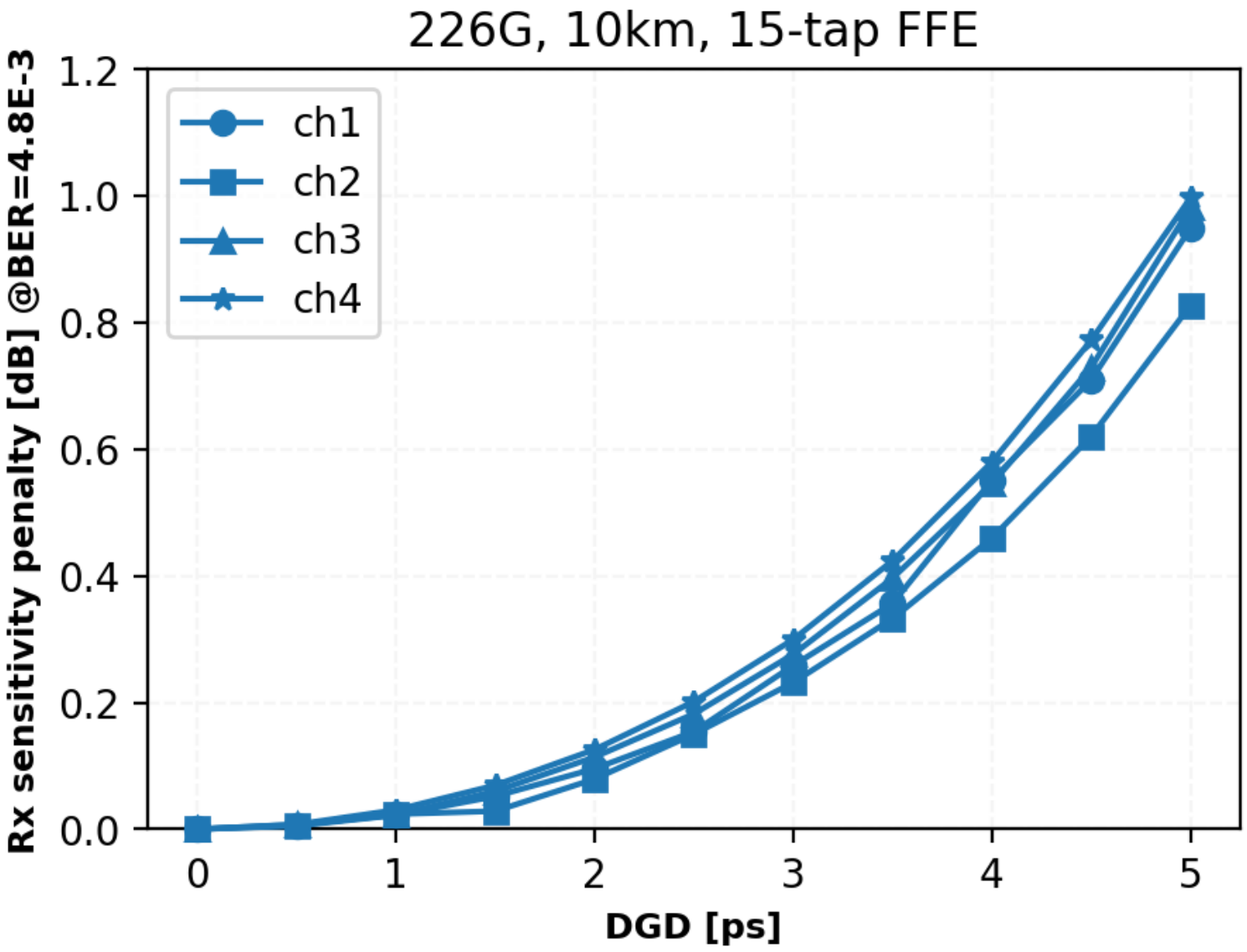


Previous results (kuschnerov_3dj_optx_01_230829)



✓ The test results validate the DGD tolerance reported in kuschnerov_3dj_optx_01_230829.

800G-LR4 “TDECQ-TECQ” – repeat DGD for 15-taps @ 113GBd



800G LR4 EML Typical Performance: AOP launching powers

Sample #1: TEC temp = 53C, EA = 0V

	Lane 0 (mW) Ibias = 50mA	Lane 1 (mW) Ibias = 40mA	Lane 2 (mW) Ibias = 40mA	Lane 3 (mW) Ibias = 40mA
After coupling	4.85	4.5	4.3	4.9
After UV Cure	4.45	4.3	4	4.6
Before Bake	2.78	4.3	3.18	3.6
Ater Bake	4.45	4.2	4	4.6

Sample #2: TEC temp = 53C, EA = 0V

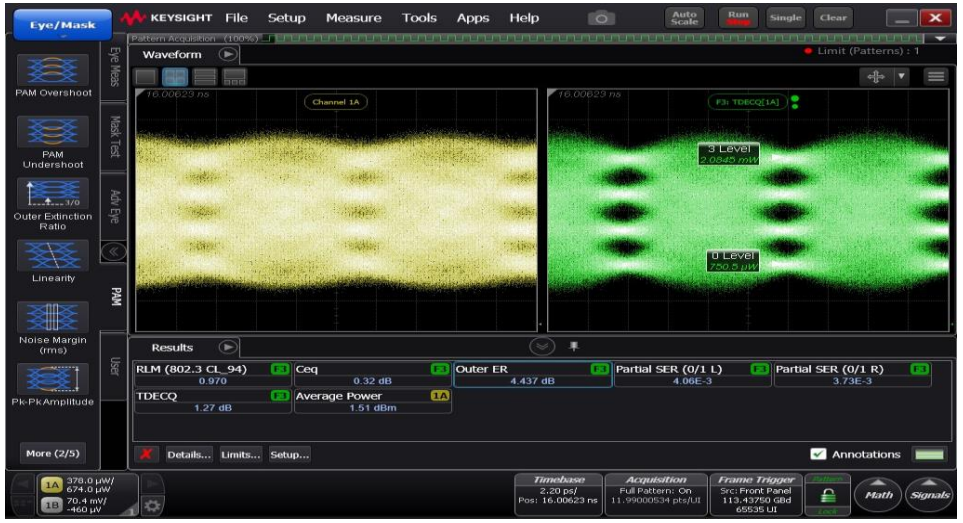
	Lane 0 (mW) Ibias = 50mA	Lane 1 (mW) Ibias = 50mA	Lane 2 (mW) Ibias = 50mA	Lane 3 (mW) Ibias = 50mA
After coupling				
After UV Cure	5.1	5.4	6	6.8
Before Bake	5	5.18	5.6	6.5
Ater Bake	5.06	5.2	5.6	6.5

800G OSFP LR4 Typical Performance @ B2B 113.4GBd

L1

L2

L3

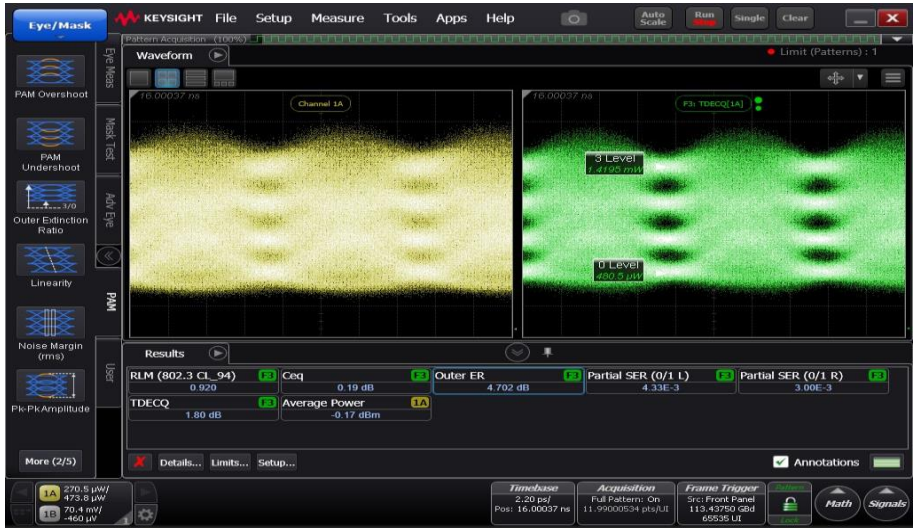


L4

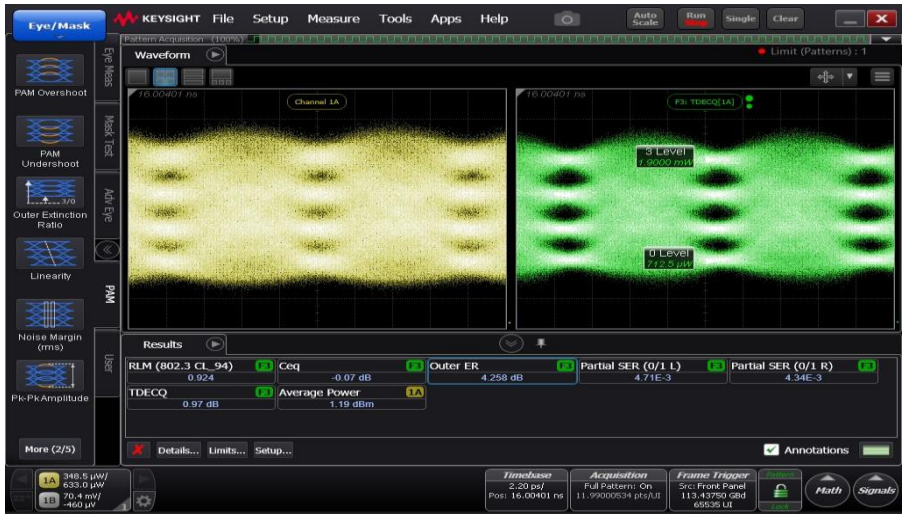
Note: FlexDCA FW V7.5 LSNR setting used for new LSNR (low signal to noise) feature in the advanced session of the TDECQ reference Rx.

800G OSFP LR4 Typical Performance @10.5km 113.4GBd

L1

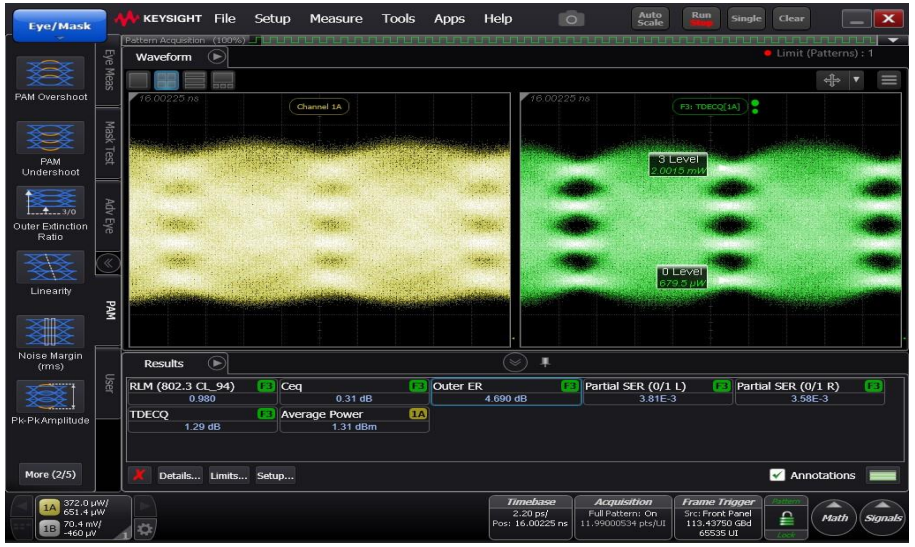


L2



L3

L4



800G OSFP LR4 Typical Performance: B2B vs 10.5km 113.4GBd

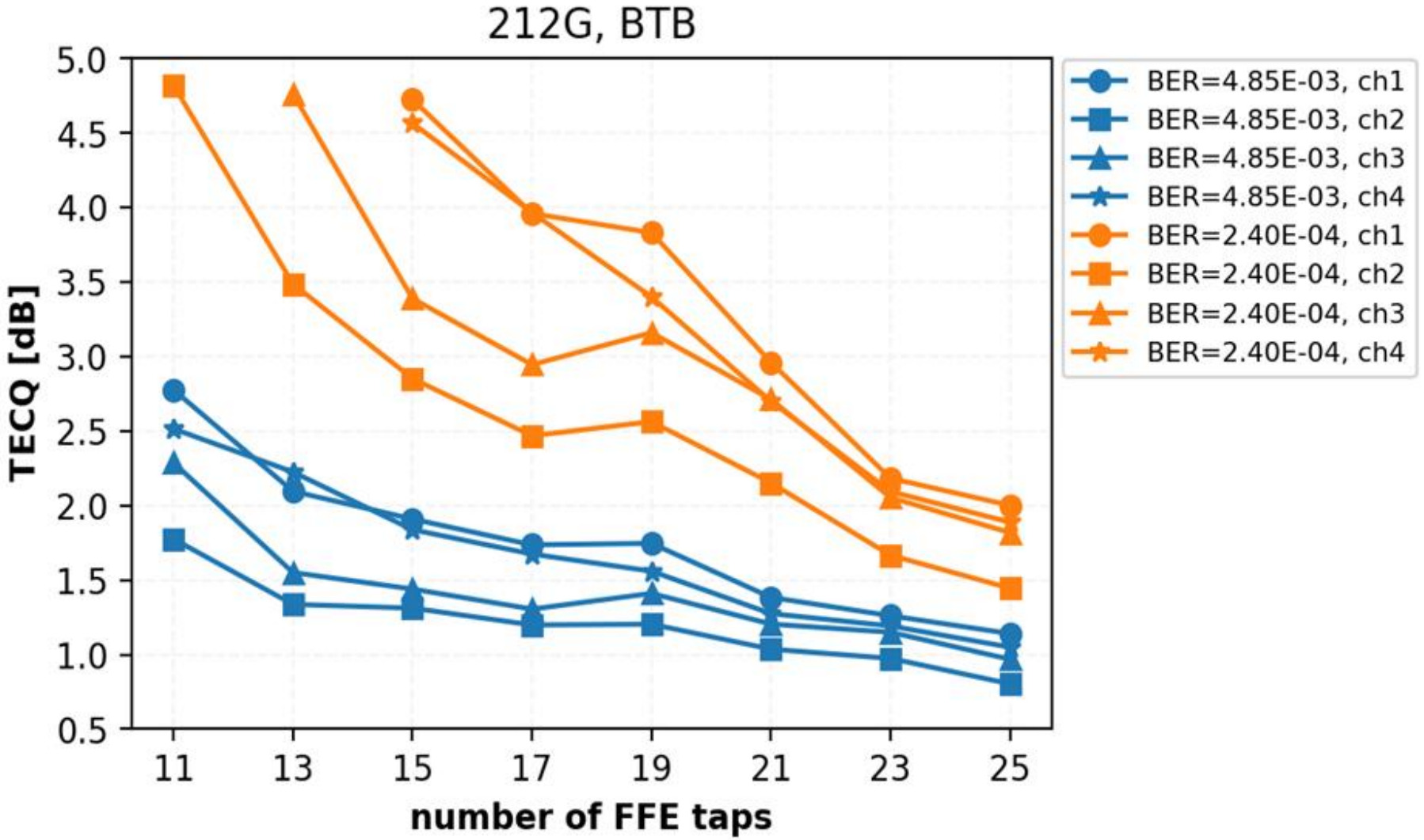
At BTB

Lane	Wavelength (nm)	TECQ (dB)	Ceq (dB)	ER (dB)	RLM
#1	1296	1.49	0.36	4.632	0.946
#2	1300	1.21	0.28	4.299	0.985
#3	1304	1.27	0.32	4.437	0.970
#4	1309	1.22	0.21	4.659	0.973

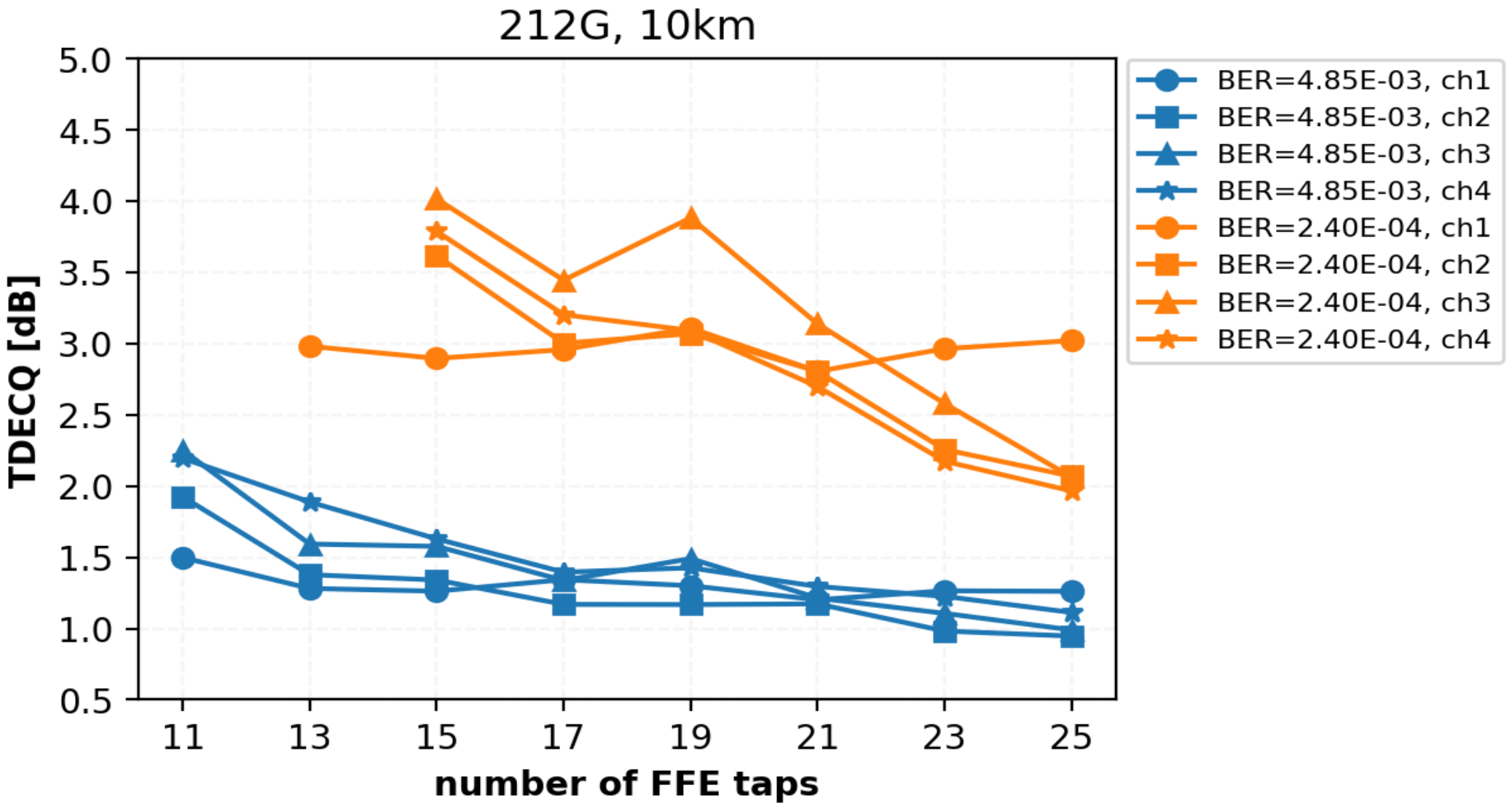
After 10km fiber

Lane	Wavelength (nm)	TDECQ (dB)	Ceq (dB)	ER (dB)	RLM
#1	1296	1.80	0.19	4.702	0.920
#2	1300	0.97	-0.03	4.258	0.924
#3	1304	1.08	0.15	4.573	0.942
#4	1309	1.29	0.31	4.690	0.980

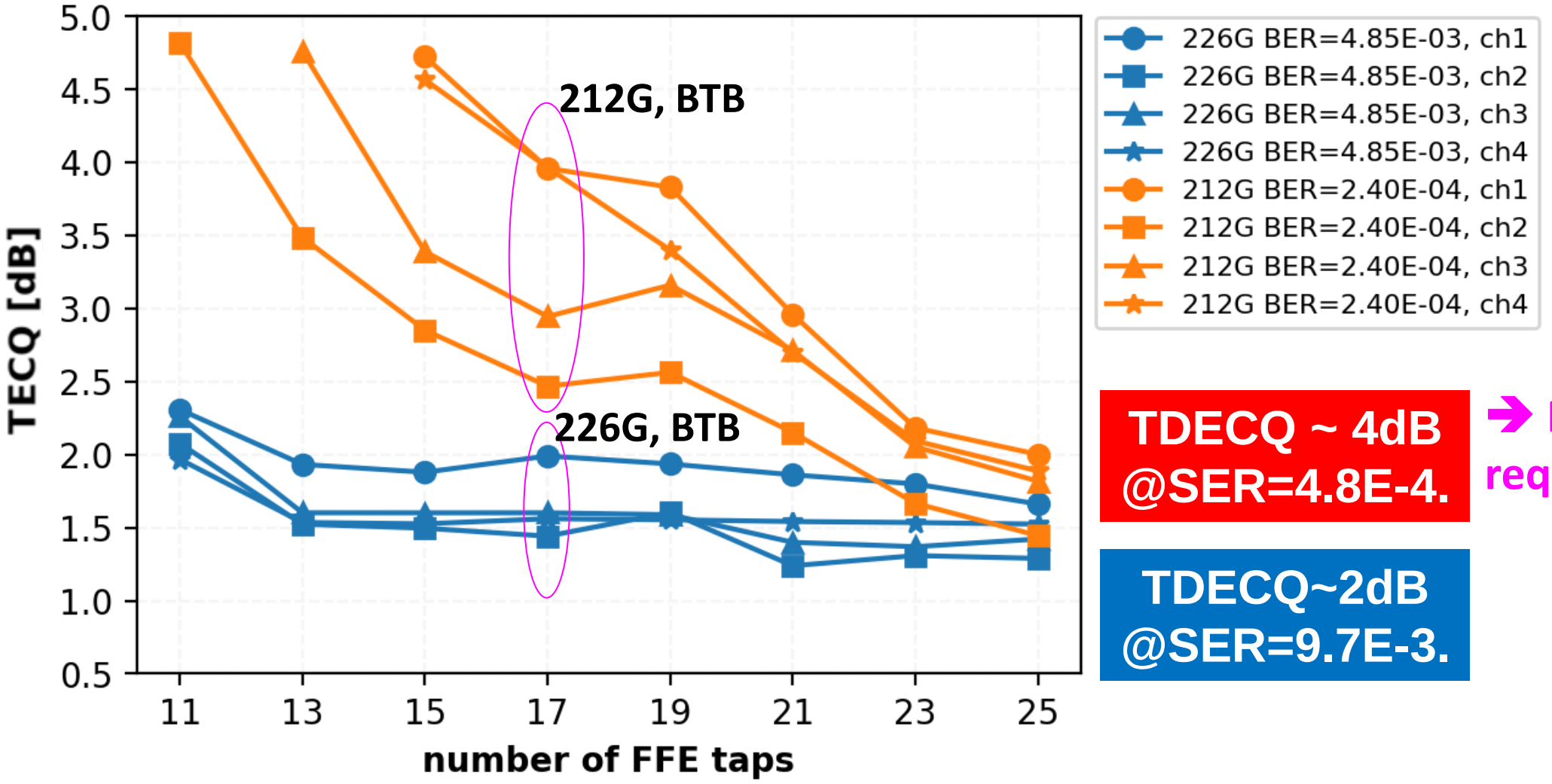
800G OSFP LR4 TECQ vs FFE tap number, L=0km (BTB) 106GBd



800G OSFP LR4 TECQ vs FFE tap number, L~10.5km 106GBd



Study on FEC Reqs for 106.25 vs. 113.4GBd, L=0km (BTB)

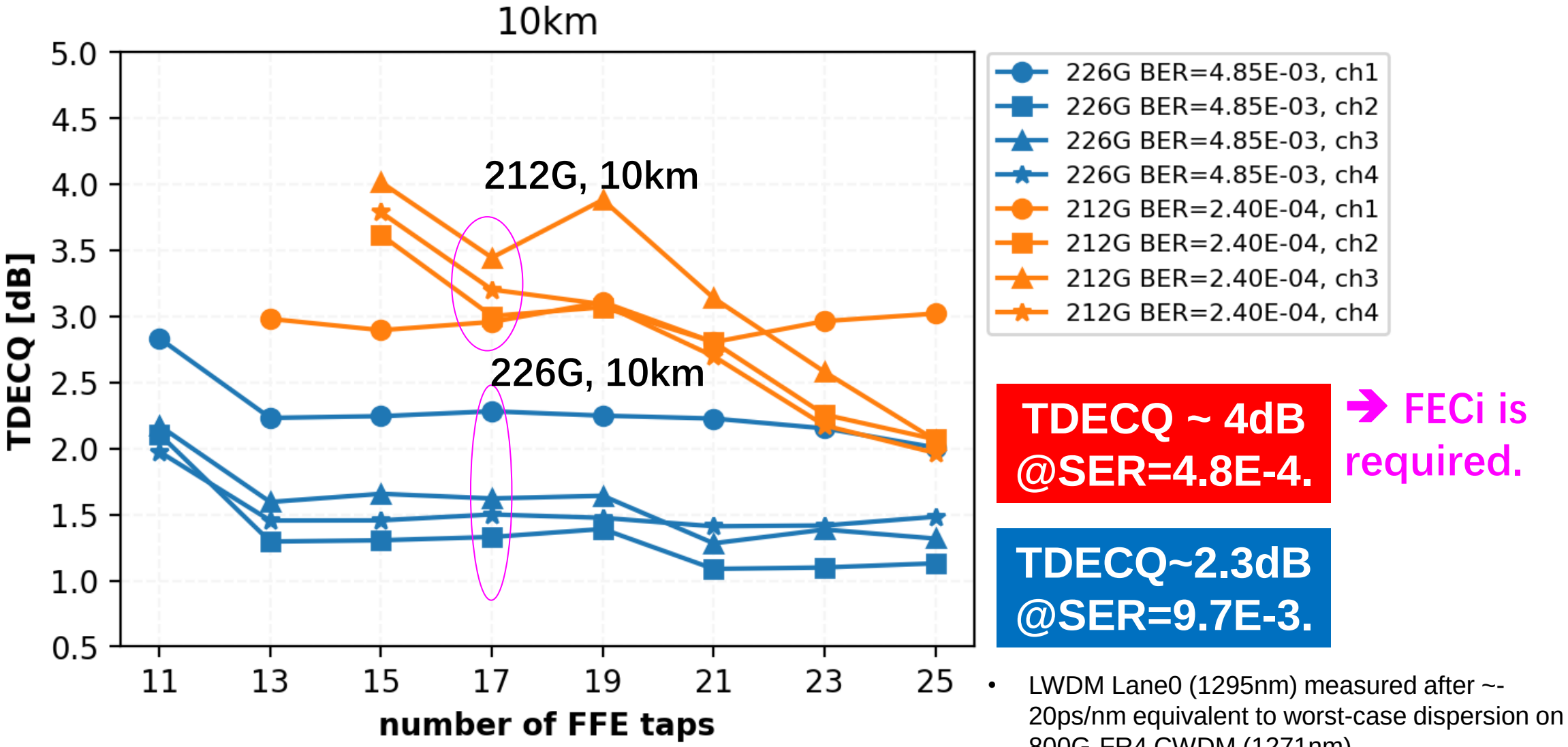


TDECQ ~ 4dB @SER=4.8E-4.

➔ **FECi is required.**

TDECQ~2dB @SER=9.7E-3.

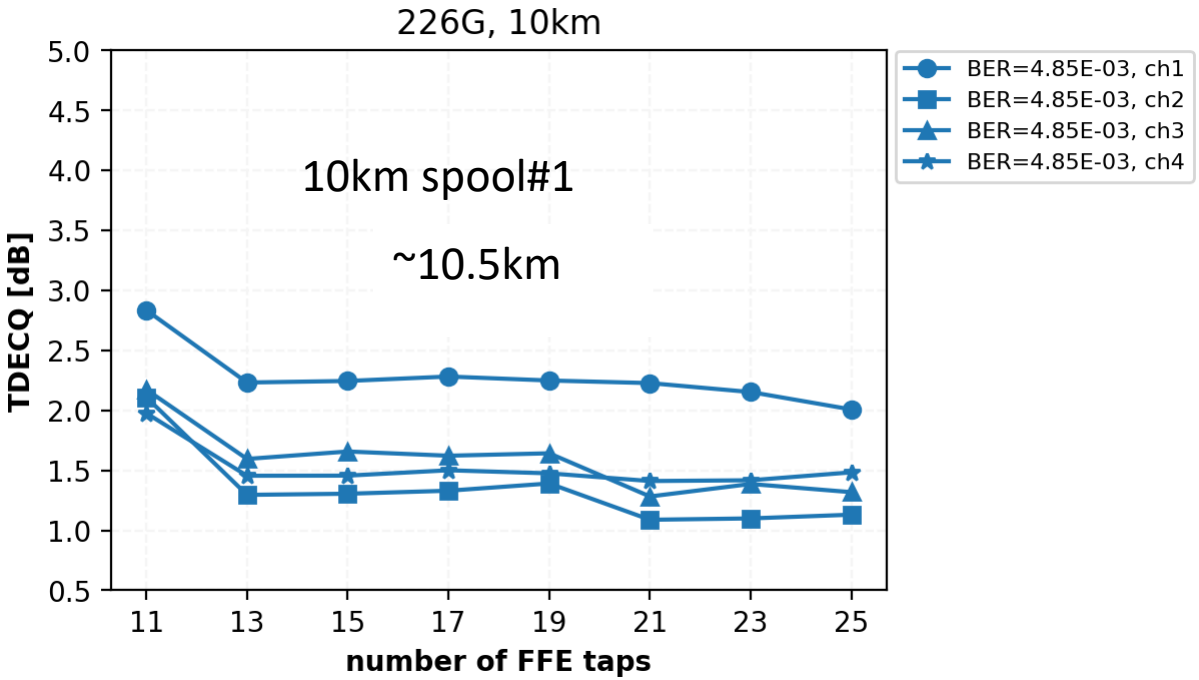
Study on FEC Reqs for 106.25 vs. 113.4GBd, L~10km

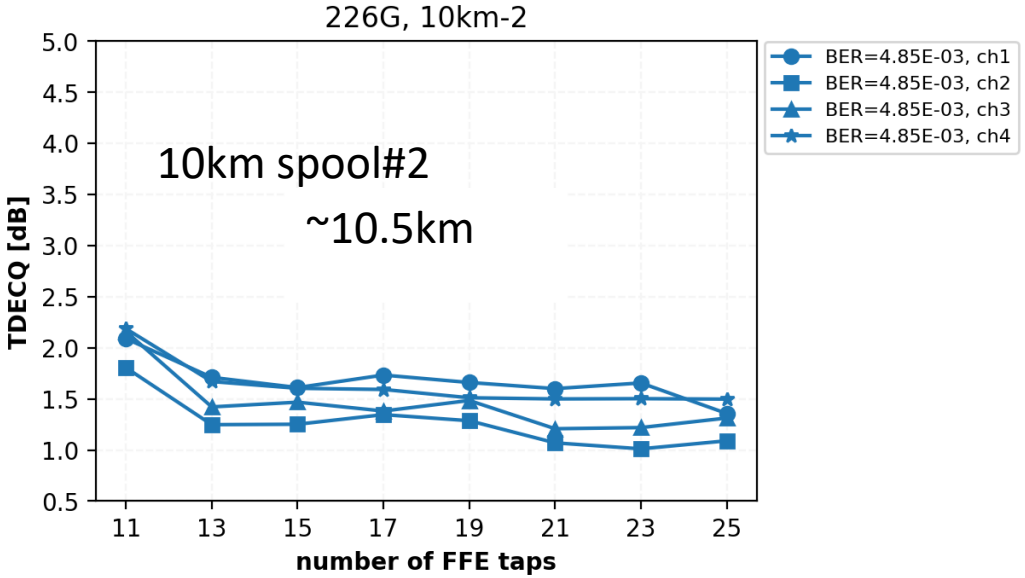


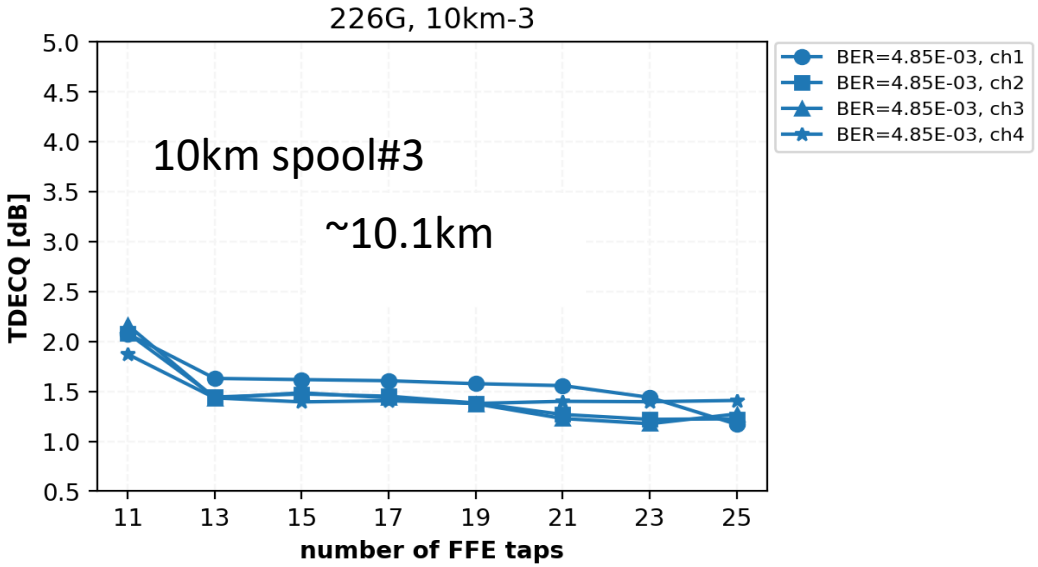
- LWDM Lane0 (1295nm) measured after ~-20ps/nm equivalent to worst-case dispersion on 800G-FR4 CWDM (1271nm)

Study of Worst-case fibers for L~10km fiber spools

Originally worst-case fiber
for testing 400G LR8 10km
(Lambda0 ~1320nm)

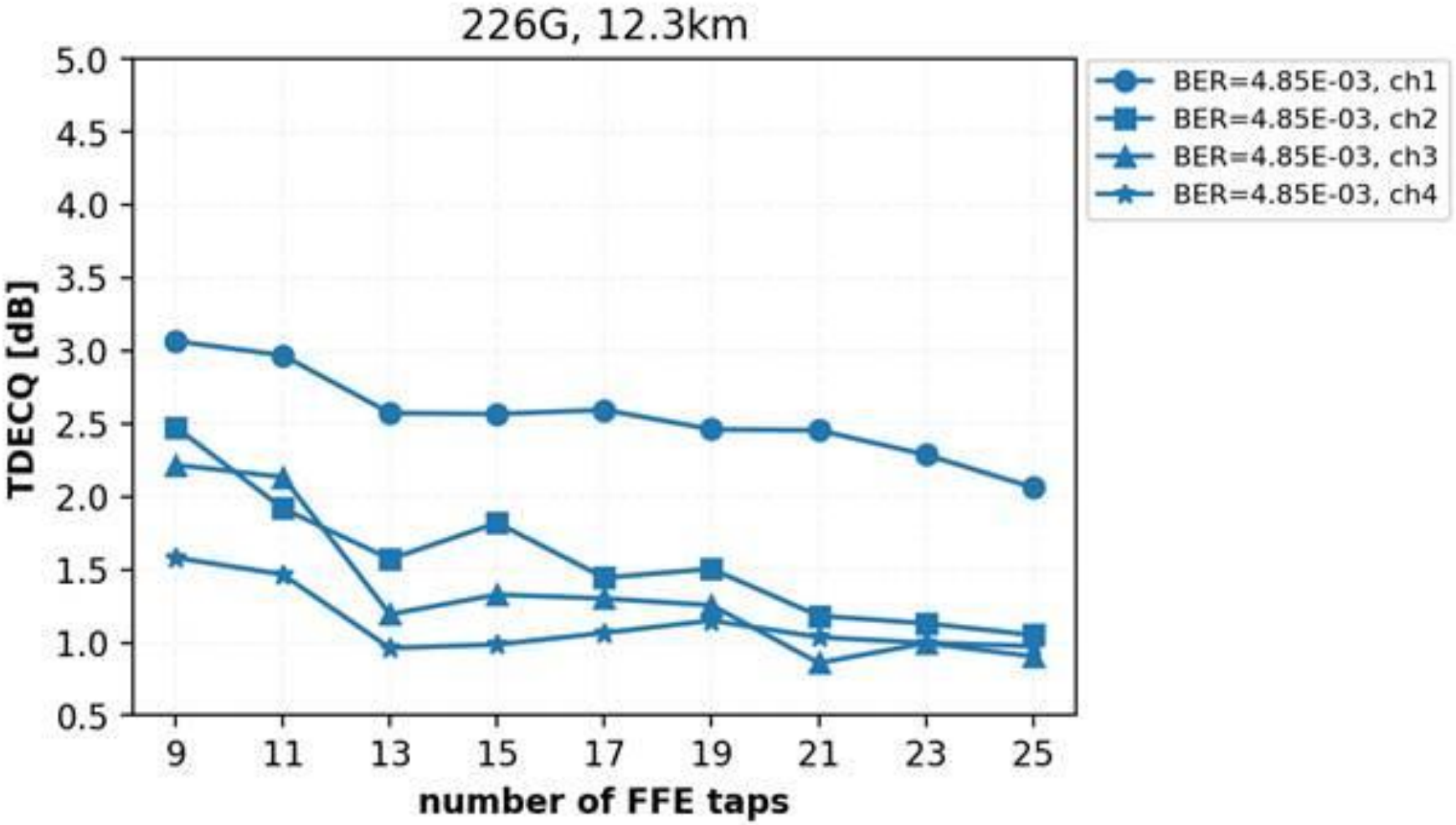






Study on worst case fibers @ 113.4GBd, L~12.3km

Beyond IEEE802.3 worst-case fiber characteristics



Validation on Key 800G-LR4 Baseline Specs

	Baseline[1]	Test	Remark
Transmitter Power/Channel	-0.9~5.5 dBm	~5 dBm	Pass
Extinction ratio	≥3.5 dB	~4.2 dB	Pass
OMA_{outer}	1.9~5.7 dBm	~4.5 dBm	Pass
TDECQ @SER=9.7E-3	≤3.2 dB	~2.3 dB	Pass[2]
TDECQ-TECQ (after 10.5km)[2]	≤2.5 dB	~1.3 dB	Pass[2]
TDECQ-TECQ at DGD=4 ps[3]	≤0.7dB	<0.7dB	Pass

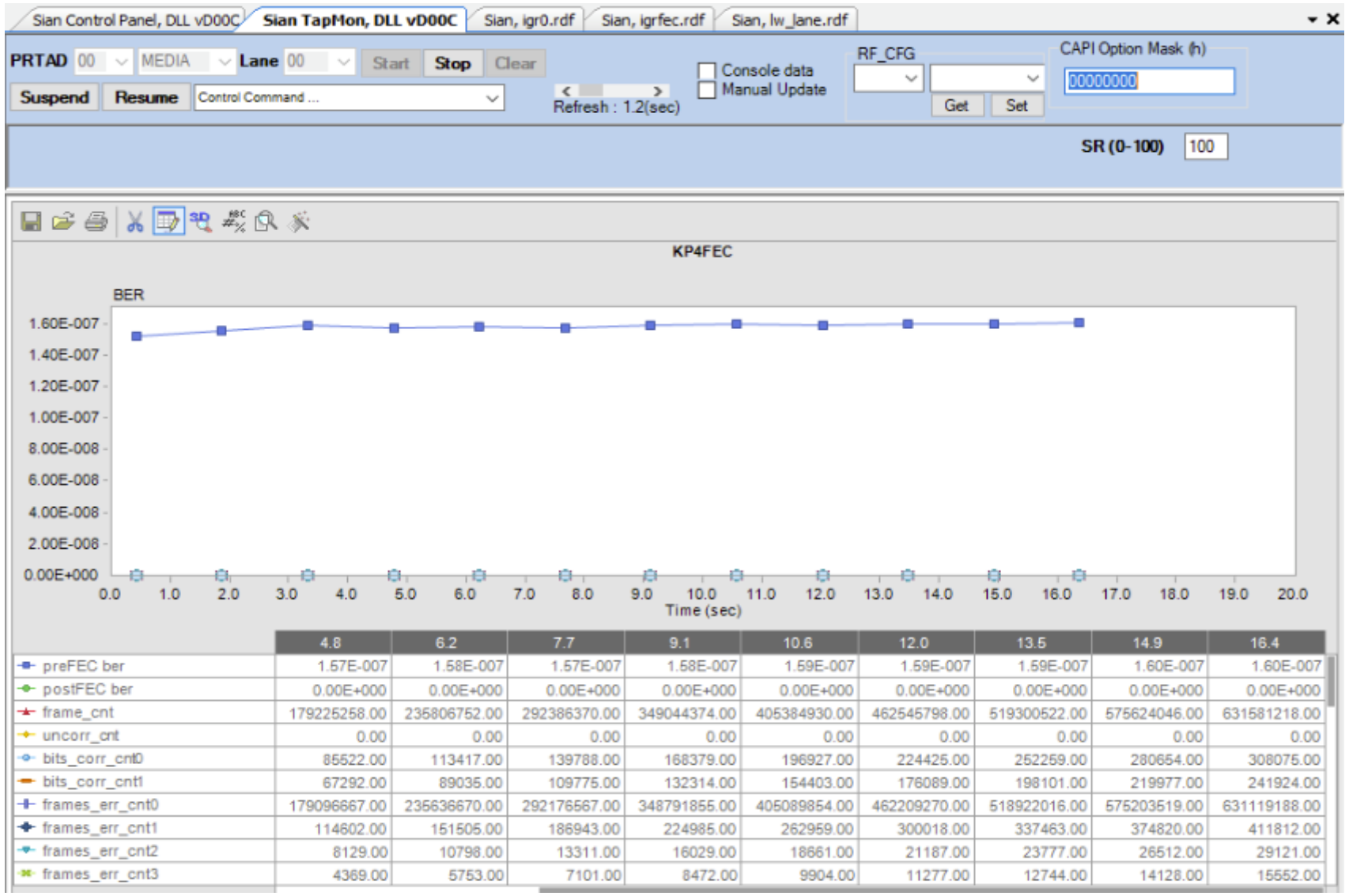
[1]: rodes_3dj_01_2309;
[2]: Measured near the worst-case CD_Q limit specified as in [1].
[3]: Assuming, conservatively, 2 extreme fiber DGD sections (e.g., out of M=4 sections).

✓ The test results support the 800G-LR4 baseline described in rodes_3dj_01_2309.

Investigating Rx Performance (Continued)

Investigating 800G LR4 (LWDM) BER Floor Performance

Ref. TX
Rx Sens
@ 106.25GBd

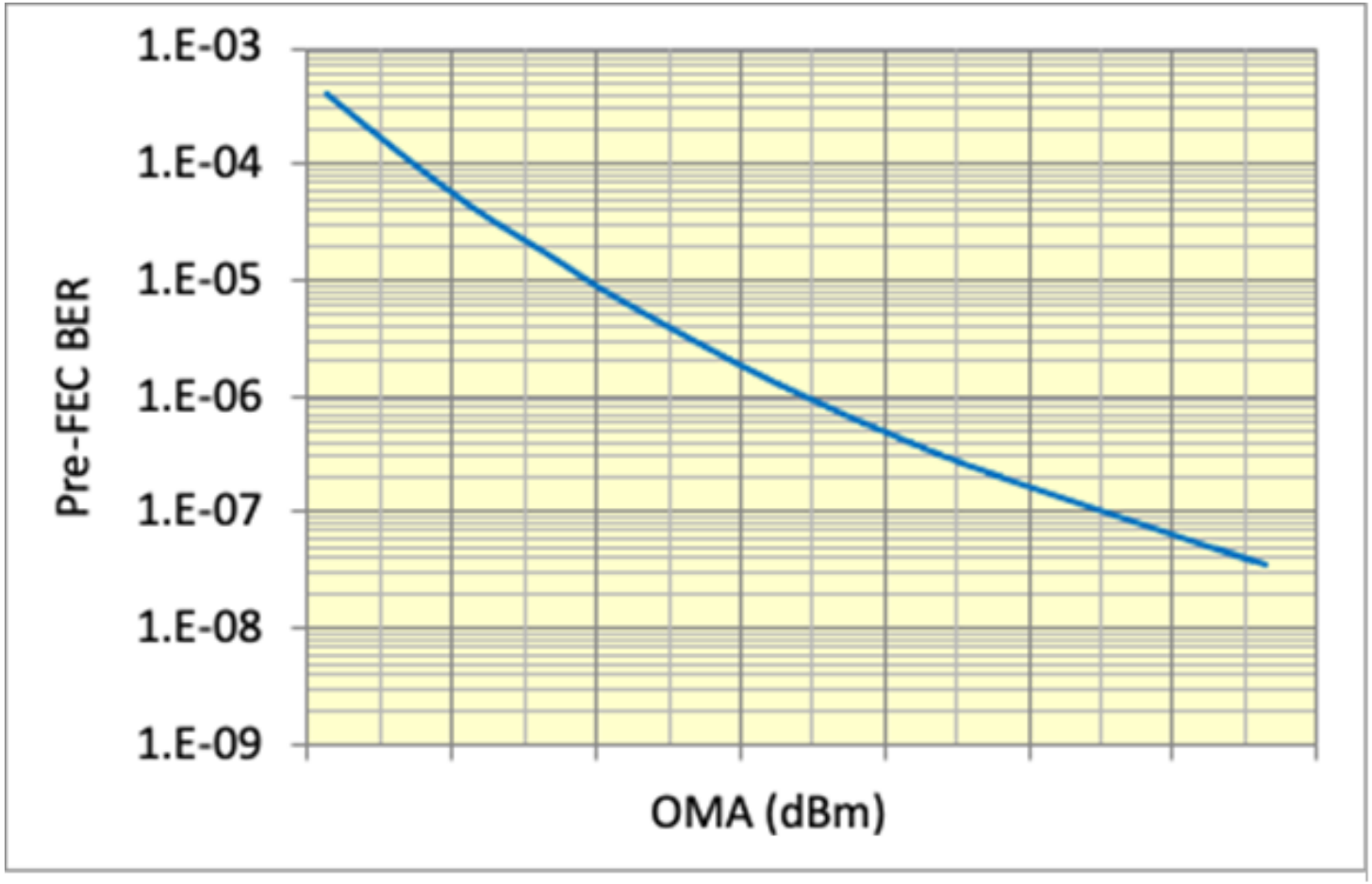


	4.8	6.2	7.7	9.1	10.6	12.0	13.5	14.9	16.4
preFEC ber	1.57E-007	1.58E-007	1.57E-007	1.58E-007	1.59E-007	1.59E-007	1.59E-007	1.60E-007	1.60E-007
postFEC ber	0.00E+000	0.00E+000	0.00E+000	0.00E+000	0.00E+000	0.00E+000	0.00E+000	0.00E+000	0.00E+000
frame_cnt	179225258.00	235806752.00	292386370.00	349044374.00	405384930.00	462545798.00	519300522.00	575624046.00	631581218.00
uncorr_cnt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
bits_corr_cnt0	85522.00	113417.00	139788.00	168379.00	196927.00	224425.00	252259.00	280654.00	308075.00
bits_corr_cnt1	67292.00	89035.00	109775.00	132314.00	154403.00	176089.00	198101.00	219977.00	241924.00
frames_err_cnt0	179096667.00	235636670.00	292176567.00	348791855.00	405089854.00	462209270.00	518922016.00	575203519.00	631119188.00
frames_err_cnt1	114602.00	151505.00	186943.00	224985.00	262959.00	300018.00	337463.00	374820.00	411812.00
frames_err_cnt2	8129.00	10798.00	13311.00	16029.00	18661.00	21187.00	23777.00	26512.00	29121.00
frames_err_cnt3	4369.00	5753.00	7101.00	8472.00	9904.00	11277.00	12744.00	14128.00	15552.00

Investigating 800G LR4 (LWDM) BER Floor Performance

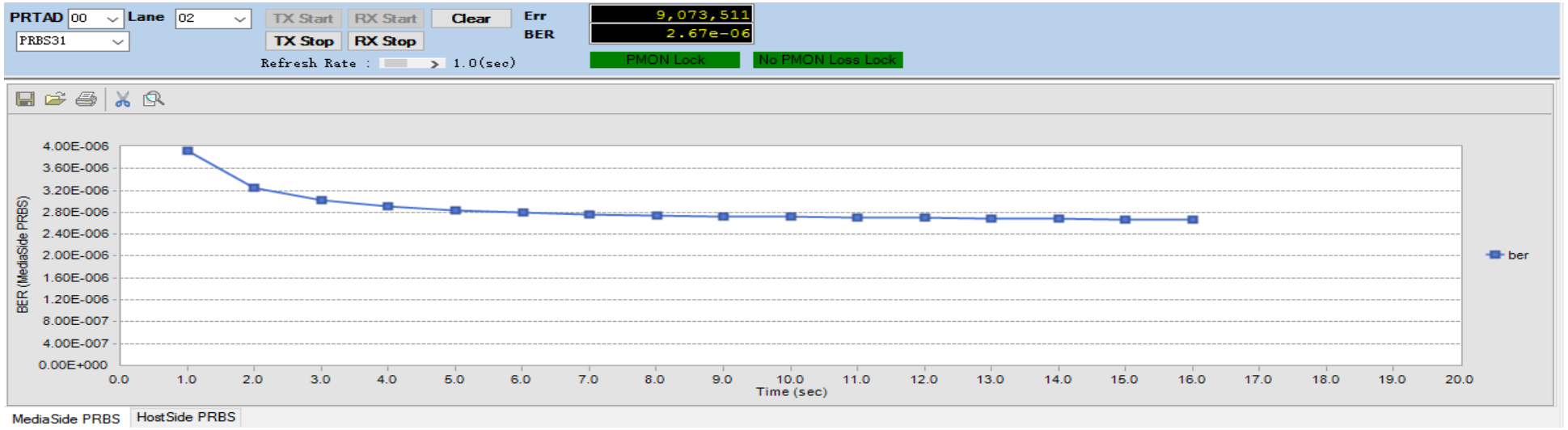
Typical Rx sens curve as example, work still in progress

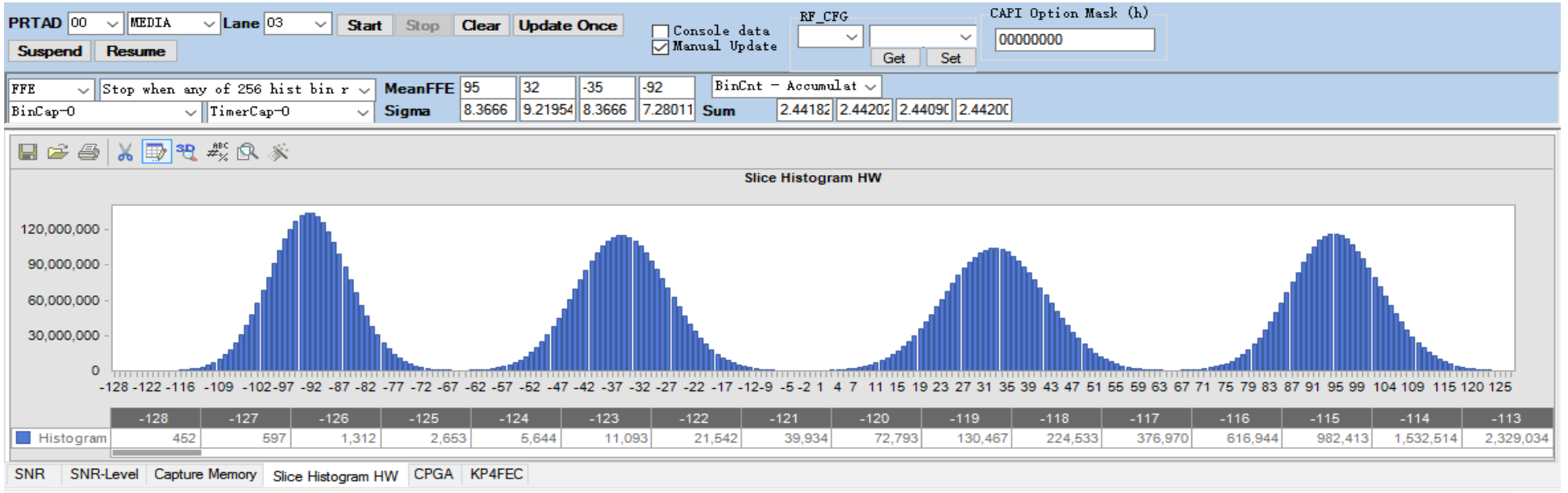
Ref. TX
Rx Sens
@ 106.25GBd



Investigating 800G LR4 (LWDM) BER Floor Performance

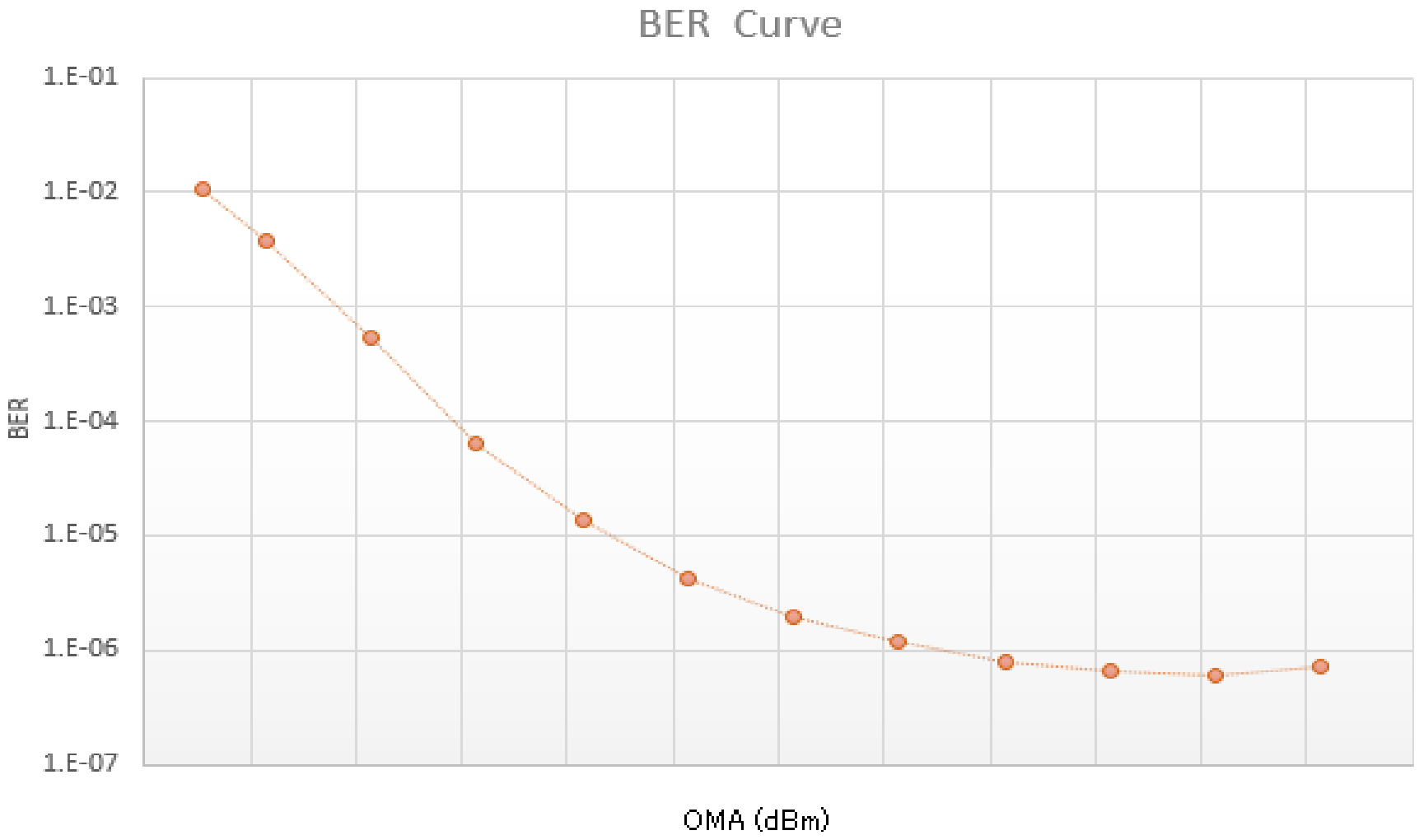
Self loopback
@ 113.4GBd
With Tx/Rx Xtalk





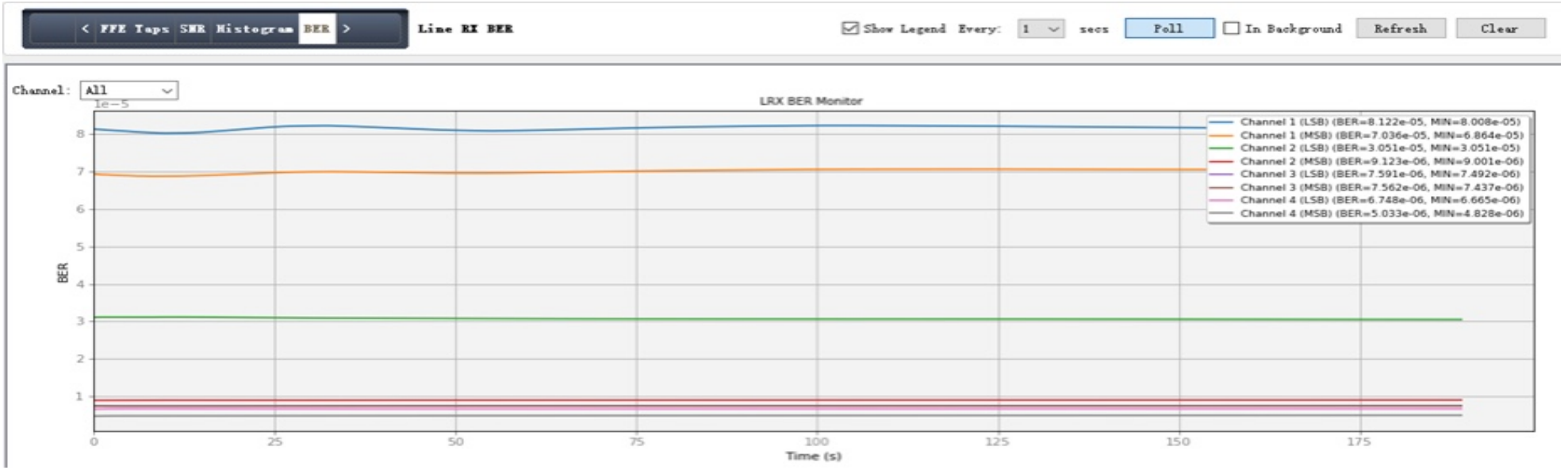
Investigating 800G LR4 (LWDM) BER Floor Performance

Self loopback @ 113.4GBd (single lane with no xtalk)

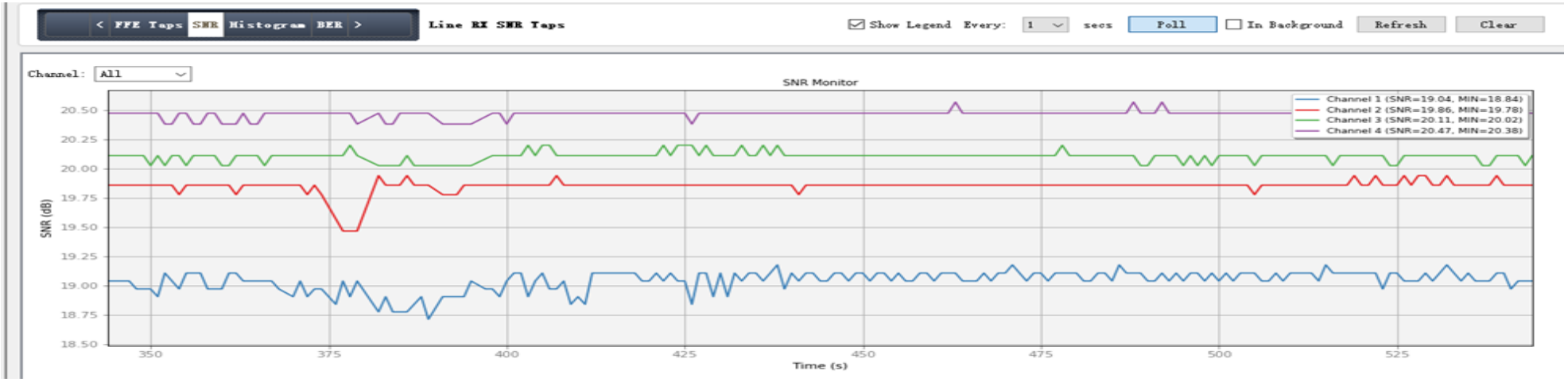


Investigating 800G FR4 (CWDM4) BER Floor Performance

Self loopback
@ 107.91GBd
With Tx/Rx xtalk



SNR ~ 20.5dB
Expect ~ 1E-7



Conclusions

- Based on real 800G-LR4 pluggable modules, we have conducted the first test validation on the transmitter power, extinction ratio, OMA, TECQ, TDECQ with DGD and worst case fibers.
- The first set of test results validate the DGD tolerance reported in kuschnerov_3dj_optx_01_230829, and support the 800G-LR4 baseline described in rodes_3dj_01_2309.
- It is also found that FECo only is insufficient, so FECi is required for either 2km or 10km by similarity in terms of dispersion tolerance.
  - Pre FEC BER threshold makes major differences in estimating TDECQ.

Thank you!

Backup slides:
Baseline Proposal for 800GBASE-LR4
by rodes_3dj_01_2311

Transmit Characteristics

Description	800G-LR4 proposal	Unit
Signaling rate, each lane (range)	113.4375	GBd
Modulation format	PAM4	
Lane wavelengths (range)	1294.6 to 1296.6 1299.1 to 1301.1 1303.6 to 1305.6 1308.1 to 1310.1	nm
Side-mode suppression ratio (SMSR), (min)	30	dB
Total average launch power (max)	11.5	dBm
Average launch power, each lane (max)	5.5	dBm
Average launch power, each lane (min)	-0.9	dBm
Outer Optical Modulation Amplitude (OMAouter), each lane (max)	5.7	dBm
Outer Optical Modulation Amplitude (OMAouter), each lane (min) for TDECQ <1.4 dB for 1.4 dB ≤ TDECQ ≤ 3.9 dB	 1.9 0.5+TDECQ	 dBm dBm
Difference in launch power between any two lanes	3	dB
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max) *	3.9	dB
Transmitter eye closure for PAM4 (TECQ), each lane (max)	3.2	dB
|TDECQ-TECQ| (max)	2.5	dB
Over/under-shoot (max)	22	%
Transmitter power excursion (max)	3.1	
Extinction ratio, each lane (min)	3.5	dB
Transmitter transition time (max)	13	ps
Average launch power of OFF transmitter, each lane (max)	-16	dBm
$RIN_{15.6}OMA$ (max)	-139	dB/Hz
Optical return loss tolerance (max)	15.6	dB
Transmitter reflectance (max)	-26	dB

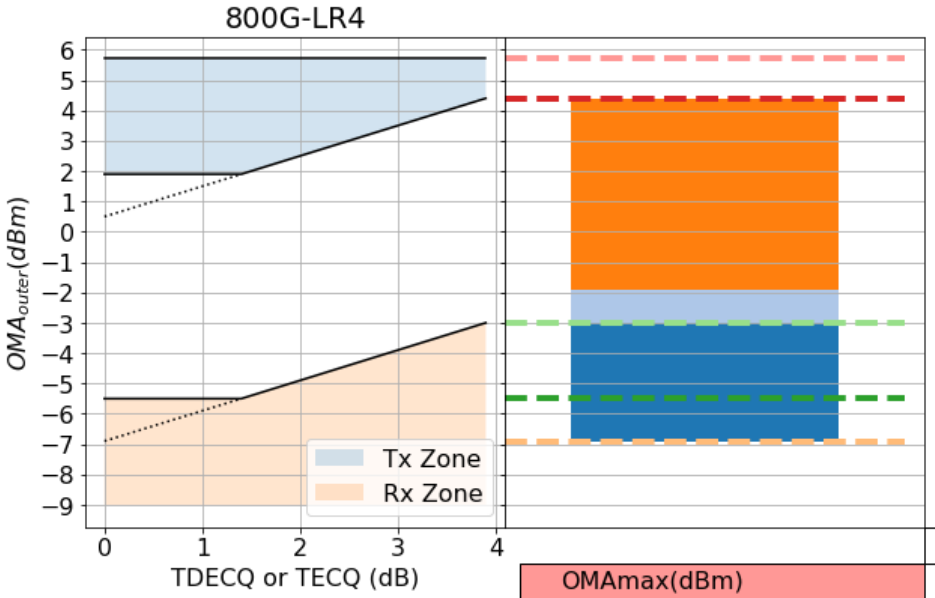
*Measured with a 17-tap FFE reference equalizer

Receive Characteristics

Description	800G-LR4 proposal	Unit
Signaling rate, each lane (range)	113.4375	GBd
Modulation format	PAM4	
Lane wavelengths (range)	1294.6 to 1296.6 1299.1 to 1301.1 1303.6 to 1305.6 1308.1 to 1310.1	nm
Damage threshold, each lane	6.5	dBm
Average receive power, each lane (max)	5.5	dBm
Average receive power, each lane (min)	-8	dBm
Receive power (OMAouter), each lane (max)	5.7	dBm
Difference in receive power between any two lanes (OMAouter) (max)	3.3	dB
Receiver reflectance (max)	-26	dB
Receiver sensitivity (OMAouter), each lane (max) for TECQ <1.4 dB for 1.4 dB ≤ TECQ ≤ 3.9 dB	 -5.5 -6.9 + TECQ	 dBm dBm
Stressed receiver sensitivity (OMAouter), each lane (max)	-3	dBm
Conditions of stressed receiver sensitivity test:		
Stressed eye closure for PAM4 (SECQ), lane under test *	3.9	dB
OMAouter of each aggressor lane	1.3	dBm

*Measured with a 17-tap FFE reference equalizer

Tx & Rx specs



	800G-LR4
OMAmax(dBm)	5.7
OMA-TDECQ(dBm)	0.5
OMAmin@TDECQmax(dBm)	4.4
SRS(dBm)	-3.0
Rx Sens (TECQ <= 1.4dB)	-5.5
RSnominal(dBm)	-6.9
OpticalLossBudget	6.3
AdditionalPenalties	1.1
TDECQmax	3.9
PowerBudget	11.3

Link Power Budget

Parameter	800G-LR4 proposal	Unit
Power budget (for maximum TDECQ)	11.3	dB
Operating Distance	10	km
Channel insertion loss	6.3	dB
Maximum discrete reflectance	-35	dB
Allocation for penalties (for maximum TDECQ) *	5	dB

*DGD=0.7dB and MPI= 0.4dB , kuschnerov_3dj_optx_01_230829 , kuschnerov_3df_02a_221012

Transmitter compliance channel specifications

Dispersion		Max mean DGD
Minimum*	Maximum*	
-19.88 ps/nm	+3.22 ps/nm	0.8 ps

* For maximum and minimum wavelengths allowed by the wavelength plan.

Fiber optic cabling (channel) characteristics

Description	800GBASE-LR4	Unit
Channel insertion loss (max)	6.3	dB
Positive dispersion (max)	3.22	ps/nm
Negative dispersion (min)	-19.88	ps/nm
DGDmax	4	ps

CDq min/max proposal

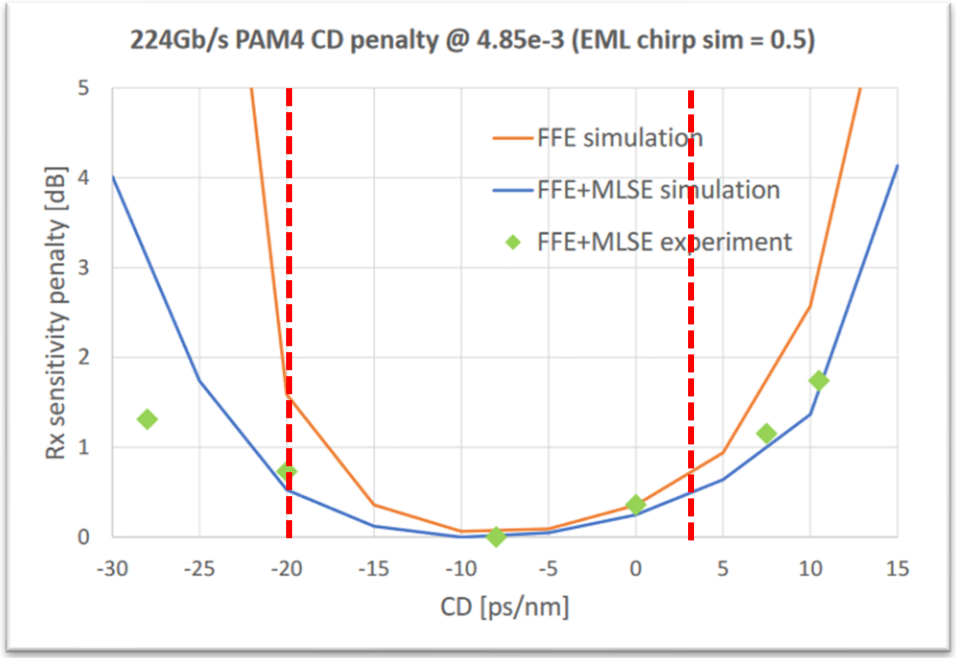
liu_3dj_01a_2307

Case 1: CD_{min} and CD_{max} at Q=1E-4

M	CD_{min}
1	-22.90
2	-21.09
3	-20.33
4	-19.88
5	-19.58
6	-19.36
7	-19.18
8	-19.05
9	-18.94
10	-18.85

M	CD_{max}
1	5.99
2	4.40
3	3.71
4	3.32
5	3.04
6	2.84
7	2.69
8	2.56
9	2.46
10	2.38

kuschnerov_3df_02_221012



We propose to use CDminQ= -19.88ps/nm and CDmaxQ = 3.32ps/nm. This corresponds to fiber segmentation M=4 and correlation between the different segment.
This CDq range is expected have < 2dB penalty in Rx Sensitivity even with a linear receiver