Baseline CD_Q Values for 800GBASE-LR4

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Introduction

- In the "SMF Channel Dispersion Penalty Specification Proposal" presented in Cole_3dj_optx_01_230427 [1], with ~30 supporting experts, the G.652 Zero Dispersion Wavelength (ZDW) values for TDECQ measurements are proposed to be
  - ZDW_1=1305 nm， ZDW_2=1319 nm

- The proposed model distribution is a normal distribution having a sigma of 2nm, and a mean value that is uniformly distributed from 1309 to 1315nm, i.e.,
  - N(ZDW_{mean}=1309~1315nm, sigma=2nm),

  which accounts for variation among fiber manufacturers and mean shifts [2].

- Similar to the definition of PMD_Q [3], CD_Q can be defined for 800G-LR4 [4], where the minimum CD_Q ($CD_{min,Q}$) and the maximum CD_Q ($CD_{max,Q}$) are corresponding to the shortest and longest signal wavelengths of 800G-LR4.

- In a recent contribution [5], we analytically evaluated the dependence of the $CD_{min,Q}$ and $CD_{max,Q}$ on Q and the number of fiber segments (M) in 800G-LR4, where S_0 is fixed at 0.092 ps/nm/km^2.

- In this presentation, we provide an improved assessment by additionally considering the statistical distribution of S_0, as done by John Johnson [6], where $S_0 \sim \mathcal{N}(0.0825, 0.002^2)$ ps/nm/km^2 truncated to [0.073, 0.092].

[1] https://www.ieee802.org/3/dj/public/adhoc/optics/0427_OPTX/cole_3dj_optx_01_230427.pdf
[2] https://www.ieee802.org/3/df/public/22_10/22_1012/rodes_3df_01b_221012.pdf#page=8
[3] See, for example, https://www.corning.com/media/worldwide/coc/documents/Fiber/white-paper/WP5051-12_12.pdf
[4] Vince Ferretti and Angie Lambert, "802.3dj SMF Channel Definition CDQ approach utilizing PMDQ methodology", contribution to the IEEE 802.3dj 15 June 2023 ad-hoc meeting.
[5] https://www.ieee802.org/3/dj/public/adhoc/optics/0623_OPTX/liu_3dj_optx_01_230615.pdf
[6] IEEE 802.3dj July 2023 contribution Johnson_3dj_2307.

Background on PMD_Q

- Due to the fact that fibers used in cable manufacturing have different polarization mode dispersion (PMD) coefficients, PMD requirements for fiber are expressed in terms of PMD_Q in modern ITU standards such as G.652, G.653, G.654, G.655 and G.656 [3].

- The definition of PMD_Q is based on a statistical approach where an imaginary reference link consisting of M equal length fiber segments (or sections) is considered.

- The value of PMD_Q for a transmission link depends on M and Q, where Q is the probability of the link PMD being exceeding PMD_Q, which is chosen to be acceptably small.

- In G.652-656, M=20 and Q=1E-4 (or 0.01%) are chosen.

ZDW distributions for LR (10km) links

- Per Cole_3dj_optx_01_230427 [1], $Z \sim \mathcal{N}(\mathrm{ZDW}_{\mathrm{mean}}, \sigma^2)$, where σ=2nm.
- The distribution of $\mathrm{ZDW}_{\mathrm{mean}}$ inside [1309nm, 1315nm] is uniform (which is on the conservative side).
- To evaluate the probability density function (PDF) of ZDW, we assume that

  Case 1:

  The fiber cable segments in a given 10-km link when they happen to come from the same manufacturing batch are correlated and have a fixed $\mathrm{ZDW}_{\mathrm{mean}}$ that is inside [1309nm, 1315nm] (which is on the conservative side); or

  Case 2:

  The fiber cable segments in a given 10-km link have uncorrelated ZDWs.

Analytical evaluation of link CD distribution

We can derive the distribution of link CD at λ using 3rd order Sellmeier equation

$$D(\lambda) = \frac{\lambda S_0}{4}\left[1 - \left(\frac{\lambda_0}{\lambda}\right)^4\right]$$

where

$$\lambda_0 \sim \mathcal{N}\left(\mu_{\lambda_0}, \sigma_{\lambda_0}^2\right)$$

$$\mu \sim \mathcal{U}(a, b)$$

$$S_0 \sim \mathcal{N}\left(\mu_{S_0}, \sigma_{S_0}^2\right)$$ (as suggested in Johnson_3dj_2307)

In the case of cable segmentations,

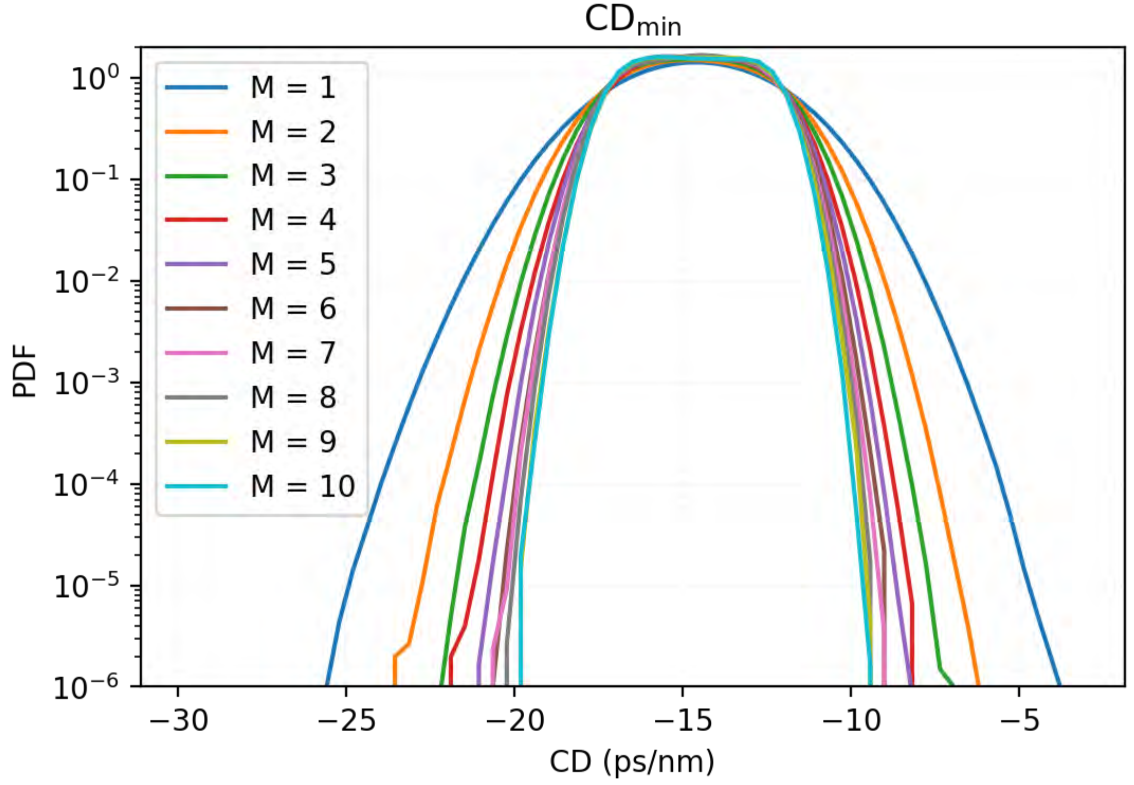
$$CD_M(\lambda) = \sum_{i=1}^{M} L_{Cab} D_i(\lambda)/M$$

$$where\ L_{Cab} = 10\ \mathrm{km\ for\ LR}$$

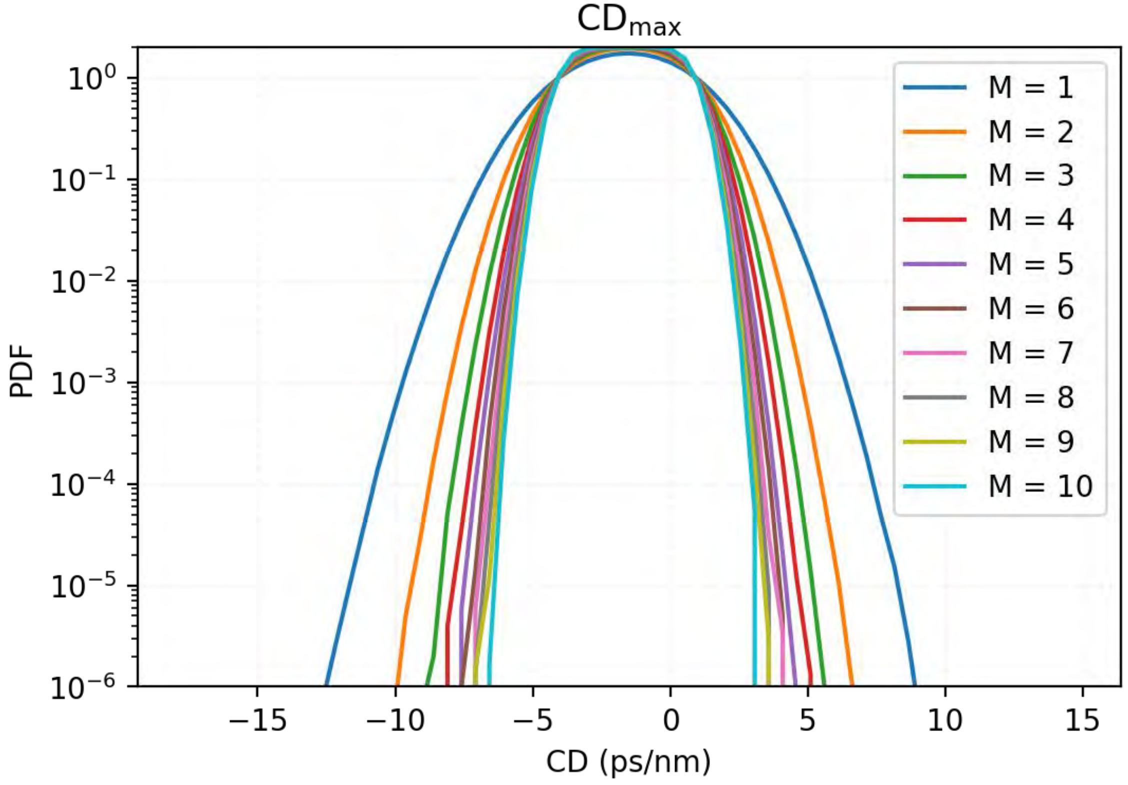
Numerically, $D(\lambda)$ and $CD_M(\lambda)$ are evaluated via Monte Carlo Analysis.

Case 1: Distributions of CD_{min} and CD_{max}

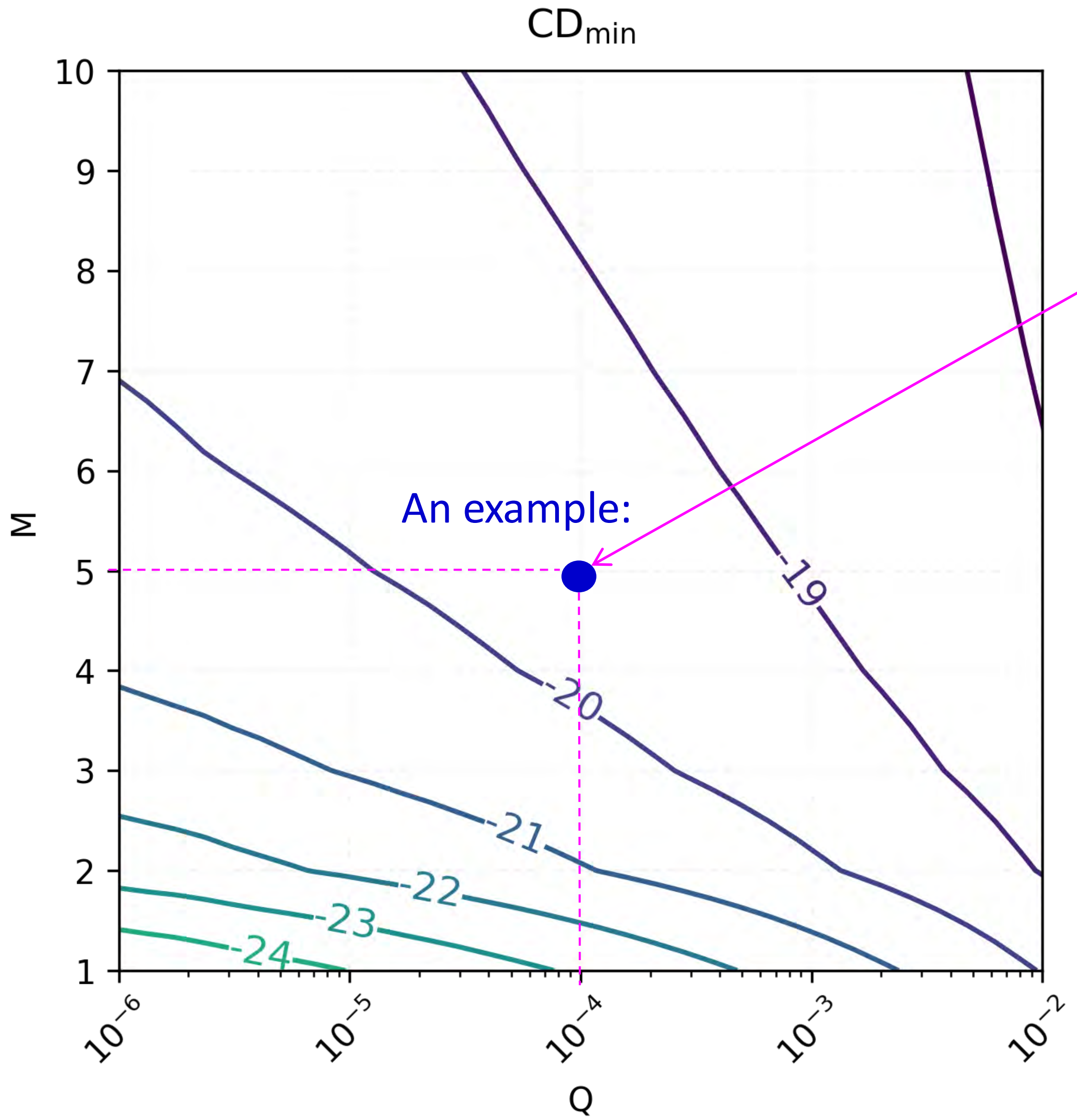
For the shortest 800G-LR4 signal wavelength of 1294.6nm, we have:



For the longest 800G-LR4 signal wavelength of 1310.1nm, we have:



Case 1: Dependence of CD_{min} on Q and M

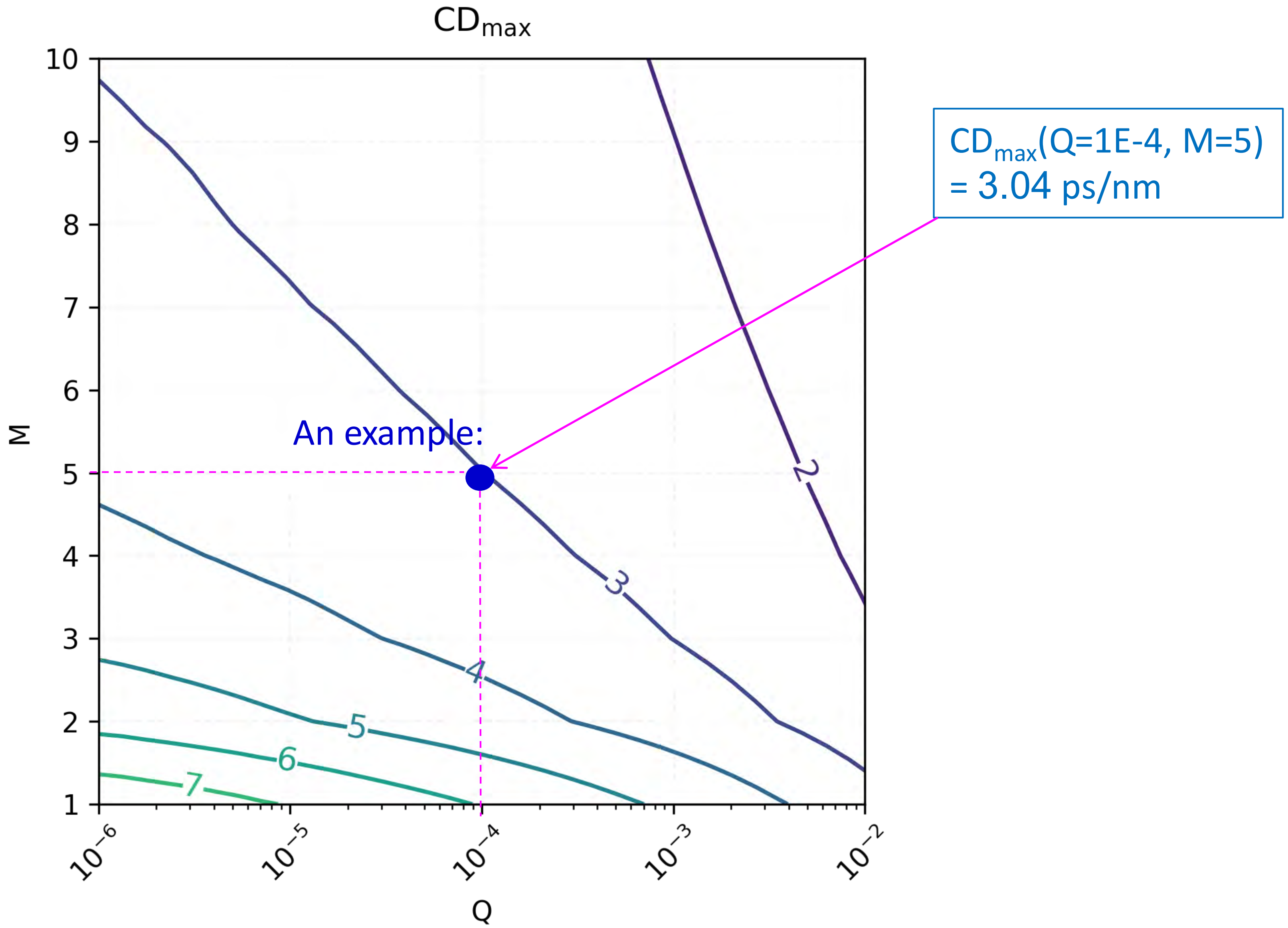


CD_{min}(Q=1E-4, M=5) = -19.58 ps/nm

For Q=1E-4, we have:

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

Case 1: Dependence of CD_{max} on Q and M



For Q=1E-4, we have:

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

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

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1	-22.90
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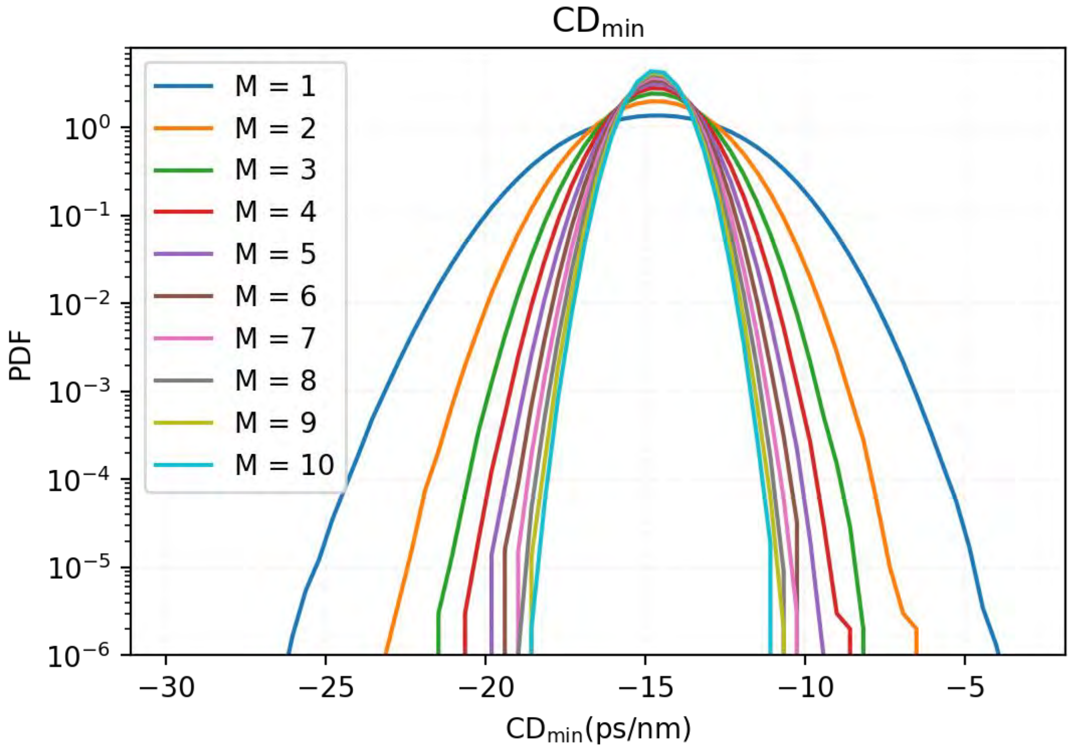
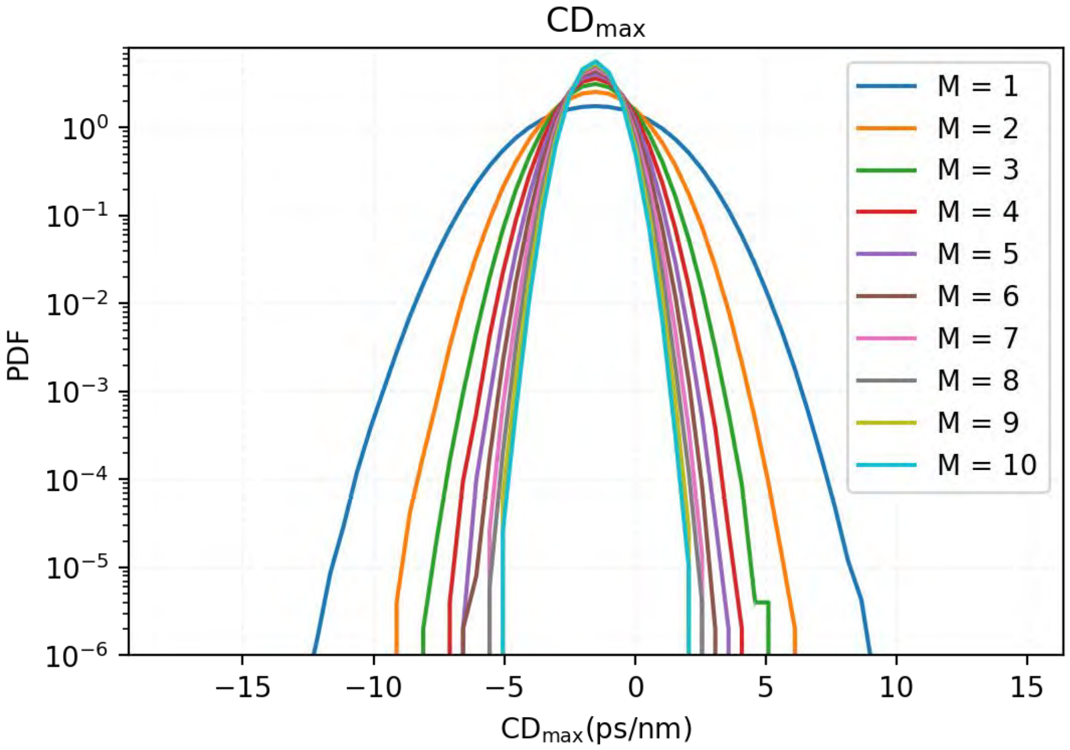
CD range @ Q=1E-4,M=5: (3.04+19.58) = 22.62 ps/nm
Worst case CD range: (9.2+28) = 37.2 ps/nm
CD range reduction: 1- 22.62/37.2 = 39%

Case 2: Distributions of CD_{min} and CD_{max}

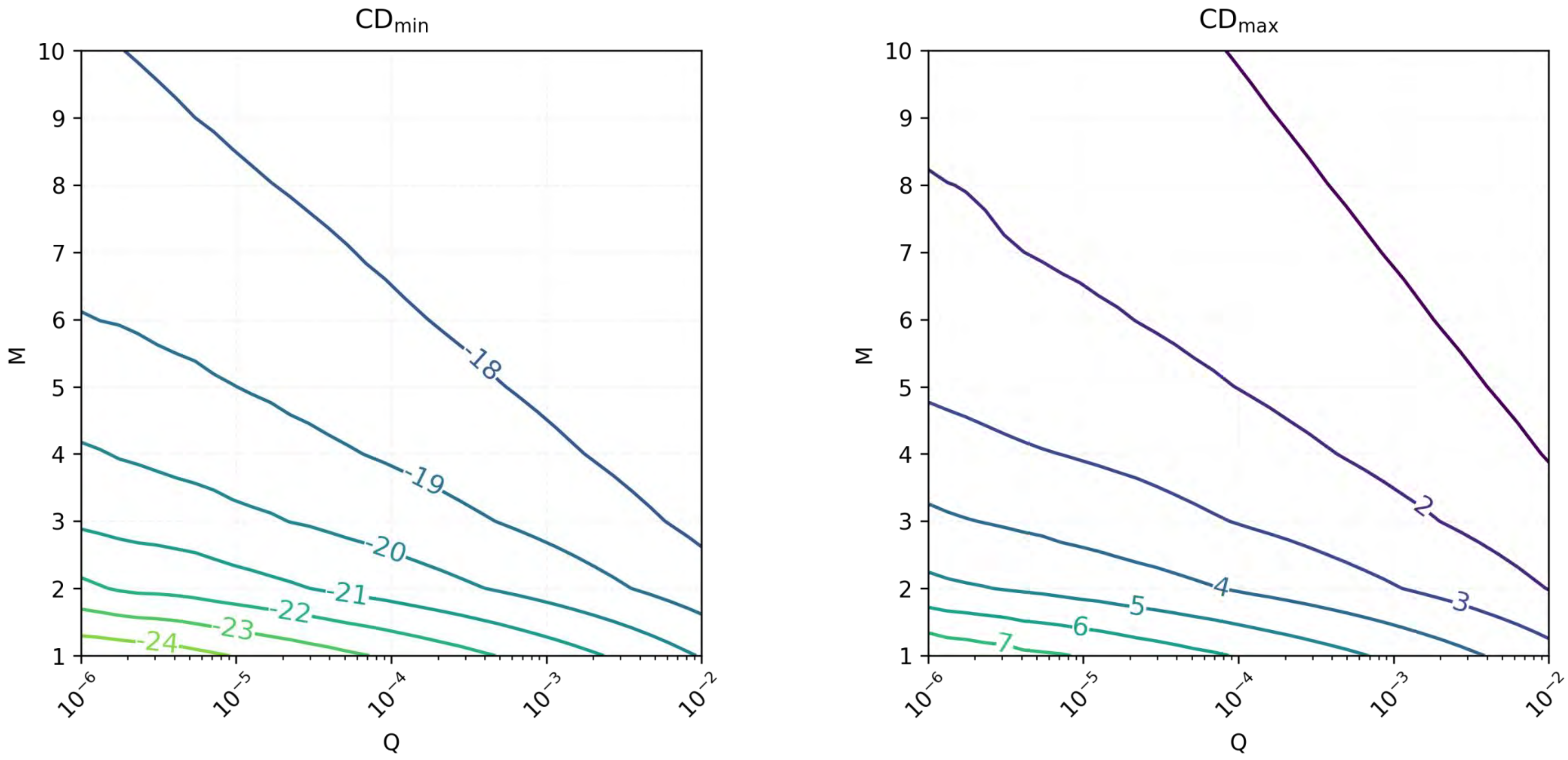
For the shortest 800G-LR4 signal wavelength of 1294.6nm, we have:



For the longest 800G-LR4 signal wavelength of 1310.1nm, we have:



Case 2: Dependence of CD_{min} and CD_{max} on Q and M



Case 2: CD_{min} and CD_{max} at Q=1E-4

M	CD_{min}
1	-22.86
2	-20.59
3	-19.56
4	-18.92
5	-18.49
6	-18.17
7	-17.91
8	-17.70
9	-17.54
10	-17.39

M	CD_{max}
1	5.97
2	3.94
3	2.99
4	2.42
5	2.02
6	1.73
7	1.49
8	1.29
9	1.14
10	1.00

CD range @ Q=1E-4,M=5: (2.02+18.49) = 20.51 ps/nm
Worst case CD range: (9.2+28) = 37.2 ps/nm
CD range reduction: 1- 20.51/37.2 = 45%

Baseline CD_Q values (M=5, Q=1E-4)

	Channel 1		Channel 2		Channel 3		Channel 4	
	$CD_{min,Q}$ @1294.56nm	$CD_{max,Q}$ @1296.56nm	$CD_{min,Q}$ @1299.05nm	$CD_{max,Q}$ @1301.05nm	$CD_{min,Q}$ @13003.58nm	$CD_{max,Q}$ @1305.58nm	$CD_{min,Q}$ @1308.14nm	$CD_{max,Q}$ @1310.14nm
Case 1	-19.58	-8.23	-15.66	-4.47	-11.76	-0.71	-7.87	3.04
Case 2	-18.49	-9.27	-14.58	-5.51	-10.69	-1.74	-6.83	2.02

Discussion & Conclusion

1) We have analytically evaluated the dependence of the $CD_{min,Q}$ and $CD_{max,Q}$ on Q and the number of fiber segments (M) in 800G-LR4 based on a realistic fiber ZDW distribution. (Other fiber ZDW distributions may also be considered in the analytical model.)

2) The CD_Q methodology is very meaningful and can reduce the CD range of the 800G-LR4 by 39% (assuming correlated ZDWs) or 45% (assuming uncorrelated ZDWs) from the worst case (without using the CD_Q methodology), potentially reducing the CD penalty to <0.5 dB.

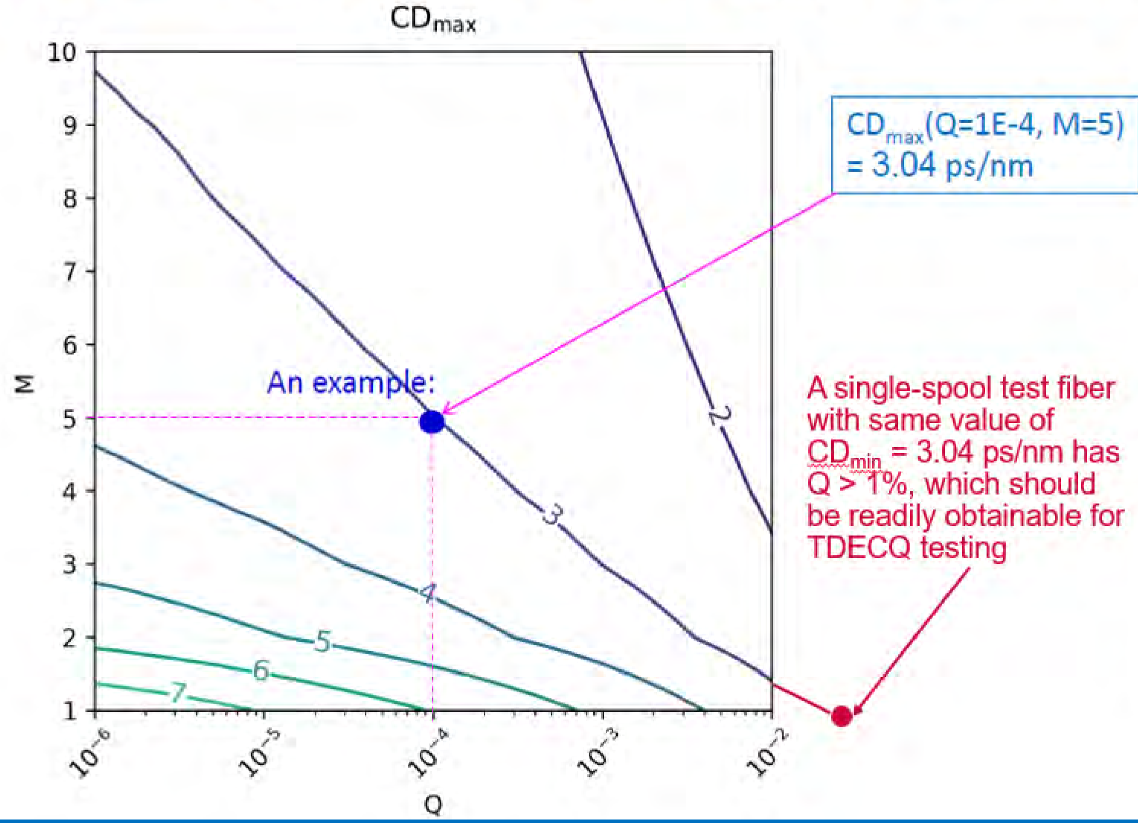
3) The IEEE 802.3dj group can select the suitable Q and M values for the specification of CD_Q.

4) It seems reasonable to consider the baseline [$CD_{min,Q}$, $CD_{max,Q}$] values as [-18.5ps/nm, +2ps/nm] or [-19.6ps/nm, +3ps/nm] for 800GBASE-LR4.

Thank you!

Appendix

Case 1: Dependence of CD_{max} on Q and M



For Q=1E-4, we have:

M	CD_{max}
1	5.99
2	4.40
3	3.71
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Because of the significant relaxation of CD_Q(M=5, Q=1e-4) relative to the worst case, a 10 km single-spool test fiber (M=1) with the same value of CD has Q > 1%. This means that such a test fiber should be readily obtainable, since it represents >1% of fiber vendors' production. This is a vast improvement over trying to obtain a 10km test fiber with 9.2 ps/nm CD, or having to use up to >30 km of nominal fiber in the test set.