Dependence of $CD_{min,Q}$ and $CD_{max,Q}$ on Q and the Number of Fiber Segments (M) in 800G-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 this presentation, we analytically evaluate the dependence of the $CD_{min,Q}$ and $CD_{max,Q}$ on Q and the number of fiber segments (M) in 800G-LR4.

[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.

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].

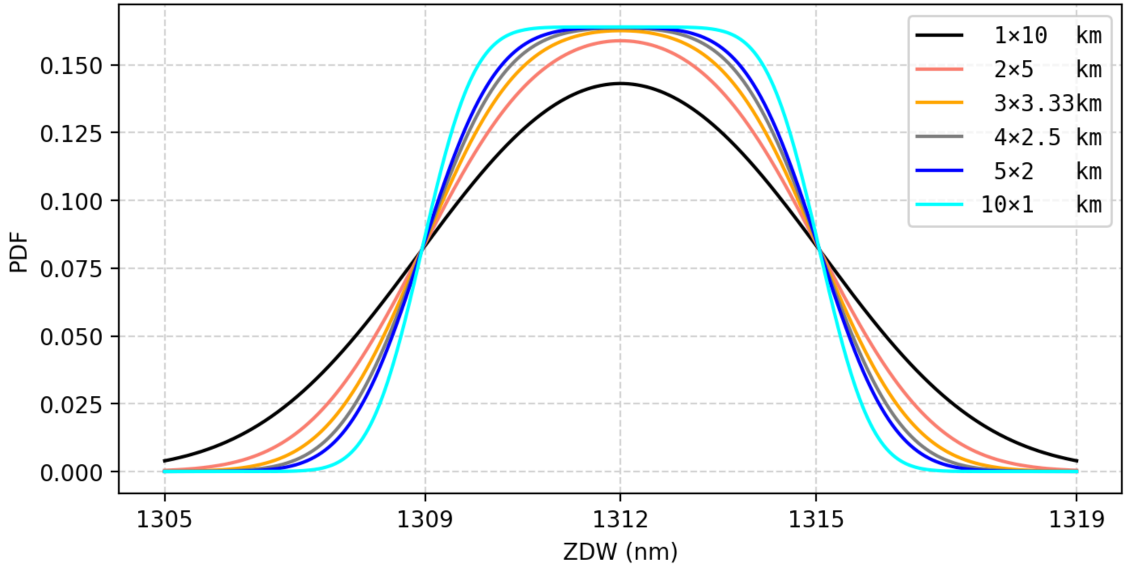
- The definition of PMD_Q is based on a statistical approach where an imaginary reference link consisting of M equal length fiber segments (or sections) is considered.

- 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.

A realistic distribution of ZDW for LR (10km) links

- Per Cole_3dj_optx_01_230427 [1], $Z \sim \mathcal{N}(\text{ZDW}_{\text{mean}}, \sigma)$, where σ=2nm.
- With n-segment fiber concatenation, the average ZDW is subject to: $Z_n \sim \mathcal{N}(\text{ZDW}_{\text{mean}}, \frac{\sigma}{\sqrt{n}})$
- To evaluate the probability density function (PDF) of ZDW, we assume that
  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 ZDW_{mean} that is inside [1309nm, 1315nm] (which is on the conservative side); and
  2) The distribution of ZDW_{mean} inside [1309nm, 1315nm] is uniform (which is also on the conservative side).
- The resulting PDF of the ZDW of the entire 10-km link is as follows:



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

$$\lambda_0 \sim \mathcal{N}\left(\mu, \frac{\sigma}{\sqrt{n}}\right)$$

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

In the case of cable segmentations,

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

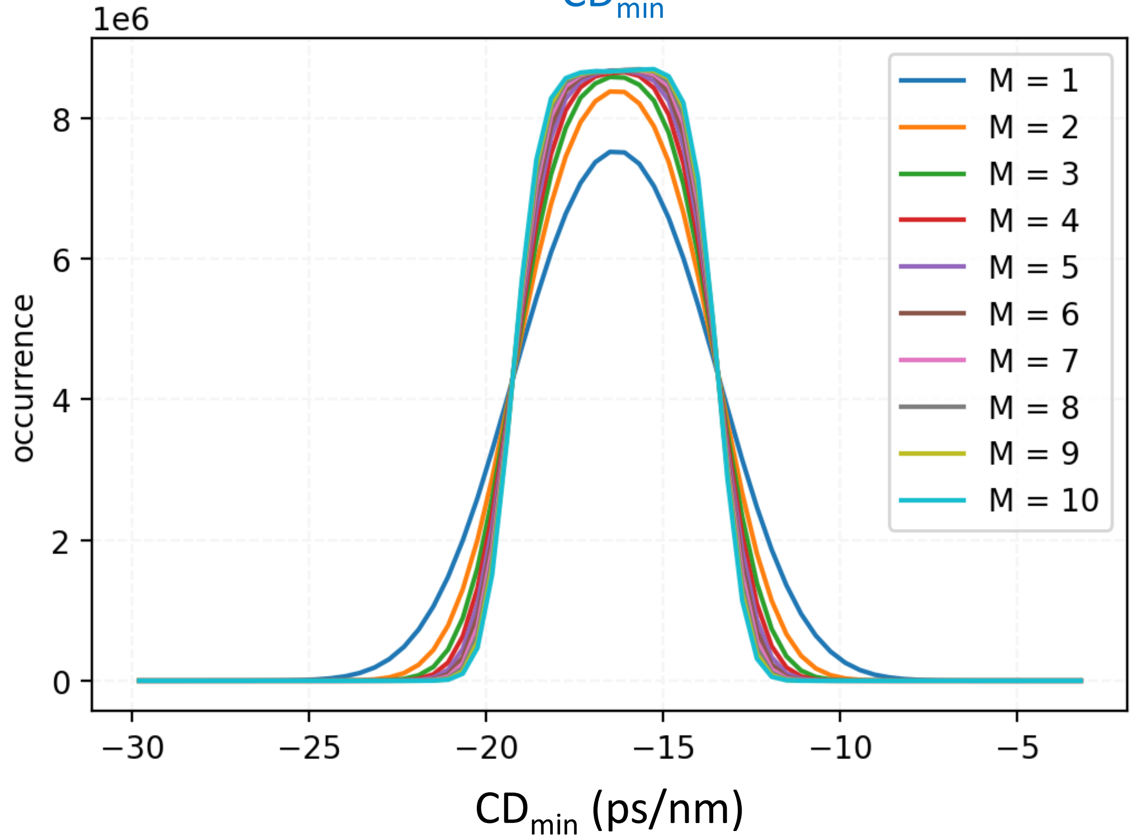
$$where\ L_{Cab} = 10 \text{ km for LR}$$

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

Distributions of CD_{min} and CD_{max}

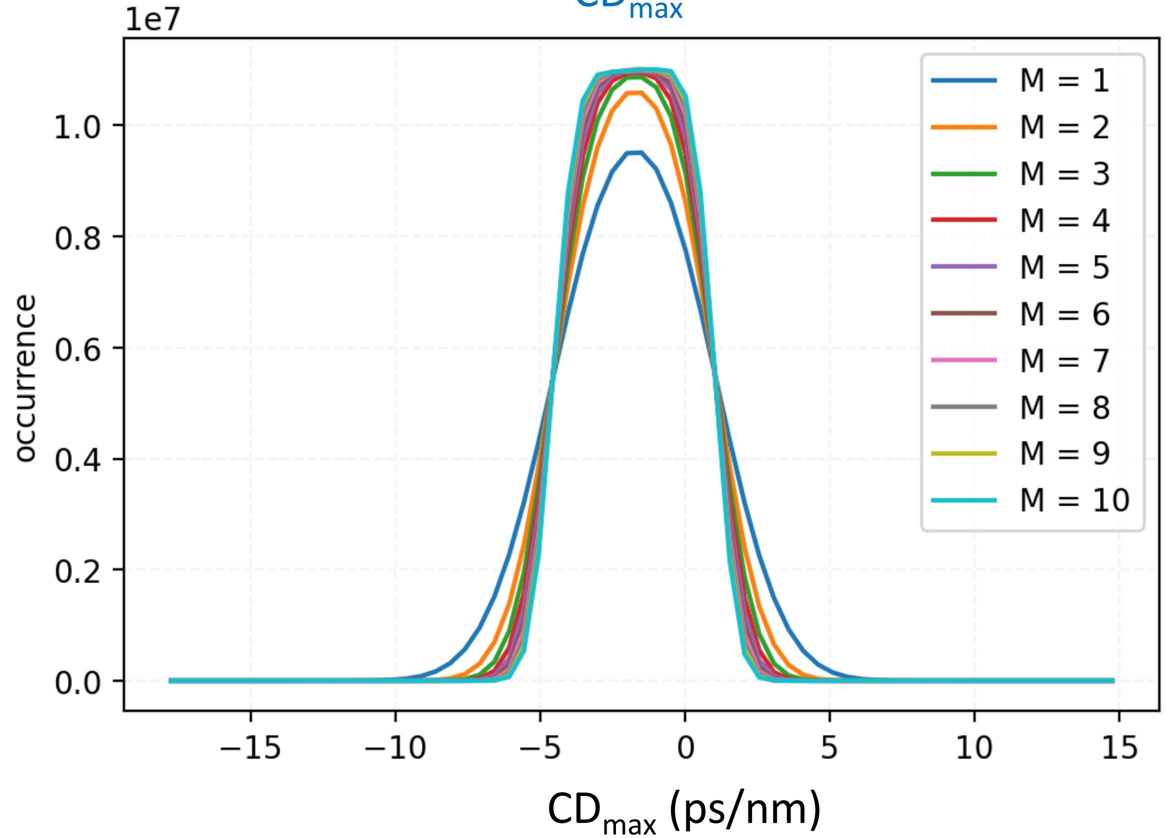
For the shortest 800G-LR4 signal wavelength of 1294.6nm, we have:

CD_{min}

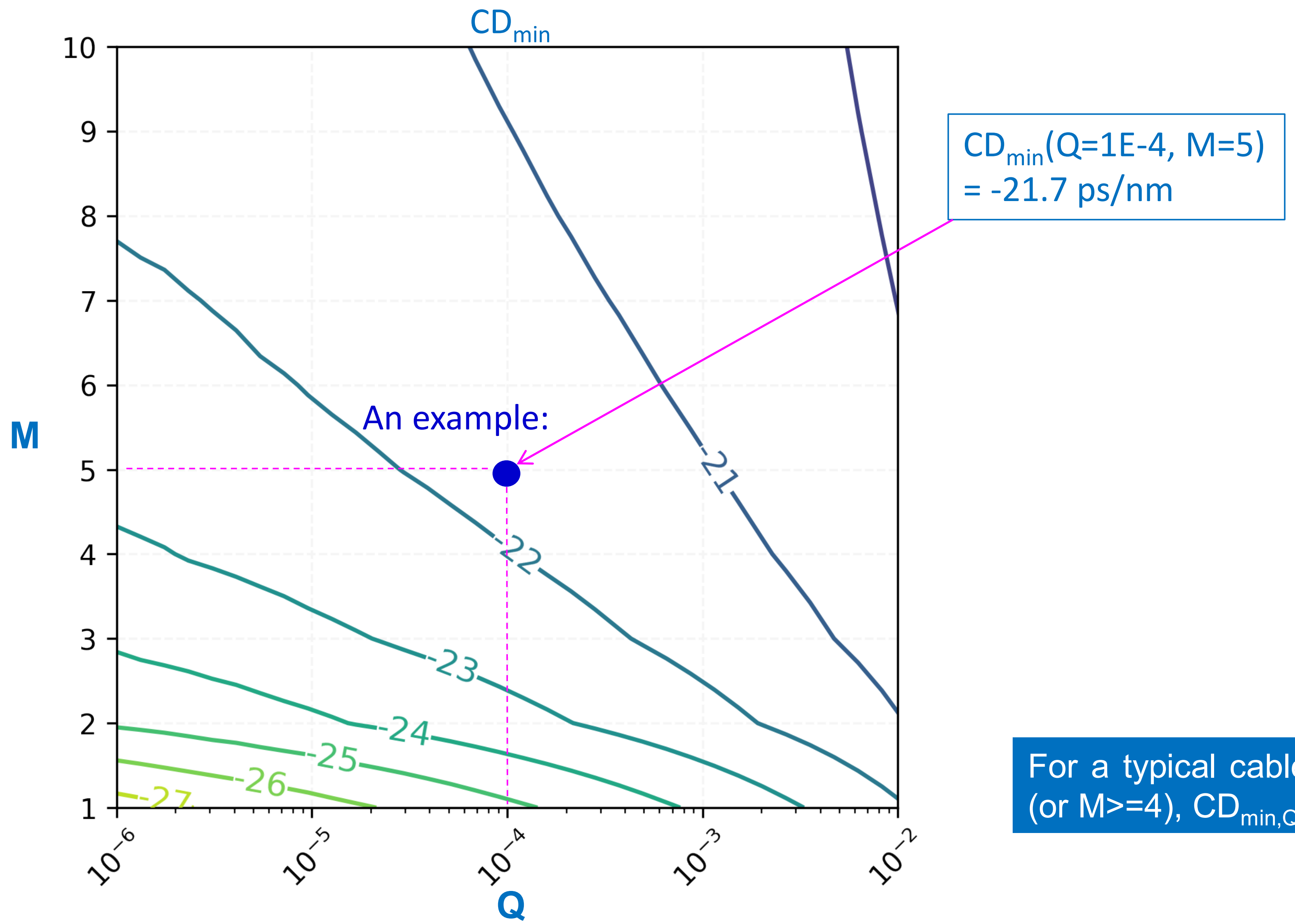


For the longest 800G-LR4 signal wavelength of 1310.1nm, we have:

CD_{max}



Dependence of CD_{min} on Q and M

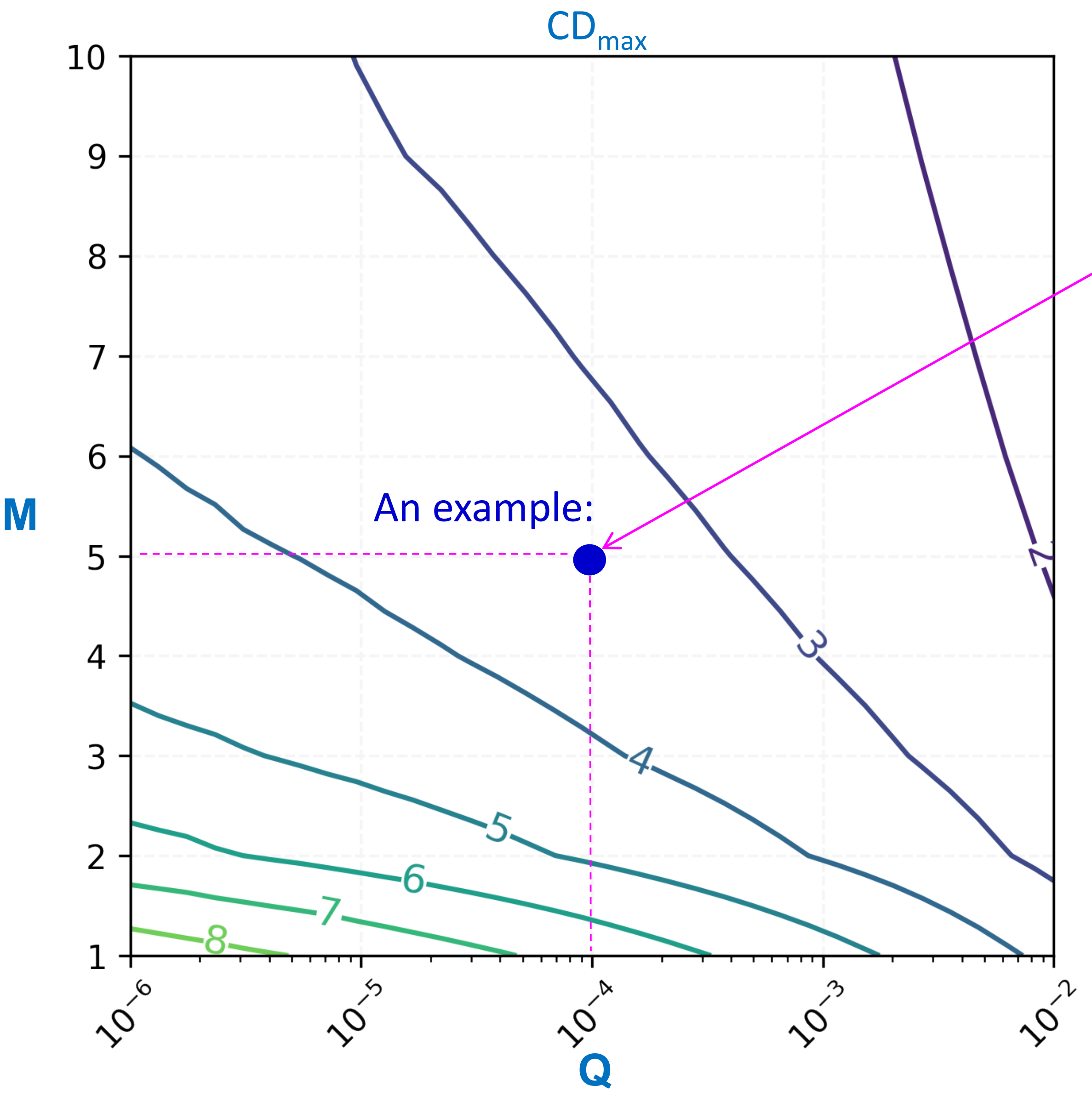


For Q=1E-4, we have:

M	CD_{min}
1	-25.19
2	-23.31
3	-22.49
4	-22.01
5	-21.69
6	-21.45
7	-21.27
8	-21.12
9	-21.00
10	-20.91

For a typical cable segment length of <=2.5km (or M>=4), $CD_{min,Q}$ is acceptable for 800G-LR4.

Dependence of CD_{max} on Q and M



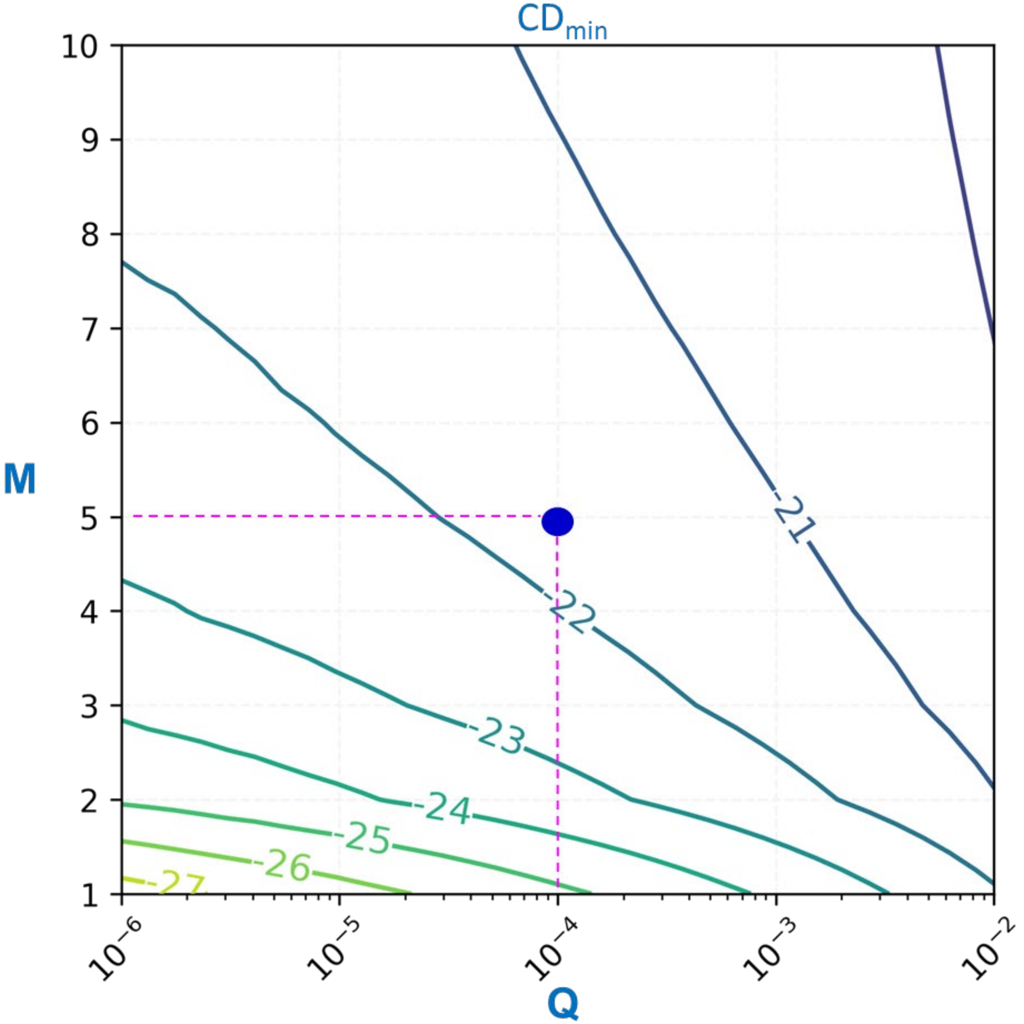
CD_{max}(Q=1E-4, M=5) = 3.35 ps/nm

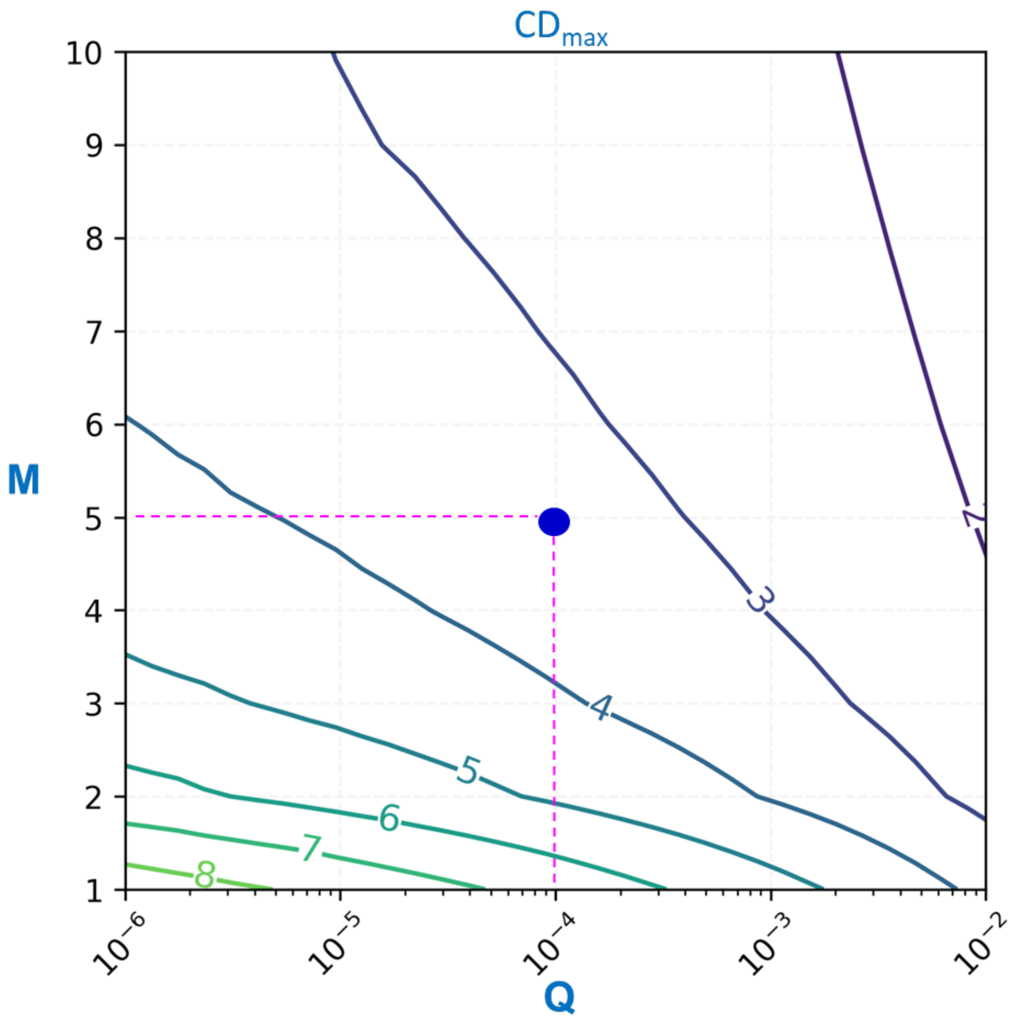
For Q=1E-4, we have:

M	CD_{max}
1	6.62
2	4.86
3	4.10
4	3.65
5	3.35
6	3.13
7	2.95
8	2.82
9	2.70
10	2.60

For a typical cable segment length of <=2.5km (or M>=4), $CD_{max,Q}$ is acceptable for 800G-LR4.

Dependence of CD_{min} and CD_{max} on Q and M





For a typical cable segment length of <=2.5km (or M>=4), both $CD_{min,Q}$ and $CD_{max,Q}$ (with Q=1E-4) are acceptable for 800G-LR4, and the CD range can be reduced by ~30% from the worst case (without using the CD_Q methodology).

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 ~30% from the worst case (without using the CD_Q methodology).

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

Given the above, we support the proposal to use the CD_Q approach (following the PMD_Q methodology) for the IEEE 802.3dj SMF Channel Definition [4].

Thank you!