IEEE P802.3dj July 2023 Meeting

# Baseline $CD_Q$ Values for 800GBASE-LR4

Xiang Liu[(1)], Qirui Fan[(1)], John Johnson[(2)], Roberto Rodes[(3)], Maxim Kuschnerov[(4)], Rang-Chen (Ryan) Yu[(5)], Ernest Muhigana[(6)], Nobuhiko Kikuchi[(7)], Frank Chang[(8)], and Chris Cole[(3)]

[(1)]Huawei Hong Kong Research Center, China; [(2)]Broadcom, USA; [(3)]Coherent, USA; [(4)]Huawei European Research Institute, Germany; [(5)]SiFotonics, USA; [(6)]Lumentum, USA; [(7)]Hitachi, Japan; [(8)]Source Photonics, USA.

# 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], $Z \sim \mathcal{N}(\text{ZDW}_{\text{mean}}, \sigma^2)$, where σ=2nm.
- The distribution of $\text{ZDW}_{\text{mean}}$ 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 $\text{ZDW}_{\text{mean}}$ 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 $\lambda$ 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,

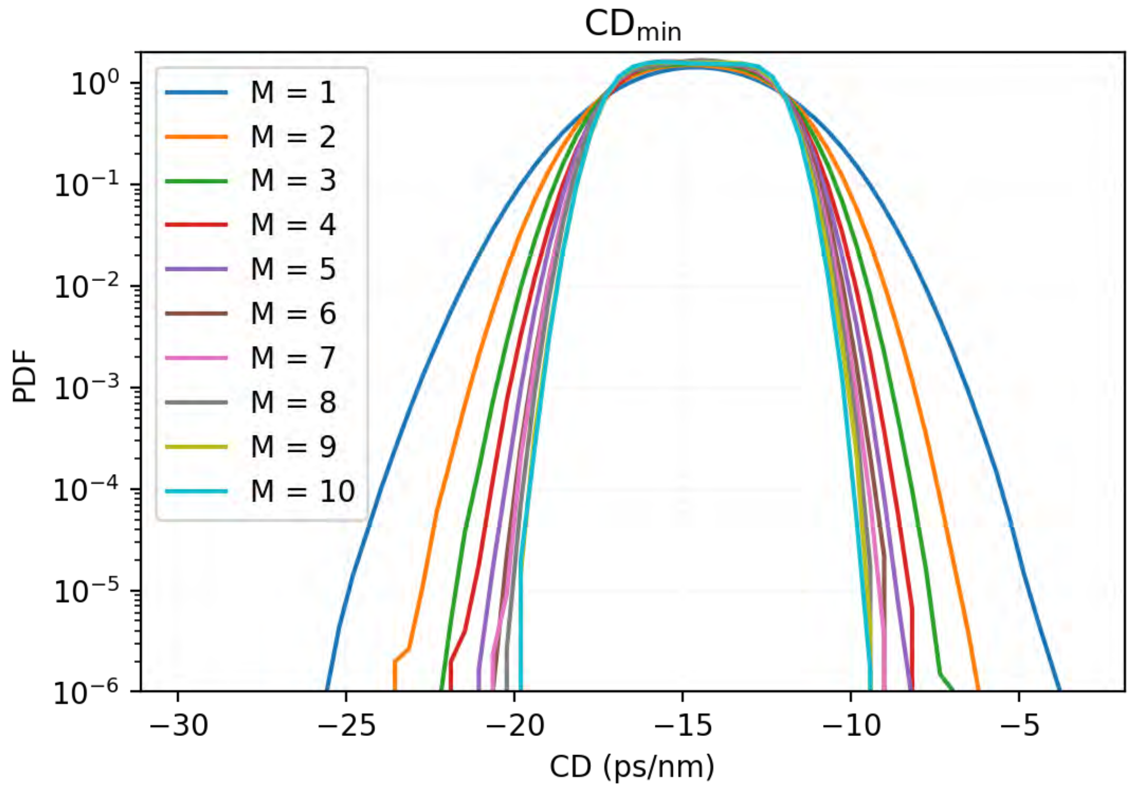
$$CD_M(\lambda) = \sum_{i=1}^{M} L_{Cab} D_i(\lambda)/M$$

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

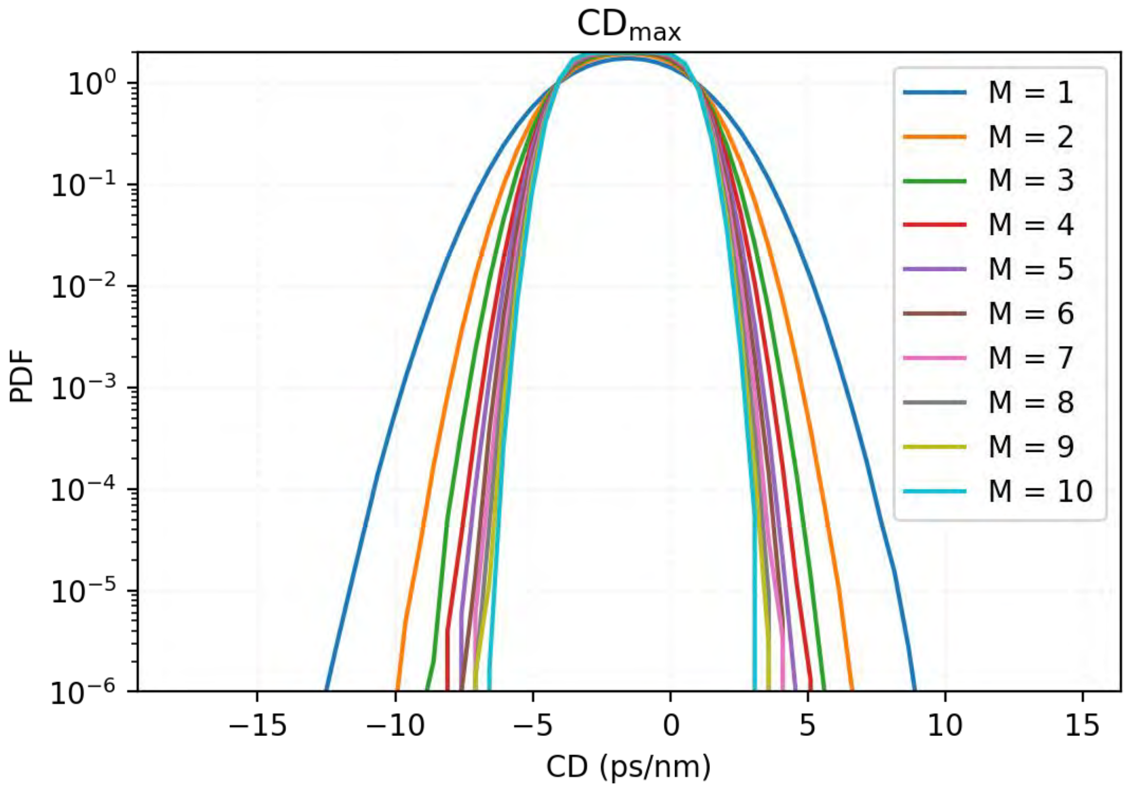
Numerically, $D(\lambda)$ and $CD_M(\lambda)$ are evaluated via Monte Carlo Analysis.

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

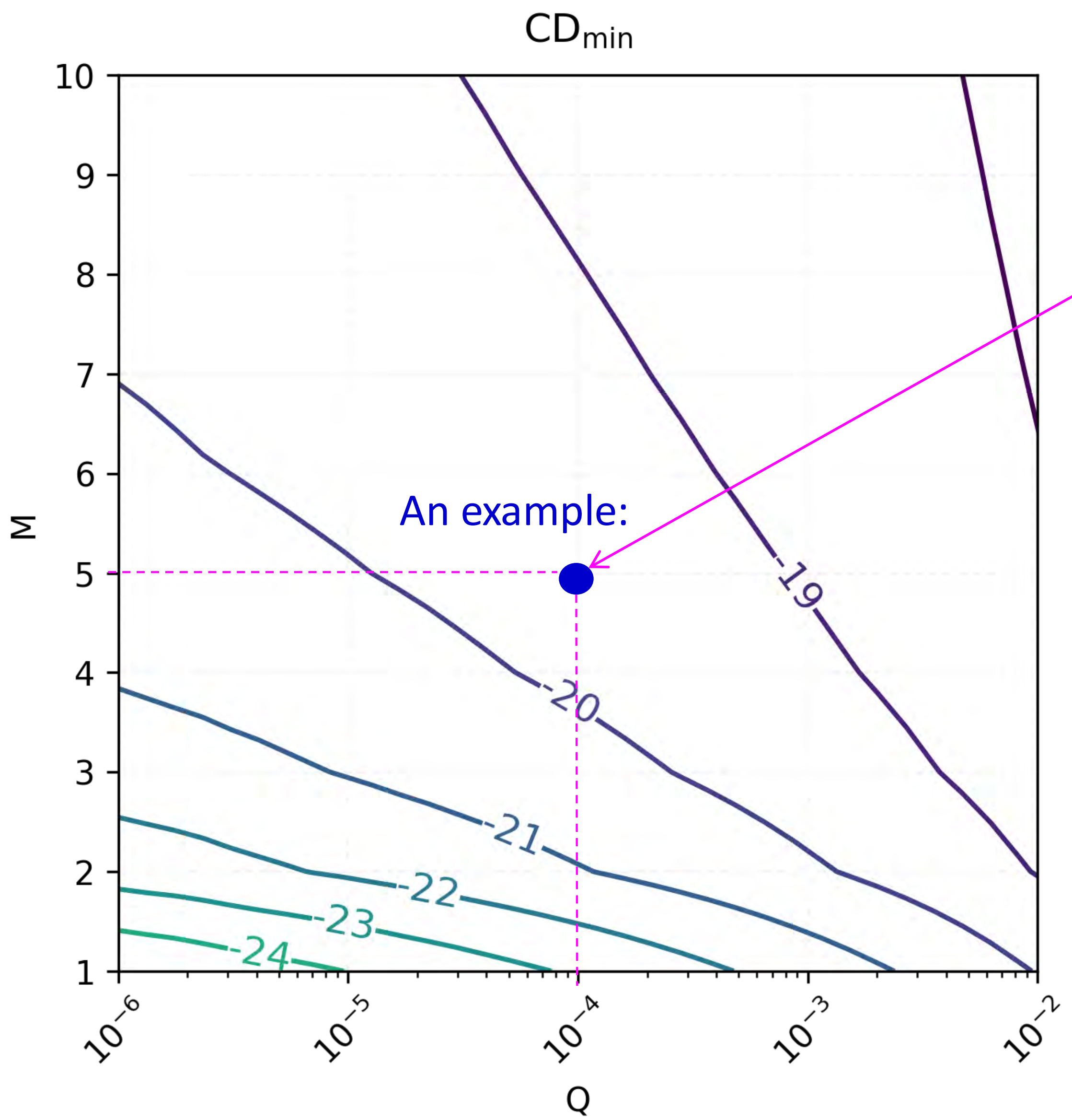
For the shortest 800G-LR4 signal wavelength of 1294.6nm, we have:




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



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

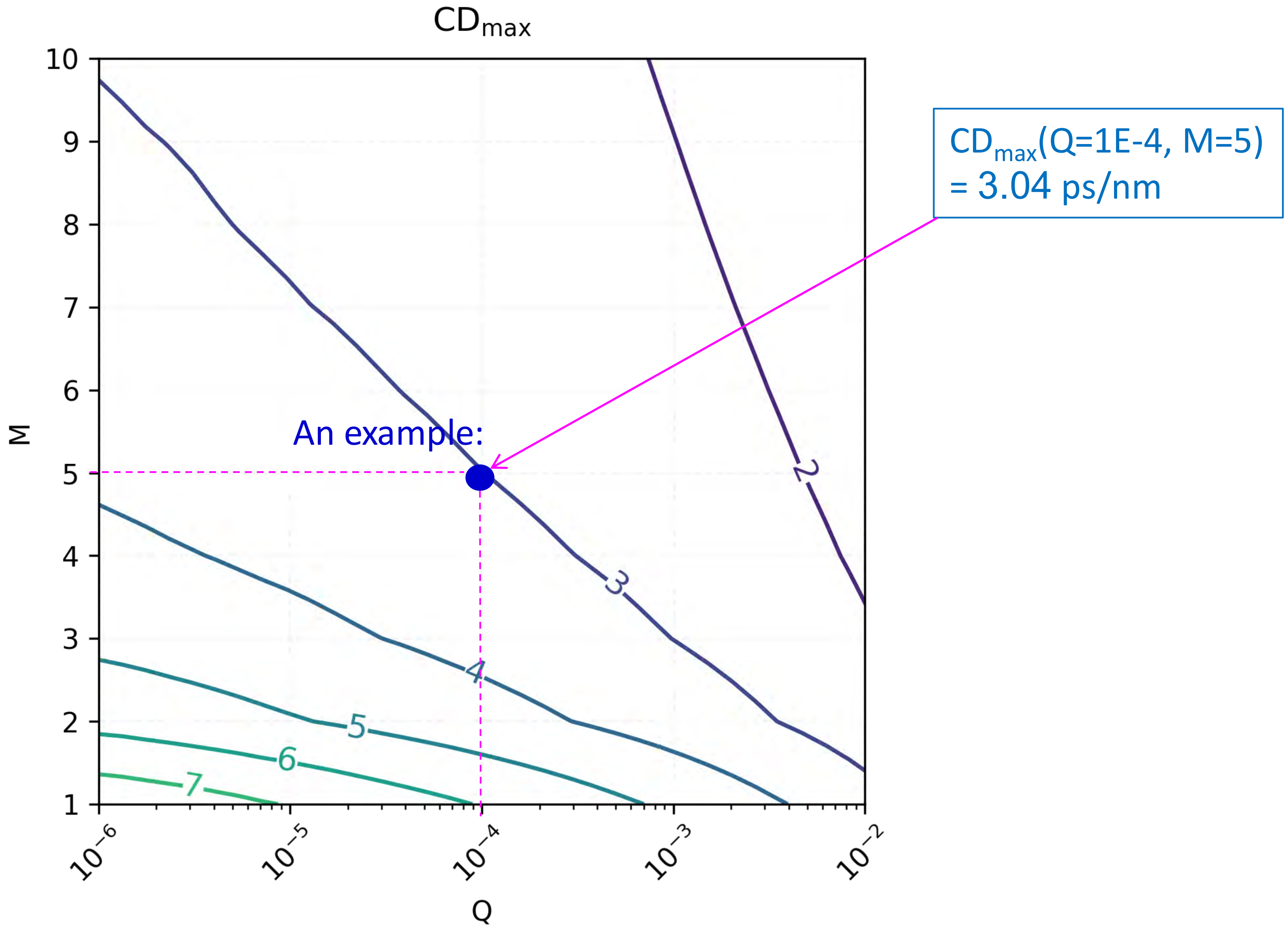



$CD_{min}$(Q=1E-4, M=5) = -19.58 ps/nm

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

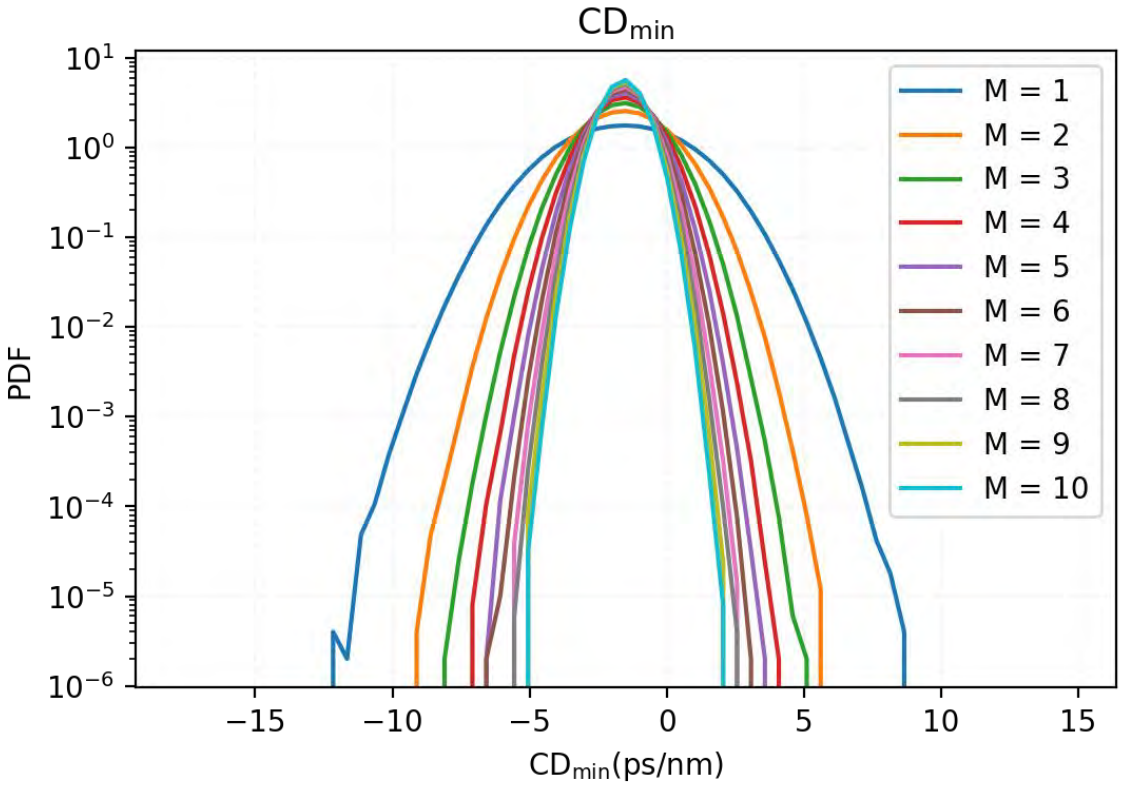
| M | $CD_{min}$ |
|---|---|
| 1 | -22.90 |
| 2 | -21.09 |
| 3 | -20.33 |
| 4 | -19.88 |
| 5 | -19.58 |
| 6 | -19.36 |
| 7 | -19.18 |
| 8 | -19.05 |
| 9 | -18.94 |
| 10 | -18.85 |

| 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 |

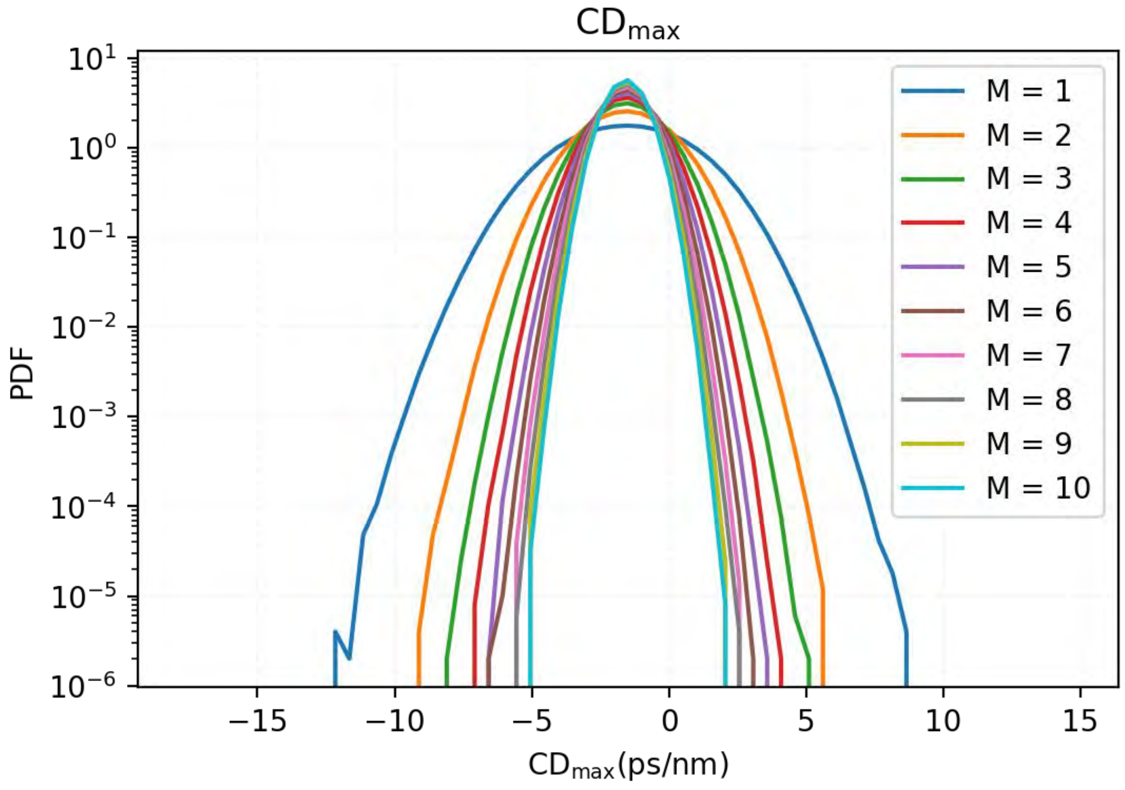
CD range @ Q=1E-4,M=5: (3.04+19.58) = 22.62 ps/nm
Worst case CD range: (9.2+28) = 37.2 ps/nm
CD range reduction: 1- 22.62/37.2 = 39%

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

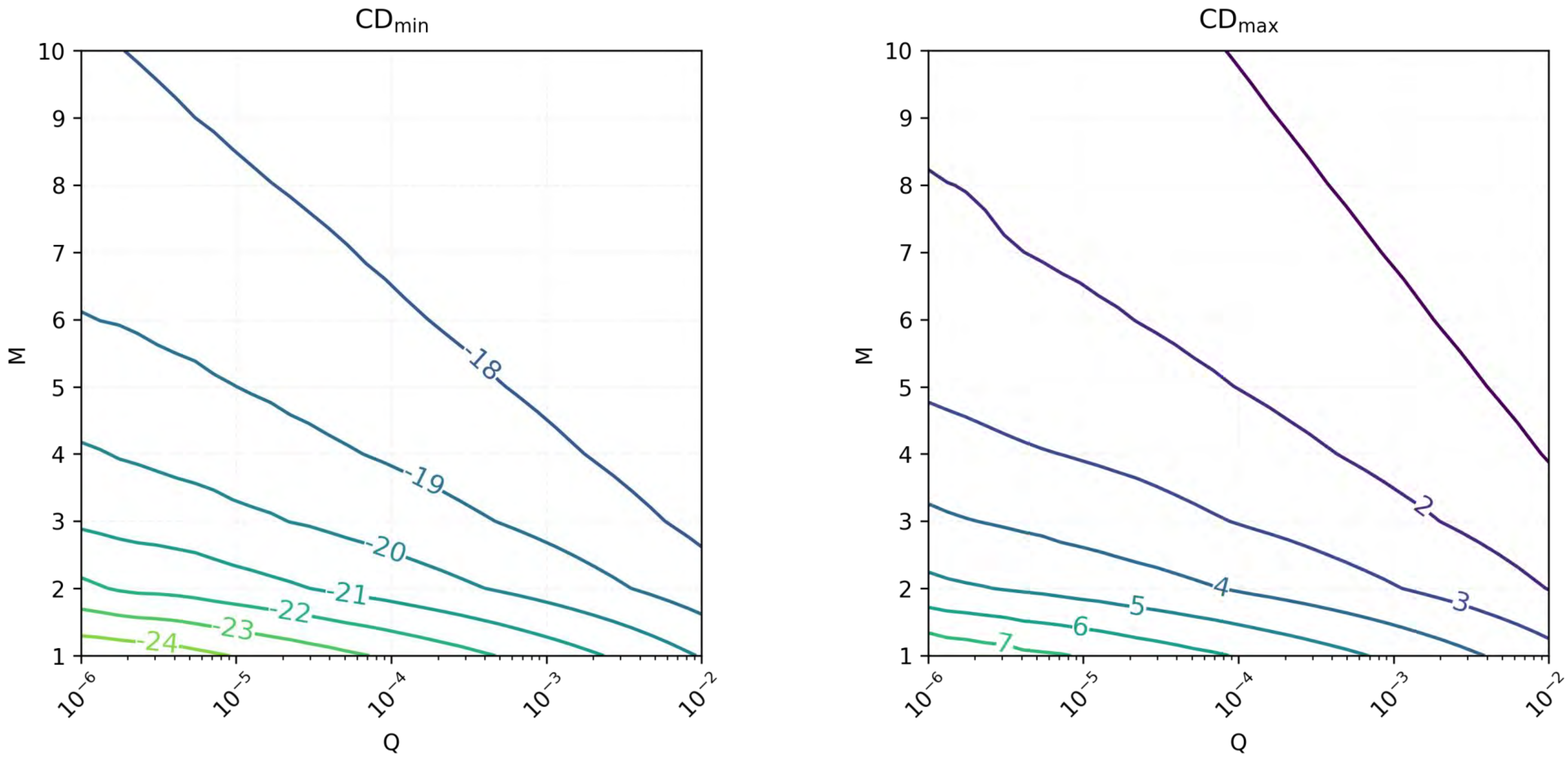
For the shortest 800G-LR4 signal wavelength of 1294.6nm, we have:




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.

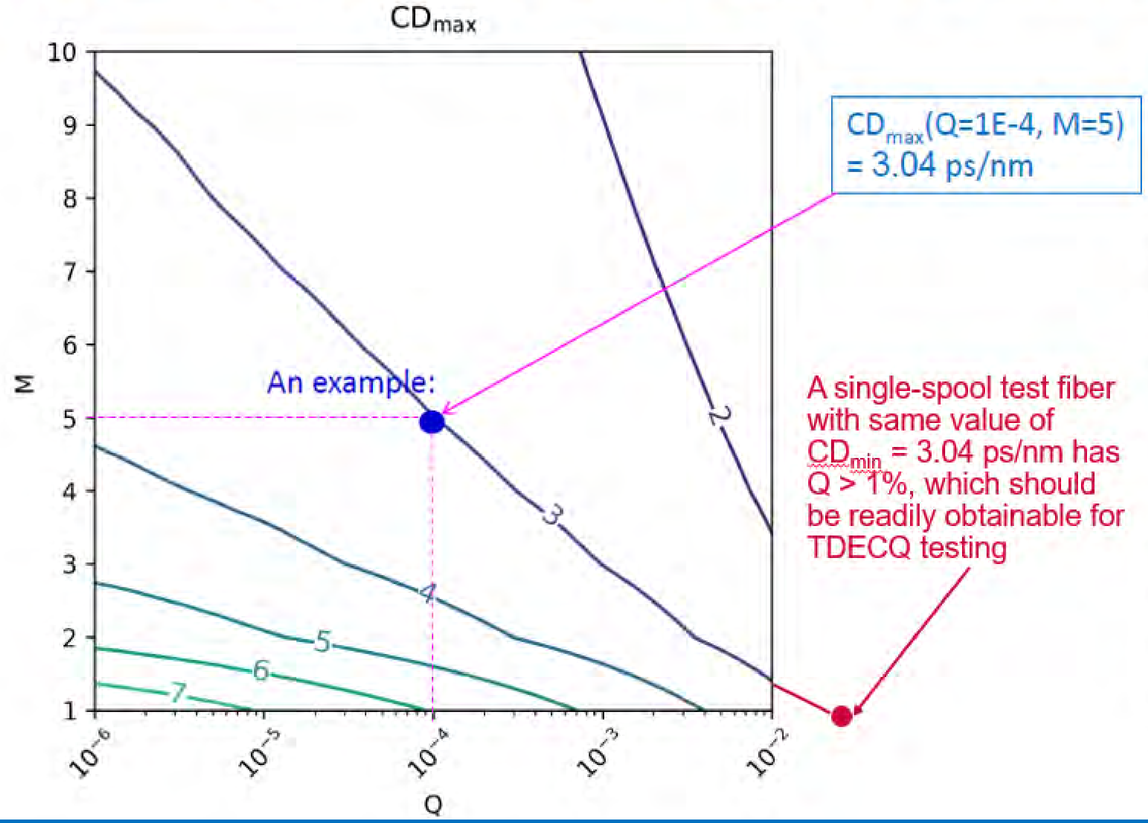
3) The IEEE 802.3dj group can select the suitable Q and M values for the specification of $CD_Q$.

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 |
| 4 | 3.32 |
| 5 | 3.04 |
| 6 | 2.84 |
| 7 | 2.69 |
| 8 | 2.56 |
| 9 | 2.46 |
| 10 | 2.38 |

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.