Probability of CD penalty higher than that predicted by TDECQ measurement at 1305 and 1319nm

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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

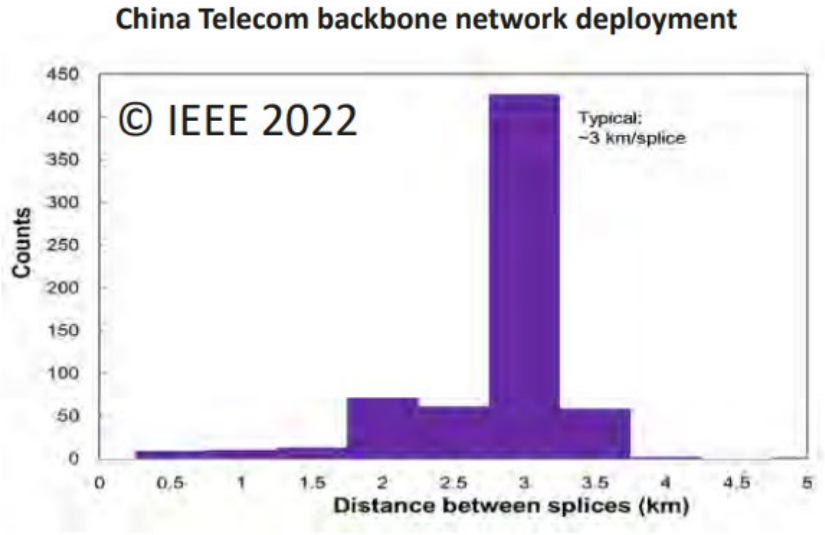
- The proposed model distribution is a normal distribution having a sigma of 2nm, and a mean value that is uniformly distributed from 1309 to 1315nm, i.e.,
  - N(ZDW_{mean}=1309~1315nm, sigma=2nm),
    which accounts for variation among fiber manufacturers and mean shifts [2].

- In this presentation, we show that the probability of CD penalty higher than that predicted by TDECQ measurement at 1305 and 1319nm (P_{CD}), using a statistical approach as in [3], is very low (e.g., <1E-6) when actual fiber cable segmentation [4-6] is taken into consideration in a rigorous analysis.

[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] https://www.ieee802.org/3/dj/public/23_01/23_0206/johnson_3dj_01a_230206.pdf
[4] https://www.ieee802.org/3/df/public/22_11/kuschnerov_3df_01a_2211.pdf
[5] https://www.ieee802.org/3/dj/public/23_01/23_0206/kikuchi_3dj_01b_230206.pdf
[6] https://www.ieee802.org/3/dj/public/23_03/liu_3dj_01_2303.pdf

Actual Fiber Cable Segmentation

- As each deployed fiber cable generally consists of multiple cable segments that are sliced together, and the each segment is usually less than 3km (even for ultra-long-haul systems), as shown on the below (after kuschnerov_3df_01a_2211), we need to consider the realistic randomization of ZDW from segment to segment.

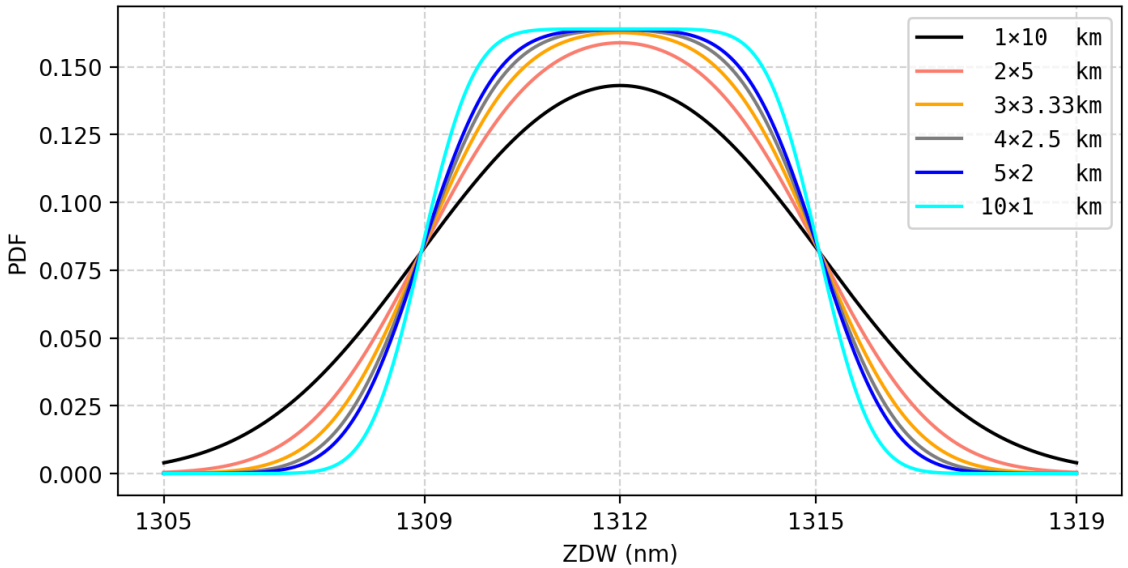


C. Zhang *et al.*, "Optical Layer Impairments and Their Mitigation in C+L+S+E+O Multi-Band Optical Networks With G.652 and Loss-Minimized G.654 Fibers," in *Journal of Lightwave Technology*, vol. 40, no. 11, pp. 3415-3424, 1 June, 2022. https://ieeexplore.ieee.org/document/9756341

- In this contribution, we evaluate the probability of CD penalty higher than that predicted by TDECQ measurement at 1305 and 1319nm (P_{CD}) in a 10-km G.652 fiber link consisting of (i) 2x 5km, (ii) 3x 3.33km, (iii) 4x 2.5km, (iv) 5x 2km, and (v) 10x 1km cable segments with the assumption that the ZDW is randomized between segments, in comparison with a hypothetic 10km link without cable segmentation.

Rigorous Modeling Result (1)

- 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: $Z_n \sim \mathcal{N}(\text{ZDW}_{\text{mean}}, \frac{\sigma^2}{n})$
- 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:

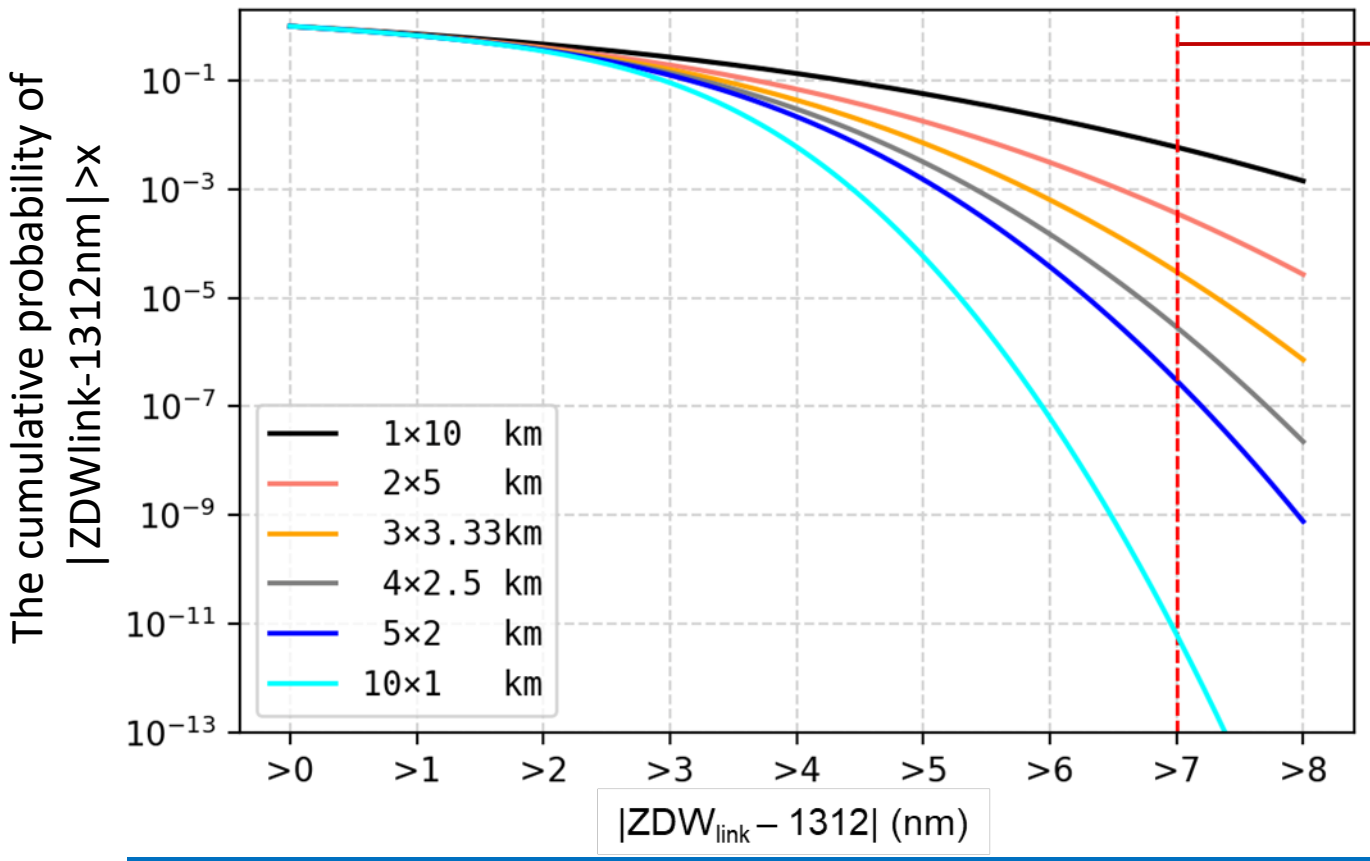


[7]] https://www.ieee802.org/3/dj/public/adhoc/optics/0427_OPTX/cole_3dj_optx_01_230427.pdf

Rigorous Modeling Result (2)

- The static OP's for the ZDW of the entire 10-km link (ZDW_{link}*) being outside the [1305nm, 1319nm] window in a 10-km G.652 fiber link consisting of (i) 2x 5km, (ii) 3x 3.33km, (iii) 4x 2.5km, (iv) 5x 2km, and (v) 10x 1km cable segments are shown below, as compared to a hypothetic 10km link without cable segmentation.

(: ZDW_{link} is the average of the segment ZDWs)*



ZDW_{link} being outside [1305nm, 1319nm]

Segmentation scenario	P_{CD}
1 x 10km	5.9E-3
2 x 5km	3.6E-4
3 x 3.33km	3.0E-5
4 x 2.5km	2.9E-6
5 x 2km	3.0E-7
10 x 1km	6.4E-12

For a typical cable segment length of ~2km (e.g., used in FR), P_{CD} is <1E-6.

Discussion & Conclusion

1) Even with the conservative assumption of G.652 fiber ZDW distribution, N(ZDW_{mean}=1312±3nm, sigma=2nm), the probability of CD penalty higher than that predicted by TDECQ measurement at 1305 and 1319nm is very low (e.g., <1E-6) when actual fiber cable segmentation with the assumption that the ZDW is randomized between segments is taken into consideration.

2) Field-deployed systems are operating with extra margin, because of statistical distribution of component and fiber losses and impairments, therefore the actual P_{CD} is even lower.

3) Thus, the two ZDW test points proposed in the "SMF Channel Dispersion Penalty Specification Proposal" [1],
   - ZDW_1=1305 nm, ZDW_2=1319 nm

   represent statistically significant worst-case dispersion scenarios.

Given the above, the "SMF Channel Dispersion Penalty Specification Proposal" [1] for link budget calculations and transceiver testing is well supported.

Thank you!

Backup Slides

Background on Fiber Cable Segmentation

- Fiber cables are deployed on a segment-by-segment basis, where each segment is typically 1~3 km in length (due to deployment considerations on transportation and installation etc., as illustrated in https://www.istockphoto.com/de/search/2/image?phrase=laying+fiber+optic+cable)
- Each fiber cable contains many fibers (e.g., 144 fibers).
- All the fibers in the adjacent segments are sliced together.
- Two exemplary fiber cable specifications are show below:

Cable Type	Fiber Count	Loose tube count	Cable Diameter (mm)	Cable Weight (Kg/km)
GYTY53-2～6	2～6	1	12.5	160
GYTY53-130～144	134～144	12	18.0	290

Source: https://mefiberoptic.com/product/144-core-gyty53-fiber-optic-cable/