PMD penalty for 400GBASE-LR4

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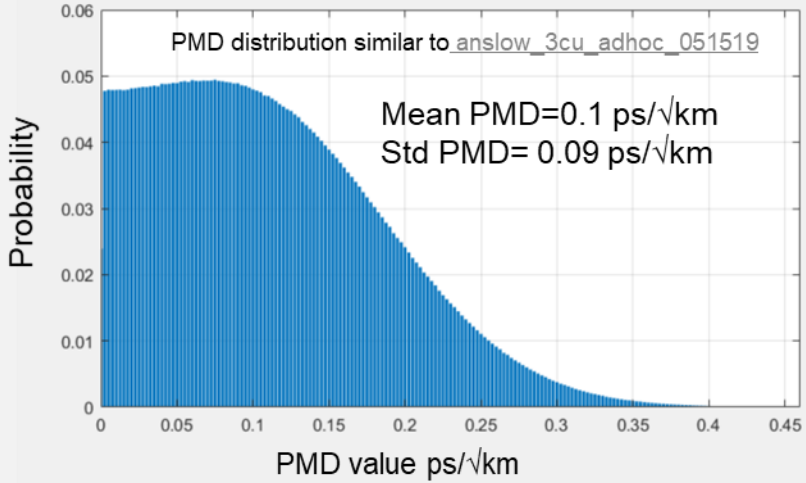
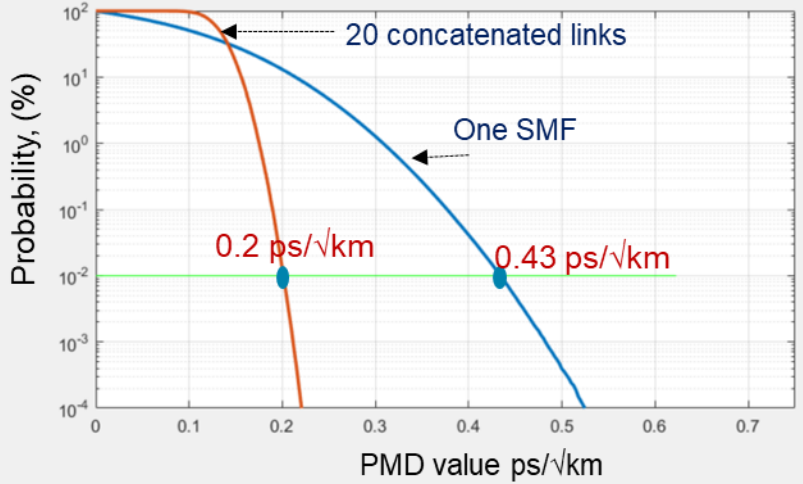
Introduction

- Previous investigations indicates that IEEE 802.3 variants 100GBASE-LR and 400GBASE-LR4 might require an additional power budget allocation of 0.6 dB compared to 25G and 50G where a DGD_max of 8 ps was used.
- A DGD_max of 5 ps was proposed in anslow_3cu_adhoc_051519 for fibers with a maximum PMD_Q of 0.2 ps/√km such as G.652.B and G.652.D.
- This DGD_max would require an additional allowance of ~0.25 dB.
- This contribution uses statistics from PMD measurements presented at OFC 2005 to investigate the magnitude of the additional allowance required for PMD.

PMD distribution used to estimate PMD penalty

If the PMD_Q (20 concatenated cables) is 0.2 ps/sqrt(km) what is the maximum PMD for one that occurs with probability of 0.01% ?





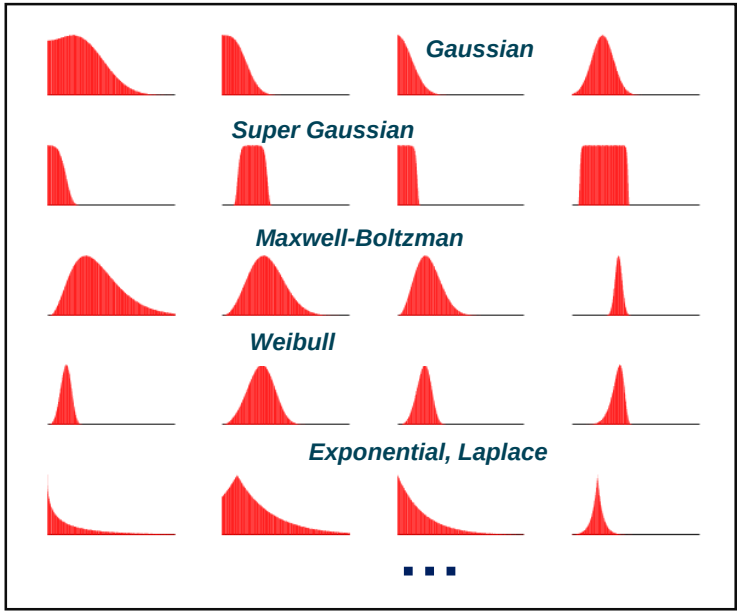
For this distribution the max PMD for one cable is 0.43 ps/sqrt(km)

From the distribution a DGD_max of 3.75x0.43x √10 =5.01 ps was obtained.

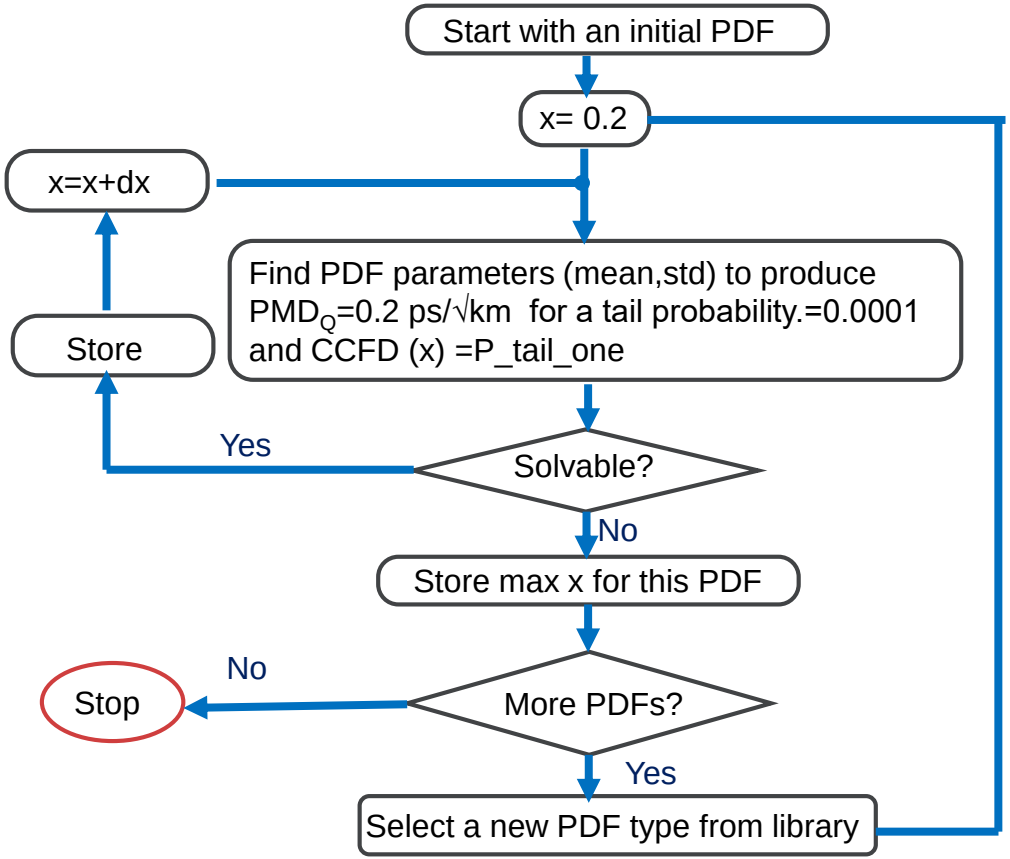
The correct parameters for the shown distribution are: MEAN= 0.1 ps/ √km STD i=0.074 ps/ √km

Simulations of worst-case PMD (single cable)

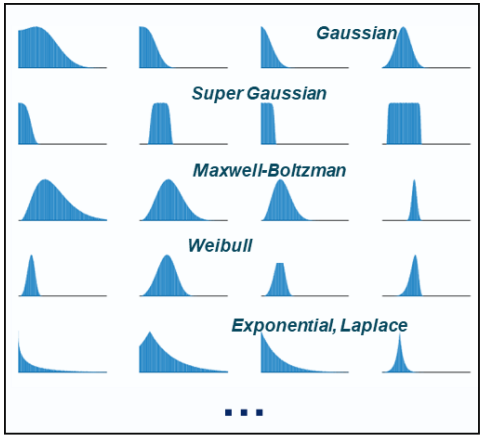
- The analysis shown with modified Gaussians is expanded by using a larger set of probability distributions (PDF).
- Each PDF represents an assumed PMD distribution for individual cable.
  - Not all the PDF shapes are representative of PMDs production but they are used in the quantitative evaluation of max PMD.
  - The non-representative PDFs can be discarded after qualitative evaluation.



Evaluation Method



Sample of PDF's library



x: max PMD

PDF: probability distribution function from library

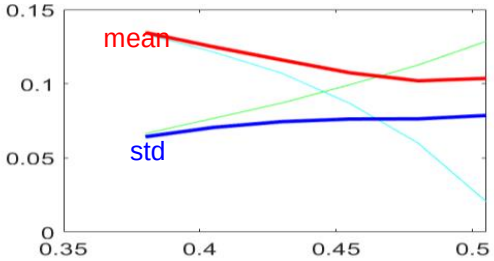
CDF: cumulative distribution function of selected

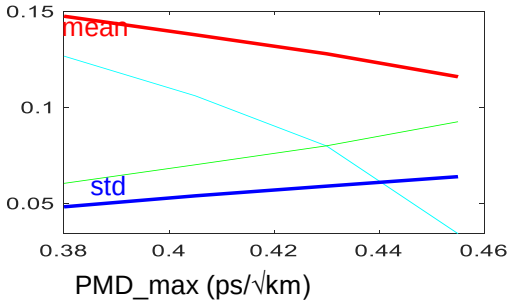
CCDF: Complementary CDF = 1-CDF

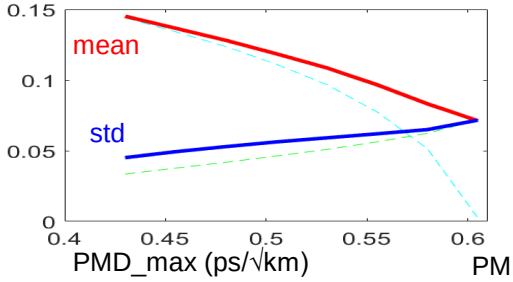
P_tail_one: Probability that PMD > x for one cable. Values used in the simutation are 0.01% and 0.1%.

Examples

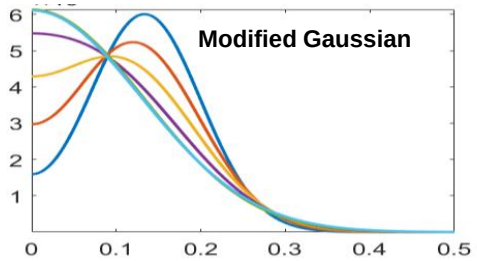
Parameters one link

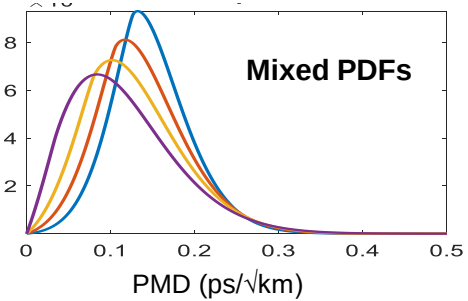


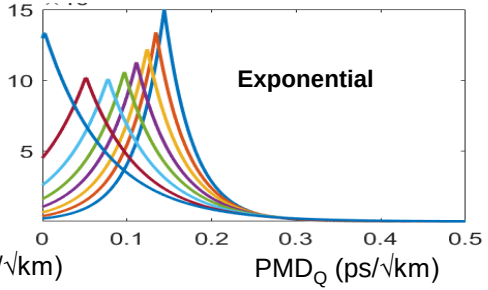




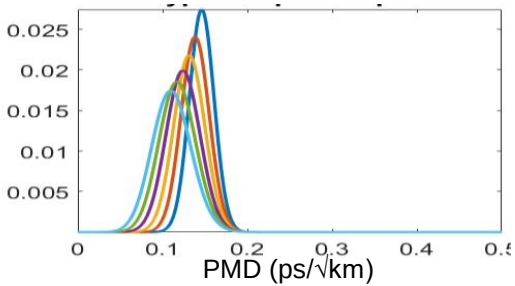
PDFs one link

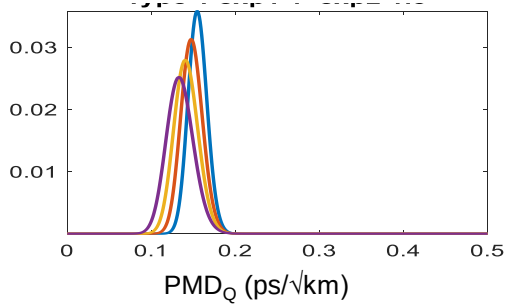


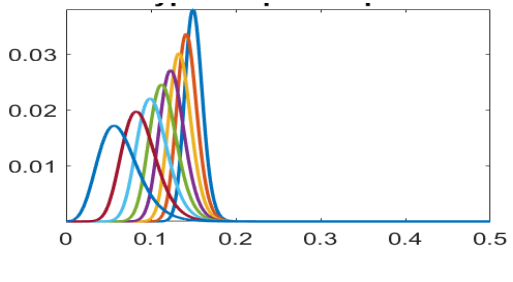




PDFs 20 concatenated links

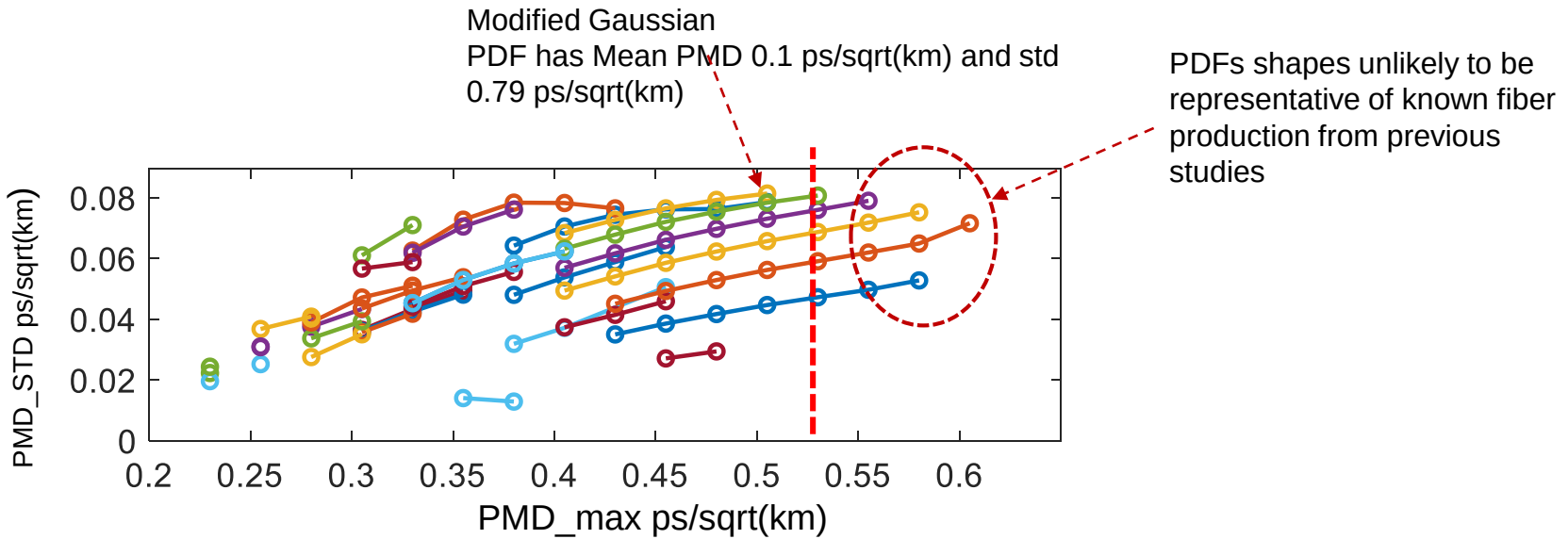






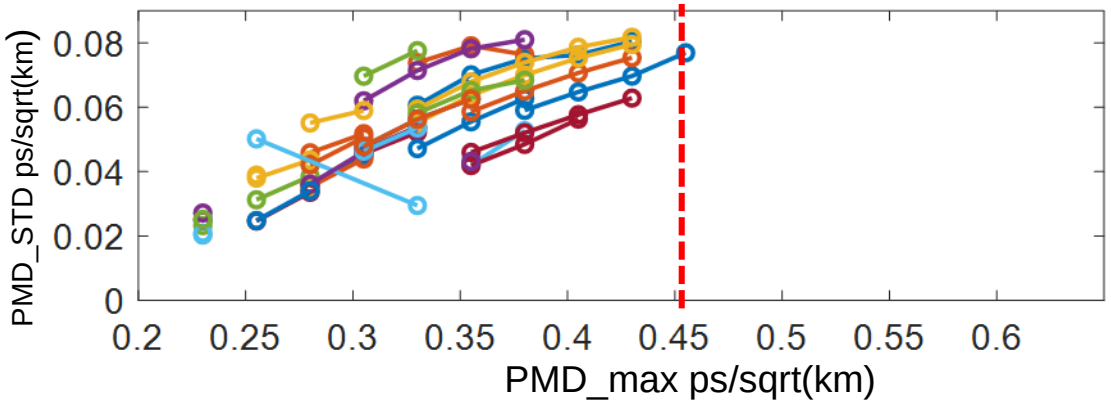
Simulation Results for tail probability =0.01%

Using a restrictive P_tail_one=0.01% and arbitrary PDF shape a max. PMD of 0.625 ps/sqrt(km) was found.
However, it is expected that representative probabilities should have a max. PMD of 0.525 ps/sqrt(km).
Using a safety margin, S=3.75 (2.6 sec/year), produces DGD_max =3.75x0.525*sqrt(10)=6.22 ps
Using S=3.3 (2.5 min/year), produce DGD_max=5.47 ps.

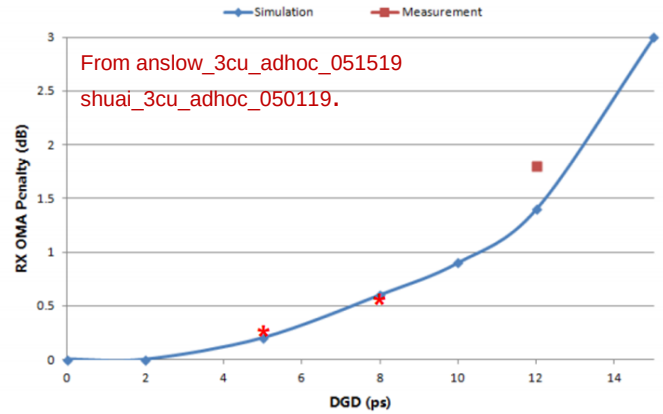


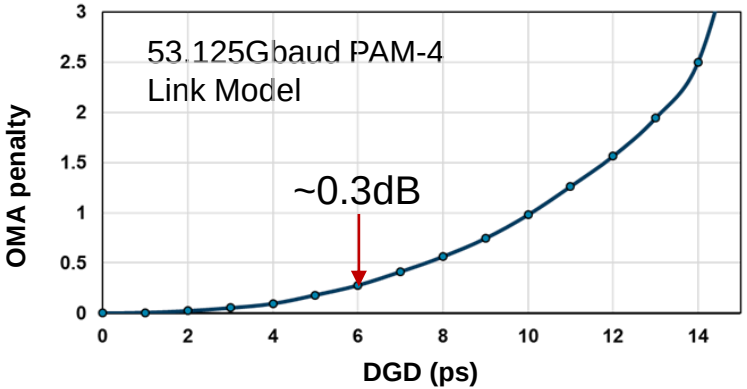
Simulation Results for Tail probability of 0.1%

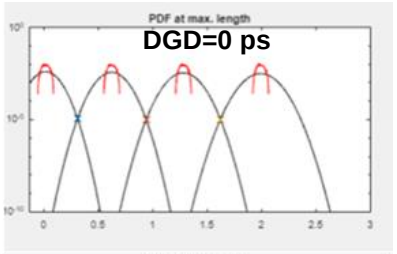
Relaxing the probability tolerances for individual cable to P_tail_one=0.1% significantly reduce the PMD max to 0.45 ps/sqrt(km).
Using a safety margin, S=3.75 (2.6 sec/year), produces DGD_max =5.33 ps
Using S=3.3 (2.5 min/year), produce DGD_max=4.7 ps.

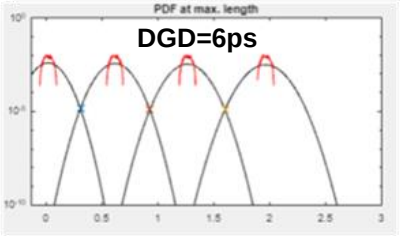


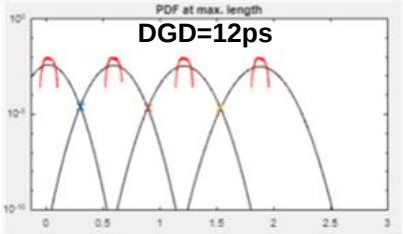
DGD Penalties

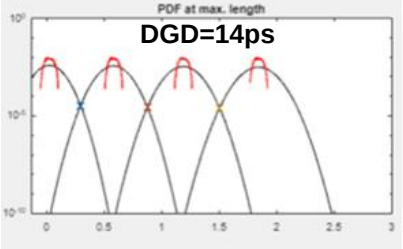




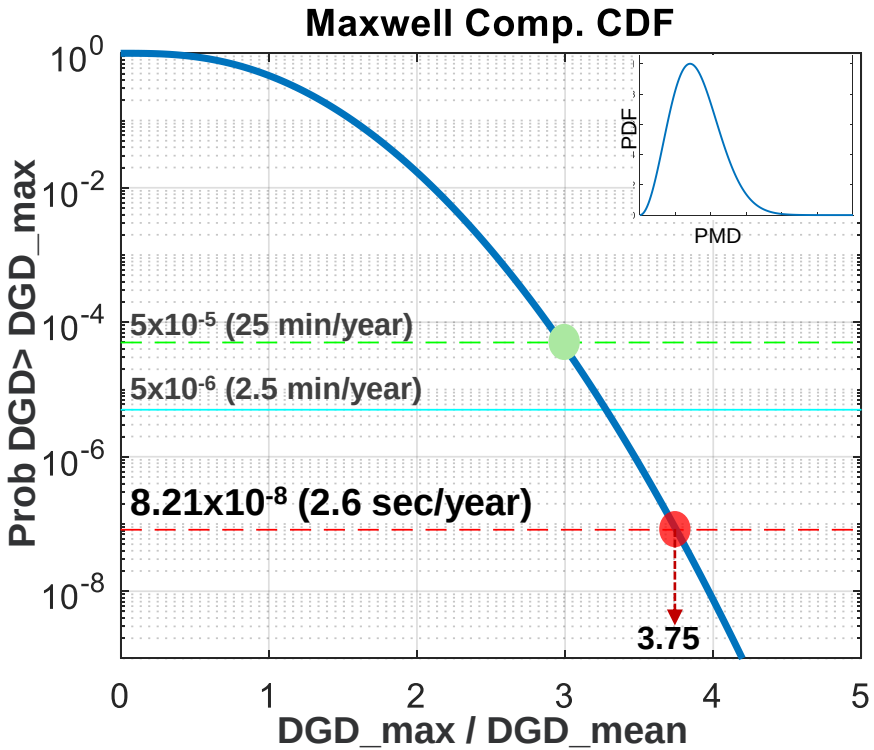


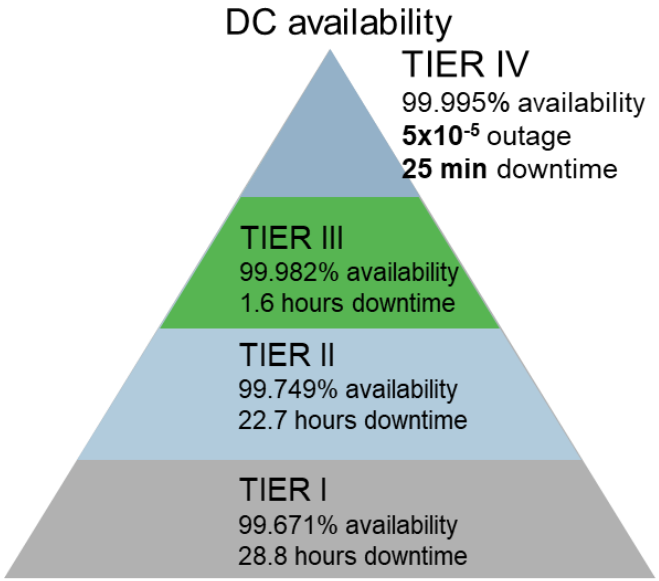






Safety Margin, S





Link failure probability and DC availability are completely different metrics. The Uptime Institute classification focus on infrastructure performance and does not include the link uptime in the availability categories.
However, from an user perspective, the availability of DC services to the user needs to include the network availability. which is affected by link penalties and redundancy of the network architecture..

Discussion

- Using P_tail_one=0.01% for PMD> 0.525ps/sqrt(km) and a safety margin of 3.75, indicates that one in 10000 installed cables will have a DGD_max of 6 ps. This DGD_max requires allocation of 0.3 dB to compensate for PMD penalties. Only for 2.6 sec/year the PMD penalties will be higher than the allocated.
- This results seems conservative. Most of the cables that have PMD_Q < 0.2 ps/sqrt(km) will not require this allocation for PMD penalties.
- It seems reasonable to increase the tail probability for one cable to 0.1%. In this case, one in 1000 installed cables will have an DGD_max of 5.33 ps. This DGD_max requires an allocation of 0.2 dB. Only for 2.6 sec/year the PMD penalties will be higher than the allocated.

Summary

- A broad range of PDFs including different PDF shapes and tail probabilities of 0.01% for single cable produced a conservative DGG_max of 6 ps and penalties ~0.3 dB for cables with PMDQ=0.2ps/sqrt(km).Using less restrictive tail probabilities for single cable, the DGD_max can be reduced to ~5 ps.

- A specification of ~5 ps for DGD_max for 100GBASE-LR and 400GBASE-LR4 using fibers with PMD_Q <0.2 ps/sqrt(km), such as G652.D seems to be a reasonable worst-case value.

- More work with more recent data can help to define the penalties better. Also, due to the statistical nature of both MPI and PMD and dependence on polarization it might be possible to define a joint penalty lower than the sum of individual penalties.

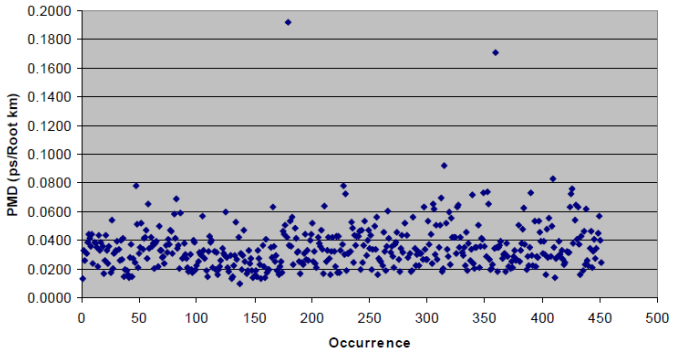
Acknowledgement

- Thank you to Allan McCurdy from OFS for the interesting discussion on the topic.

Backup

Experimental Data

- Available measured data could be used to get a better insight of the statistical parameters such as the mean PMD and PMD standard deviation.
- The mean and StdDev from 450 measurements with an average length of 97.6 km were presented in OFC 2005*.
  - The measurements were made over 3 months at different times of the day and varied regions in US.
  - For each fiber, the worst case of 3 measured values was reported.
- The measured data includes two type of fiber populations with different PMD specs.
  - One population has a spec. of PMD_Q <**0.08** ps/ √km, and the second population has a spec of PMD_Q< **0.04**/ √km
  - The measurements or proportions corresponding to each population were not reported.

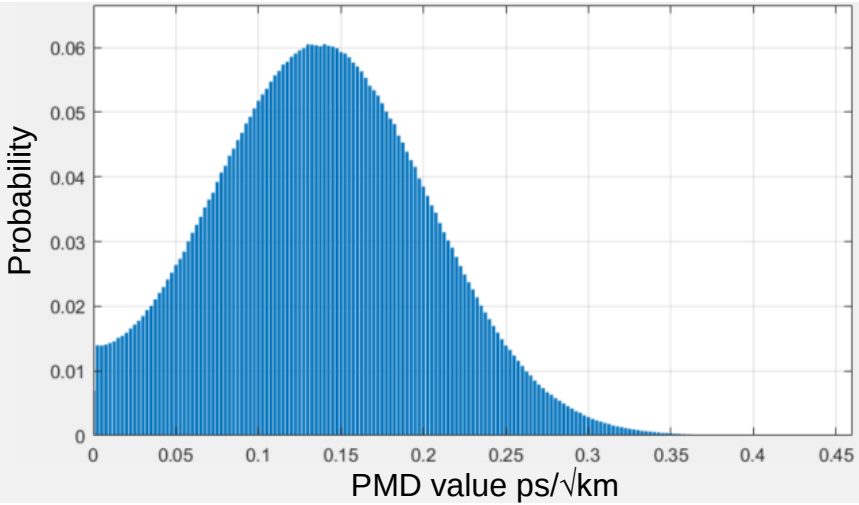


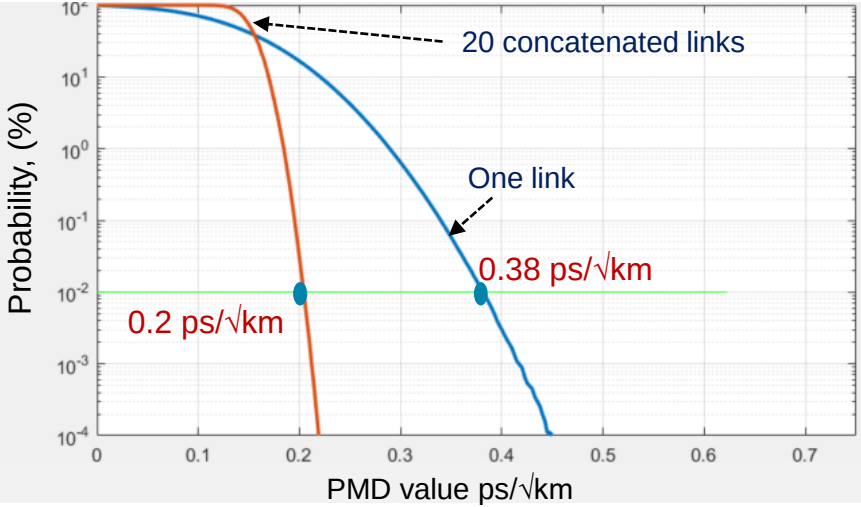
•*Robert J Feuerstin, Optical Fiber Communication Conference and The National Fiber Optic Engineers Conference, Technical Digest (CD) (Optical Society of America, 2005), paper NThC4

Scaling distribution from Experimental Data

- The mixed population with specified PMD_Q <**0.08** ps/√km and PMD_Q< **0.04**/√km has a PMD mean of **0.0352** ps/√km and PMD StdDev of **0.0169** ps/ √km
- For worst-case scaling, we numerically found a scaling factor by simulating different modified Gaussian distributions to produce a PMD_Q equal to **0.2** ps/ √km
  - The scaling factor obtained was 3.9
  - This scaling factor was used to multiply the mean and StdDev of the measured distribution
  - The PMD parameters for a single link was obtained (next slide)

Scaled distribution





Used ~3.9 times the value reported in the OFC paper produces:

- Mean=0.13 ps/sqrt(km)
- Std_0.066 ps/sqrt(km)

The obtained PMD for 0.01% was 0.38 ps/sqrt(km).

The mean DGD is 1.2 ps. The max DGG is 4.5 ps

The additional allocation for this DGD is ~0.2 dB

Estimation of Penalties