

Statistical PMD Specification – Evolution, Utilization and Control

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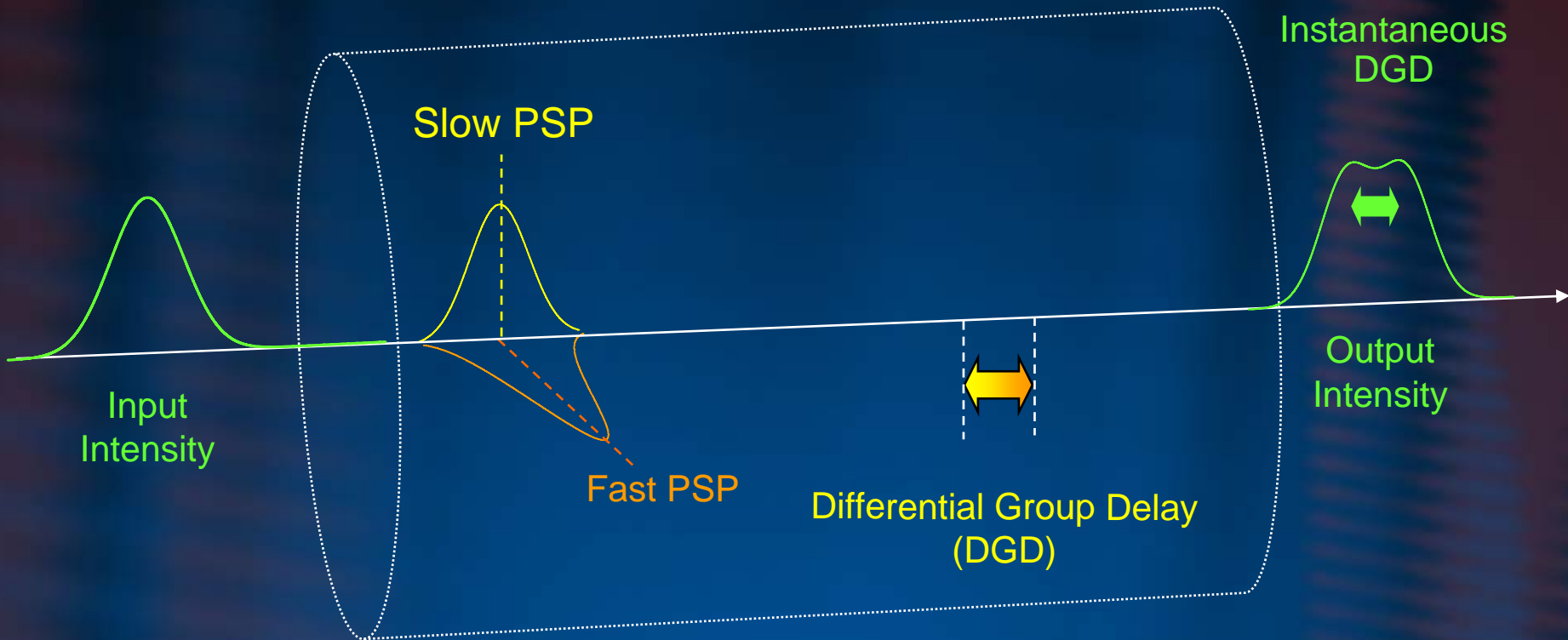


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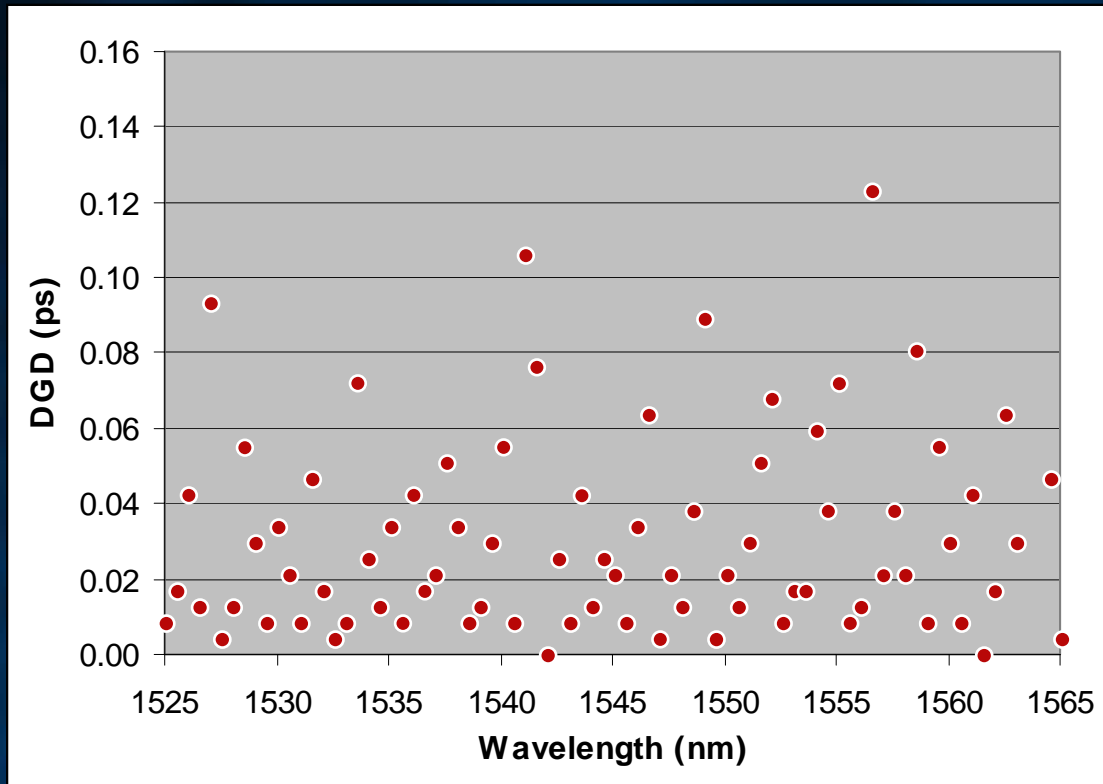
Presentation Outline

- Statistical Nature of DGD and PMD
- Historical Approach to System Design
- Statistical Approach to System Design
- Case Study
- Control of Statistical Specifications
 - Fiber Spinning
 - Outliers
- Conclusions
- Questions

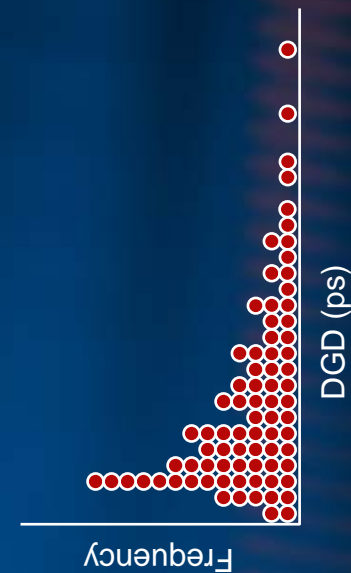
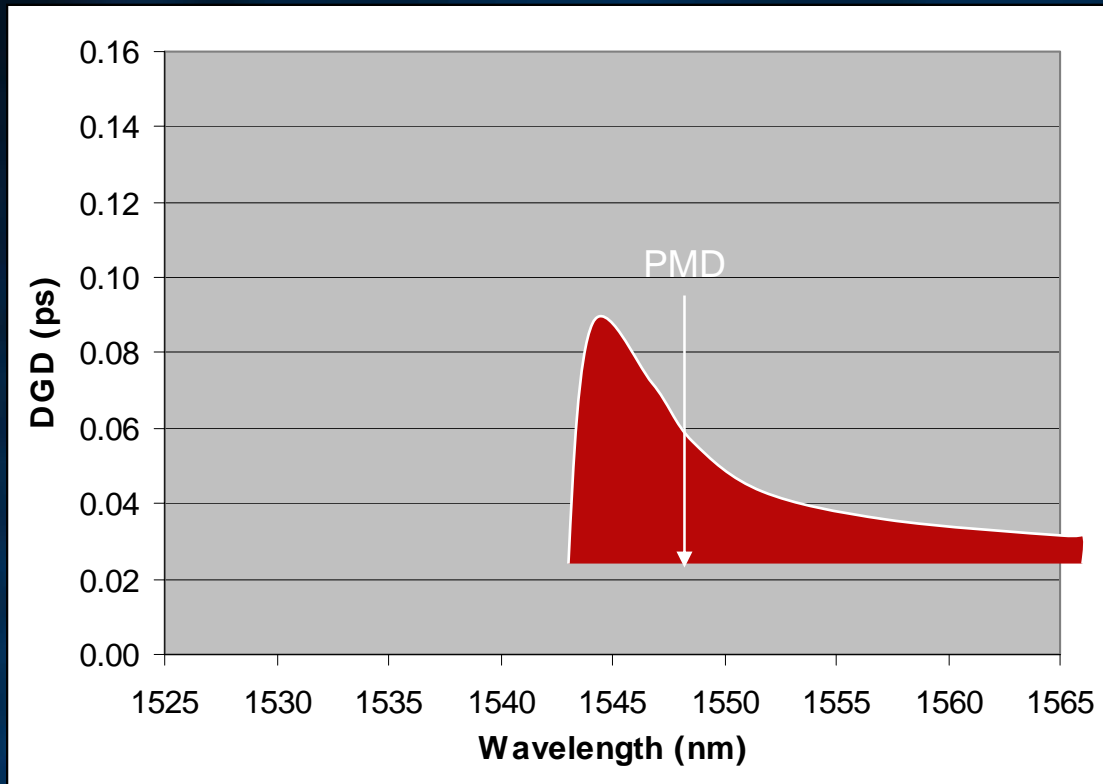
PMD is a Statistical Attribute



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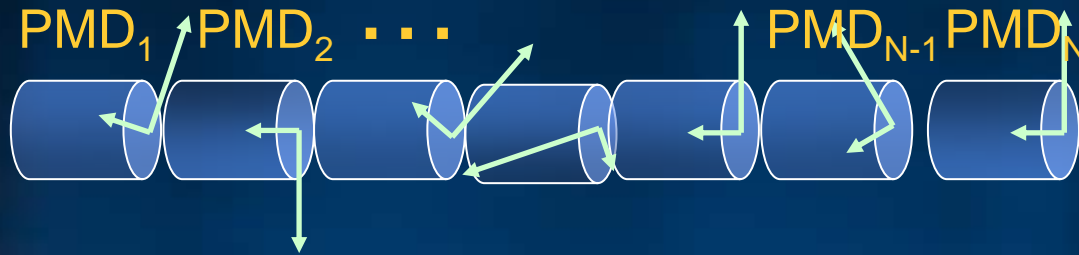


PMD is a Statistical Attribute



Real-Life Systems are Also Statistical

- Links are produced by joining a number of individual cabled fiber sections, each with their own PMD characteristics

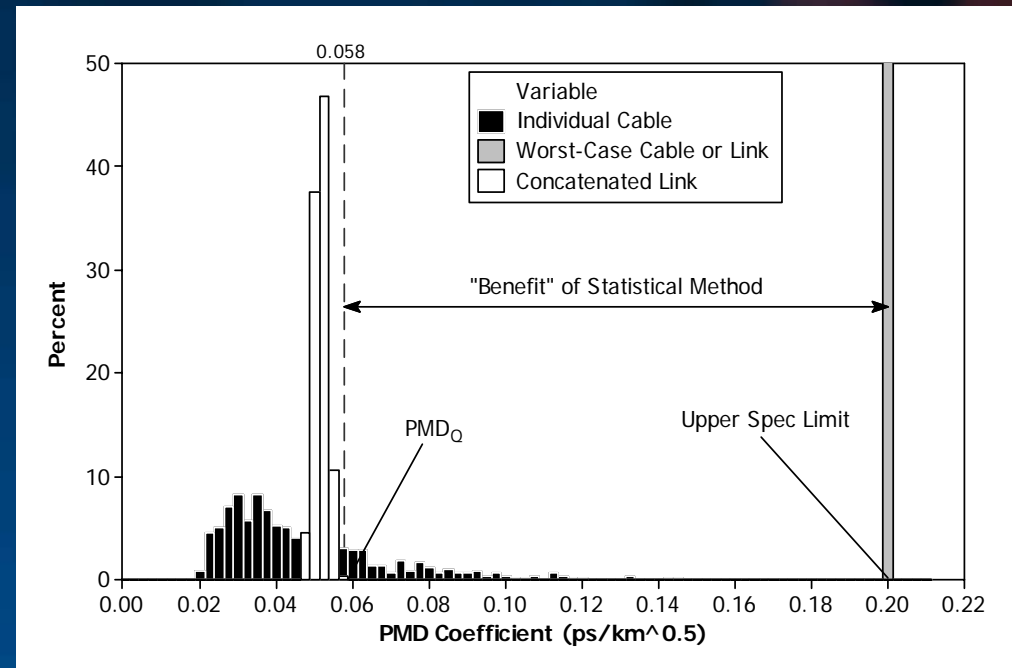


- Additional sources of PMD, such as amplifiers and dispersion compensation modules, are also present
- For fiber, a historical approach has been to assume that all fibers have the maximum specified PMD value

$$PMD_{link} = \left[\frac{1}{L_{link}} \sum_{i=1}^N L_i x_i^2 \right]^{1/2}$$

Statistical Approach

- More recent and now internationally standardized approach is to take into account the actual distribution of PMD comprising the link
- Done by calculating PMD_Q , or link design value, which is the statistical upper bound on the distribution of possible link PMD coefficients
- Standardized in IEC 60794-3, ITU-T G.652, IEC TR 61282-3



Additional Benefits of Statistical Approach

- Directly applicable to system design. “Method 2” allows one to calculate the probability of exceeding a given DGD value
- Additional formulae can be utilized to examine the combined contribution from fiber and components

$$PMD_{tot} = \left[L_{link} PMD_Q^2 + \sum_i PMD_{R_i}^2 + \sum_j PMD_{D_j}^2 \right]^{1/2}$$

$$DGD \max_{tot} = \left[DGD \max_F^2 + S^2 \left(\sum_i PMD_{R_i}^2 + \sum_j PMD_{D_j}^2 \right) \right]^{1/2}$$

S is a Maxwell adjustment factor

Subscripted *F* denotes fiber

Subscripted *R* denotes random components

Subscripted *D* denotes embedded deterministic components

Case Study

- A Chinese cabler measured the PMD distributions of cabled Corning® SMF-28e® (DUF) and LEAF® (NZDSF) optical fibers in 2002

	Case 1 - "Worst Case" Approach	Case 2 - Statistical Approach	Case 3 - China Long Haul Trunk Line, Statistical Approach	Case 4 - China Long Haul Trunk Line, Statistical Approach
Transmission Rate (Gb/s)	40	40	40	40
Reference Link Length (km)	400	400	800	800
Reference Cable Length (km)	10	10	2	2
Allowable Total DGDmax (ps)	7.5	7.5	7.5	7.5
Total Cable DGDmax (ps)	5	5	5	3.5
Total Component PMDmax (ps)	1.5	1.5	1.5	1.8
Allowable Probability of Exceeding DGDmax	1.3×10^{-7}	1.3×10^{-7}	1.3×10^{-7}	1.3×10^{-7}
Due to Cable	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}
Due to Components	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}	6.5×10^{-8}
Probability of Exceeding Total DGDmax				
SMF-28e (DUF)	N/A	7.4×10^{-11}	2.5×10^{-8}	2.7×10^{-4}
LEAF (NZDSF)	N/A	$< 10^{-20}$	8.3×10^{-17}	1.8×10^{-8}

Total Cable DGDmax 7.55-15.1 ps

Control of Statistical Specification

PMD Distribution:

$$p(\tau) = \sqrt{\frac{2}{\pi}} \frac{\tau^2}{\sigma^3} \exp\left(-\frac{\tau^2}{2\sigma^2}\right)$$

τ is the PMD coefficient

σ is a constant that determines the distribution

Fiber Spinning:

$$\sigma_{sp} = \xi \sigma_0$$

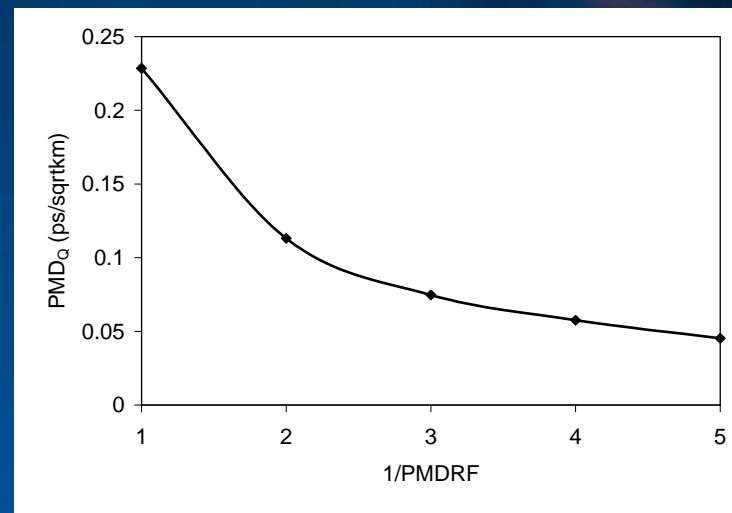
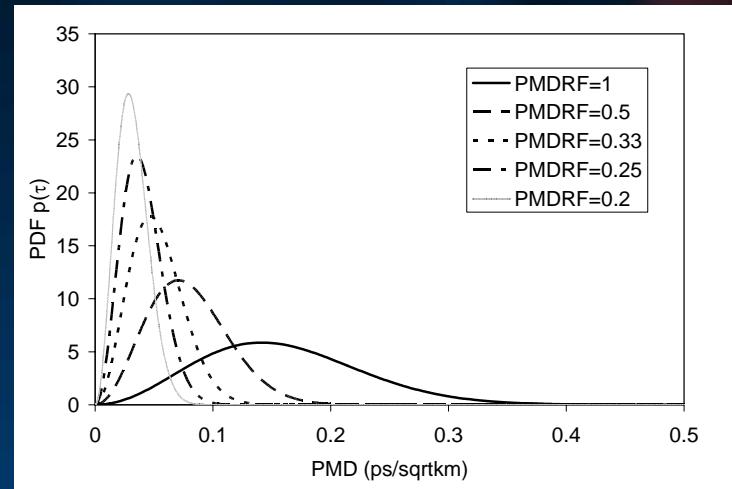
σ_0 is the distribution constant of unspun fiber

σ_{sp} is the distribution constant of spun fiber

ξ is the PMD reduction factor (ratio of spun to unspun fiber)

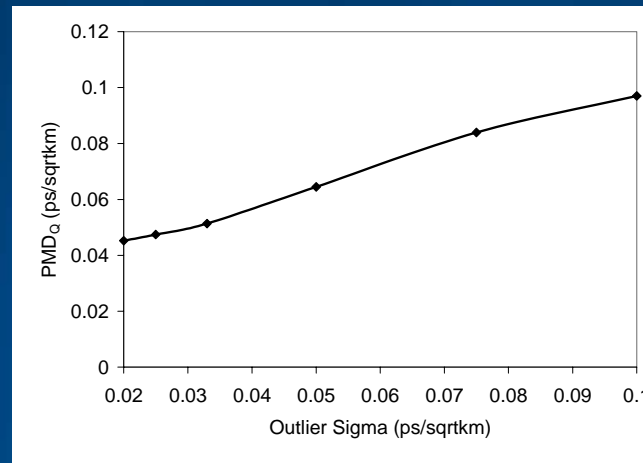
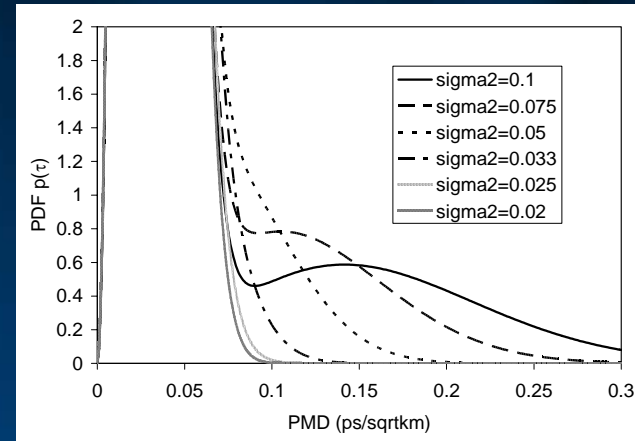
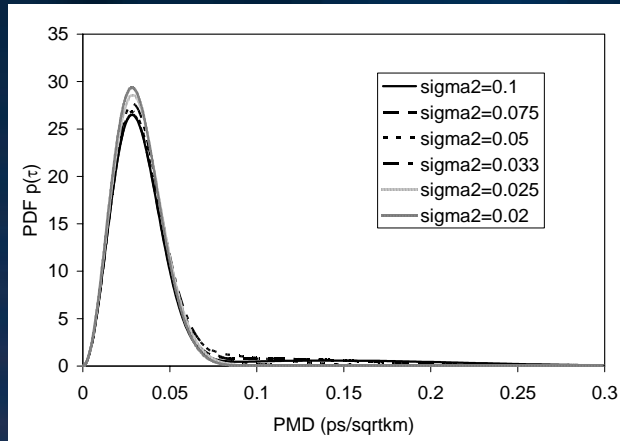
Conclusions:

- PMD_Q is reduced through fiber spinning
- PMD_Q decreases rapidly with initial spin reduction, then becomes less responsive to higher spinning effectiveness

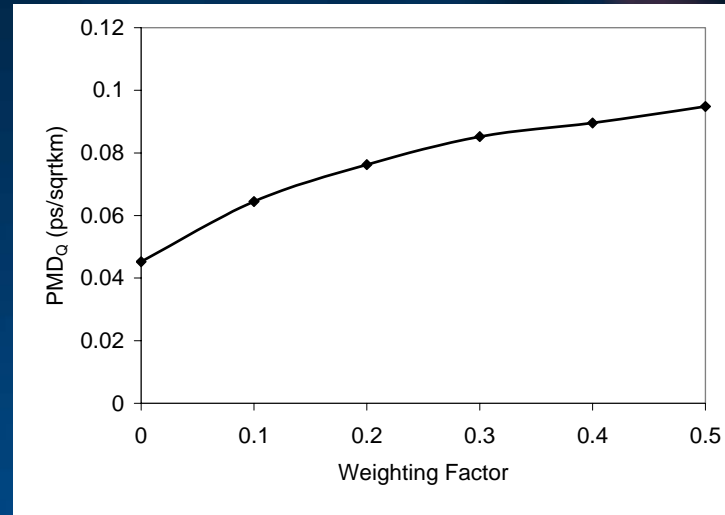
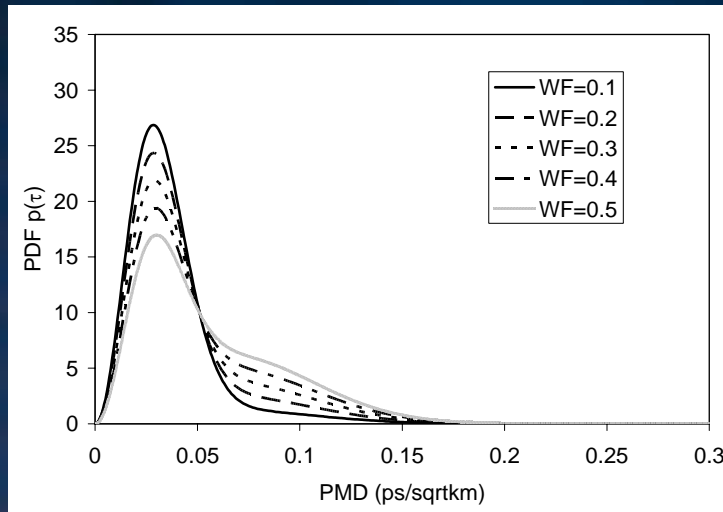


Impact of Outliers on Statistical Specification

$$p(\tau) = (1 - g) \sqrt{\frac{2}{\pi}} \frac{\tau^2}{\sigma_1^3} \exp\left(-\frac{\tau^2}{2\sigma_1^2}\right) + g \sqrt{\frac{2}{\pi}} \frac{\tau^2}{\sigma_2^3} \exp\left(-\frac{\tau^2}{2\sigma_2^2}\right)$$



Impact of Outliers on Statistical Specification



Conclusions

- The historical “worst case” approach to system design is not appropriate and leads to overly conservative limitations
- The statistical approach to PMD specifications is more deeply rooted in reality and has been standardized by international bodies such as the IEC and ITU-T
- A case study has been used to show the benefit of the statistical approach
- Such statistical specification methods require adequate control of the manufactured PMD distribution, including both its general form and outlier population
- Adequate control can be achieved through optimized fiber spinning, control of fiber geometry and other manufacturing controls

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