SMF Channel Dispersion Penalty
Updated Specification Proposal

IEEE P802.3dj Optics Ad Hoc

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Background

- ITU-T G.652 codes, used in all IEEE 802.3 SMF optical standards, define ZDW (Zero Dispersion Wavelength) from 1300 to 1324nm.
- ZDW in 1300 – 1305nm or 1319-1324nm is rarely seen in modern applications.
- Restricting transceiver design and manufacturing to only use ZDW limit unnecessarily burdens cost and power.
- Over the past decade, we have proposed to update the ZDW spec and/or how to use it, in the ITU-T and IEEE 802.3, for example:
  - https://www.ieee802.org/3/cu/public/May19/cole_3cu_01a_0519.pdf [ieee802.org],
  - https://www.ieee802.org/3/df/public/22_11/cole_3df_01a_2211.pdf,
  - Consideration of G.652 fibers, ITU-T contribution C0574, Frank Effenberger, April 2023.
- There must be fundamental reason(s) for the lack of progress.
- Let's step back and understand what's going on.

SMF Manufacturing Observations

- Fiber has been manufactured for over 50 years.
- It is a highly complex process, requiring massive R&D, extensive measurements and continuous improvement.
- Fiber manufacturing requires the latest techniques, most importantly statistical process control.
- Link parameters of interest like dispersion are not controlled directly (there is no dispersion knob) but are determined by complex interaction of many other fiber parameters whose measurement generates large datasets enabling statistical process control.
- Confirmation that fiber manufacturers use modern practices on next page.

Top Fiber Cable Manufacturers Quality System Confirmation

	ISO 9001	Six Sigma or ISO 13053*	Confirmation By Web Search	Confirmation by an Individual(s)
Sumitomo	Yes	Yes	Yes	Yes
Corning	Yes	Yes	Yes	Yes
Prysmian	Yes	Yes	Yes	No
CommScope	Yes	Yes	Yes	Yes
Zhongtian (ZTT)	Yes	Yes	Yes	Yes
Hengtong (JHPCCL)	Yes	Yes	Yes	Yes
Furukawa (OFS)	Yes	Yes	Yes	Yes
Fujikura	Yes	Yes	Yes	Yes
Belden	Yes	Yes	Yes	No
Yangtze (YOFC)	Yes	Yes	Yes	Yes
Shanghai (SDGI)	Yes	Yes	Yes	Yes

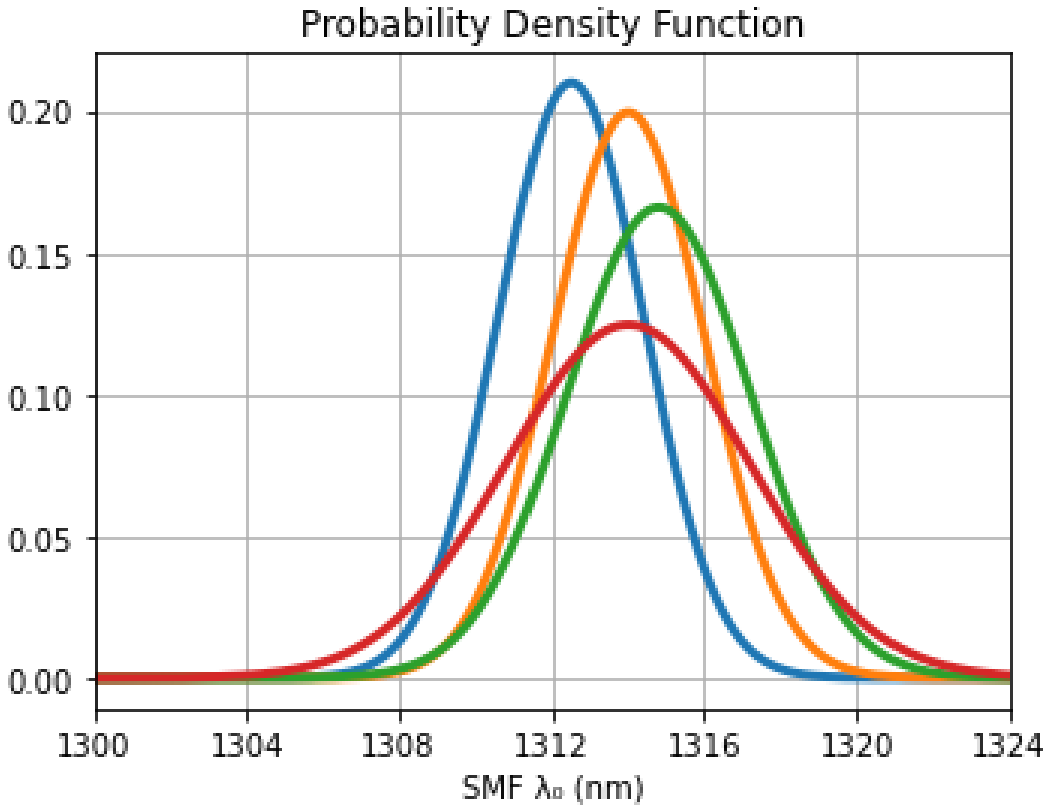
* or equivalent

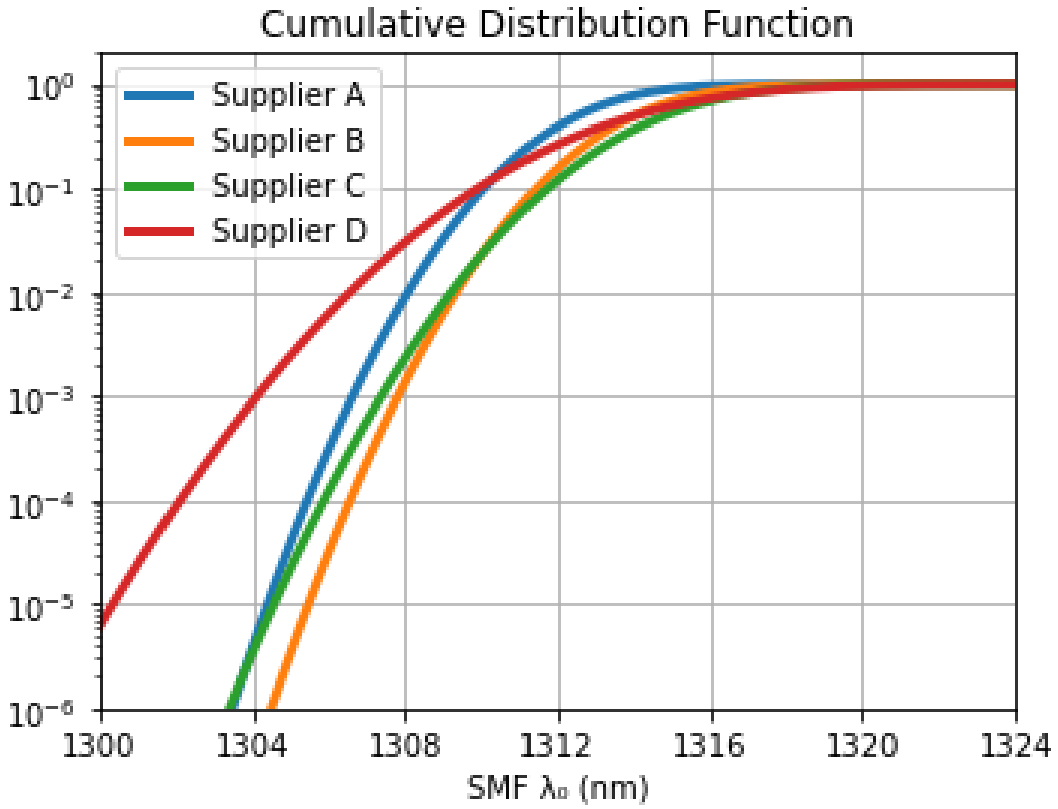
What do G.652 Codes Mean to Fiber Manufacturers?

- G.652 ZDW (Zero Dispersion Wavelength) spec is a SMF manufacturing process limit:
  - Min = 1300nm
  - Max = 1324nm.
- Confirmation by 8 suppliers at ITU-T SG15/Q5 meeting in Nov. 2016.

  https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.652-201611-I!!PDF-E&type=items [itu.int]
- A Six Sigma process, with the above limit, specifies the below normal distribution:
  - Mean (μ) nominal = 1312nm
  - Mean (μ) variation$_{max}$ = ±3nm
  - Sigma (σ) = 2nm.
- Confirmation this model is accurate on next page.

Data from Four SMF Suppliers Representing ~50% Market Share





- Suppliers from China, Japan and United States
- Each PDF is normalized (same final CDF value)

SMF ZDW Spec Change Implication to Fiber Manufacturers

- Example of previously proposed SMF ZDW spec change:
  - Min = 1300nm → 1306nm, and
  - Max = 1324nm → 1318nm.
- This would require an extensive and costly manufacturing process change:
  - Mean variation cut in half = ±3nm → ±1.5nm , and
  - Sigma cut in half = 2nm → 1nm.
- No wonder this has been vigorously opposed.
- G.652 codes should be unchanged: their ZDW limit is fine for fiber manufacturing.
- The problem is using the same limit for transceiver design and manufacturing:
  - Ex. Realistic testing requires rare SMF: 3.4 PPM best case, 3.2 PPT worst case
- The solution is to use different limit for transceiver design and manufacturing.

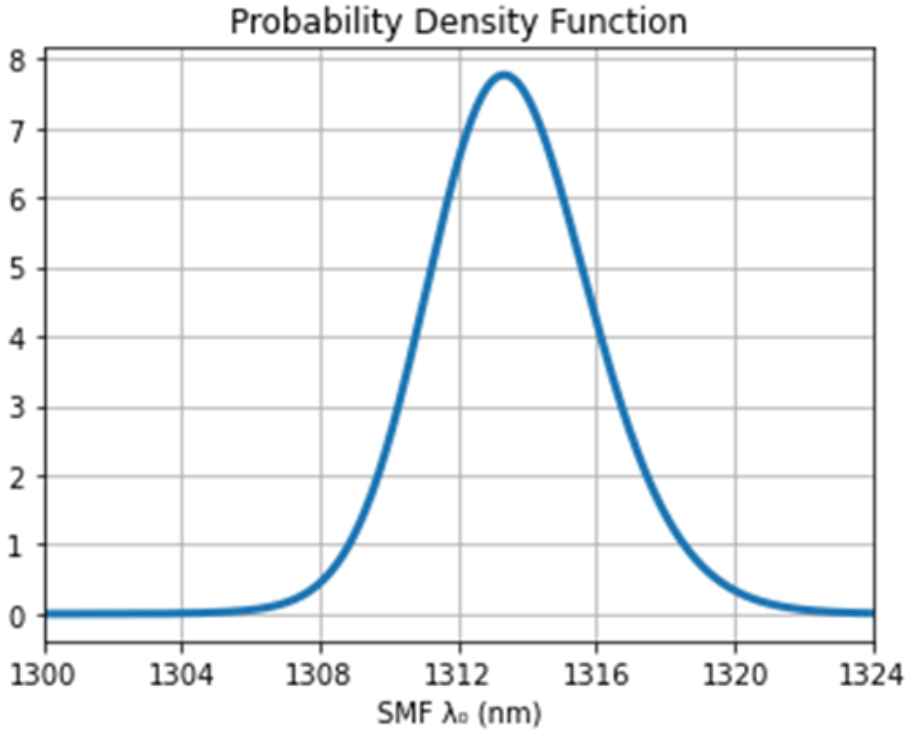
Link Budget Calculation and Dispersion Penalty Test Proposal

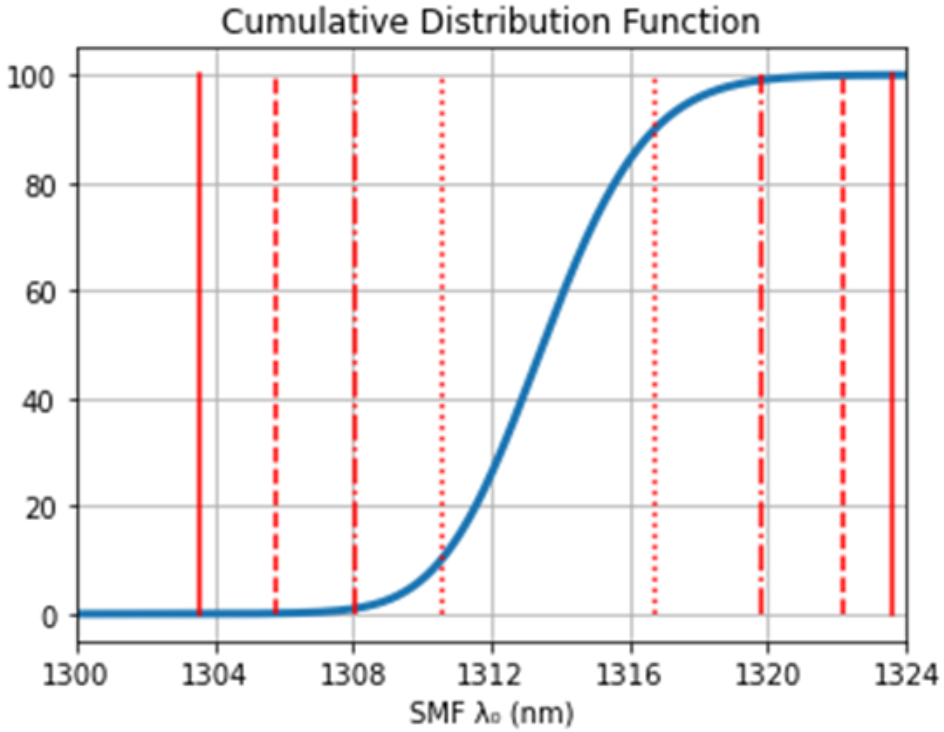
- Use ZDW normal distribution in statistical (ex. Monte Carlo) link budget analysis:
  - $Mean_{min}$ (μ_{min}) = 1309nm (for most positive dispersion)
  - $Mean_{max}$ (μ_{max}) = 1315nm (for most negative dispersion)
  - Sigma (σ) = 2nm
  - ex. https://www.ieee802.org/3/df/public/22_10/22_1012/rodes_3df_01b_221012.pdf#page=8.
- Use nominal $\pm 3.5\sigma$, ~99.95% (worst-case $\pm 2\sigma$, ~98%) ZDW values in TDECQ testing:
  - Min = 1305nm
  - Max = 1319nm.
- The dispersion penalty component of this TDECQ measurement may be slightly lower than the dispersion penalty component in the statistical link budget analysis.
  - The difference, if any, must be shown in the analysis to be acceptable.

ZDW Normal Distribution Mean Distribution Proposal

- Six Sigma places no constraints on the mean distribution besides limits.
- The sample mean of the obtained data is spread out between 1312 and 1315nm.
- Data on individual fiber manufacturers long term mean distribution is not available.
- Fiber manufacturers do not coordinate their process parameters, i.e., uncorrelated.
  - G.652 nominal ZDW is 1310 nm but is not a requirement or normative target,
  - therefore, uniform overall mean distribution is conservative.
- Use uniform mean distribution for ZDW Normal distribution:
  - $Mean_{min}$ = 1309nm
  - $Mean_{max}$ = 1315nm.
- Confirmation this model is conservative on next page.

Data from Four SMF Suppliers Combined by Market Share





The combined function has a narrower mean distribution than uniform.

ZDW Range
0.01% - 99.99%: 1303.6nm - 1323.6nm
0.10% - 99.90%: 1305.8nm - 1322.1nm
1.00% - 99.00%: 1308.1nm - 1319.8nm
10.00% - 90.00%: 1310.6nm - 1316.7nm

Channel Improvement Proposal

- Normative fiber specifications are in G.652 codes developed by ITU-T.
- No changes are needed or requested for fiber specifications.
- The proposal improves the 802.3 SMF Channel for use in statistical link analysis.
- Channel improvements are required because SMF is less ideal with increasing rates.
- The proposed improvement follows 802.3 link budget analysis not being worst case.
- 802.3 has previously improved the Channel to more realistically model the fiber plant
  - Ex.1: statistical connector loss analysis instead of just loss addition (worst case),
  - Ex.2: Max mean DGD limit in Transmitter Compliance Channel.
- While realistic, the proposed Channel improvement still makes conservative assumptions about Six Sigma ZDW distribution.

Fiber Optic Cable (Channel) Characteristics Table

Description	code	Unit
Operating distance (max)		km
Channel insertion loss[a, b] (max)		dB
Channel insertion loss[a, b] (min)		dB
Positive dispersion[b] (max)	*value calculated using 1300nm ZDW (unchanged)*	ps/nm
Negative dispersion[b] (min)	*value calculated using 1324nm ZDW (unchanged)*	ps/nm
Dispersion distribution[d]	$0.02325 \bullet d \bullet \lambda \bullet [1 - (N(\mu, \sigma) / \lambda)^4]$	ps/nm
DGD (max)[f]		ps
Optical return loss (min)		dB

[d] The channel dispersion distribution is used for the Channel wavelength in statistical link analysis (λ in nm). It is not a fiber specification. N(μ, σ) is normal distribution with mean μ uniformly distributed between 1309 and 1315nm, and standard deviation σ = 2nm. The coefficient uses d kms.

Optical Fiber and Cable Characteristics Table (unchanged)

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)		dB/km
Zero dispersion wavelength (λ_0)	$1300 \leq \lambda 0 \leq 1324$	nm
Dispersion slope (max) (S_0)		ps/nm^2 km

Transmitter Compliance Channel Specification Table

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
	$0.02325 \bullet d \bullet \lambda \bullet [1 - (1305/\lambda)^4]$	$0.02325 \bullet d \bullet \lambda \bullet [1 - (1319/\lambda)^4]$	Minimum	dB	ps

[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient uses d kms.

Channel Improvement Proposal Comments

- A reason for Ethernet's great success is that it is not driven by corner cases.
  - Mainstream applications are the target
- The Channel model resulting from proposed improvements is a work in progress.
  - As we learn more, and most importantly as we get more data, the Channel model will be further improved.
  - Everyone is encouraged to refine the algorithms.
  - Everyone is encouraged to contribute more data.
- An example future improvement area is DGD (not part of this proposal).
  - ITU-T G.652 PMD statistical parameters are not fully utilized in 802.3.
  - Statistical link analysis will give more realistic DGD penalty budget component.
- Fiber specifications are unchanged and left to ITU-T.

SMF Channel Dispersion Penalty Updated Specification Proposal

Thank you