802.3 SMF Channel Proposal Using Existing ITU-T Codes

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Background

- ITU-T G.652 codes, used in all IEEE 802.3 SMF optical standards, define ZDW (Zero Dispersion Wavelength) min and max as 1300 and 1324nm, respectively.
- ZDW in 1300 – 1305nm or 1319-1324nm range is rarely seen in modern applications.
- Restricting transceiver design and manufacturing to only use ZDW min and max 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 slow 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 is on the next page.

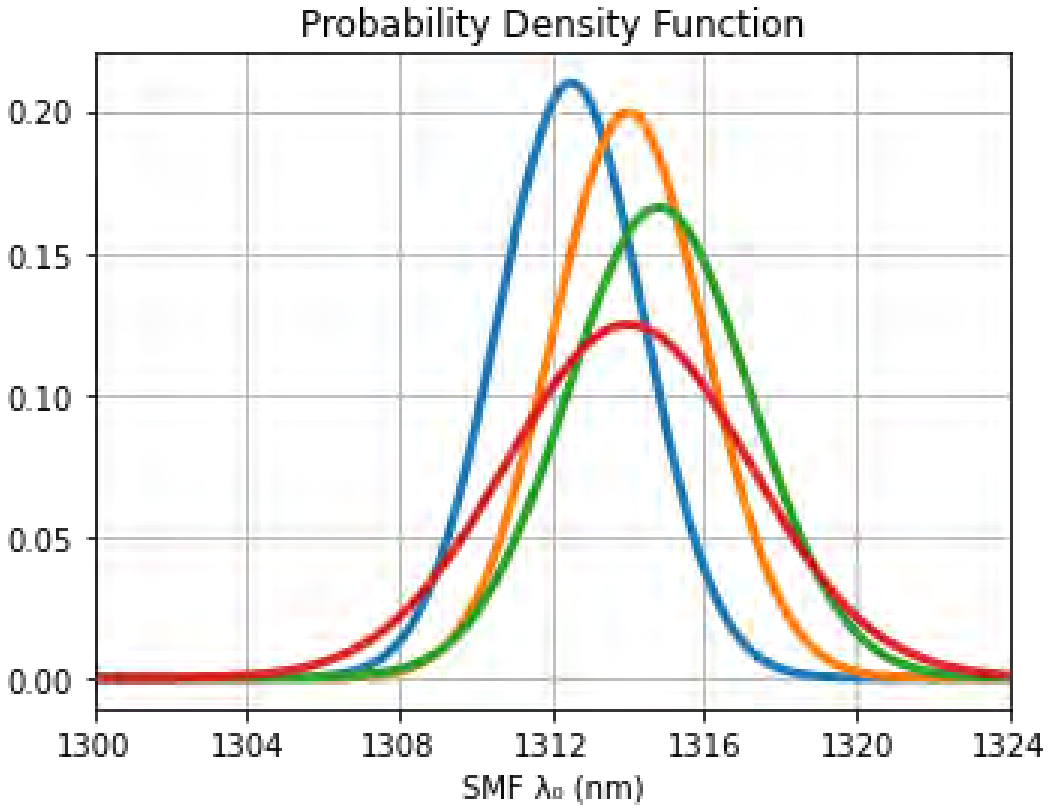
Top Fiber Cable Manufacturers Quality System Confirmation

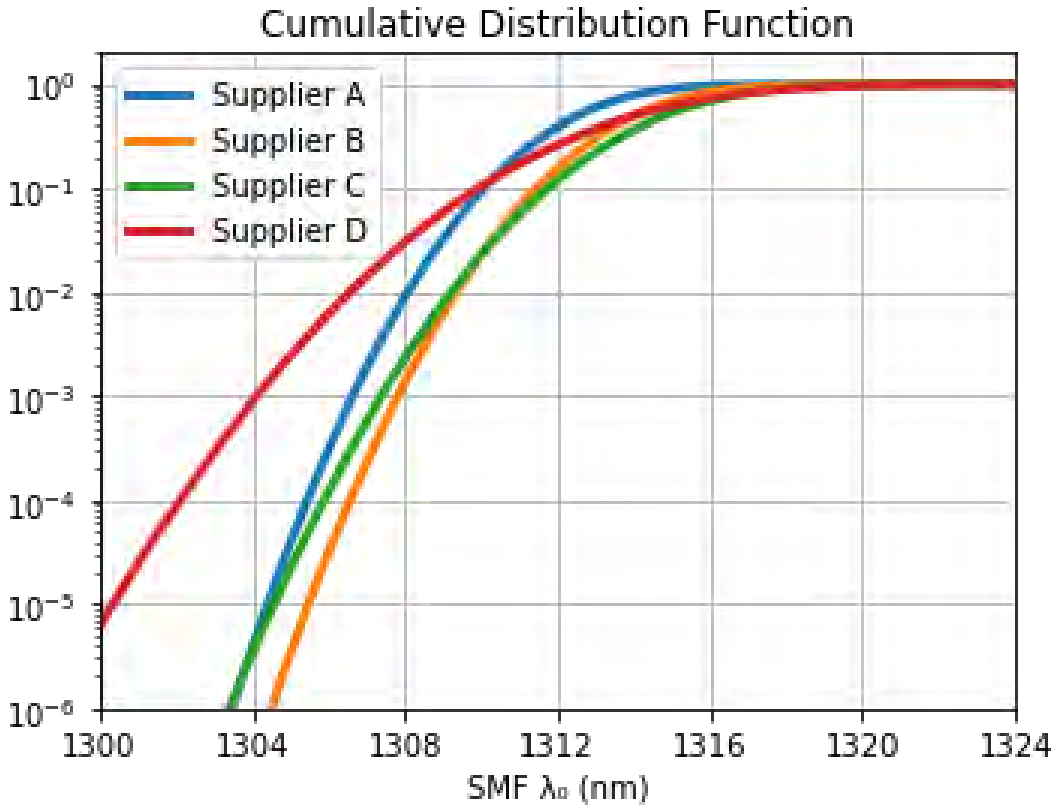
	ISO 9001	ISO 13053 or Six Sigma or ≡	Confirmation By Web Search	Confirmation by an Individual(s)
Sumitomo	Yes	Yes	Yes	Yes
Corning	Yes	Yes	Yes	Yes
Prysmian	Yes	Yes	Yes	No
CommScope	Yes	Yes	Yes	Yes
Zhongtian (ZTT)	Yes	Yes	Yes	Yes
Hengtong (JHPCCL)	Yes	Yes	Yes	Yes
Furukawa (OFS)	Yes	Yes	Yes	Yes
Fujikura	Yes	Yes	Yes	Yes
Belden	Yes	Yes	Yes	No
Yangtze (YOFC)	Yes	Yes	Yes	Yes
Shanghai (SDGI)	Yes	Yes	Yes	Yes
Sterlite Tech	Yes	Yes	Yes	Yes
FiberHome	Yes	*not found*	Yes	No

ITU-T G.652 Codes Meaning to Fiber Manufacturers

- G.652 ZDW (Zero Dispersion Wavelength) spec is a SMF manufacturing process limit:
  - Min = 1300nm
  - Max = 1324nm
  - Confirmation by 8 suppliers in Nov. 2016, ITU-T SG15/Q5 meeting.
    https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.652-201611-I!!PDF-E&type=items [itu.int]
- Six Sigma process, with the above limit, defines the below normal distribution:
  - Mean (μ) nominal = 1312nm
  - Mean (μ) variation$_{max}$ = ±3nm
  - Sigma (σ) = 2nm.
- Confirmation that this model is accurate is on the 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 past proposal for 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 appropriate values for transceiver design and manufacturing.

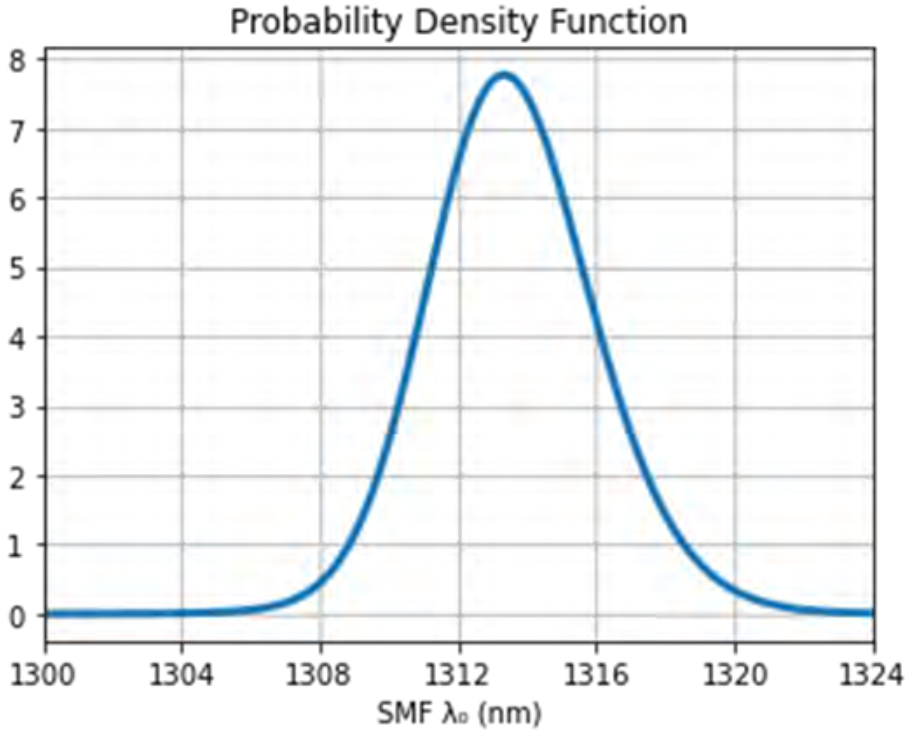
Link Budget Analysis and TDECQ Testing Proposal

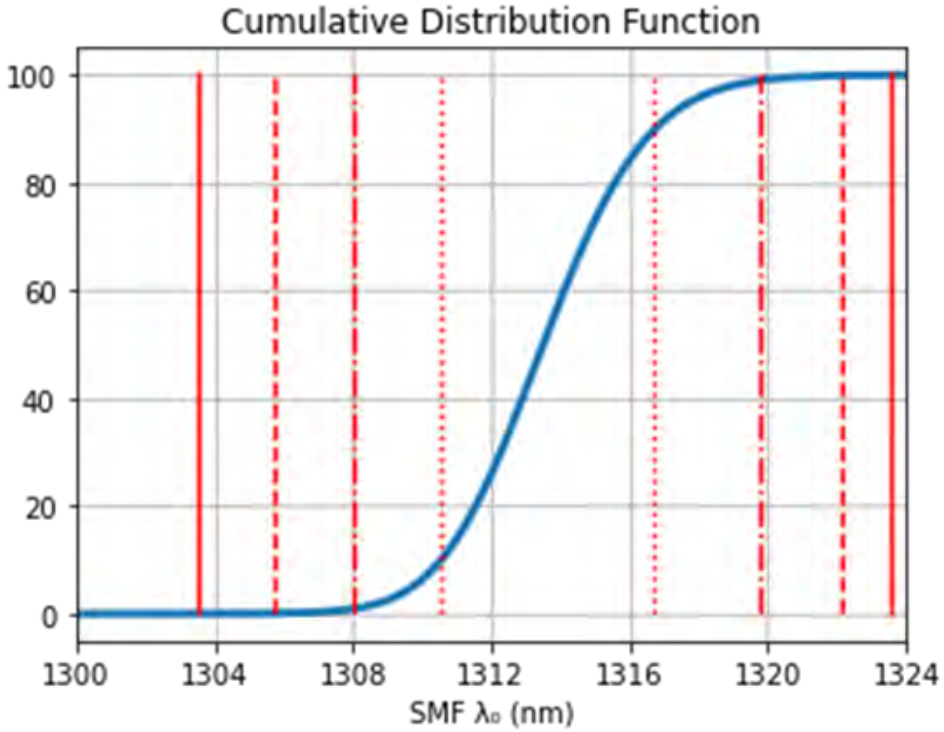
- Use ZDW normal distribution for calculating dispersion in link budget analysis:
  - $Mean_{min}$ (μ_{min}) = 1309nm (for most positive dispersion)
  - $Mean_{max}$ (μ_{max}) = 1315nm (for most negative dispersion)
  - Sigma (σ) = 2nm
  - Statistical ex. https://www.ieee802.org/3/df/public/22_10/22_1012/rodes_3df_01b_221012.pdf#page=8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

ZDW Normal Distribution Mean Distribution Proposal

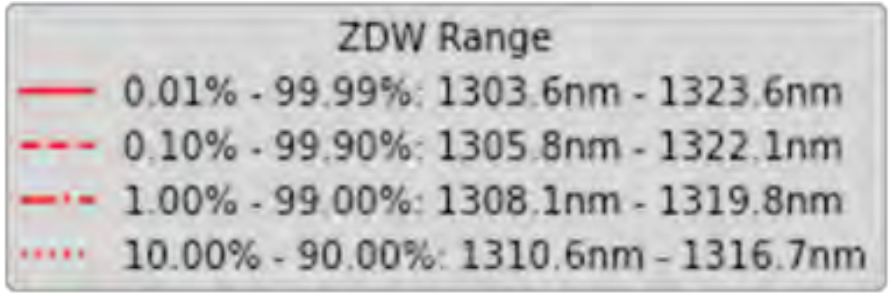
- G.652 nominal ZDW = 1310 nm but is not a requirement nor a normative target.
- Six Sigma places no constraints on the mean distribution in between limits.
- The means of ZDW distributions from four suppliers are between 1312 and 1315nm.
- Data on individual fiber manufacturers long term mean distribution is not available.
- Processes are not coordinated between fiber manufacturers, i.e., are uncorrelated.
- Use a conservative uniform mean distribution for ZDW Normal distribution:
  - $Mean_{min}$ = 1309nm
  - $Mean_{max}$ = 1315nm.
- Confirmation that this distribution is conservative is on the next page.

Data from Four SMF Suppliers Combined by Market Share





The combined function has a narrower mean distribution than uniform.



802.3 SMF Channel 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 link budget analysis and transmitter compliance testing because SMF links are less ideal with increasing rate.
  - It is consistent with 802.3 Channel not being worst case.
  - It is only complete when made together with specific PMD proposal.
- 802.3 has previously improved the SMF Channel to realistically model fiber links:
  - ex.1: statistical connector loss analysis instead of simple addition (worst case),
  - ex.2: max mean DGD limit in Transmitter Compliance Channel.
- The proposed 802.3 SMF Channel improvement makes conservative assumptions about Six Sigma ZDW mean distribution.

Fiber Optic Cabling (Channel) Characteristics Table

Description	code	Unit
Operating distance (max)	d	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 coefficient assumes d km. *The coefficient dispersion slope component is unchanged. The channel dispersion distribution is used for the Channel wavelength (λ in nm) in link analysis. It is not a fiber specification. N(μ, σ) is normal distribution with mean μ uniformly distributed between 1309 and 1315 nm, and standard deviation σ = 2 nm.*

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)	0.093	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 assumes d km. *The coefficient dispersion slope component is unchanged.*

802.3 SMF Channel Improvement Proposal Comments

- A reason for Ethernet's great success is not being driven by corner cases:
  - mainstream high-volume applications are the target.
- The proposed 802.3 SMF Channel is a work in progress.
  - As we learn more and get more data, the 802.3 SMF Channel will be improved.
  - Everyone is encouraged to refine the model:
    ex. ITU-T proposal to use ZDW & dispersion slope distributions in calculating CD.
  - Everyone is encouraged to contribute more data:
    ex. IEC and ITU-T will gather new data as per methodology in G.652 Appendix.
- An example possible improvement area is DGD (not part of this proposal).
  - ITU-T G.652 PMD statistical parameters are not fully utilized in 802.3 Channel.
  - Statistical link analysis will give more realistic DGD penalty budget component.
- ITU-T owns fiber specifications, while IEEE 802.3 owns Ethernet Channel.

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Thank you