Statistical approach to chromatic dispersion

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Introduction

- Chromatic dispersion penalty increases with square of baud rate
- For 200G lanes we need to consider chromatic dispersion parameters
  - Zero dispersion wavelength (lambda0)
  - Zero dispersion slope (S0)
- This contribution does not propose a new fiber definition or change to existing fiber parameters
- Ethernet standard references ITU-T fiber types, parameters in ITU-T and IEEE should be consistent
- A new fiber type needs to be standardized in ITU-T before reference here
- Any deviation from ITU-T specifications in our standard will create confusion in the market
- A statistical approach to chromatic dispersion reveals that extreme dispersion cases are unlikely

Example: Clause 151 (802.3cu)

151.11.1 Optical fiber cable

The optical fiber cable requirements are satisfied by cables containing ITU-T G.652.B (dispersion unshifted), type G.652.D (low water peak, dispersion unshifted), or type G.657.A1, or type G.657.A2 (bend insensitive) fibers, or the requirements in Table 151–14 where they differ.

Table 151–14—Optical fiber and cable characteristics

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.47[a] or 0.5[b]	dB/km
Zero dispersion wavelength (λ_0)	$1300 \le \lambda_0 \le 1324$	nm
Dispersion slope (max) (S_0)	0.092	ps/nm^2 km

[a] The 0.47 dB/km at 1264.5 nm attenuation for optical fiber cables is derived from Appendix I of ITU-T G.695.
[b] The 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3.

Table 151–13—Fiber optic cabling (channel) characteristics

Description	400GBASE-FR4	400GBASE-LR4-6	Unit
Operating distance (max)	2	6	km
Channel insertion loss[a, b] (max)	4	6.3	dB
Channel insertion loss (min)	0	0	dB
Positive dispersion[b] (max)	6.6	19.9	ps/nm
Negative dispersion[b] (min)	–11.7	–35.2	ps/nm
DGD_max[c]	2.3	4	ps
Optical return loss (min)	25	22	dB

[a] These channel insertion loss values include cable, connectors, and splices.
[b] Over the wavelength range 1264.5 nm to 1337.5 nm for 400GBASE-FR4 and 400GBASE-LR4-6.
[c] Differential Group Delay (DGD) is the time difference at reception between the fractions of a pulse that were transmitted in the two principal states of polarization of an optical signal. DGD_max is the maximum differential group delay that the system is required to tolerate.

- Dispersion usually calculated using worst case
- Instead, we can take a statistical approach
- For 10 km with LAN WDM grid (1294.6 to 1310.1 nm)
  - -28.0 to +9.2 ps/nm dispersion worst case

$$D\left({}^{ps}/_{nm}\right) = \frac{S_0}{4}\left[\lambda - \frac{{\lambda_0}^4}{\lambda^3}\right]L$$

Monte Carlo simulations, 100,000 scenarios

Basic assumptions

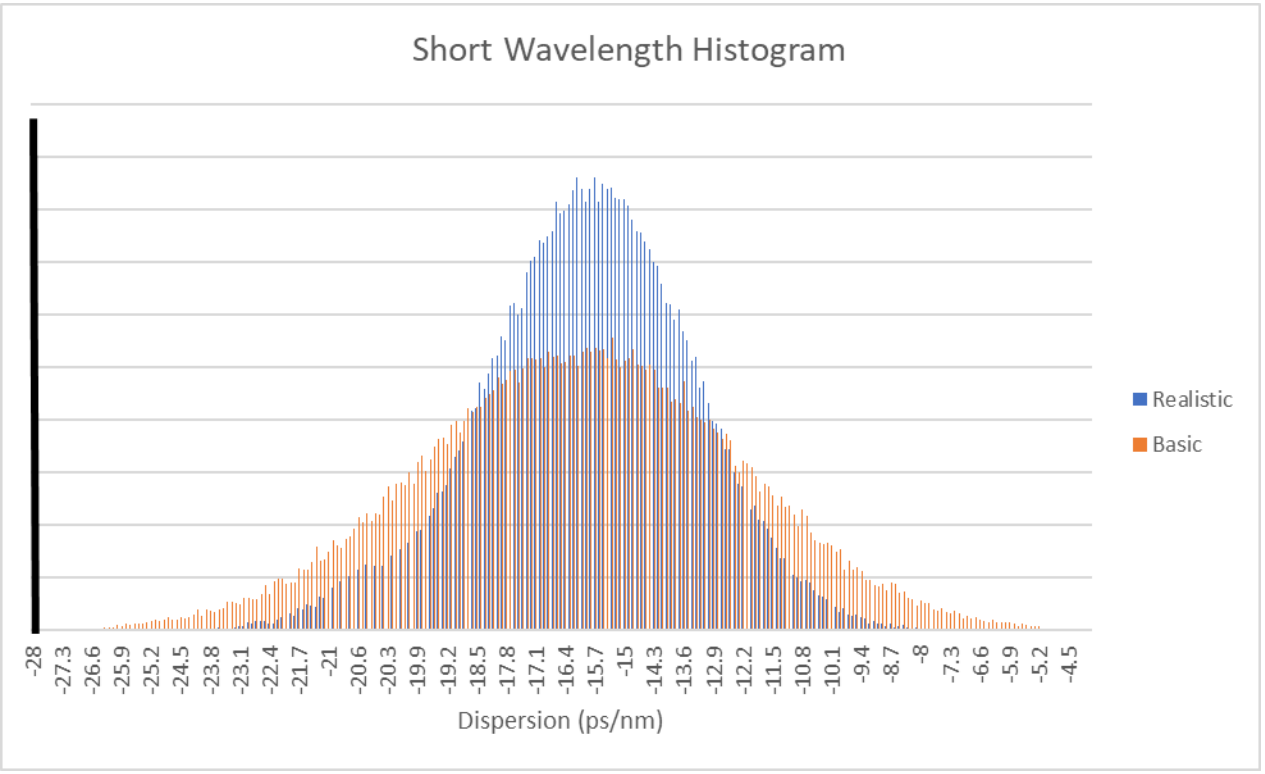
- Length: 10 km, single fiber
- Short wavelength:
  - Truncated normal distribution
  - 1295.6 nm +/- 1 nm, 3 sigma
- Long wavelength:
  - Truncated normal distribution
  - 1309.1 nm +/- 1 nm, 3 sigma
- Lambda0:
  - Truncated normal distribution
  - 1312 nm +/- 12 nm, 3 sigma
- S0:
  - Truncated normal distribution
  - 0.09 ps/(nm^2*km) +/- .002, 3 sigma

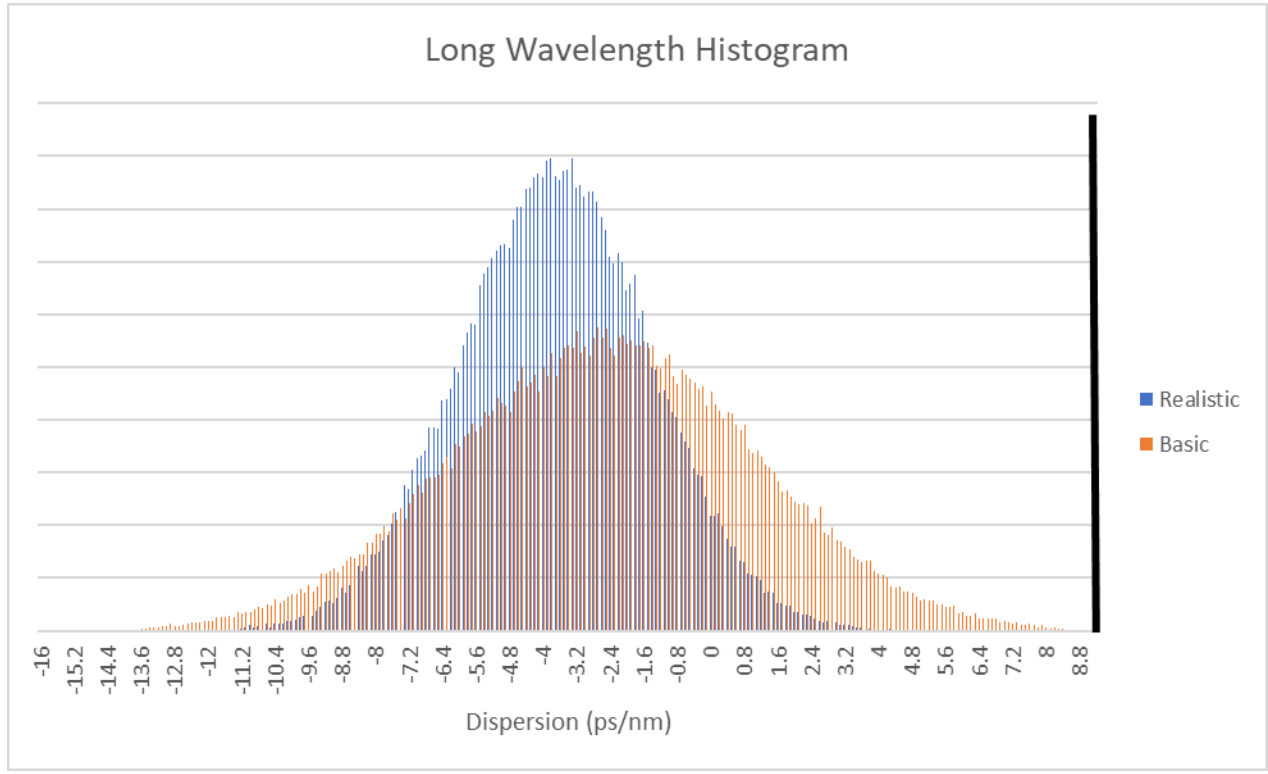
Realistic fiber parameters

- Length: 10 km, single fiber
- Short wavelength:
  - Truncated normal distribution
  - 1295.6 nm +/- 1 nm, 3 sigma
- Long wavelength:
  - Truncated normal distribution
  - 1309.1 nm +/- 1 nm, 3 sigma
- Lambda0:
  - Truncated normal distribution
  - 1313.4 nm +/- 2.6 nm, 3 sigma
- S0:
  - Truncated normal distribution
  - 0.086 ps/(nm^2*km) +/- .000879, 3 sigma

Lambda0 and S0 from 250,000 fibers from 2020

Unlikely to see -28 or +9.2 ps/nm





Realistic	
Short Wavelength	
Max	-6.92889
Min	-24.224
Mean	-15.7721
Std Dev	2.358467
Mean+3 Sigma	-8.7 ps/nm
Mean-3 Sigma	-22.8 ps/nm

Basic	
Short Wavelength	
Max	-3.4576
Min	-27.1133
Mean	-15.107
Std Dev	3.699438
Mean+3 Sigma	-4.0 ps/nm
Mean-3 Sigma	-26.2 ps/nm

Realistic	
Long Wavelength	
Max	4.514683
Min	-11.8742
Mean	-3.72254
Std Dev	2.282292
Mean+3 Sigma	3.1 ps/nm
Mean-3 Sigma	-10.6 ps/nm

Basic	
Long Wavelength	
Max	8.686157
Min	-14.2747
Mean	-2.61142
Std Dev	3.584352
Mean+3 Sigma	8.1 ps/nm
Mean-3 Sigma	-13.4 ps/nm

Conclusions

- A new fiber standard is not needed for 200G lanes
- Fiber specifications should match existing ITU-T standards
- Extreme dispersion (e.g., +9.2 or -28 ps/nm) values unlikely to be seen
- A statistical approach can be taken for channel simulation and power budgets

- Further refinements can be made including:
  - Realistic Tx wavelength distributions
  - Multiple fibers in link
  - Multiple fiber manufacturers