Analysis of statistical data on SMF chromatic dispersion parameters in Liaison Statement from ITU-T SG15

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Introduction

- In December IEEE 802.3 WG received a response Liaison Statement (LS) from ITU-T SG15 on the examination of the statistical chromatic dispersion properties of G.652 / G.657 fiber

- This LS can be found at: https://www.ieee802.org/3/minutes/jan24/index.html

- In this presentation the authors provide an analysis of the data provided in this LS which could be a potential path towards usage of appropriate dispersion limits in P802.3dj for primarily 800GBASE-LR4 and secondarily for 800GBASE-FR4

- The analysis in this presentation is purely based on the information available to IEEE 802.3 WG, ignoring any inside information from discussions in ITU-T SG15

General G.652 versus G.657 fibers: G.652

- G.652 fiber is what is generally referred to as SSMF (standard single-mode fiber) in our industry.
- Recommendation ITU-T G.652 is publicly available at: https://www.itu.int/itu-t/recommendations/rec.aspx?rec=13076
- The first version is from 1984 and the most recent, in-force version is edition 9 from 2016.
- It specifies characteristics of cabled fiber, especially so-called B and D types (where older A and C types have been deleted from the specification), bending radius 30mm min.
- It refers to IEC specification IEC 60793-2-50 Ed. 5.0 (2015), Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single mode fibres.
- This IEC specification has been generally referred to in IEEE 802.3, but in recent clauses references to ITU-T Recommendation have been used.

General G.652 versus G.657 fibers: G.657

- G.657 fibers have been additionally defined to address markets needing reduced bending loss sensitivity. It specifies characteristics of a bending-loss insensitive single-mode optical fiber
- Recommendation ITU-T G.657 is publicly available at: https://www.itu.int/itu-t/recommendations/rec.aspx?rec=13078
- The first version is from 2006 and the most recent, in-force version is edition 4 from 2016.
- It also refers to IEC specification IEC 60793-2-50 Ed. 5.0 (2015), Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single mode fibres.
- There are 2 categories, A and B:
  - Category A fibers are optimized for reduced macrobending loss compared to ITU-T G.652.D fibers and can be deployed throughout the access network. Minimum bending radius 10mm for Type A1 and 7.5mm for Type A2.
  - Category B fibers are optimized for further reduced macrobending loss and therefore are capable of being used at very low values of bend radius, as low as 5 mm.
- In our applications generally G.657.A1 or G.657.A2 is used, as in Clause 151.
- G.657.A (A1 and A2) fibers have the same chromatic dispersion requirements for zero-dispersion wavelength and dispersion slope as G.652 fibers.

Why G.652 and G.657?

- All G.657A fiber is compliant to the G.652D standard.
- Some vendors' highest volume fibers are now G.652D/G.657A1 (10mm bend) or G.652D/G.657A2 (7.5mm bend) compliant.
- Prior to G.657 becoming a standard, G.652D fibers were for the most part good enough to be used most cables.
- The progression of G.657 fibers being used initially only in Access networks to becoming the highest volume fibers deployed has been necessitated by their use in high density cables where larger bending forces are present, such as in DCI and other constrained duct applications. This applies to smaller fiber count denser (therefore smaller OD) cables as well as cables with several thousand fibers
- Vendors have transitioned or are transitioning their highest volume fibers to be G.657A compliant. If this IEEE standard is to apply to the installed base as well as future deployments, then this shift needs to be taken into account.
- Fiber vendors use proprietary index profile designs to meet these performance requirements which results in different means and distributions. Applying a one size fits all model does not accurately depict actual deployed or future conditions.

Relevant quotes from the SG15 Liaison Statement

- The currently in-force Recommendations (G.652 and G.657) give minimum and maximum boundaries for the dispersion parameters; however, it is known that practical fiber links have better effective dispersion properties. Study group 15 has undertaken an examination of the statistical properties of CD for G.652 / G.657 fiber links. This has been done as a correspondence activity between questions Q2, Q5, and Q6 of the study group.
- The initial phase of the work was to determine what is the best way to represent the statistical nature of fiber link CD. It was agreed that a set of prototypical links (each of a certain overall length and composed of a certain number of fiber cable segments) would be considered. The CD of these links would be analyzed using a Monte-Carlo simulation, with the objective of finding the 99.99% confidence maximum and minimum CD curves (as a function of wavelength).
- It was agreed to make a questionnaire to the fiber manufacturers to gather their estimations of the minimum and maximum CD curves. That information was collected from eight fiber manufacturers, representing installed G.652.D and G.657.A fibers. It should be noted that this examination has been done with past and present data but it is not predictive of future fiber performance. The Q5/15 rapporteur compiled the information, and determined global minimum and maximum curves that would enclose all the individual responses. These curves and their representative Sellmeier equations, as well as one numerical example which illustrates the impact of qualification level, are given in the attached [248-GEN].

Details from the SG15 LS

- Calculation details provided in Attachment 1, 248-GEN

- Eight vendors of G.652/G.657 SMF optical fibers (Corning, Fujikura, Furukawa, OFS, Prysmian, Sterlite, Sumitomo, and YOFC) provided the wavelength dependence of statistical accumulated chromatic dispersion properties based on their own products.

- The wavelength dependence of max/min accumulated chromatic dispersion boundaries has been derived and captured in several figures assuming a 2, 10, 20, 30, and 40 km long link with a 2.5 km cable piece length and with a 99.99% confidence level.

- These curves can be found in 248-GEN, pages 2 – 4.

- The equation for creating the approximation curves has been provided in the LS as equation (1) on page 4, which values for equation constants on page 5.

- Detailed calculation results on next slide

Calculation details of neg and pos chromatic dispersion limits

Using equation (1) in Attachment 1, 248-GEN, the following negative and positive dispersion limits for the LAN-WDM 4 wavelength set for usage in 800GBASE-LR4 can be calculated, with the lowest negative dispersion at 1294.53 nm and the highest positive dispersion at 1310.19 nm:

Distance [km]	Worst case [ps/nm]	SG15 LS [ps/nm]	Reduction
2	-5.61 / +1.86	-5.66 / +1.91 ± 0.4	0%
10	-28.05 / +9.27	-26.3 / +4.57 ± 0.8	6.3% / 51%
20	-56.1 / +18.54	-50.51 / +7.03 ± 2.2	10% / 62%
40	-112.2 / +37.08	-95.05 / +6.94 ± 4.6	15.5% / 81%

Observations from LS results

- The effect of splitting the link into 2.5 km sections becomes stronger for longer distances, thus going from 2 km (1 section), to 10 km (4 sections), to 20 km (8 sections), to 40 km (16 sections).
- This is strongest for positive dispersion, where the reduction is 51% for 10 km, 62% for 20 km and 81% for 40 km.
- This is much less for negative dispersion where the reduction is only 6.3% for 10 km up to 15.5% for 40 km.

- However ….. See next slide

Alternative view on dispersion equations in the LS

- The general, Sellmeier equation based, formula for chromatic dispersion in terms of dispersion slope (S_0) and zero dispersion wavelength (ZDW or λ_0) is:

$$D(\lambda) = 0.25*\lambda* S_0(1 – (\lambda_0/ \lambda)^4)$$

- It occurred to us that we can rewrite the equations in the ITU LS and then extract the assumed ZDW/ λ_0 and slope S_0 with the following results:

Distance [km]	Slope S_0 for min CD [ps/nm^{2}km]	ZDW/λ_0 [nm]	Slope S_0 for max CD [ps/nm^{2}km]	ZDW/λ_0 [nm]	Average ZDW/λ_0
Current	0.092	1324	0.092	1300	1312
2	0.0864	1326.1	0.0864	1299.0	1312.55
10	0.0856	1324.2	0.088	1305	1314.6
20	0.0872	1322.6	0.0908	1306.3	1314.45
40	0.0888	1320.5	0.0908	1308.3	1314.4

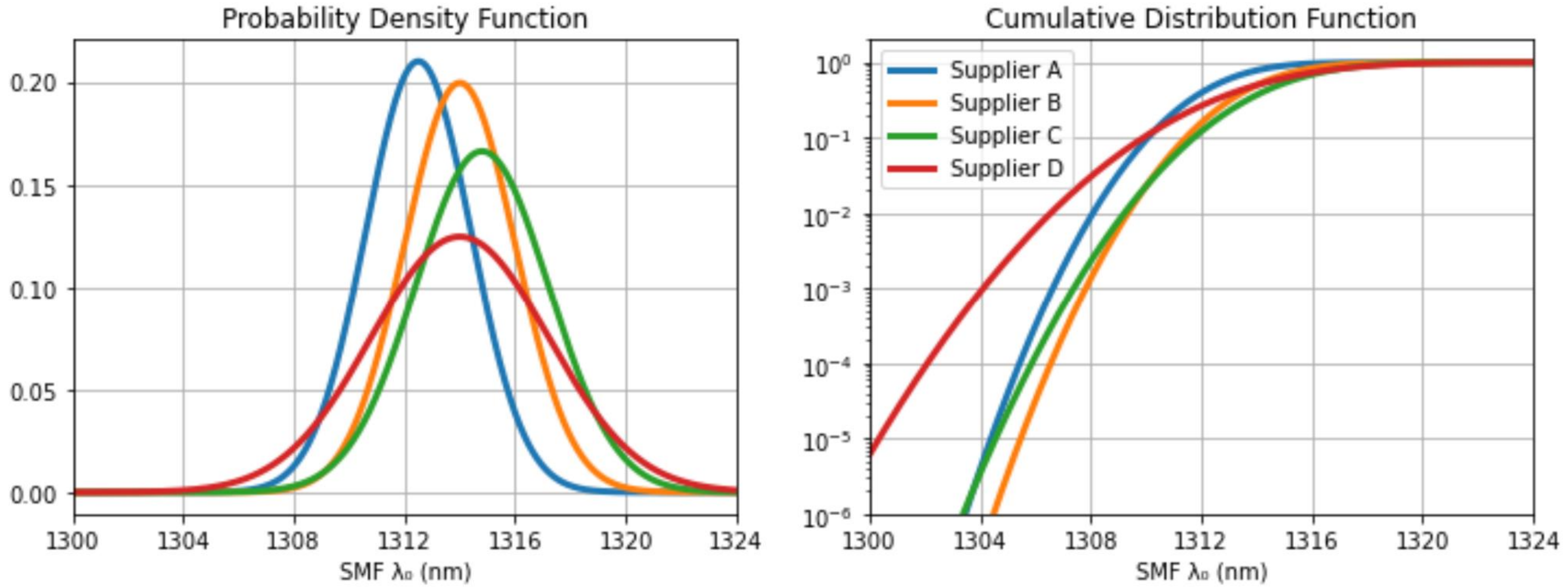
Secondary observations from LS results

- For the minimum (negative) dispersion a significant part of the reduction of chromatic dispersion seems to come from a reduced slope coefficient.
- Some vendors seem to not comply to the assumption of a six-sigma distribution, resulting in ZDW lower than 1300 nm for 2 km and higher than 1324 nm for 2 km.
- The LS however specifically states "*Thus, the approximation curves for 2 km link seems to potentially violate the CD specifications around the 1300 and 1324 nm regions. However, it should noted that there are no products and links which do not satisfy the zero-dispersion wavelength of 1300-1324 nm in the actual field.*"
- So one of the questions we could ask the ITU-T could be to use the worst case ZDW instead of the values outside 1300 – 1324 nm for our estimations for 2 km and 10 km.
- The analysis seems to indicate a clear offset in CD distributions to a center around 1314.5 nm (instead of previously assumed 1312 nm).

Further observations from LS results

The observation of a shift of the general average ZDW from 1312 nm towards 1314.5 nm is completely consistent with the reporting of ZDW distribution data for 4 vendors on slide 5 in cole_3df_01a_2211

Data from Four SMF Suppliers Representing ~50% Market Share



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

Update to Modern SMF Parameters for Calculating PMD (Physical Medium Dependent) Penalties / IEEE P802.3df / 15 November 2022 / C. Cole, et al. 5

Calculation details of neg and pos chromatic dispersion limits using revised LS equations

As indicated in a previous slide we could recalculate the numbers from the ITU-T equations, where ZDW is maintained within the window of 1300 – 1324 nm.

Calculated limits for LAN-WDM 4 wavelength set for usage in 800GBASE-LR4, lowest negative dispersion at 1294.53 nm and highest positive dispersion at 1310.19 nm, with in BOLD font the resulting revised values:

Distance [km]	Worst case [ps/nm]	Revised SG15 LS [ps/nm]	Reduction
2	-5.61 / +1.86	**-5.27 / +1.74 ± 0.4**	**6.1% / 6.5%**
10	-28.05 / +9.27	**-26.1** / +4.57 ± 0.8	**6.9%** / 51%
20	-56.1 / +18.54	-50.51 / +7.03 ± 2.2	10% / 62%
40	-112.2 / +37.08	-95.05 / +6.94 ± 4.6	15.5% / 81%

Comparison with other proposals for 800GBASE-LR4

- During the P802.3dj ad hoc call on 14 December 2023 an alternative proposal SMF dispersion limits for 800GBASE-LR4 was proposed by Xiang Liu, et al, in liu_3dj_optx_01_231214
- In the following table the values from worst case approach are compared with the values calculated from the LS and the values in liu_3dj_optx_01_231214

Distance [km]	Worst case [ps/nm]	Revised SG15 LS [ps/nm]	Xiang Liu, et al [ps/nm]
10	-28.05 / +9.27	-26.1 / +4.57 ± 0.8	-20.34 / +3.78

- The positive limit of 3.78 ps/nm proposed by Xiang Liu et al fits with 4.57 ± 0.8 ps/nm calculated from the LS equations.
- Xiang Liu et al propose to use a single distribution with an average of 1312 nm, which will lead to too optimistic values, especially for negative dispersion, because, as shown in the LS and also cole_3df_01a_2211, the average ZDW more likely to be around 1314.5 nm.
- The LS seems to indicate that a single ZDW distribution is not appropriate, because ZDW heavily depends on the fiber vendor used in networks, each with different ZDW distributions (average and sigma), as also shown in cole_3df_01a_2211.

Calculations for 800GBASE-FR4

In a similar way as for 800GBASE-LR4 the revised equations from the LS can be used to define appropriate CD limits over 2km link for 800GBASE-FR4.

Calculated limits (using revised ITU-T equations with ZDW window of 1300 – 1324 nm) for CDM 4 wavelength set for usage in 800GBASE-FR4, lowest negative dispersion at 1264.5 nm and highest positive dispersion at 1337.5 nm:

Distance [km]	Worst case [ps/nm]	Revised SG15 LS [ps/nm]	Reduction	John Johnson [ps/nm]
2	-11.75 / +6.62	-11.03 / +6.21 ± 0.4	6.1% / 6.2 %	-10.2 / +5.6

As already indicated in the LS, the benefits of this statistical approach for a single section of 2km is pretty limited, but not zero at the extreme CWDM wavelengths.

In the most right column values proposed by John Johnson in johnson_3dj_01a_2307 are shown. These are based upon the assumption of a CD_Q statistical method, which apparently has not been endorsed/embraced by ITU-T SG15.

Further messages from SG15 LS

- Q5 of ITU-T SG15 intends to incorporate the information from 248-GEN in an informative Appendix to Recommendation ITU-T G.652, anticipating approval of a revised Recommendation during the SG15 Plenary Meeting in Montreal, July 2024.

- At the last ITU-T SG15 Plenary Meeting, 20 November – 1 December 2023, a new work item was agreed, as shown in Attachment 3 to the LS:
  - Aiming to provide new example guideline for the statistical accumulated chromatic dispersion property in a 2–40 km link as additional contents for the existing Appendix I.
  - Investigating PMD_Q values for a short link in this revision work.
  - Specifically not aiming to modify the existing chromatic dispersion specifications.

Thanks!