Optical fiber tables and chromatic dispersion specs

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Introduction

- Within a PMD clause, there are several tables where chromatic dispersion (CD) specs occur:
  - Optical fiber and cable characteristics
  - Optical channel characteristics
  - Transmitter compliance channel specifications
- Because prior PMDs have consistently followed the worst case CD methodology of ITU-T G.652, the distinction between the purposes of these tables may not be clear.
- They do in fact serve different purposes, and as we move away from a default worst case CD methodology, the implied CD values in these three tables will diverge.
  - This new statistical CD methodology is referred to here generically as “CM2”, details of which will be proposed in separate contributions.
  - Some prior “CM2” contributions: parsons_3dj_01b_2403, rodes_3dj_01a_2403, castro_3dj_01a_2403, parsons_3dj_optx_01_240411
  - This contribution is not a CM2 proposal, and implementation details will depend on the final adopted model and how it is documented in the standard.
- It’s worthwhile to review the purpose of each of these tables, and how the CD values in each are derived, so that they can be properly applied in the P802.3dj PMD clauses.

Optical fiber tables

- Optical fiber and cable characteristics
  - Lists the specification for the optical fiber cables that are used in the application
  - References external fiber and cabling standards, e.g. ITU-T G.652 and G.657
  - Think of this as **a fiber cable procurement requirement** for the end users
- Optical channel characteristics
  - Lists the specifications for the optical channel, which is made up of one or more optical fiber cables with connectors between them
  - These specs were calculated by the 802.3 Task Forces based on analyses of external standards and other data on how optical channels for the specific application are constructed
  - Think of this as the range of optical channels **over which the PMD link budget and TX/RX specifications are defined to work**
- Transmitter compliance channel specifications
  - Lists the specifications for optical fiber cables used to test transmitter compliance (TDECQ)
  - The CD specs are consistent with the CD methodology used for the optical channel characteristics, but are specific to the wavelengths of the transmitter implementation
  - Think of this as how **transmitters must be tested in order to insure compliance over the optical channel requirements**

Example CD specs from Clause 151

Table	Example	400GBASE-FR4	400GBASE-LR4-6
Optical fiber and cable characteristics	Table 151-14	Worst case S_0 and ZDW from G.652 and G.657	
Fiber optic cabling (channel) characteristics	Table 151-13	G.652 using worst case S_0 and ZDW, calculated at worst case TX wavelengths and worst case fiber length	
Transmitter compliance channel specifications	Table 151-12	G.652 using worst case S_0, ZDW and fiber length, in equations as a function of TX wavelength	

The same worst-case ITU-T G.652 CD methodology is used for all three tables.

Optical fiber and cable characteristics

151.11 Characteristics of the fiber optic cabling (channel)

The 400GBASE-FR4 and 400GBASE-LR4-6 fiber optic cabling shall meet the specifications defined in Table 151–13. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together.

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)	$1300 \leq \lambda_0 \leq 1324$	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.

- Clause 151.11 specifies fiber cables meeting G.652B/D and G.657A1/A2 satisfy the requirements of Table 151-14, with the exception of the attenuation specs, which are taken from ITU-T G.695 and ANSI/TIA 568-C-3.
- The specs in this table have not been re-analyzed or otherwise re-interpreted by 802.3. They are simply reporting values from the external standards.

Optical channel characteristics

151.10 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 151–7.

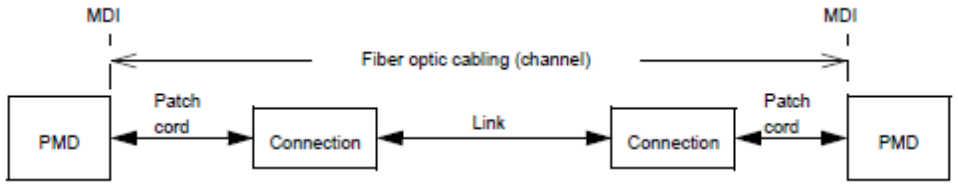

Figure 151–7—Fiber optic cabling model

The channel insertion loss is given in Table 151–13. A channel may contain additional connectors as long as the optical characteristics of the channel, such as attenuation, dispersion, reflections, and polarization mode dispersion meet the specifications. Insertion loss measurements of installed fiber cables are made in accordance with IEC 61280-4-2 one-cord reference method. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term channel is used here for consistency with generic cabling standards..

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.

- Table 151-13 uses the worst case S0 and ZDW given in Table 151-14, and calculates the worst case positive and negative dispersion using the worst case TX wavelengths given in Table 151-7 and footnote (b), and the worst case fiber length (operating distance).
- In this table, 802.3 has analyzed available information on connector loss, optical return loss and PMD in order to define optical channel characteristics for those parameters that are specific to these PMDs. They are not copied from external standards.

Transmitter compliance channel specifications

151.8.5.1 Channel requirements

The transmitter is tested using an optical channel that meets the requirements listed in Table 151–12.

Table 151–12—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
400GBASE-FR4	$0.046\times\lambda\times[1-(1324/\lambda)^4]$	$0.046\times\lambda\times[1-(1300/\lambda)^4]$	Minimum	17.1 dB	0.8 ps
400GBASE-LR4-6	$0.138\times\lambda\times[1-(1324/\lambda)^4]$	$0.138\times\lambda\times[1-(1300/\lambda)^4]$	Minimum	15.6 dB	0.8 ps

[a] The dispersion is measured for the wavelength of the transmitter lane under test (λ in nm). The coefficient assumes 2 km for 400GBASE-FR4 and 6 km for 400GBASE-LR4-6.
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.
[c] The optical return loss is applied at TP2.

A 400GBASE-FR4 or 400GBASE-LR4-6 transmitter is to be compliant with a total dispersion at least as negative as the "minimum dispersion" and at least as positive as the "maximum dispersion" columns specified in Table 151–12 for the wavelength of the transmitter lane under test. This may be achieved with channels consisting of fibers with lengths chosen to meet the dispersion requirements.

To verify that the fiber has the correct amount of dispersion, the measurement method defined in IEC 60793-1-42 may be used. The measurement is made in the linear power regime of the fiber.

The channel provides an optical return loss specified in Table 151–12. The state of polarization of the back reflection is adjusted to create the greatest RIN.

The mean DGD of the channel is to be less than the value specified in Table 151–12.

- Table 151-12 uses the worst case S_0, ZDW and fiber length in the Sellmeier equation specified in G.652, and applies them to the implementation-specific wavelengths of the TX under test.
- A TX need only be tested at the dispersion given by it's own expected range of wavelengths, not the worst case wavelengths and dispersion shown in Table 151-7, to be considered compliant.

CD specs for 802.3dj

Table	DRn, FR4-500, DRn-2 PMDs	800GBASE-FR4	800GBASE-LR4
Optical fiber and cable characteristics	Worst case S_0 and ZDW from G.652 and G.657 (no different than previous PMD clauses)		
Optical channel characteristics	G.652 using worst case S_0 and ZDW at worst case TX WL and fiber length	"CM2" with correlated S_0 and ZDW, at M=1, Q=tbd at worst case TX WL and fiber length	"CM2" with correlated S_0 and ZDW, at M=4, Q=tbd at worst case TX WL and fiber length
Transmitter compliance channel specifications	Same methodology as above, but as a function of TX wavelength		

- The tables for DRn, DRn-2 and FR4-500 PMDs use the traditional worst case CD methodology throughout.
- FR4 and LR4 PMDs use the "CM2" statistical channel model(s), which will be described in an informative Annex of P802.3, rather than in an external fiber cable standard.
- Even if CM2 is based on numerical computations, there needs to be a fitted equation describing the fiber cable CD(M,Q; λ) to be used for TX compliance testing.

Clause 180 – 500m DRn PMDs

- For 500m PMDs, the CD is low enough that the worst case G.652 methodology can be used with little penalty
- Optical fiber and cable characteristics
  - Cl. 180.7.1, Table 180-11. No changes necessary.
- Optical channel characteristics
  - Cl. 180.7, Table 180-10. No changes necessary.
- Transmitter compliance channel specifications
  - Cl. 180.8.5 references the TX compliance channel defined in 400GBASE-DR4 Cl. 121.8.5.2, Table 121-11.
  - No changes necessary to the CD specs, but an exception is needed for the ORL of 200GBASE-DR1, which is 15.1dB. (johnson_3dj_01_2405)
- The tables in Clauses 181 and 182 are similar

Table 180–11—Optical fiber and cable characteristics

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.5[a]	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 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3.

Table 180–10—Optical channel characteristics

Description	200GBASE-DR1	400GBASE-DR2 800GBASE-DR4 1.6TBASE-DR8	Unit
Operating distance (max)	500		m
Channel insertion loss[a,b] (max)	3		dB
Channel insertion loss (min)	0		dB
Positive dispersion[b] (max)	0.79		ps/nm
Negative dispersion[b] (min)	–0.92		ps/nm
DGD_max[c]	2.24		ps
Optical return loss (min)	27	37	dB

[a] These channel insertion loss values include cable, connectors, and splices.
[b] Over the wavelength range 1304.5 nm to 1317.5 nm.
[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.

Table 121–11—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
200GBASE-DR4	$0.011625\times\lambda\times[1-(1324/\lambda)^4]$	$0.011625\times\lambda\times[1-(1300/\lambda)^4]$	Minimum	21.4 dB	0.5 ps

[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes 500 m for 200GBASE-DR4.
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.
[c] The optical return loss is applied at TP2.

Clause 183 – 800GBASE-FR4/LR4 PMDs

- For FR4/LR4 PMDs, the CM2 statistical methodology must be used to minimize dispersion penalty
- Optical fiber and cable characteristics
  - Cl. 183.7.1 is TBD, but this can use the worst-case G.652 S_0 and ZDW for the fiber cables as in the other PMD clauses.
  - Comments #125-126 propose to copy text and Table 182-11 from Cl. 182.7.1 as Cl. 183.7.1 and Table 183–xx. (Johnson_3dj_01_2405)
- Optical channel characteristics
  - Cl. 183.7, Table 183-9 has TBD CD limits, which will be replaced with CM2 values. For FR4: M = 1 and Q = TBD. For LR4: M = 4 and Q = TBD.
  - Footnote (b) should read: "Using the statistical dispersion model described in Annex XXX with M = 1 and Q = TBD over the wavelength range 1264.5 nm to 1337.5 nm for 800GBASE-FR4, and M = 4 and Q = TBD over the wavelength range of 1294.53 nm to 1310.19 nm for 800GBASE-LR4."
- Transmitter compliance channel specifications
  - Cl. 183.8.5, Table 183-13 has TBD CD limits, which will be replaced with CM2 equations for CD vs. WL.
  - Footnote (a) should read: "Using the statistical dispersion model described in Annex XXX, Equation XXX–X, with M = 1 and Q = TBD for 800GBASE-FR4, and with M = 4 and Q = TBD for 800GBASE-LR4. The dispersion is measured for the wavelength of the transmitter …"
- The final language will depend on the adopted CM2 statistical model and how it's documented in the informative annex.

Table 183–xx —Optical fiber and cable characteristics

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.5[a]	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 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3.

Table 183–9—Optical channel characteristics

Description	800GBASE-FR4	800GBASE-LR4	Unit
Operating distance (max)	2	10	km
Channel insertion loss[a, b] (max)	4	6.3	dB
Channel insertion loss (min)	0		dB
Positive dispersion[b] (max)	TBD	TBD	ps/nm
Negative dispersion[b] (min)	TBD	TBD	ps/nm
DGD_max[c]	TBD	4	ps
Optical return loss (min)	TBD	TBD	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 800GBASE-FR4, and 1294.53 nm to 1310.19 nm for 800GBASE-LR4.
[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.

Table 183–13—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
800GBASE-FR4	TBD	TBD	Minimum	17.1 dB	0.8 ps
800GBASE-LR4	TBD	TBD	Minimum	15.6 dB	0.8 ps

[a] The dispersion is measured for the wavelength of the transmitter lane under test (λ in nm). The coefficient assumes 2 km for 800GBASE-FR4 and 10 km for 800GBASE-LR4.
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.
[c] The optical return loss is applied at TP2.

Conclusions

- The differences in purposes between the several tables that specify CD in PMD clauses have been clarified
  - Optical fiber and cable characteristics
  - Optical channel characteristics
  - Transmitter compliance channel specifications
- Optical fiber cable specs are not changing, so there is no change to these tables from the ITU-T G.652 worst case S_0 and ZDW specs for any PMD.
- DRn, DRn-2 and FR4-500 PMDs have low enough CD that the ITU-T G.652 worst case S_0 and ZDW can continue to be used to specify the optical channel and TX compliance channel CD limits.
- The FR4 and LR4 PMDs have significant CD penalties, and will use the CM2 statistical methodology for the optical channel characteristics and TX compliance channel.
  - The optical channel and TX compliance channel CD specs will no longer align with the optical fiber cable specs.
  - An Annex describing the CM2 methodology and results will be created.
  - How the CM2 CD limits could be included in these tables and reference the new Annex was discussed.

Thank You

Backup slides

Clause 181 – 800GBASE-FR4-500 PMD

- For 500m PMDs, the CD is low enough that the worst case G.652 methodology can be used with little penalty
- Optical fiber and cable characteristics
  - Cl. 181.7.1, Table 181-9. No changes necessary.
- Optical channel characteristics
  - Cl. 181.7, Table 181-8. No changes necessary.
- Transmitter compliance channel specifications
  - Cl. 181.8.5 references the TX compliance channel defined in 400GBASE-DR4 Cl. 121.8.5.2, Table 121-11.
  - No changes necessary to the CD specs, but an exception is needed for the ORL of 400GBASE-FR4-500, which is 17.1dB. (johnson_3dj_01_2405)

Table 181–9—Optical fiber and cable characteristics

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

[a] The 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3.

Table 181–8—Optical channel characteristics

Description	800GBASE-FR4-500	Unit
Operating distance (max)	500	m
Channel insertion loss[a, b] (max)	3.5	dB
Channel insertion loss (min)	0	dB
Positive dispersion[b] (max)	1.66	ps/nm
Negative dispersion[b] (min)	–2.94	ps/nm
DGD_max[c]	0.8	ps
Optical return loss (min)	17.1	dB

[a] These channel insertion loss values include cable, connectors, and splices.
[b] Over the wavelength range 1264.5 nm to 1337.5 nm.
[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.

Table 121–11—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
200GBASE-DR4	$0.011625\times\lambda\times[1-(1324/\lambda)^4]$	$0.011625\times\lambda\times[1-(1300/\lambda)^4]$	Minimum	21.4 dB	0.5 ps

[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes 500 m for 200GBASE-DR4.
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.
[c] The optical return loss is applied at TP2.

Clause 182 – 2km DRn-2 PMDs

- For 2km DRn-2 PMDs, the CD is low enough that the worst case G.652 methodology can be used with little penalty
- Optical fiber and cable characteristics
  - Cl. 182.7.1, Table 182-11. No changes necessary.
- Optical channel characteristics
  - Cl. 182.7, Table 182-10. No changes necessary.
- Transmitter compliance channel specifications
  - Cl. 182.8.5 references the TX compliance channel defined in 400GBASE-DR4 Cl. 121.8.5.2, Table 121-11.
  - No changes necessary to the CD specs, but an exception is needed for the ORL of 200GBASE-FR1, which is 17.1dB. (johnson_3dj_01_2405)

Table 182–11—Optical fiber and cable characteristics

Description	Value	Unit
Nominal fiber specification wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.5[a]	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 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA 568-C.3.

Table 182–10—Optical channel characteristics

Description	200GBASE-FR1	400GBASE-DR2-2 800GBASE-DR4-2 1.6TBASE-DR8-2	Unit
Operating distance (max)	2000		m
Channel insertion loss[a,b] (max)	4		dB
Channel insertion loss (min)	0		dB
Positive dispersion[b] (max)	3.16		ps/nm
Negative dispersion[b] (min)	–3.67		ps/nm
DGD_max[c]	2.3		ps
Optical return loss (min)	25	37	dB

[a] These channel insertion loss values include cable, connectors, and splices.
[b] Over the wavelength range 1304.5 nm to 1317.5 nm.
[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.

Table 121–11—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
200GBASE-DR4	$0.011625\times\lambda\times[1-(1324/\lambda)^4]$	$0.011625\times\lambda\times[1-(1300/\lambda)^4]$	Minimum	21.4 dB	0.5 ps

[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes 500 m for 200GBASE-DR4.
[b] There is no intent to stress the sensitivity of the O/E converter associated with the oscilloscope.
[c] The optical return loss is applied at TP2.