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400GBASE-LR4 (6 km) Baseline Proposal

IEEE P802.3cu Task Force meeting

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400GBASE-LR4 Baseline Proposal(s)

- Task Force adopted objective:
  Define a four-wavelength 400 Gb/s PHY for operation over SMF with lengths up to at least 10 km

- This proposal:
  6 km reach with 10.5 dB power budget with 6.3 dB insertion loss and 4.2 dB for penalties.
  Penalties include **3.5** dB TDECQ, **0.7** dB MPI & DGD.

Transmit Characteristics

Table 151–7—400GBASE-FR4 and 400GBASE-LR4 transmit characteristics

Description	400GBASE-FR4	400GBASE-LR4	Unit
Signaling rate, each lane (range)	53.125 ± 100 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5		nm
Side-mode suppression ratio (SMSR), (min)	30		dB
Total average launch power (max)	9.5	11.6	dBm
Average launch power, each lane (max)	3.5	5.6	dBm
Average launch power, each lane[a] (min)	–3.3	–2.8	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	3.7	4.4	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min)[b]	–0.3	0.2	dBm
Difference in launch power between any two lanes (OMA_{outer}) (max)	4	4	dB
Launch power in OMA_{outer} minus TDECQ, each lane (min): for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 –1.7 –1.6	 –1.2 –1.1	 dBm dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	3.4	3.5	dB
TDECQ – $10\log_{10}(C_{eq})$[c] (max)	3.4	3.5	dB
TDECQ – SECQ	—	TBD	dB
Average launch power of OFF transmitter, each lane (max)	–20	–20	dBm
Extinction ratio, each lane (min)	3.5	3.5	dB
Transmitter transition time (max)	17		ps
$RIN_{17.1}OMA$ (max)	–136	—	dB/Hz
$RIN_{15.6}OMA$ (max)	—	–136	dB/Hz
Optical return loss tolerance (max)	17.1	15.6	dB
Transmitter reflectance[d] (max)	–26		dB

[a] Average launch power, each lane (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.
[b] Even if the TDECQ < 1.4 dB for an extinction ratio of ≥ 4.5 dB or TDECQ < 1.3 dB for an extinction ratio of < 4.5 dB, the OMA_{outer} (min) must exceed this value.
[c] C_{eq} is a coefficient defined in 121.8.5.3, which accounts for reference equalizer noise enhancement.
[d] Transmitter reflectance is defined looking into the transmitter.

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Receive Characteristics

Table 151–8—400GBASE-FR4 and 400GBASE-LR4 receive characteristics

Description	400GBASE-FR4	400GBASE-LR4	Unit
Signaling rate, each lane (range)	53.125 ± 100 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5		nm
Damage threshold[a], each lane	4.5	6.6	dBm
Average receive power, each lane (max)	3.5	5.6	dBm
Average receive power, each lane[b] (min)	–7.3	–9.1	dBm
Receive power (OMA_{outer}), each lane (max)	3.7	4.4	dBm
Difference in receive power between any two lanes (OMA_{outer}) (max)	4.1	4.3	dB
Receiver reflectance (max)	–26		dB
Receiver sensitivity (OMA_{outer}), each lane[c] (max)	Equation (151–1)	Equation (151–2)	dBm
Stressed receiver sensitivity (OMA_{outer}), each lane[d] (max)	–2.6	–4.7	dBm
Conditions of stressed receiver sensitivity test:[e]			
Stressed eye closure for PAM4 (SECQ), lane under test	3.4	3.5	dB
SECQ – $10\log_{10}(C_{eq})$, lane under test (max)	3.4	3.5	dB
OMA_{outer} of each aggressor lane	1.5	–0.4	dBm

[a] The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level.
[b] Average receive power, each lane (min) is informative and not the principal indicator of signal strength. A received power below this value cannot be compliant; however, a value above this does not ensure compliance.
[c] Receiver sensitivity (OMA_{outer}), each lane (max) is informative and is defined for a transmitter with a value of SECQ up to 3.4 dB for 400GBASE-FR4 and up to 3.5 dBfor 400GBASE-LR4.
[d] Measured with conformance test signal at TP3 (see 151.8.10) for the BER specified in 151.1.1.
[e] These test conditions are for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

Tables for 6 km –LR4 PMD

Table 151–6—400GBASE-FR4 and 400GBASE-LR4 operating ranges

PMD type	Required operating range
400GBASE-FR4	2 m to 2 km
400GBASE-LR4	2 m to 6 km

Table 151–9—400GBASE-FR4 and 400GBASE-LR4 illustrative link power budgets

Parameter	400GBASE-FR4	400GBASE-LR4	Unit
Power budget (for maximum TDECQ): for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 7.7 7.8	 10.5 10.6	 dB dB
Operating distance	2	6	km
Channel insertion loss	4[a]	5[b]	dB
Maximum discrete reflectance	See 151.11.2.2	See 151.11.2.2	dB
Allocation for penalties[c] (for maximum TDECQ): for extinction ratio ≥ 4.5 dB for extinction ratio < 4.5 dB	 3.7 3.8	 4.2 4.3	 dB dB
Additional insertion loss allowed	0	1.3	dB

[a] The channel insertion loss is calculated using the maximum distance specified in Table 151–6 for 400GBASE-FR4 and fiber attenuation of 0.5 dB/km plus an allocation for connection and splice loss given in 151.11.2.1.
[b] The channel insertion loss is calculated using the maximum distance specified in Table 151–6 for 400GBASE-LR4 and fiber attenuation of 0.5 dB/km plus an allocation for connection and splice loss given in 151.11.2.1.
[c] Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

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	$0.0465 \cdot \lambda \cdot [1 - (1324 / \lambda)^4]$	$0.0465 \cdot \lambda \cdot [1 - (1300 / \lambda)^4]$	Minimum	17.1 dB	0.8 ps
400GBASE-LR4	$0.138 \cdot \lambda \cdot [1 - (1324 / \lambda)^4]$	$0.138 \cdot \lambda \cdot [1 - (1300 / \lambda)^4]$	Minimum	15.6 dB	0.8 ps

[a] The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes 2 km for 400GBASE-FR4 and 6 km for 400GBASE-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.

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

Description	400GBASE-FR4	400GBASE-LR4	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)	6.7	19.9	ps/nm
Negative dispersion[b] (min)	–11.9	–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.
[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 must tolerate.

Summary

- Proposed 400GBASE-LR4 (6 km) baseline:
  - Modified Tx and Rx characteristics for 10.5 dB link budget.
  - 6 km reach on worst-case G.652 fiber limits dispersion to a range of -35.2 to +19.9 ps/nm
  - Channel insertion loss of 6.3 dB allows the use of 0.5 dB/km cables with up to 3.3 dB for connectors.