802.3cu D1.1 PMD Spec Comments

P802.3cu 100 Gb/s and 400 Gb/s over SMF at 100 Gb/s per Wavelength Task Force Ad Hoc

11 December 2019

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Outline

- 400G Clause 151 Transmit Characteristics
- 400G Clause 151 Receive Characteristics
- 100G Clause 140 Transmit Characteristics
- 100G Clause 140 Receive Characteristics

Draft 1.1 Clause 151 Transmit Characteristics

Table 151–7—400GBASE-FR4 and 400GBASE-LR4-6 transmit characteristics

Description	400GBASE-FR4	400GBASE-LR4-6	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
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	3.4	3.5	dB
~~TDECQ – $10\log_{10}(C_{eq})$ (max)~~ [c]	~~3.4~~	~~3.5~~	dB
TDECQ – TECQ	—	2.5	dB
Average launch power of OFF transmitter, each lane (max)	–16	–16	dBm
Extinction ratio, each lane (min)	3.5	3.5	dB
Transmitter transition time (max)	17		ps

[c] C_{eq} is a coefficient defined in 121.8.5.3, which accounts for reference equalizer noise enhancement.

TDECQ, C_{eq} 121.8.5 Definition

TDECQ $= 10\log_{10}(OMA_{outer} / (6\ Q_t\ R))$ (121-12)

R $= \sqrt{(\sigma_G^2 + \sigma_S^2)}$ (121-11)

R ≜ RMS noise that can be added by the RX

σ_S ≜ standard deviation of the noise of the O/E and oscilloscope combination

σ_G ≜ standard deviation of Gaussian PDF mask, maximized by iteratively adapting RX equalizer

C_{eq} ≜ coefficient which quantifies RX equalizer $H_{eq}(f)$ noise enhancement

$= \sqrt{\int df\ N(f)\ |H_{eq}(f)|^2}$ (121-9)

$\int df\ N(f) = H_{eq}(f{=}0) = 1$ (121-10)

$C_{eq} > 1$ if $H_{eq}(f)$ is HPF vs. 4^{th} B-T w/ BW = 26.6 GHZ

$C_{eq} < 1$ if $H_{eq}(f)$ is LPF vs. 4^{th} B-T w/ BW = 26.6 GHZ

TDECQ - $10\log_{10}(Ceq)$ Definition

- dawe_3cd_01b_0718:

  http://www.ieee802.org/3/cd/public/July18/dawe_3cd_01b_0718.pdf#page=12

  “penalty of the signal after the reference equalizer”

  $$TDECQ - 10\log_{10}(C_{eq}) = 10\log_{10}(OMA_{outer} / (6\ Q_t\ R_2))$$

  $$R_2 = \sqrt{(C_{eq}\ \sigma_G)^2 + (C_{eq}\ \sigma_S)^2}$$

- $C_{eq}\ \sigma_G$ term is the noise signal out of the reference equalizer
- $C_{eq}\ \sigma_S$ term is not relevant
- Correct definition: $10\log_{10}(OMA_{outer} / (6\ Q_t\ C_{eq}\ \sigma_G))$

TDECQ - $10\log_{10}(C_{eq})$ Original Derivation (1)

- dawe_3cd_01b_0718 agrees:

  http://www.ieee802.org/3/cd/public/July18/dawe_3cd_01b_0718.pdf#page=4

  - $TDECQ = 10\log_{10}(OMA_{outer}/(6Q_t R))$ (121–12)
    - Q_t is a constant for a given modulation (PAM4) and BER limit
  - $R = \sigma_G$ (121–11)
    - (Setting σ_S, a measurement correction, to 0 for simplicity)
  - $\sigma_G = \sigma_{eq}/C_{eq}$ where σ_{eq} is the noise that could be added after the ideal reference equalizer, and C_{eq} is the noise enhancement coefficient
  - So $TDECQ = 10\log_{10}(OMA_{outer}/(6Q_t\sigma_{eq}/C_{eq}))$
  - $= 10\log_{10}(OMA_{outer}/(6Q_t\sigma_{eq})) + 10\log_{10}(C_{eq})$

- Correct definition

TDECQ - $10\log_{10}(C_{eq})$ Explanation

- TDECQ - $10\log_{10}(C_{eq})$ stops use of "… excessive emphasis to make a bad (noisy and/or distorted and/or inappropriate chirp) transmitter pass when it should have failed." PD 11/10/19
- "Free by-product of TDECQ measurement" PD 07/15/19
- TX with excessive emphasis results in RX $H_{eq}(f)$ adapting to LPF response vs. 4^{th} B-T response:
  - $C_{eq} < 1 \rightarrow 10\log_{10}(C_{eq}) < 0$
  - TDECQ - $10\log_{10}(C_{eq})$ > TDECQ
  - <u>Yes, it's this simple!</u>
- TX emphasis correlation to TDECQ - $10\log_{10}(C_{eq})$:
  - qualitative: up $\rightarrow$ up, down $\rightarrow$ down
  - limit dB value has no exact relation to TX emphasis value

TDECQ - $10\log_{10}(C_{eq})$ Jonathan King Analysis

http://www.ieee802.org/3/cd/public/July18/king_3cd_02a_0718.pdf

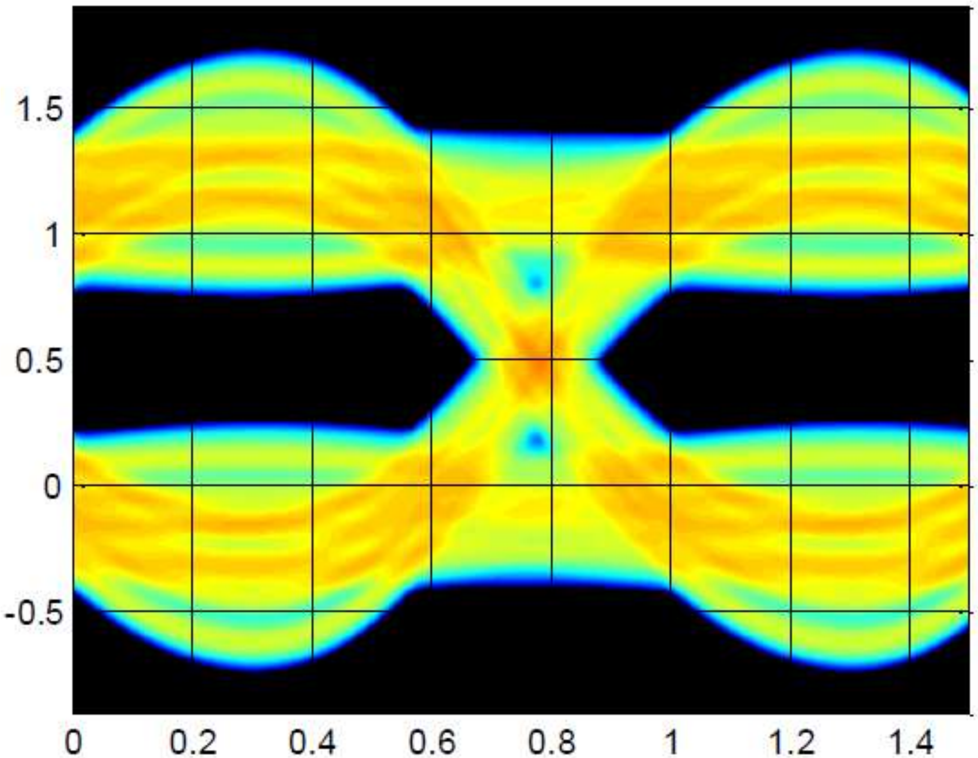
- "TDECQ-$10\log_{10}(C_{eq})$ is not a good indicator of how hard the EQ has to work, nor of it's likely resilience to receiver impairments."
- "The transmitter most likely to be affected by receiver non-linearity, quantization, or other sampling errors, is the TX with the most severe effective eye-closure out of the O/E"
  - severe TX eye closure → RX $H_{eq}(f)$ is HPF vs. 4^{th} B-T
  - TX eye closure up → TDECQ - $10\log_{10}(C_{eq})$ down
  - TDECQ - $10\log_{10}(C_{eq})$ does the inverse of desired
- "There is no value in adding a TDECQ-$10\log_{10}(C_{eq})$ limit. Adding one unnecessarily limits the use of a tool (transmitter pre-emphasis) which can improve transmitter yield and cost, and link margins."

TDECQ - $10\log_{10}(C_{eq})$ Original Derivation (2)

- dawe_3cd_01b_0718 example of "very bad" TX that can be stopped by TDECQ - $10\log_{10}(C_{eq})$ penalty spec:

  http://www.ieee802.org/3/cd/public/July18/dawe_3cd_01b_0718.pdf#page=11

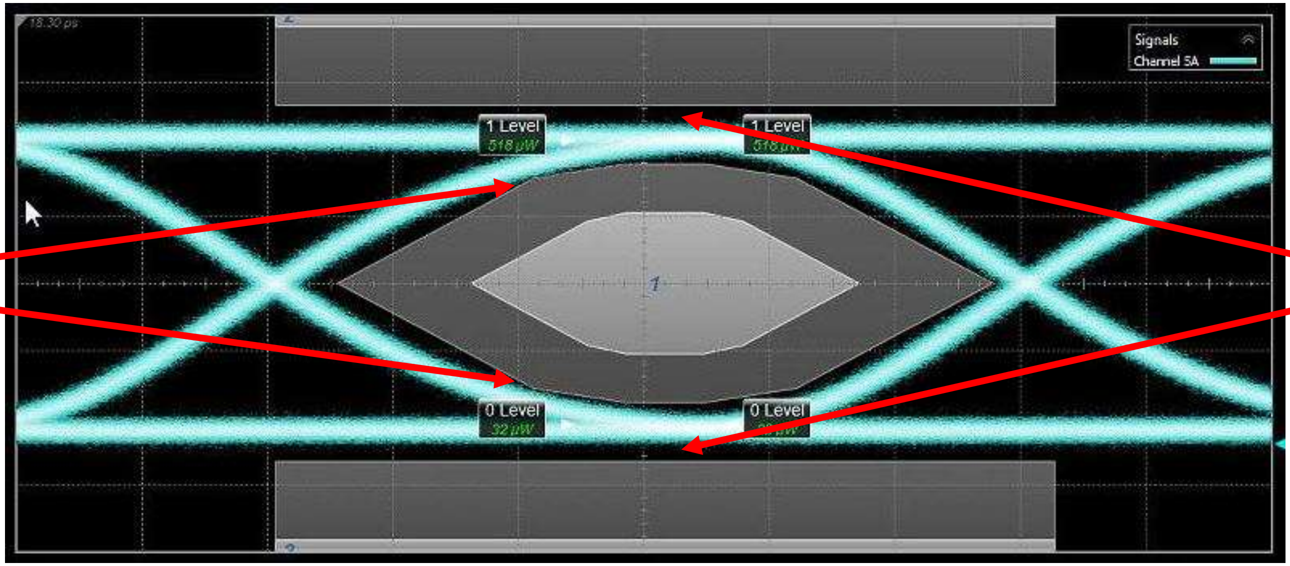
- LPF RX $H_{eq}(f)$ vs. 4^{th} B-T is fully quantified by C_{eq}
- TDECQ is irrelevant
- Only C_{eq} matters
- Only a time domain limit
- Is there a direct, easy to understand method to stop bad TX like this?



TX Signal Historical Time Domain Spec Limits

- Eye Mask (ex. 10G NRZ eye using Keysight DCA)

slow limit



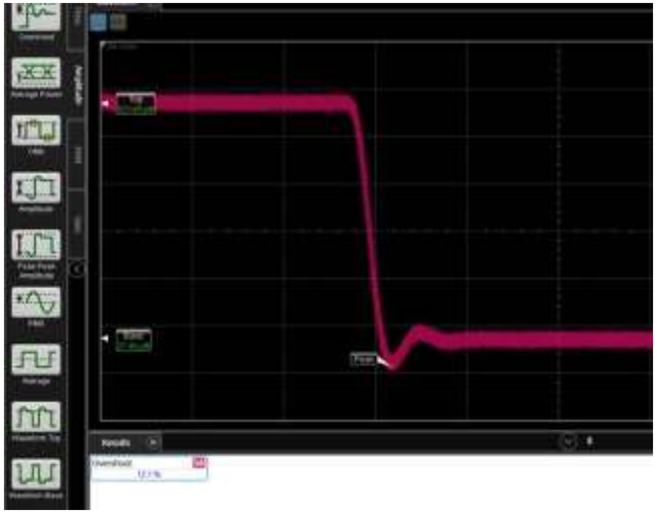
fast limit

- Successfully used with BER spec limits for decades
- Requires open TX eye, which NRZ signals have
- Dropped as spec for PAM4 signals because the TX eye can be closed, yet still recoverable by an adaptive equalizer
- Simple solution: use NRZ signal for TX time domain tests

Mask Limit Jonathan King 2/15/19 Proposal

- Square wave is perfect for time domain basics
- Easy to generate and lock to
- Long stretch of “0s” and “1s” either side of each transition
- Direct TX measurement with short patch cord to the scope generating no significant timing wander
- Direct read out of over-shoot and under-shoot in OMA units

email to Greg D Le Cheminan, Steve Sekel; Keysight, Pavel Zivny; Tektronix, Qing Wang; Facebook



Images courtesy of Greg D Le Cheminan (Keysight) 2/27/19

Dispersion Penalty Component of TDECQ

- Brian Welch pointed out that for 1291, 1311nm λs, typical Dispersion Penalty is much less than for 1271, 1331nm λs:

  http://www.ieee802.org/3/cu/public/Sept19/cole_3cu_01b_0919.pdf#page=5

  IF TDECQ = TECQ + D *AND* D ≈ 0 *THEN* TDECQ ≈ TECQ

- This requires testing with worst case dispersion SMF to reserve portion of TDECQ for D (Dispersion Penalty)

  http://www.ieee802.org/3/cu/public/Nov19/cole_3cu_02a_1119.pdf#page=6

- TDECQ - TECQ spec offers an easy solution because it requires TECQ

  TECQ spec limit enables quick testing because it explicitly reserves portion of TDECQ for D (Dispersion Penalty)

- Ex. 400GBASE-LR4-6 can be production tested over 10km typical SMF to confirm that there is margin to full SMF spec

Proposed Clause 151 Transmit Characteristics

Table 151–7—400GBASE-FR4 and 400GBASE-LR4-6 transmit characteristics

Description	400GBASE-FR4	400GBASE-LR4-6	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
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	3.4	3.5	dB
TECQ	3.0	2.5	dB
TDECQ – TECQ	2.0	2.5	dB
Average launch power of OFF transmitter, each lane (max)	–16	–16	dBm
Extinction ratio, each lane (min)	3.5	3.5	dB
Transmitter transition time[c] (max)	17		ps
Transmitter over/under-shoot[c] (max)	12		%

[c] Using NRZ test pattern; defined for transition, over-shoot in 120.5.11.2.3, 120.5.11.2.4, respectively

Proposed Clause 151 Transmit Characteristics

- Alternative for Transmitter over/under-shoot (max) spec:
  - Instead of square wave pattern defined in 120.5.11.2.4
  - Use SSPRQ pattern defined in 120.5.11.2.3
  - Footnote c changed to:

    [c] Using NRZ test pattern defined in 120.5.11.2.3

- Alternative to TECQ (max) normative spec:
  - Informative spec
  - Footnote e added:

    [e] TECQ is informative. A transmitter penalty above this value may exceed TDECQ (max) when used over fiber with greater Dispersion than fiber used in testing.

Outline

- 400G Clause 151 Transmit Characteristics
- **400G Clause 151 Receive Characteristics**
- 100G Clause 140 Transmit Characteristics
- 100G Clause 140 Receive Characteristics

Draft 1.1 Clause 151 Receive Characteristics

Table 151–8—400GBASE-FR4 and 400GBASE-LR4-6 receive characteristics

Description	400GBASE-FR4	400GBASE-LR4-6	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
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

[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 dB for 400GBASE-LR4-6.~~
[d] Measured with conformance test signal at TP3 (see 151.8.11) for the BER specified in 151.1.1.

$$RS = \max(-4.6, \sout{SECQ} - 6) \quad (\text{dBm}) \qquad (151\text{–}1)$$

$$RS = \max(-6.8, \sout{SECQ} - 8.2) \quad (\text{dBm}) \qquad (151\text{–}2)$$

802.3 Receiver Sensitivity (RS) Conventions

- Equation reference entries in spec tables are cumbersome
- Historical 802.3 RS definition is with a perfect, zero penalty reference TX, ex. .3ae, .3ba, making the spec conceptual
- Direct measurement is impractical, therefore an informative RS spec has been a pragmatic standards approach
- When end users require RS verification, any reference TX used in supplier testing has non-zero penalty
- Resulting RS is better than required, or ad hoc penalty is subtracted, which may introduce an interoperability problem
- Definition of reference TX with finite TECQ makes RS measurement practical and normative RS spec pragmatic
- Normative RS spec definition leads to consistent testing and reduced risk of interoperability problem

Support Changing RS to Normative Spec

- Thang Pham, Facebook
- Zuowei Shen, Google

Proposed Clause 151 Receive Characteristics

Table 151–8—400GBASE-FR4 and 400GBASE-LR4-6 receive characteristics

Description	400GBASE-FR4	400GBASE-LR4-6	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
Receiver sensitivity (OMA_{outer}), each lane[c] (max)	-4.6	-6.8	dBm
Stressed receiver sensitivity (OMA_{outer}), each lane[d] (max)	–2.6	–4.7	dBm

[c] Receiver sensitivity (OMA_{outer}), each lane (max) is defined for a reference transmitter with a value of TECQ up to 1.4 dB. For TECQ greater than 1.4 dB, see equations (151-1), (151-2), for 400GBASE-FR4, 400GBASE-LR4-6 reference transmitters, respectively.

[d] Measured with conformance test signal at TP3 (see 151.8.11) for the BER specified in 151.1.1.

$$RS = \max(-4.6,\ TECQ - 6) \quad (\text{dBm}) \tag{151–1}$$

$$RS = \max(-6.8,\ TECQ - 8.2) \quad (\text{dBm}) \tag{151–2}$$

Outline

- 400G Transmit Clause 151 Characteristics
- 400G Receive Clause 151 Characteristics
- ➢ 100G Clause 140 Transmit Characteristics
- 100G Clause 140 Receive Characteristics

Draft 1.1 Clause 140 Transmit Characteristics

Table 140–6—100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 transmit characteristics

Description	~~Value~~ 100GBASE-DR	100GBASE-FR1	100GBASE-LR1	Unit
Signaling rate (range)	53.125 ± 100 ppm			GBd
Modulation format	PAM4			—
Wavelength (range)	1304.5 to 1317.5			nm
Transmitter and dispersion eye closure for PAM4 (TDECQ) (max)	3.4	3.4	3.4	dB
~~TDECQ – 10log$_{10}$(C_{eq})[c] (max)~~	~~3.4~~	~~3.4~~	~~3.4~~	dB
Average launch power of OFF transmitter (max)	–15	–15	–15	dBm
Extinction ratio (min)	3.5	3.5	3.5	dB
Transmitter transition time (max)	17	17	17	ps

[c] C_{eq} is a coefficient defined in 121.8.5.3, which accounts for reference equalizer noise enhancement.

[g] 100BASE-DR to 100GBASE-DR1 name change will be considered in future Maintenance Project

Proposed Clause 140 Transmit Characteristics

Table 140–6—100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 transmit characteristics

Description	~~Value~~ 100GBASE-DR	100GBASE-FR1	100GBASE-LR1	Unit
Signaling rate (range)	53.125 ± 100 ppm			GBd
Modulation format	PAM4			—
Wavelength (range)	1304.5 to 1317.5			nm
Transmitter and dispersion eye closure for PAM4 (TDECQ) (max)	3.4	3.4	3.4	dB
TECQ	3.0	3.0	2.5	dB
TDECQ - TECQ	2.0	2.0	2.5	dB
Average launch power of OFF transmitter (max)	–15	–15	–15	dBm
Extinction ratio (min)	3.5	3.5	3.5	dB
Transmitter transition time[c] (max)	17			ps
Transmitter over/under-shoot[c] (max)	12			%

[c] Using NRZ waveforms; defined for transition & overshoot in 120.5.11.2.3 & 120.5.11.2.4, respectively

Proposed Clause 140 Transmit Characteristics

- Alternative for Transmitter over/under-shoot (max) spec:
  - Instead of square wave pattern defined in 120.5.11.2.4
  - Use SSPRQ pattern defined in 120.5.11.2.3
  - Footnote c changed to:

    [c] Using NRZ test pattern defined in 120.5.11.2.3

- Alternative to TECQ (max) normative spec:
  - Informative spec
  - Footnote e added:

    [e] TECQ is informative. A transmitter penalty above this value may exceed TDECQ (max) when used over fiber with greater Dispersion than fiber used in testing.

Outline

- 400G Clause 151 Transmit Characteristics
- 400G Clause 151 Receive Characteristics
- 100G Clause 140 Transmit Characteristics
- **100G Clause 140 Receive Characteristics**

II-VI

Draft 1.1 Clause 140 Receive Characteristics

Table 140–7—100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 receive characteristics

Description	~~Value~~ 100GBASE-DR	100GBASE-FR1	100GBASE-LR1	Unit
Signaling rate (range)	53.125 ± 100 ppm			GBd
Modulation format	PAM4			—
Wavelengths (range)	1304.5 to 1317.5			nm
Receiver sensitivity (OMA_{outer})[c] (max)	~~Equation (140–1)~~	~~Equation (140–2)~~	~~Equation (140–3)~~	dBm
Stressed receiver sensitivity (OMA_{outer})[d] (max)	–1.9	–2.5	–4.1	dBm

~~[c]Receiver sensitivity (OMA_{outer}) (max) is informative and is defined for a transmitter with a value of SECQ up to 3.4 dB.~~
[d]Measured with conformance test signal at TP3 (see 140.8) for the BER specified in 140.1.1.

$$RS = \max(-3.9, \sout{SECQ} - 5.3) \quad \text{(dBm)} \qquad (140\text{–}1)$$

$$RS = \max(-4.5, \sout{SECQ} - 5.9) \quad \text{(dBm)} \qquad (140\text{–}2)$$

$$RS = \max(-6.1, \sout{SECQ} - 7.5) \quad \text{(dBm)} \qquad (140\text{–}3)$$

II-VI

Proposed Clause 140 Receive Characteristics

Table 140–7—100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 receive characteristics

Description	~~Value~~ 100GBASE-DR	100GBASE-FR1	100GBASE-LR1	Unit
Signaling rate (range)	53.125 ± 100 ppm			GBd
Modulation format	PAM4			—
Wavelengths (range)	1304.5 to 1317.5			nm
Receiver sensitivity (OMA_{outer})[c] (max)	-3.9	-4.5	-6.1	dBm
Stressed receiver sensitivity (OMA_{outer})[d] (max)	–1.9	–2.5	–4.1	dBm

[c] Receiver sensitivity (OMA_{outer}), each lane (max) is defined for a reference transmitter with a value of TECQ up to 1.4 dB. For TECQ greater than 1.4 dB, see equations (140-1), (140-2), (140-3), for 100GBASE-DR, 100GBASE-FR1, 100GBASE-LR1 reference transmitters, respectively.

[d] Measured with conformance test signal at TP3 (see 140.8) for the BER specified in 140.1.1.

[g] 100BASE-DR to 100GBASE-DR1 name change will be considered in future Maintenance Project

$$RS = \max(-3.9,\ TECQ - 5.3) \quad \text{(dBm)} \qquad (140\text{–}1)$$

$$RS = \max(-4.5,\ TECQ - 5.9) \quad \text{(dBm)} \qquad (140\text{–}2)$$

$$RS = \max(-6.1,\ TECQ - 7.5) \quad \text{(dBm)} \qquad (140\text{–}3)$$

802.3cu D1.1 PMD Spec Comments

Thank You