

Baseline Proposal for CDAUI-8 Chip-to-Module (c2m)

For IEEE 802.3bs

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* Changes since *brown_3bs_01a_0115* shown in red

Purpose

- Present a baseline specification proposal for CDAUI-8 c2m electrical interface in support of the 400 GbE Task Force to fulfill its objective of:

Support optional 400 Gb/s Attachment Unit Interfaces for chip-to-chip and chip-to-module applications

Technology Choice Highlights 1

- Channel target/requirement based on the following equation:

$$IL \leq \{ 1.076(0.075 + 0.537\text{SQROOT}(f) + 0.566f) \quad 0.01 \leq f \leq 28.05\text{GHz} \} \text{ dB}$$

as the informative insertion loss adopted by 802.3bs at the Jan/2015 Interim meeting

- Channel equalization based on a transceiver having autonomous Rx CTLE
 - Tx FIR or Rx DFE not specified in host or module transceivers. (Allowed, but not mandated.)

Technology Choice Highlights 2

- Raw BER of CDAUI-8 c2m link to be $< 1e-6$; FEC brings link system BER to $< 1e-15$

Technology Choice Highlights 3

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- Leverage the CEI-56G-VSR-PAM4 draft specification^[1] using **one** data rate:
 - 26.5625GBd
- Gray-code specified, FEC assumed but not specified
- Pre-coding not assumed since CTLE-only
- Reuse CAUI-4 c2m Tx and Rx methodologies for specifying electrical characteristics and corresponding tests
 - Diff and CM RLs and compliance point definitions
 - HCB/MCB method for channel compliance, adapted for PAM-4 signaling
 - Remove “recommended CTLE” mechanism

CDAUI-8 Chip-to-Module Link

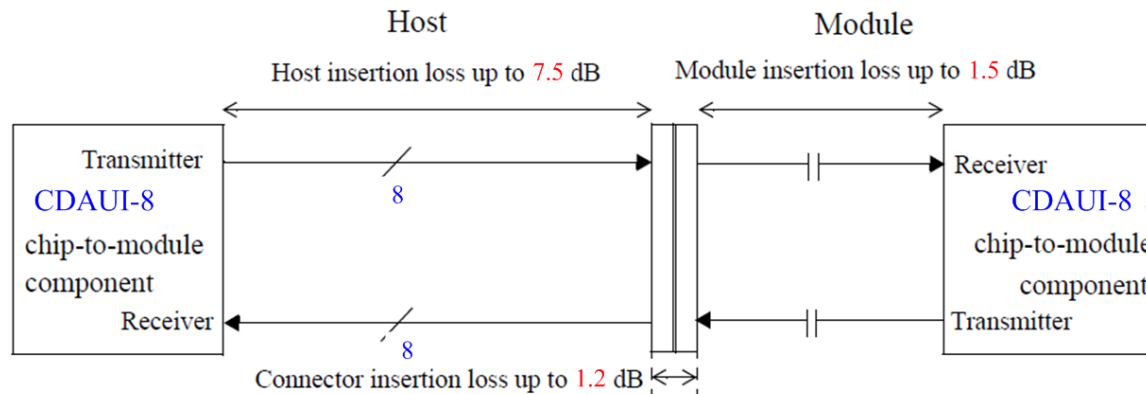
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	CAUI-4 (83E.3.1 TP1a)	VSR 56G (15.3.2, TP1a)	CDAUI-8 Chip-Module Potential
Modulation	NRZ	PAM-4 (Gray coded)	PAM-4 (Gray coded)
Nominal Signaling Rate (each lane)	25.78125 Gb/s +/- 100 ppm	19.6 ≤ fb ≤ 30 GBd	26.5625 GBd +/- 100 ppm 28 GBd (TBD)^a +/- 100 ppm
Unit Interval	38.787879 ps	33.33 ps - 51 ps	37.647059 ps 35.65 ps (TBD)^a
Loss Budget, max ^b	10 dB	10.8 dB ^c	10.3 dB
Uncorrected BER	< 1e-15	< 1e-6	< 1e-6
Corrected BER	n/a	n/a	< 1e-15

^a Two operating signaling rates, with choice of higher rate pending PMA FEC selection.

^b At 1/2 symbol rate, comprising host PCB trace, module PCB trace, AC-coupling capacitors and one connector.

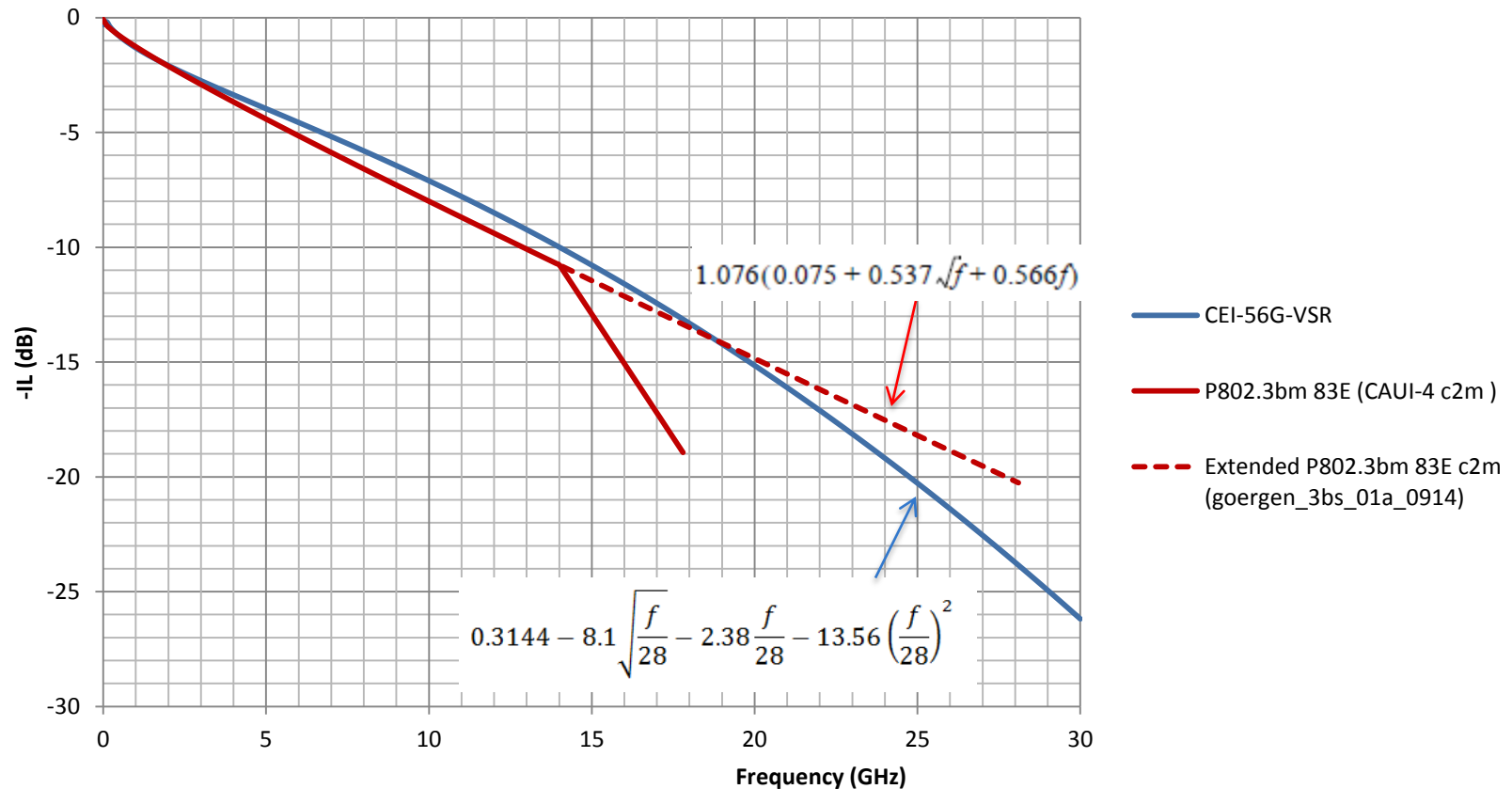
^c Informative.



Chip-to-module insertion loss budget at 13.28 GHz

CDAUI-8 c2m PAM4 Channel Insertion Loss

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- Target IL curve is “extended CAUI-4 c2m” as adopted at Jan/2015 Interim
 - Loss at Nyquist (13.28GHz) = 10.27 dB
 - Working assumption: all IL curves shown are suitable for PAM4 signaling at 28Gb/s
 - Consider potential to operate over legacy CAUI-4 c2m channels

CDAUI-8 Host Transmitter

	CAUI-4 (83E.3.1 TP1a)	VSR 56G (15.3.2, TP1a)	CDAUI-8 Chip-Module Potential
Differential peak-to-peak output voltage (max) with Tx enabled	900 mV	900 mV	900 mV
AC common-mode output voltage (max)	17.5 mVrms	17.5 mVrms	17.5 mVrms
Differential peak-to-peak output voltage (max) with Tx disabled	35 mV	-	35 mV
Differential termination mismatch (max)	10 %	10 %	10 %
Differential output return loss (min)	$\geq 9.5-0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75-7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz	≥ 11 , $0.05 \leq f \leq f_b/7$ GHz $\geq 6-9.2 \log_{10}(2f/f_b)$, $f_b/7 \leq f \leq f_b$ GHz	$\geq 9.5-0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75-7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz
Common-mode to differential output return loss (min)	$\geq 22-(20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15-(6/25.78)f$, $12.89 \leq f \leq 19$ GHz	$\geq 22-14f/f_b$, $0.05 \leq f \leq f_b/2$ GHz $\geq 18-6f/f_b$, $f_b/2 \leq f \leq f_b$ GHz	$\geq 22-(20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15-(6/25.78)f$, $12.89 \leq f \leq 19$ GHz
Common-mode output return loss (min)	-	2 dB	2 dB
DC common-mode output voltage (max)	2.8 V	2.8 V	2.8 V
DC common-mode output voltage (min)	-0.3 V	-0.3 V	-0.3 V
Eye Width (min)	0.46 UI at 1e-15	0.25 UI at 1e-6 applicable to all three PAM4 eyes	0.25 UI at 1e-6 applicable to all three PAM4 eyes
Output total jitter (max)	TJ: 0.54 UIpp @ 1e-15 Measured using CTLE	TJ: 0.75 UIpp @ 1e-6 Measured using CTLE	TJ: 0.75 UIpp @ 1e-6 Measured using CTLE
Eye Height (min)	95 mV at 1e-15	50 mV at 1e-6 applicable to all three PAM4 eyes	50 mV at 1e-6 applicable to all three PAM4 eyes
Transition time (min, 20/80%)	10 ps	-	-

CDAUI-8 Module Receiver

	CAUI-4 (83E.3.1 TP1)	VSR 56G (15.3.2, TP1)	CDAUI-8 Chip-Module Potential
Differential peak-to-peak input voltage tolerance (min)	900 mV	900 mV	900 mV
Single-ended voltage tolerance range (min)	-0.4 to 3.3 V	-	-
DC common-mode input voltage (max)	2.85 V	2.85 V	2.85 V
DC common-mode input voltage (min)	-0.35 V	-0.35 V	-0.35 V
Differential termination mismatch (max)	10 %	10 %	10 %
Differential input return loss (min)	$\geq 9.5-0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75-7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz	≥ 11 , $0.05 \leq f \leq fb/7$ GHz $\geq 6-9.2 \log_{10}(2f/fb)$, $fb/7 \leq f \leq fb$ GHz	$\geq 9.5-0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75-7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz
Differential to common mode input return loss (min)	$\geq 22-(20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15-(6/25.78)f$, $12.89 \leq f \leq 19$ GHz	$\geq 22-14f/fb$, $0.05 \leq f \leq fb/2$ GHz $\geq 18-6f/fb$, $fb/2 \leq f \leq fb$ GHz	$\geq 22-(20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15-(6/25.78)f$, $12.89 \leq f \leq 19$ GHz
Module stressed input test	83E.3.4.1	15.3.10.2.1	Same as VSR

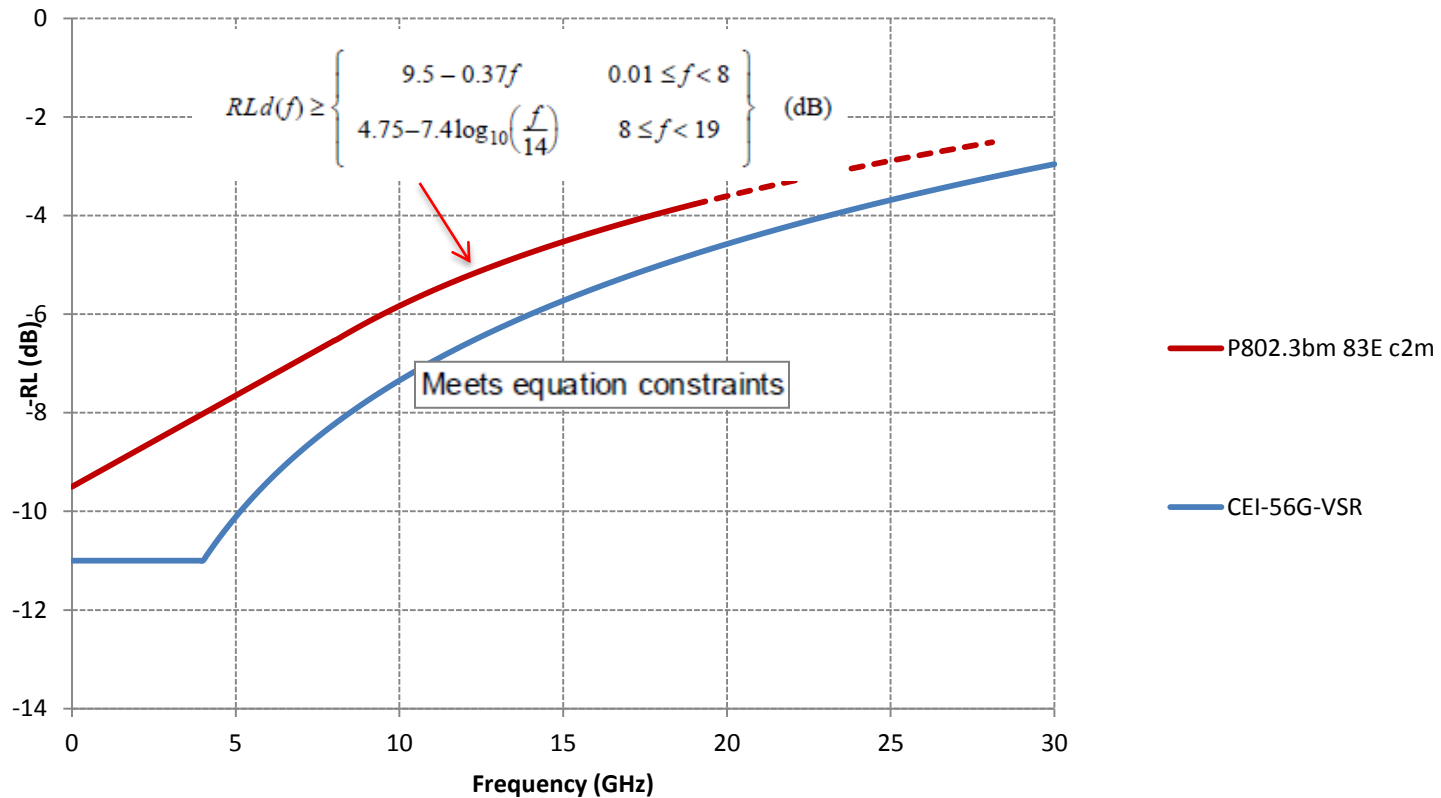
CDAUI-8 Module Transmitter

	CAUI-4 (83E.3.2 TP4)	VSR 56G (15.3.3, TP4)	CDAUI-8 Chip-Module Potential
Differential peak-to-peak output voltage (max) with Tx enabled	900 mV	900 mV	900 mV
AC common-mode output voltage (max)	17.5 mVrms	17.5 mVrms	17.5 mVrms
Differential termination mismatch (max)	10 %	10 %	10 %
Differential output return loss (min)	$\geq 9.5 - 0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75 - 7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz	≥ 11 , $0.05 \leq f \leq f_b/7$ GHz $\geq 6 - 9.2 \log_{10}(2f/f_b)$, $f_b/7 \leq f \leq f_b$ GHz	$\geq 9.5 - 0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75 - 7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz
Common-mode to differential mode output return loss (min)	$\geq 22 - (20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15 - (6/25.78)f$, $12.89 \leq f \leq 19$ GHz	$\geq 22 - 14f/f_b$, $0.05 \leq f \leq f_b/2$ GHz $\geq 18 - 6f/f_b$, $f_b/2 \leq f \leq f_b$ GHz	$\geq 22 - (20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15 - (6/25.78)f$, $12.89 \leq f \leq 19$ GHz
Common-mode output return loss (min)	-	2 dB	2 dB
DC common-mode output voltage (max)	2.85 V	2.85 V	2.85 V
DC common-mode output voltage (min)	-0.35 V	-0.35 V	-0.35 V
Vertical Eye Closure (max)	5.5 dB	5.8 dB	5.8 dB
Eye Width (min)	0.57 UI at 1e-15	0.4 UI at 1e-6 applicable to all three PAM4 eyes	0.4 UI at 1e-6 applicable to all three PAM4 eyes
Output total jitter (max)	TJ: 0.43 UIpp @ 1e-15 Measured using CTLE	TJ: 0.6 UIpp @ 1e-6 Measured using CTLE	TJ: 0.6 UIpp @ 1e-6 Measured using CTLE
Eye Height (min)	228 mV at 1e-15	120 mV at 1e-6 applicable to all three PAM4 eyes	120 mV at 1e-6 applicable to all three PAM4 eyes
Transition time (min, 20/80%)	12 ps	-	-

CDAUI-8 Host Receiver

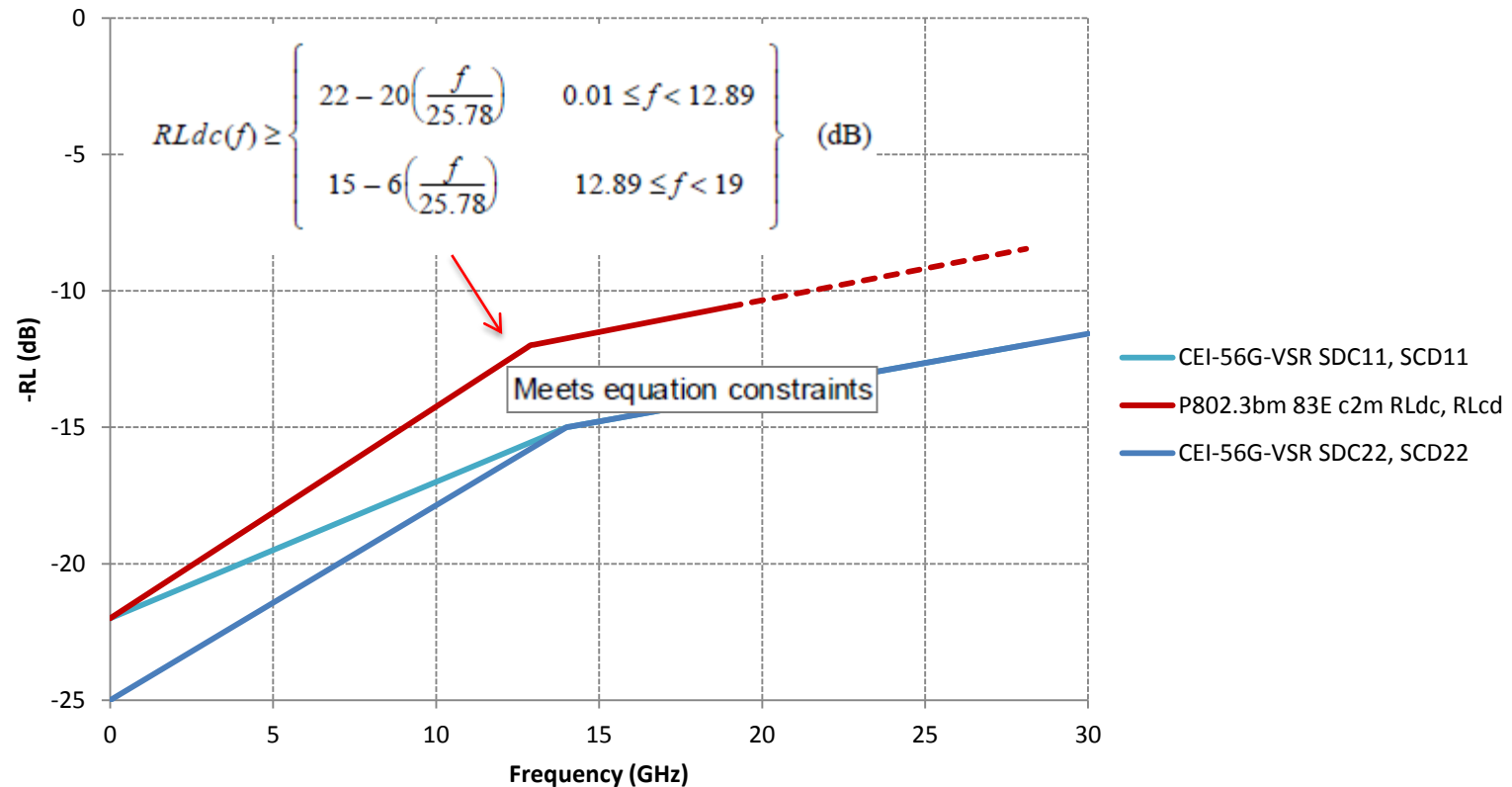
	CAUI-4 (83E.3.2 TP4a)	VSR 56G (15.3.2, TP4a)	CDAUI-8 Chip-Module Potential
Differential peak-to-peak input voltage tolerance (min)	900 mV	900 mV	900 mV
DC common-mode input voltage (max)	2.8 V	2.8 V	2.8 V
DC common-mode input voltage (min)	-0.3 V	-0.3 V	-0.3 V
Differential termination mismatch (max)	10 %	10 %	10 %
Differential input return loss (min)	$\geq 9.5 - 0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75 - 7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz	≥ 11 , $0.05 \leq f \leq fb/7$ GHz $\geq 6 - 9.2 \log_{10}(2f/fb)$, $fb/7 \leq f \leq fb$ GHz	$\geq 9.5 - 0.37f$, $0.01 \leq f \leq 8$ GHz $\geq 4.75 - 7.4 \log_{10}(f/14)$, $8 \leq f \leq 19$ GHz
Differential to common-mode input return loss (min)	$\geq 22 - (20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15 - (6/25.78)f$, $12.89 \leq f \leq 19$ GHz	$\geq 22 - 14f/fb$, $0.05 \leq f \leq fb/2$ GHz $\geq 18 - 6f/fb$, $fb/2 \leq f \leq fb$ GHz	$\geq 22 - (20/25.78)f$, $0.01 \leq f \leq 12.89$ GHz $\geq 15 - (6/25.78)f$, $12.89 \leq f \leq 19$ GHz
Host stressed input test	83E.3.3.2	15.3.10.2.1	Same as VSR
Jitter tolerance	-	-	-

CDAUI-8 c2m Tx & Rx Differential Return Loss Spec



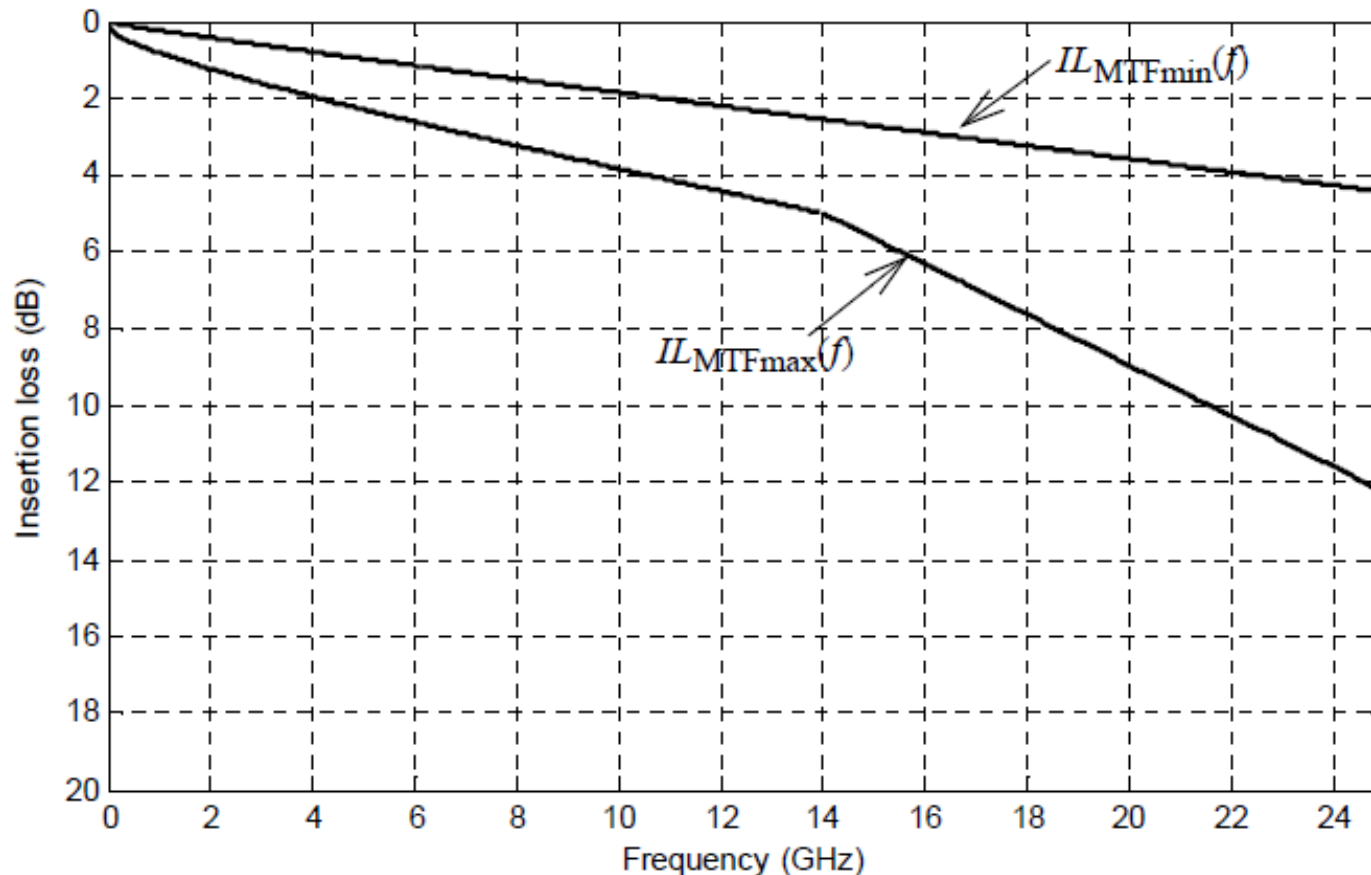
- Same as Annex 83E (CAUI-4 c2m)

CDAUI-8 c2m Tx Common-Mode to Differential & Rx Differential to Common-Mode Return Loss Specs



- Same as Annex 83E (CAUI-4 c2m)

Compliance Boards

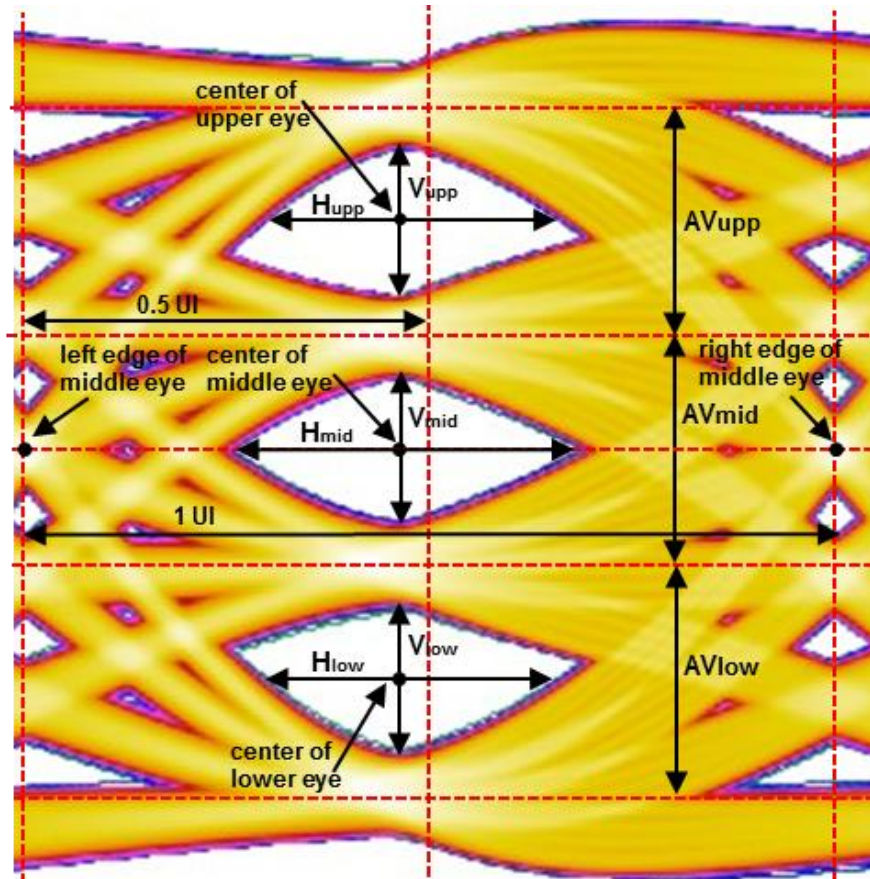


- Same as CR4 (Cl. 92)
 - No new compliance boards required

CDAUI-8 c2m Test Patterns

- CDAUI-8 PMA can reuse test pattern defined in clause 94.2.9:
 - Quaternary PRBS13 test pattern (if the termination block (i.e., 94.2.2.4) is removed, this will need to be changed accordingly)
 - Other KP4 test patterns (JP03A, JP03B) not required

CDAUI-8 c2m PAM4 Jitter and Eye Height Parameters



See Appendix for measurement procedure

Module Stressed Receiver Test

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- Same test configuration as Annex 83E
 - Modified for PAM4 testing consistent with 56G-VSR-PAM4
 - **CRU and SIJT corner frequencies pending further study**

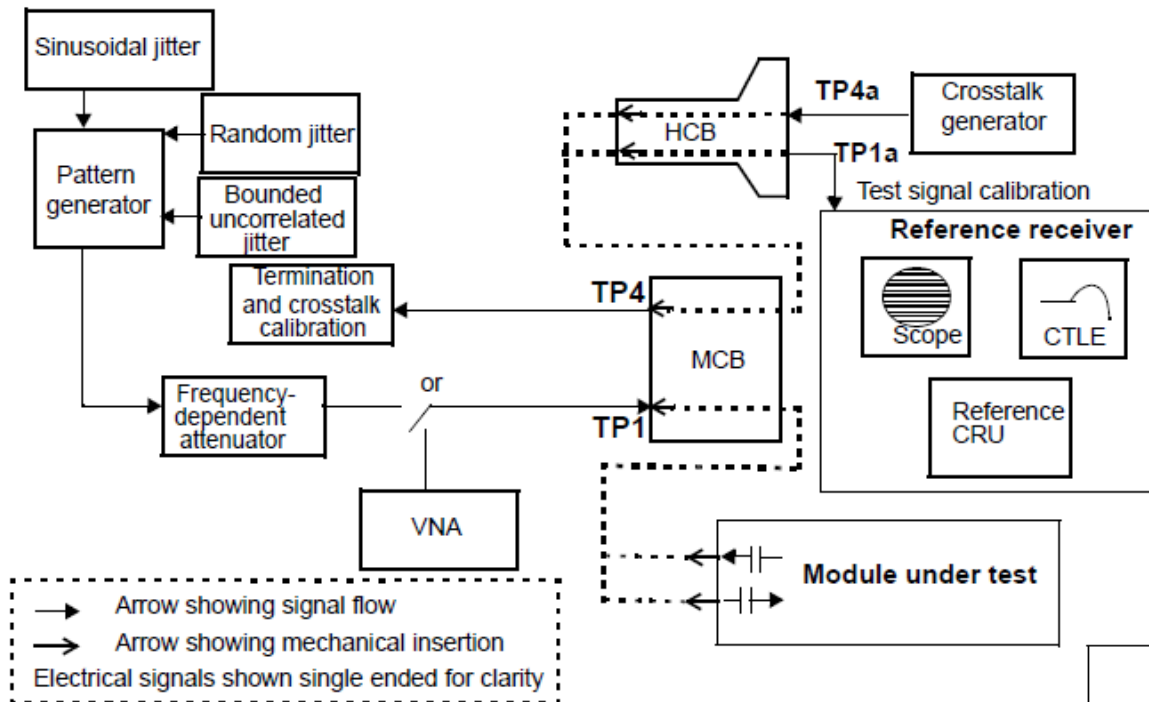


Figure 83E-15—Example module stressed input test

Table 15-7. Sinusoidal jitter frequency for TP4 and TP1 testing

Frequency Range (Hz)	Sinusoidal jitter, Peak to peak (UI)
$f < f_b/849600$	Not Specified
$f_b/849600 < f \leq f_b/8496$	$5 \cdot f_b / (849600 \cdot f)$
$f_b/8496 < f \leq 10 \times \text{LB}$	0.05
NOTES: LB = Receiver Loop Bandwidth	

Host Stressed Receiver Test

*

- Same test configuration as Annex 83E
 - Modified for PAM4 testing consistent with 56G-VSR-PAM4
 - CRU and SIJT corner frequencies pending further study

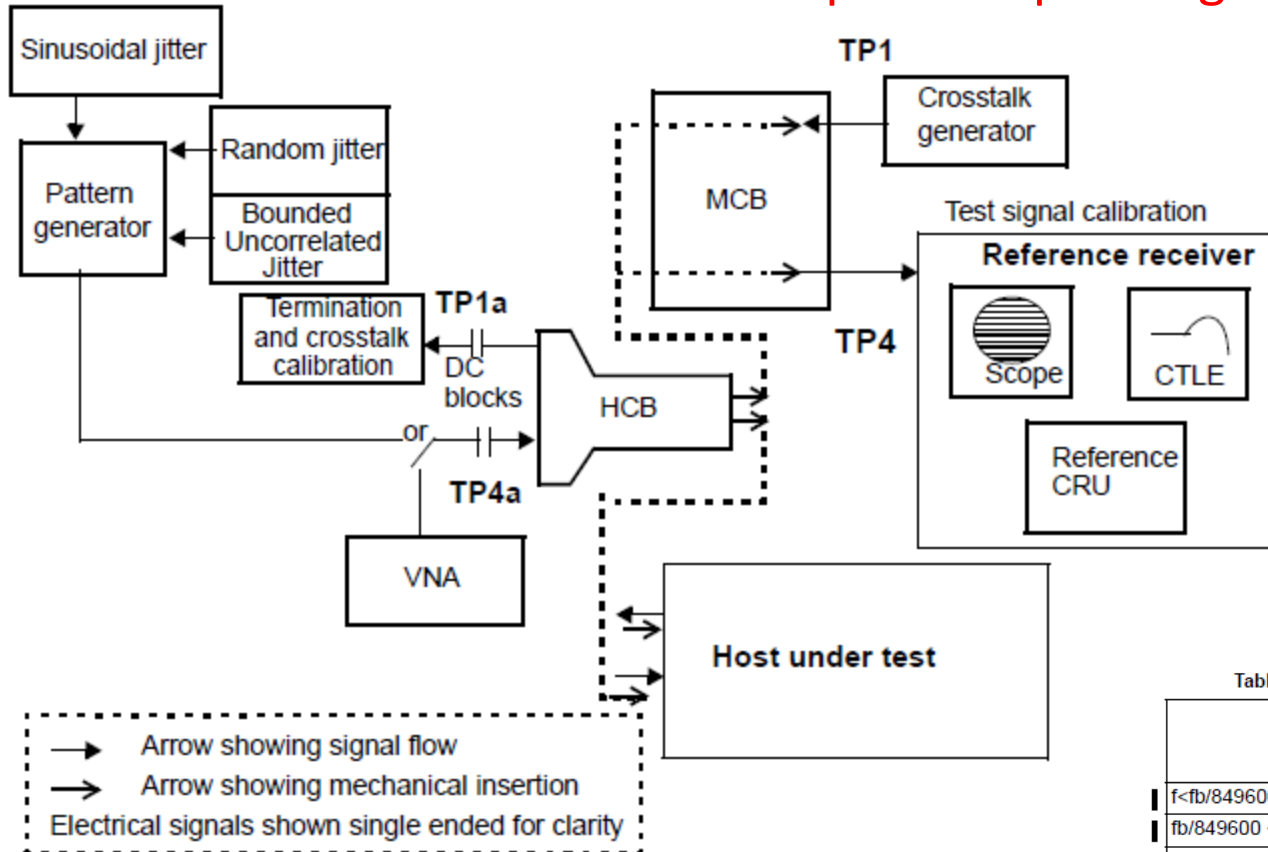


Figure 83E-14—Example host stressed input test

Table 15-7. Sinusoidal jitter frequency for TP4 and TP1 testing

Frequency Range (Hz)	Sinusoidal jitter, Peak to peak (UI)
$f < f_b/849600$	Not Specified
$f_b/849600 < f \leq f_b/8496$	$5 \cdot f_b / (849600 \cdot f)$
$f_b/8496 < f \leq 10 \cdot x_{LB}$	0.05
NOTES: LB = Receiver Loop Bandwidth	

Host / Module Output Waveform Test *

- Same test configuration as Annex 83E
 - Modified for PAM4 testing consistent with 56G-VSR-PAM4
 - CRU corner frequency pending further study

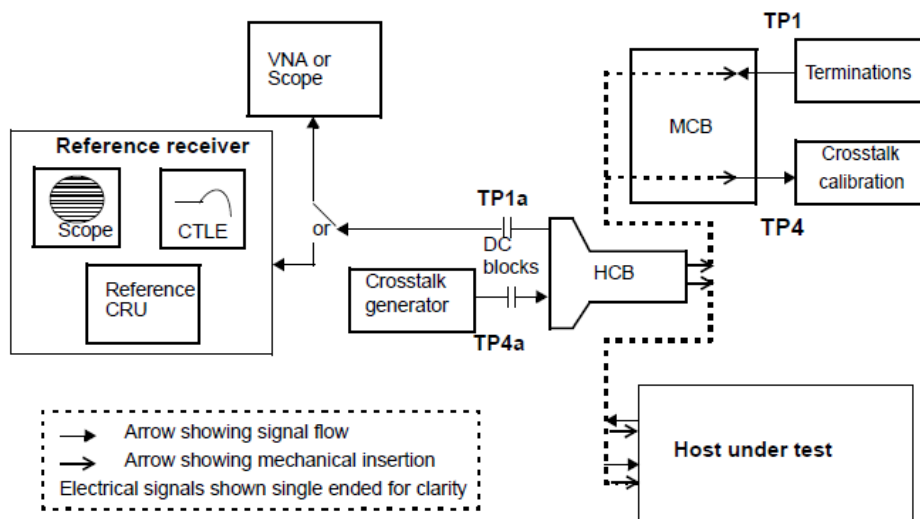


Figure 83E-9—Example host output test configuration

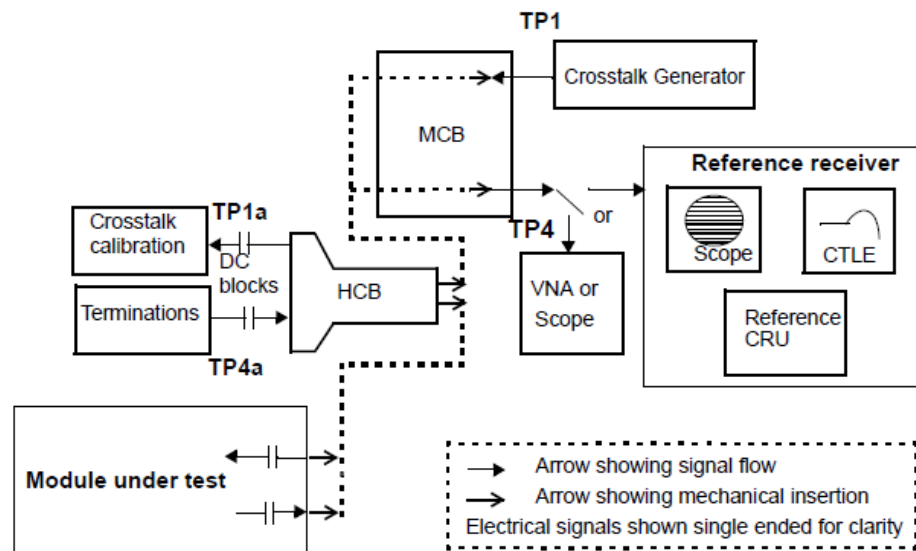


Figure 83E-11—Example module output test configuration

Summary

- Baseline proposal using PAM4 signaling for a CDAUI-8 c2m electrical interface specification:
 - Supports CAUI-4 c2m channel
 - Reuses test infrastructures and setup in Annex 83E
 - Is consistent with CEI-56G-VSR draft baseline specification
 - Straightforward to extend/modify Annex 83E specification for PAM4 signaling

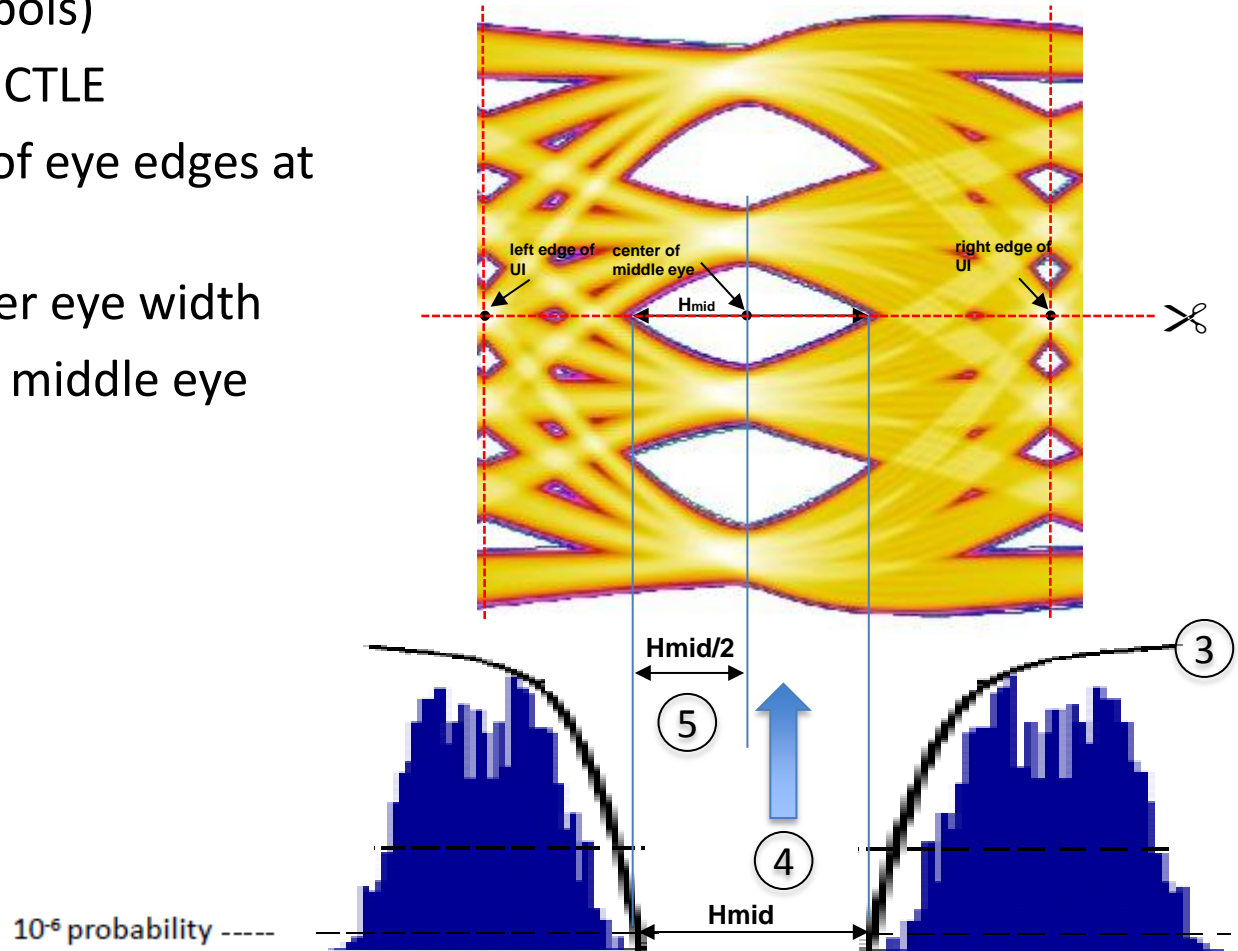
References

[1] oif.2014.230.01, www.oiforum.com (This document was provided as an attachment to the October 28, 2014 liaison from OIF to IEEE 802.3. The liaison and its attachments can be found in the IEEE P802.3bs 400 Gb/s Ethernet Task Force private area)

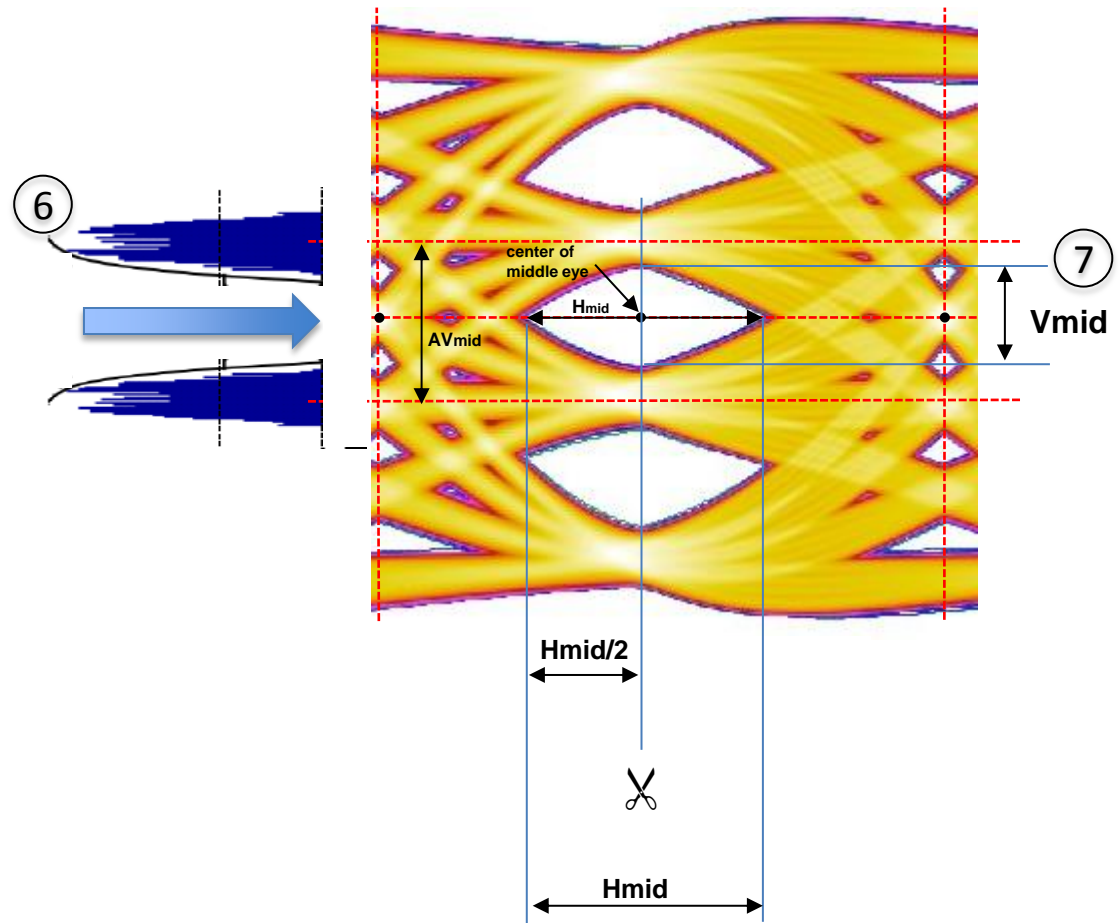
Appendix

Extracting PAM4 Eye Width and Height

- Reuse Annex 83E.4.2 method to:
 1. Capture QPRBS13 pattern (> 4 million symbols)
 2. Apply reference CTLE
 3. Construct CDFs of eye edges at zero crossing
 4. $H_{mid} = 1e-6$ inner eye width
 5. Locate center of middle eye at $H_{mid}/2$

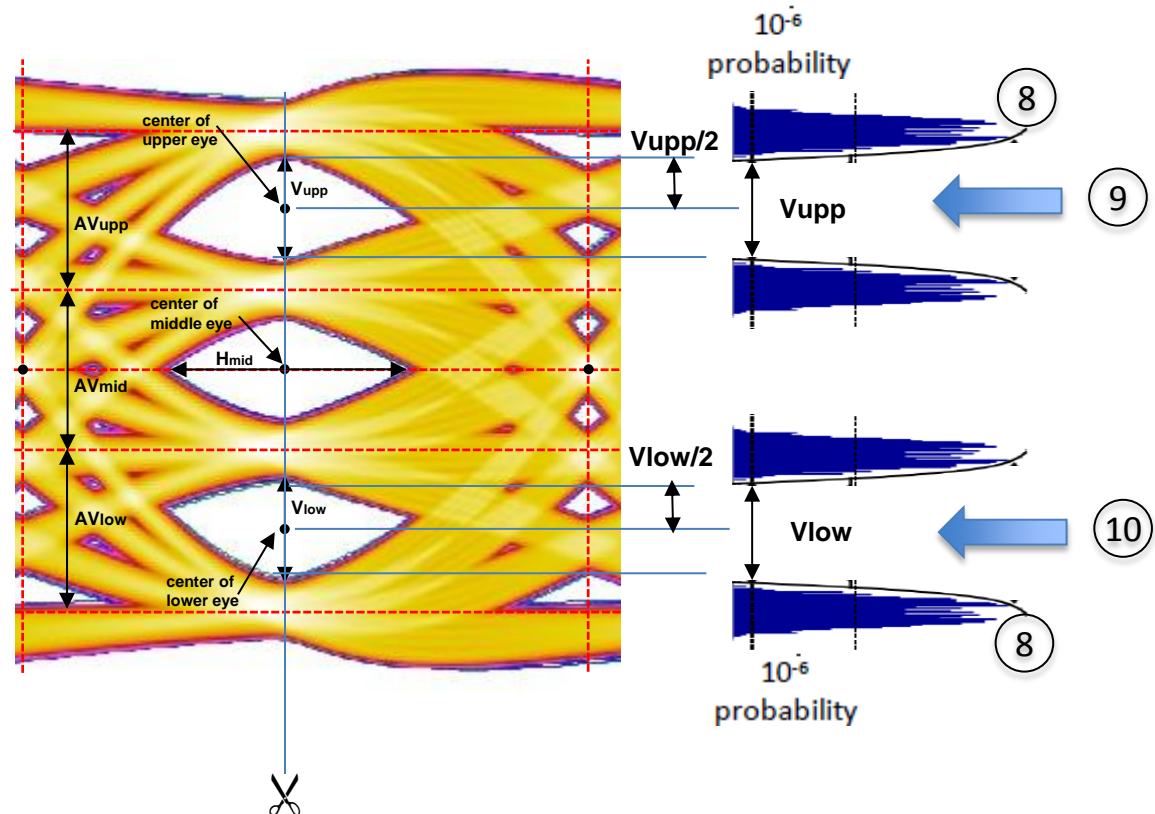


- Reuse Annex 83E.4.2 method to:
 6. Construct CDFs of signal voltages of middle eye sampled at $H_{mid}/2$
 7. $V_{mid} = 1e-6$ inner eye height

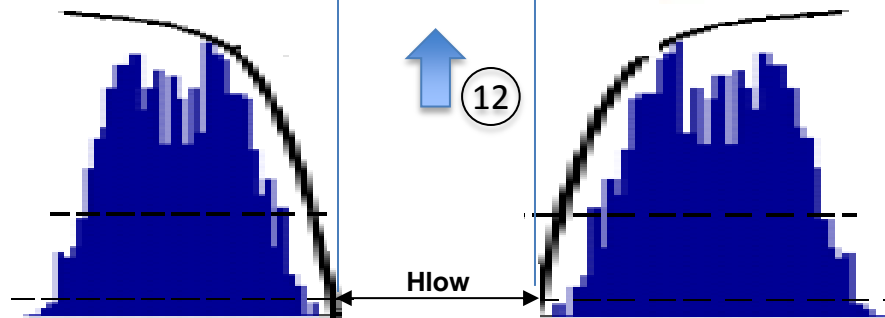
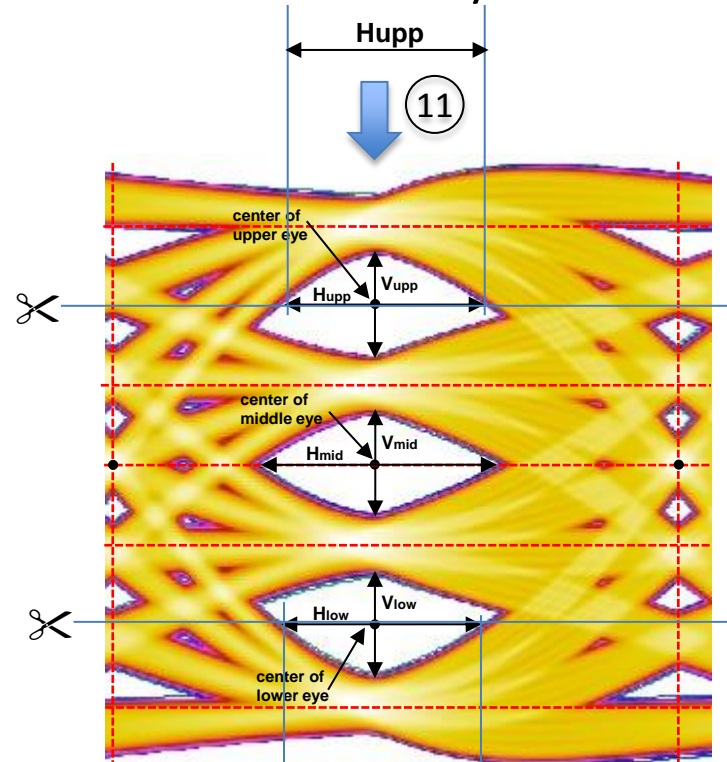


- Extract upper and lower eye heights

8. Construct CDFs of signal voltages of upper and lower eyes at $H_{mid}/2$
9. $V_{up} = 1e-6$ inner height of upper eye at $H_{mid}/2$
10. $V_{low} = 1e-6$ inner height of lower eye at $H_{mid}/2$

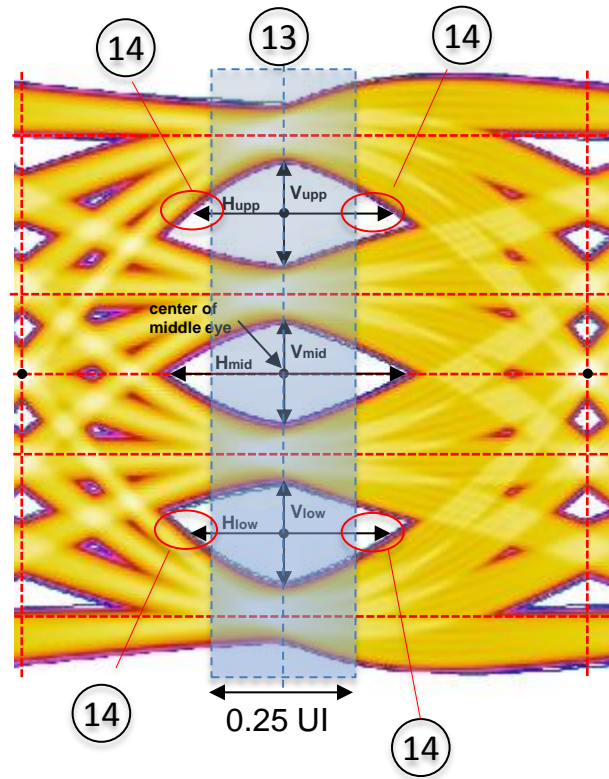


- Extract upper and lower eye widths
 11. H_{upp} = $1e-6$ inner width of upper eye sliced at $V_{upp}/2$
 12. H_{low} = $1e-6$ inner width of lower eye sliced at $V_{low}/2$



10⁻⁶ probability -----

- Check upper and lower eye alignment to middle eye
 13. Apply 0.25UI-wide mask centered on middle eye
 14. 1e-6 horizontal openings of upper and lower eyes must extend outside this mask, measured at $\frac{1}{2}$ inner eye height



- Module Output VEC Measurement

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15. Calculate VEC as $20\log[\min(AV_{upp}/V_{upp}, AV_{mid}/V_{mid}, AV_{low}/V_{low})]$

