

Completing C2M Baseline Proposal TBDs

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Introduction

- In March, [sun 3ck 04b 0319](#) was adopted as a (partial) C2M baseline
- C2M ball-ball loss $\leq 16\text{dB}$ at 26.5625 GHz, although insertion loss allocation values are TBD
- Reuse 200GAUI-4 and 400GAUI-8 methodologies, leverage Annex 120E and OIF CEI-112G-VSR-PAM4 spec
 - Host output is specified at TP1a
 - Module output TP4 has near-end and far-end specs
 - Reference receiver and eye dimensions are TBD
- This presentation makes proposals for most of the TBDs, except ERL and anti-aliasing filter BT4 vs Butterworth BW4.

C2M Loss Budget Breakdown

- C2M loss from ASIC BGA to TP1a is ≤ 16 dB
- C2M loss from module CDR BGA to TP5 is ≤ 16 dB.

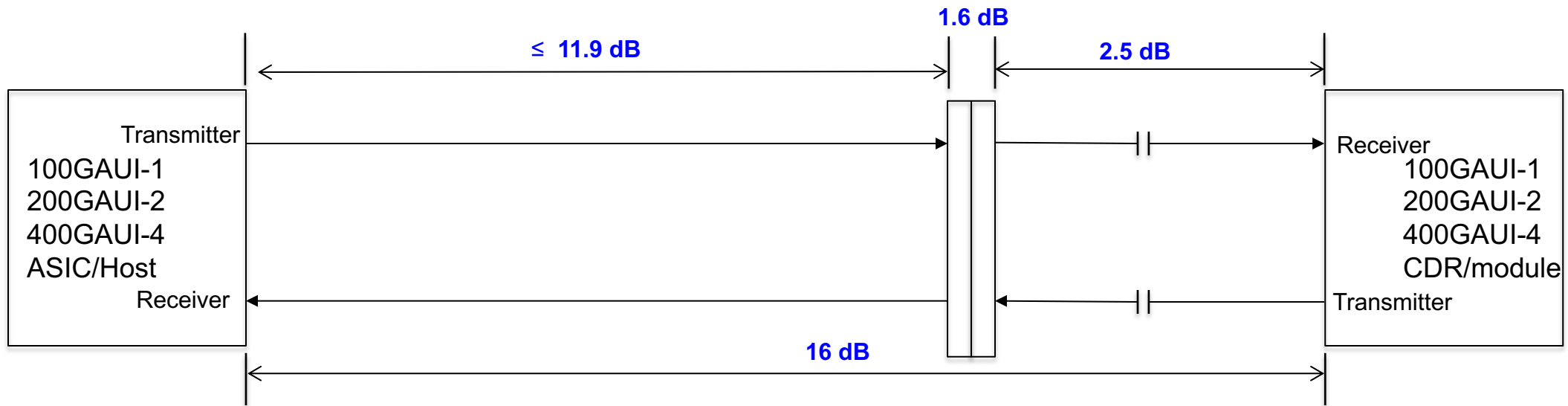


Figure 1: 100GAUI-1, 200GAUI-2, and 400GAUI-4 C2M TP0-TP1a insertion loss budget at 26.56 GHz

MCB/HCB Characteristics

- MCB characteristics is identical to “Cable Assembly Test Fixture” defined in CL162B.1.2.1
- HCB characteristics is identical to “TP2 or TP3 Test Fixture” defined in CL162B.1.1
- Mated MCB/HCB specifications are defined in 162B.1.3
- Given that C2M measurement are on high speed/low loss channels unlike high loss CR channels the frequency range may need to increase from 40 GHz to 50 GHz or 53.13 GHz for all MCB/HCB test boards
 - Frequency range $0.01 \leq f \leq \text{TBD}$.

TP1a and TP4a Test Points

- Measuring host input and output with HCB.

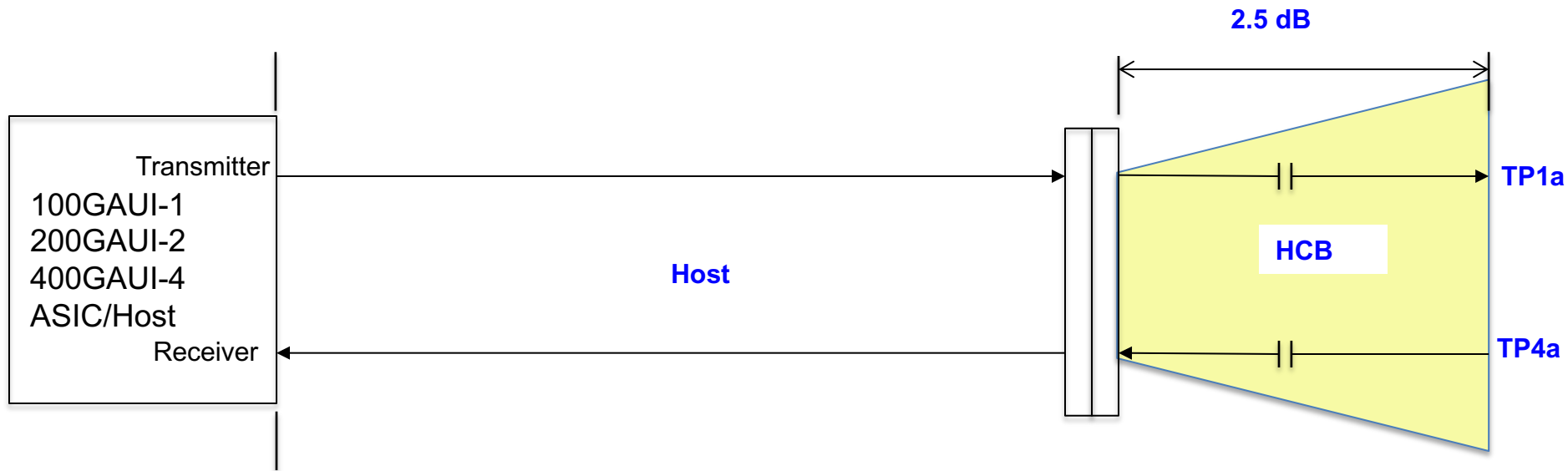


Figure 2: Host 100GAUI-1, 200GAUI-2, and 400GAUI-4 C2M compliance points

TP1, TP4 and TP5 Test Points

- Measuring module input and outputs with MCB
- All TP5 measurements are (TBD) measured with (C0, C1)= (29, 19 fF) per [benartsi_3ck_01a_0719](#)
- TP4/TP5 measurements are with addition of nV^2/GHz (TBD) noise to account for BGA crosstalk
 - Equivalent to 0.577 mV RMS in a noise bandwidth of $35.125 \times 0.75 = 39.84 \text{ GHz}$
- Transmission line parameters
 - $\gamma_0=0$, $a_1 = 3.8206 \times 10^{-4}$, $a_2 = 9.5909 \times 10^{-5}$, $\tau = 5.790 \times 10^{-3}$
 - TP4 is MCB output measurement
 - TP5-L1 measured with 68 mm transmission line
 - TP5-L1 is used to set module TX FIR
 - TP5-L2 measured with 244 mm max channel loss
 - TP5-L2 must pass with TP5-L1 TX setting.

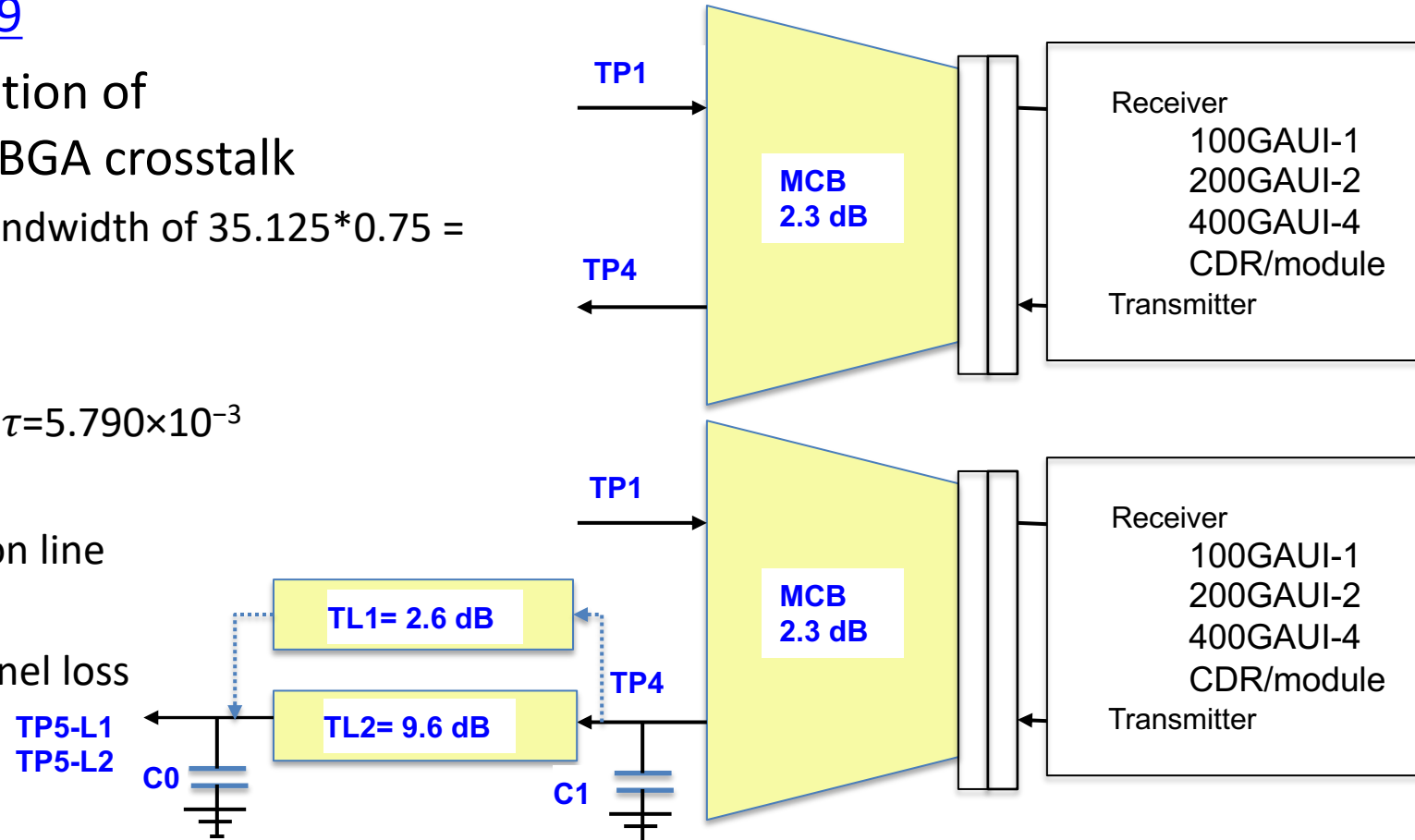


Figure 3: Module 100GAUI-1, 200GAUI-2, and 400GAUI-4 C2M compliance points

C2M Reference Equalizer

- Proposed C2M reference equalizer for 100GAUI-1, 200GAUI-2, and 400GAUI-4 is a CTLE followed by 5 taps T spaced FFE (4 post taps)
 - C2M reference equalizer is used to measure host output signal at TP1a
 - C2M reference equalizer is used to measure module output signals at TP4/TP5 test points.

C2M CTLE and Scope Post Filter

□ Proposed C2M CTLE coefficients are based on CL120E CTLE with enhanced performance for non-DFE receiver but based on CL 93 parametric definition

- 4th order Bessel-Thomson is consistent with Annex 120E and specs for oscilloscope measurements generally, with good phase response, gentle roll-off. Real receivers could be steeper.
- 4th order Butterworth offers less attenuation in the high frequency pass band for the same out-of-band attenuation (steeper roll-off). Real receivers unlikely to be as good and precise. Better anti-aliasing not relevant for an eye measurement. Effect of filter's phase response not well known in this context.
- As 4th order Butterworth seems "too good", this decision should be postponed for further study

– Low frequency gain sum of $g_{DC} + g_{DC2}$

– Low frequency zero/pole adjustable

– g_{DC} -0.5 to -14 dB in 0.5 dB steps (see table for allowed combinations)

– g_{DC2} 0 to -3 dB in 0.5 dB steps (see table for allowed combinations)

– $F_z = F_{\text{baud}}/2.862$

– $F_{p1} = F_{\text{baud}}/1.8839$

– $F_{p2} = F_{\text{baud}}$

– $F_{LF} = F_{\text{baud}}/40$

– $f_r = \text{TBD} * F_{\text{baud}}$
(depends on filter type)

Bessel-Thomson 4th Order

$$H(y) = \frac{105}{105 + 105y + 45y^2 + 10y^3 + y^4}$$

where:

$$y = 2.114p; \quad p = \frac{j\omega}{\omega_r}; \quad \omega_r = 2\pi f_r;$$

Common CTLE Filter for KR/CR/C2M

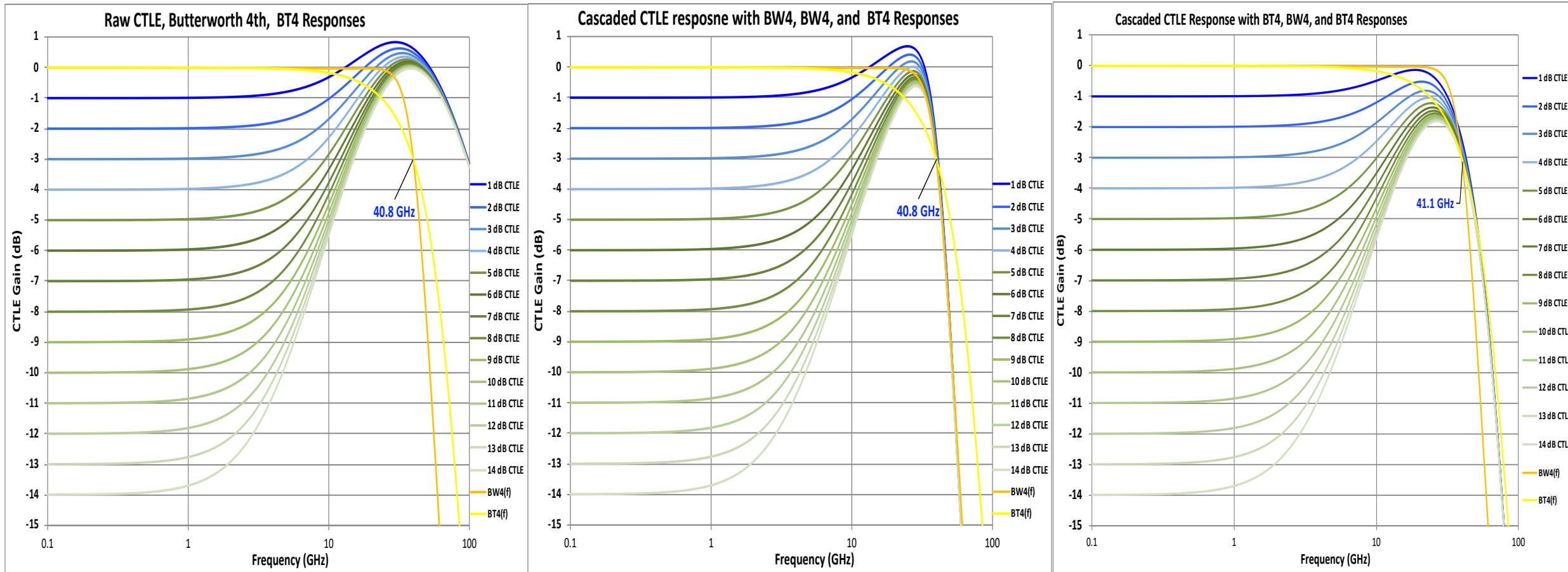
$$H_{ctf}(f) = \frac{\left(10^{\frac{g_{DC}}{20}} + j\frac{f}{f_z}\right)\left(10^{\frac{g_{DC2}}{20}} + j\frac{f}{f_{LF}}\right)}{\left(1 + j\frac{f}{f_{p1}}\right)\left(1 + j\frac{f}{f_{p2}}\right)\left(1 + j\frac{f}{f_{LF}}\right)}$$

Butterworth 4th Order

$$H_r(f) = \frac{1}{1 - 3.414214(f/f_r)^2 + (f/f_r)^4 + j2.613126(f/f_r - (f/f_r)^3)}$$

Proposed C2M CTLE Response with Cascaded Butterworth and BT4 LP Filters

- Butterworth BW4 offers steeper roll-off but different phase response to BT4. May be steeper and better than real receivers = "too good"
- Filter type, bandwidth, F_{p2} , CTLE max peaking and eye height should be investigated together.



gDC and gDC2 Reduce Set

- Table below reduces gDC and gDC2 search combination from 168 to 42.

OIF CEI-112G-VSR CTLE Gain Coefficients

Table 23-8. CTLE Low-frequency Gain Range

g _{DC2}	g _{DC}		Step size	Location
	min.	max.		
0	2	3	0.5	Near End
0	3	12	0.5	Far End and TP1a
0.5	3	12	0.5	Far End and TP1a
1	3	12	0.5	Far End and TP1a
1.5	5	12	0.5	Far End and TP1a
2	6	12	0.5	Far End and TP1a
2.5	8	12	0.5	Far End and TP1a
3	9	11	0.5	Far End and TP1a
3.5	10	11	0.5	Far End and TP1a

Proposed 802.ck C2M CTLE Gain Coefficients

g _{DC2} (dB)	g _{DC} (dB)		g _{DC} Step size in dB	Location
	min.	max.		
0.5, 1	2	3	0.5	TP4
1, 1.5	3	5	0.5	TP5-L1 and TP1a
1.5, 2.0	5.5	7.5	0.5	TP5-L2 and TP1a
2.0, 2.5	8.0	10.0	0.5	TP5-L2 and TP1a
2.5, 3.0	10.5	13	0.5	TP5-L2 and TP1a

TP1a, TP4, and TP5 Reference Equalizer

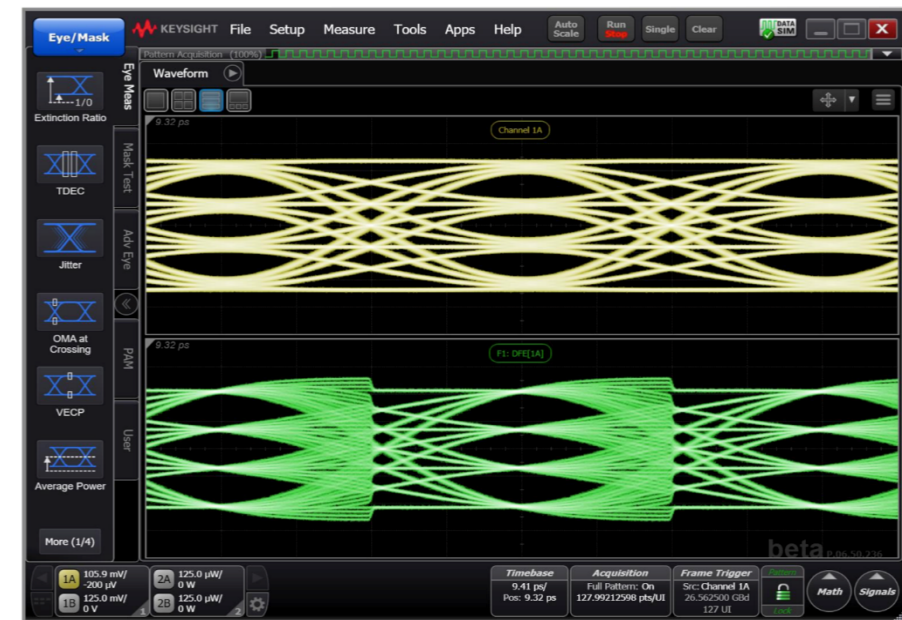
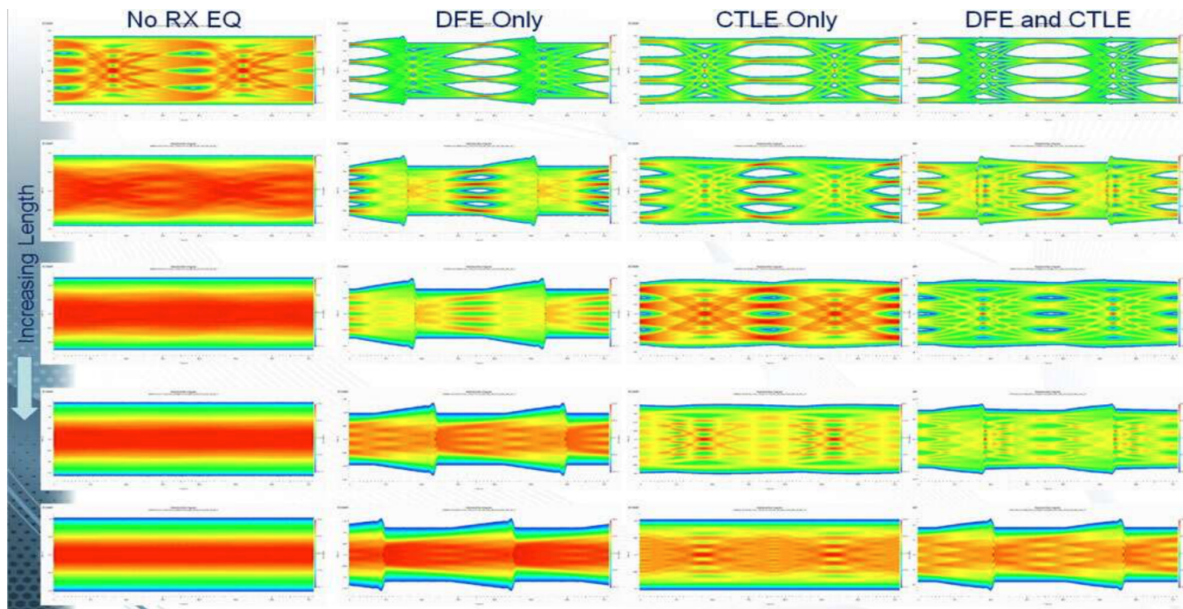
- Leverage 5T FFE TDECQ equalizer per clause 121.8.5.4 definition (see P802.3cn) with addition of CTLE to observe signals at TP1a, TP4, and TP5
 - Sum of the absolute value of taps = 1.0
 - Tap 1 has the largest magnitude tap coefficient, which is constrained to be between 1 TBC and 1.5 TBC
 - Meaning that the FFE is not allowed to work in reverse, nor provide more than ~ 6 dB peaking in addition to the CTLE
 - FFE step size 0.01
- Both Keysight, Tek, Multilane have implemented efficient, fast, and reliable TDECQ algorithm which incorporates a more complex 5T FFE where FFE may have up to 2 pre-cursors to compensate more challenging optical signals
 - Keysight and Tek scopes have been delivering production TDECQ with 5T FFE now for more than 3 years
 - Keysight and Tek likely are using MMSE for coarse FFE optimization then do exhaustive local search for best TDECQ.

Example tactical optimization implementation

- Based on 120E.4.2 Eye width and eye height measurement method and/or 121.8.5.3 TDECQ measurement method
- Objective is to find if there is a single equaliser setting that results in passing Eye Height, VEC, Eye Width, and ESMW
- Measure the signal with a 4 MHz CRU (hard or soft), without averaging
- Pick a trial CTLE gDC and gDC2 pair
 - Process measured data to provide eye, and optionally a fitted pulse response
 - Add Gaussian noise that isn't already in the scope to make up to spec amount
 - Find the time centre of the middle eye width (TCmid) OR optimise for best phase
 - Using vertical histograms extending to ± 0.025 UI OR ± 0.07 UI,
 - Optionally use fitted pulse response to determine approximate tap weights, then
 - Optimize tap weights for passing Eye Height and VEC. Also Eye Width and ESMW if used (goes with the ± 0.025 UI histograms)
 - For a host or module output measurement, can finish as soon as a pass is obtained
 - It may be quicker in most cases to optimize for eye height or VEC first and see if the others pass
 - For stressed input signal calibration, continue until the solution converges. Optimization can be done "blind" or otherwise with faster or slower convergence but the same result after convergence – no need for the standard to write this software
- If the signal hasn't passed yet, or for stressed input signal calibration, try another CTLE gDC and gDC2 pair
 - If that's worse, go the other way
- As eye width and eye height are optimum at different settings, a passing gDC and gDC2 pair might not be the best for either height or width.

CTLE/FFE Preserve Analog Signal Shape

- As DFE tap weights increase the DFE out waveform become choppy
 - DFE output may require post filtering to smooth out choppiness at expense of introducing ISI
 - DFE not compliant to [LTI \(Linear Time Invariant\)](#), DFE produces a representative EH but EW is only qualitative
 - Intermediate test points TP1a, TP4, and TP5 EH/EW measured with a DFE do not correlate linearly to slicer EH/EW – and debatable if the DFE EW is a valid compliance tool.



M Rowe, EDN, Dec. 1, 2015

http://www.ieee802.org/3/ck/public/adhoc/oct30_19/calvin_3ck_adhoc_103019.pdf

With DFE Violating LTI Principle It Require Transient Simulations!

TP1a, TP4, TP5

Functional Block of DFE

TX +
Channel

Input

$H(z)$

$y(n)$

FFE

$e(n)$

DFE
Output
 ± 1

Task force has studied
extensively DFE output
from TP1a, TP4, and TP5 ✓

Package/ESD

TX +
Channel

Via

Trace

Input

$H(z)$

$y(n)$

FFE

$e(n)$

DFE
Output
 ± 1
To
Slicer

Task force has
studied DFE output
at slicer ✓

TX +
Channel

Input

$H(z)$

$y(n)$

FFE

$e(n)$

DFE
Output
 ± 1

Via

Trace

Slicer

Task force has not
yet studied how to
propagate non-
linear DFE output
to slicer or reverse
propagate the slicer
signal to define
DFE eye ✗

What is the Best Scope Optimization

- Experience learned from TDECQ was that MMSE alone resulted as much as 2 dB higher TDECQ
 - The CK task force should not provide scope optimization recipe without substantial experimental data
 - Instead the task force should focus on providing the criteria for optimization.

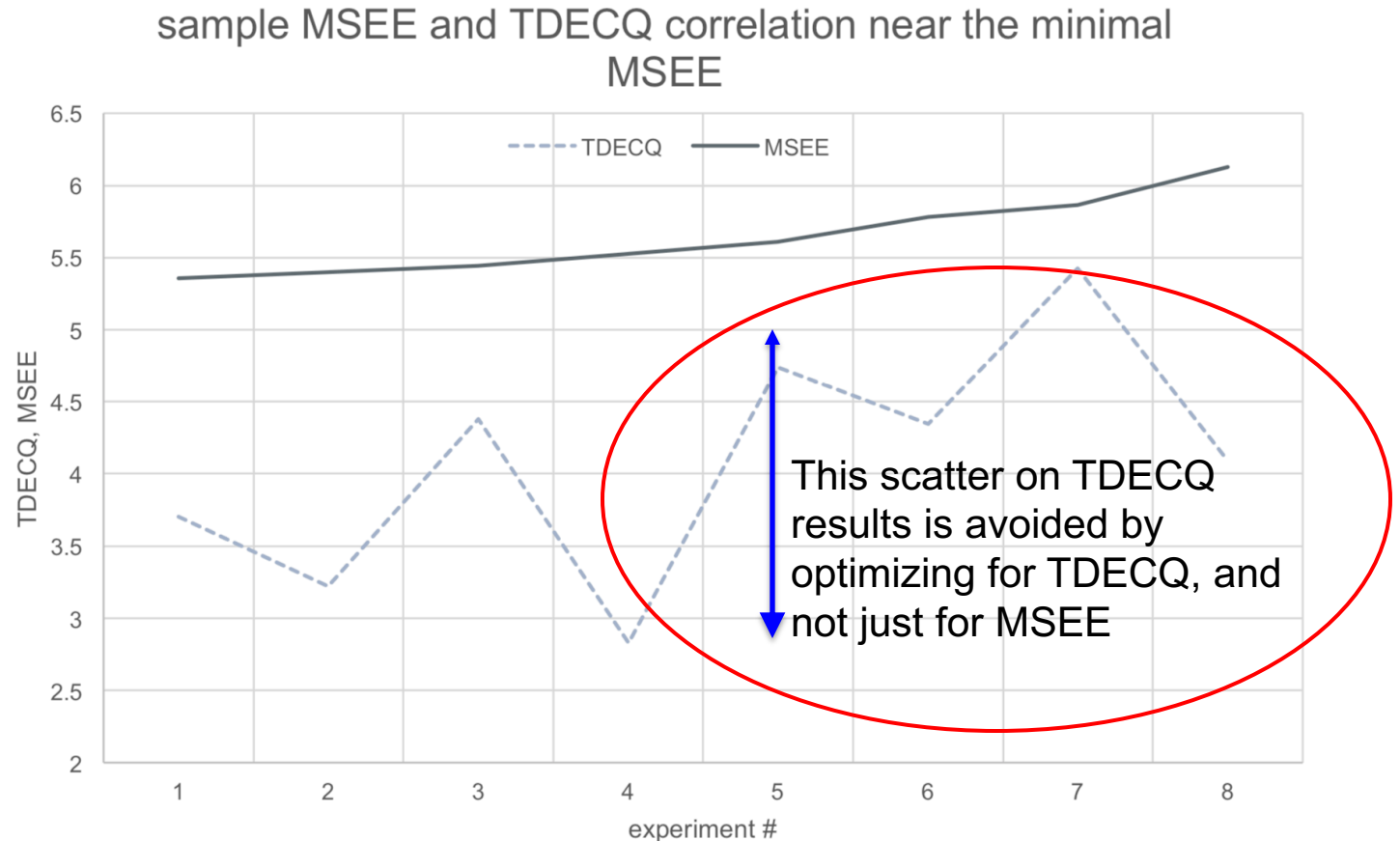


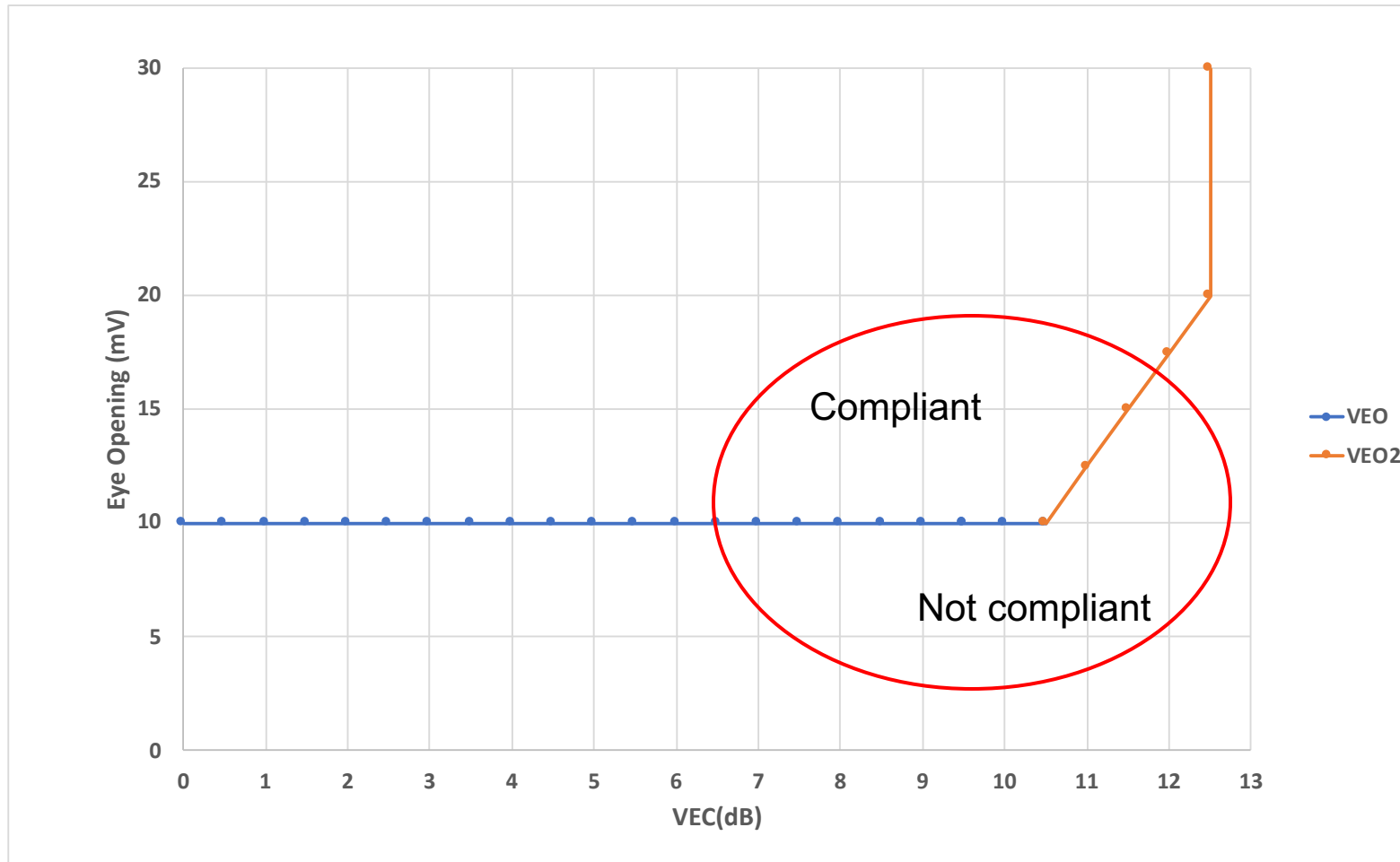
Figure 1: MSE, TDECQ with different phase and cursor positions

https://www.cadence.com/content/dam/cadence-www/global/en_US/documents/company/Events/summits/photronics/zivny-2017.pdf

100GAUI-1, 200GAUI-2, and 400GAUI-4 Host Output (at TP1a)

Parameters	400GAUI-8	100GAUI-1, 200GAUI-2, 400GAUI-4
Signaling Rate per lane	26.5625 GBd \pm 100 ppm	53.125 GBd \pm 100 ppm
DC common-mode output voltage (max)	2.8 V	2.8V
DC common-mode output voltage (min)	-0.3 V	-0.3 V
Single-ended output voltage (max)	3.3 V	3.3 V
Single-ended output voltage (min)	-0.4 V	-0.4 V
AC common-mode output voltage (max, RMS)	17.5 mV	20 mV
Differential peak-to-peak output voltage (max) Transmitter disabled Transmitter enabled	35 mV 880 mV	35 mV 870 mV
ESMW (Eye symmetry mask width)	0.22 UI	0.15 UI
Eye height VEO, differential (min) for $VEC \leq 10.5$ dB (mV)	32 mV	10 mV
Eye height VEO2, differential (min) for $10.5 \text{ dB} > VEC \leq 12.5$ dB (mV)	NA	See 1
Vertical Eye Closure (max)	12 dB	
Differential termination mismatch (max)	10%	10%
Transition time (min, 20% to 80%)	10 ps	6.5 ps
1. $VEO2 = VEC \times 5 - 42.5$ mV, VEC values are in dB. Eye height VEO2 for $VEC \geq 10.5$ dB see next slide.		

VEO, VEO2 as Function of VEC



100GAUI-1, 200GAUI-2, and 400GAUI-4 Module Output (TP4/TP5)

Parameter	400GAUI-8	100GAUI-1, 200GAUI-2, 400GAUI-4
Signaling Rate per lane	26.5625 GBd \pm 100 ppm	53.125 GBd \pm 100 ppm
AC common-mode output voltage (max, RMS)	17.5 mV	20 mV
Differential peak-to-peak output voltage (max)	900 mV	900 mV
Near-end ESMW (Eye symmetry mask width)	0.265 UI	0.25 UI
Near-end Eye height, differential (min)	70 mV	48 mV
Far-end ESMW (Eye symmetry mask width)	0.2 UI	0.175 UI
Far-end Eye height, differential (min)	30 mV	17.5 mV
Vertical Eye Closure (max) at TP4/TP5	NA	7.5 dB
Far-end pre-cursor ISI Ratio	-4.5% to +2.5%	-
Differential termination mismatch (max)	10%	10%
Transition time (min, 20% to 80%)	9.5 ps	6 ps
DC common mode voltage (min)	-350 mV	-350 mV

Summary

- C2M AUI baseline proposal has several key TBDs related to reference equalizer that needs to be completed during Nov. 2019 plenary meeting
- 5T FFE with 4 post is proposed for the C2M AUI measurements at TP1a, TP4, and TP5
 - The purposed reference equalizer reuses 5T FFE from CL 121 required for for all PAM4 optical modules
 - FFE offers lower power and without the risk of burst errors, but one can always use DFE for real receiver
- Given that TP1a, TP4, and TP5 are scope measurement the 5T FFE leverages 3+ years of TDECQ experience and the FFE preserves signal analog behavior
 - The purpose of reference equalizer is to qualify passing vs failing channels
 - The real equalizer for most implementations has to be better than reference equalizer
- Unlike FFE, the DFE output is a non-linear and with increase DFE tap weights the waveform becomes more choppy
 - The DFE slices the signal where the output is ± 1 and determining real EW not feasible
 - The task force has not yet studied if the choppy reference DFE equalizer outputs will produce the required VEO and EW at the slicer
 - DFE output must be propagated with transient simulator to determine the required EW/EH at slicer
 - Key advantage of using 4T DFE as a reference receiver is to allow noisy channels but this will force real receiver to be even better 4T DFE and further increase module power dissipation
- FFE is LTI compliant and preserves analog signals where EW/EH/ESMW at TP1a, TP4, and TP5 correlates to slicer EW/EH/ESMW!