# CAUI-4 Ad hoc

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# Agenda

- Patent Policy: The meeting is an official IEEE ad hoc. Please review the patent policy at the following site prior to the meeting.
  http://www.ieee802.org/3/patent.html
- Approval of Minutes from July 30 meeting
- TBD for CAUI-4 chip-to-chip
  - Transmit Equalizer
  - Rx Interference tolerance
  - COM

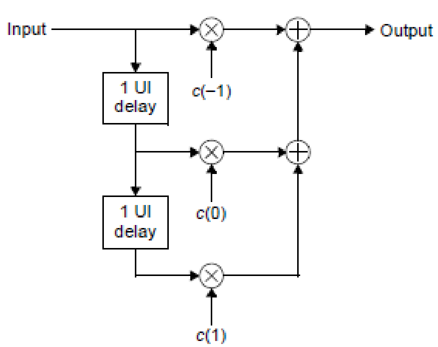
# Transmit equalizer

Table 83D–1—CAUI-4 transmitter characteristics at TP0a§

| Parameter§ | Subclause Reference§ | Value§ | Units§ |
|---|---|---|---|
| Signaling rate per lane (range)§ | 83E.3.1.1§ | 25.78125 ± 100 ppm§ | GBd§ |
| Differential peak-to-peak output voltage (max)(<br>Transmitter disabled(<br>Transmitter enabled§ | 83D.3.1.1§ | (<br>30(<br>1200§ | mV§ |
| Common-mode voltage (max)§ | 83D.3.1.1§ | 1.9§ | V§ |
| Common-mode voltage (min)§ | 83D.3.1.1§ | 0§ | V§ |
| Common-mode AC output voltage (max, RMS)§ | 83D.3.1.1§ | 12§ | mV§ |
| Differential output return loss (min)§ | 83D.3.1.2§ | Equation (83D–2)§ | dB§ |
| Common-mode output return loss (min)§ | 83D.3.1.2§ | Equation (83D–3)§ | dB§ |
| Transition time (min, 20% to 80%)§ | 83D.3.1.3§ | 8§ | ps§ |
| Output Jitter (max)(<br>Random jitter(<br>Deterministic jitter(<br>Total jitter§ | 83D.3.1.4§ | (<br>0.15(<br>0.15(<br>0.28§ | UI§ |
| Transmitter eye mask definition X1§ | 83D.3.1.5§ | 0.14§ | UI§ |
| Transmitter eye mask definition X2§ | 83D.3.1.5§ | 0.4§ | UI§ |
| Transmitter eye mask definition Y1§ | 83D.3.1.5§ | 200§ | mV§ |
| Transmitter eye mask definition Y2§ | 83D.3.1.5§ | 600§ | mV§ |
| Minimum de-emphasis[a](<br>Post Cursor(<br>Pre Cursor§ | 83D.3.1.6§ | (<br>TBD(<br>TBD§ | dB§ |

[a] Independent of optimal setting used for transmitter jitter and output waveform measurements.§

- **Transmitter de-emphasis range**
- The CAUI-4 chip-to-chip transmitter includes programmable equalization to compensate for the frequency-dependent loss of the channel and to facilitate data recovery at the receiver. The functional model for the transmit equalizer is the three tap transversal filter shown in TBD. The minimum pre cursor equalization (c(-1)) is TBD. The minimum post cursor equalization (c(1)) is TBD.
- The transmitter output equalization is characterized using the procedure described in TBD.



# Transmit equalization (leveraging 93.8.1)

- Building on Moore_01_07: In Table 93-4, delete references to coefficient step size and range and replace with min and max values for Pre-cursor and Post-cursor values at a number (3?) of discrete settings.
  - C(1): 0, -0.1, -0.2
    - C(0) = 0.4
      - » 0: 0dB
      - » -0.1: 4.4dB
      - » -0.2: 9.5dB
  - C(-1): 0, -0.04, -0.08
    - C(0) = 0.4
      - » 0: 0dB
      - » -0.04: 1.7dB
      - » -0.08: 3.5dB
  - Straight forward COM implementation for min, max and step size
    - Consider normalizing
  - Table 83D-1 would then be modified to:
    - Specify minimum de-emphasis with discrete C(-1) and C(1) values
    - have no units a
    - In reference subclause allow for +/-10% variation
  - Similar to OIF as well as 802.3bj methodology

# Transmit equalization (VMA method)

- ghiasi_010713: post cursor of 6dB in 0.5dB steps and pre is nice to have with 3dB in 0.5dB steps with below to characterize

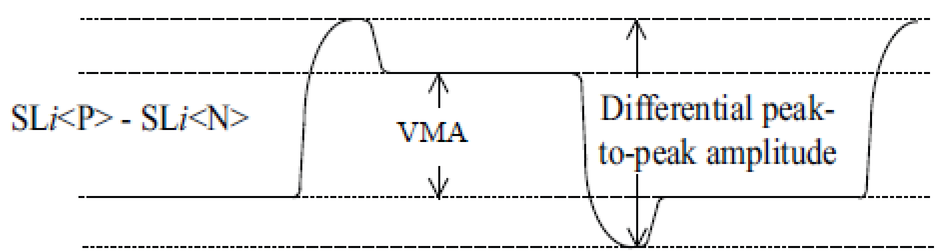



**Figure 83A–5—Driver output voltage limits and definitions**

$$\text{De-emphasis (dB)} = 20\log_{10}\left(\frac{\text{Differential peak-to-peak amplitude}}{\text{VMA}}\right) \qquad (83\text{A}–3)$$

# Interference tolerance

**Table 83D–3—Receiver interference tolerance parameters**

| Parameter | Test Value | Units |
|---|---|---|
| Maximum BER[a] | $10^{-15}$ | |
| Applied peak-to-peak sinusoidal jitter | Table 88-13 | UI |
| Applied broad band noise | TBD | |
| Applied peak-to-peak random jitter | TBD | V |
| Minimum eye height after reference CTLE | 40 (TBC) | mV |
| Minimum eye width after reference CTLE | 0.45 (TBC) | UI |
| Channel insertion loss at 12.89 GHz | TBD | |
| COM of ISI channel | TBD | |

[a]Maximum BER assumes errors are not correlated to ensure a sufficiently high mean time to false packet acceptance (MTTFPA) assuming 64B/66B coding. Actual implementation of the receiver is beyond the scope of this standard

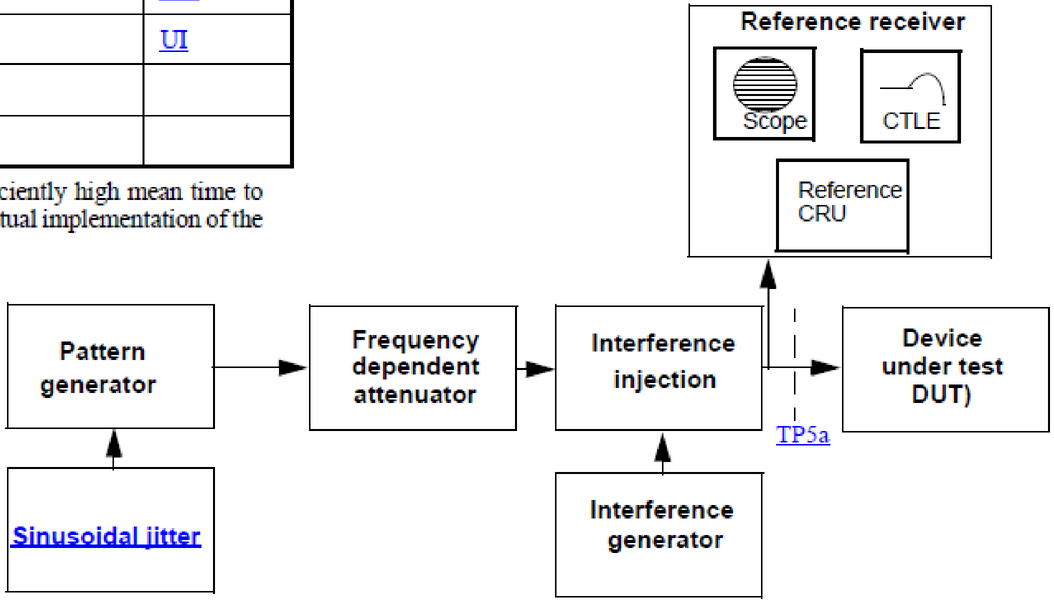
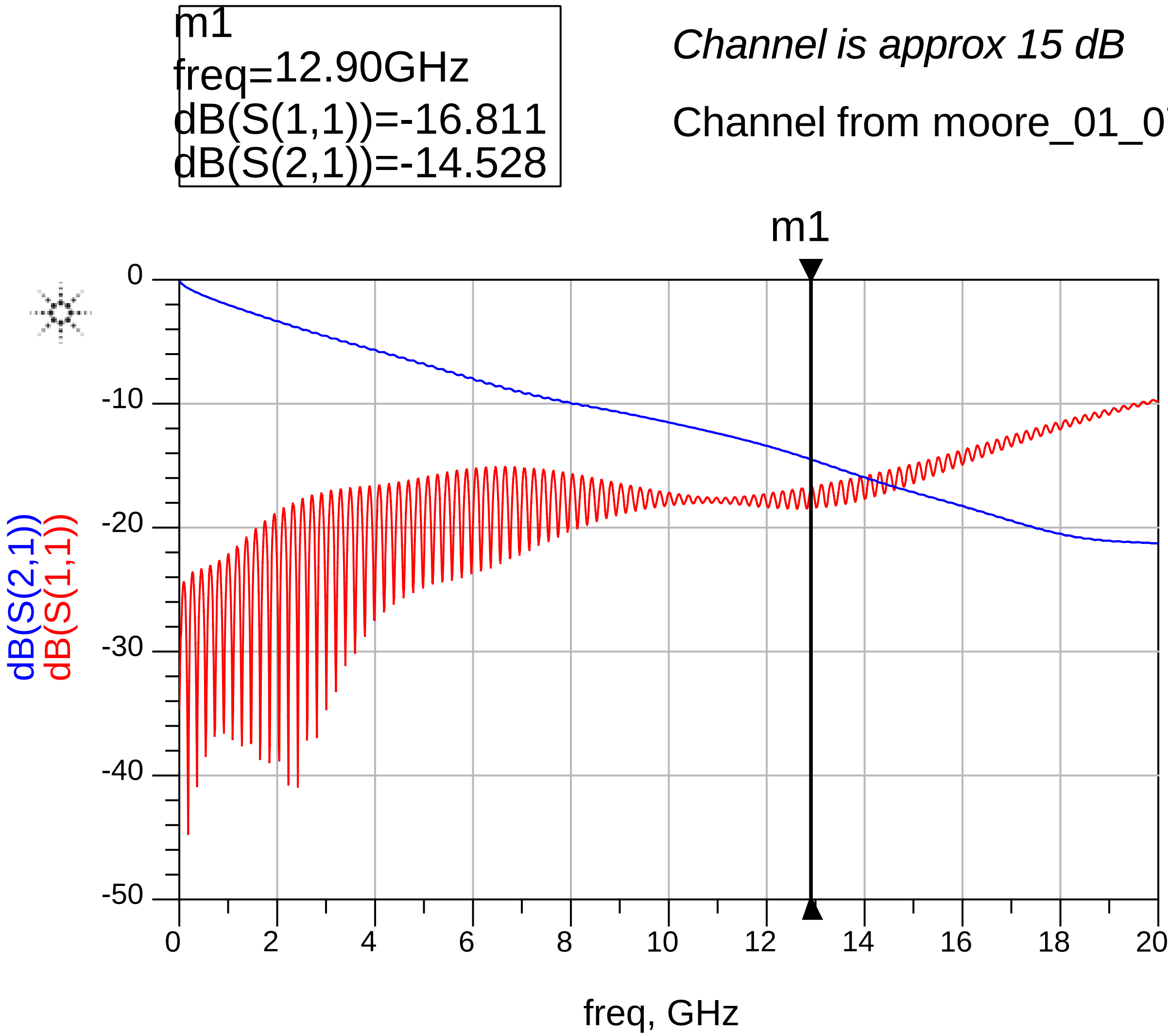



Figure 83D–12—Interference tolerance test setup

# Example frequency dependent attenuator (channel)

*Channel is approx 15 dB*

Channel from moore_01_073013



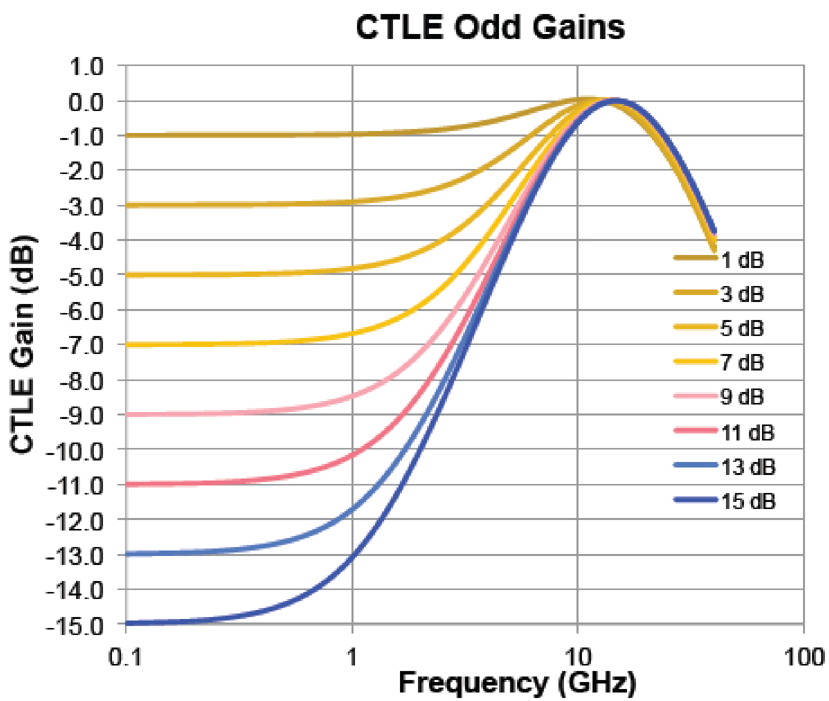
# Phase 1

(Finding CTLE sweet spot)

# Reference EQ coefficients

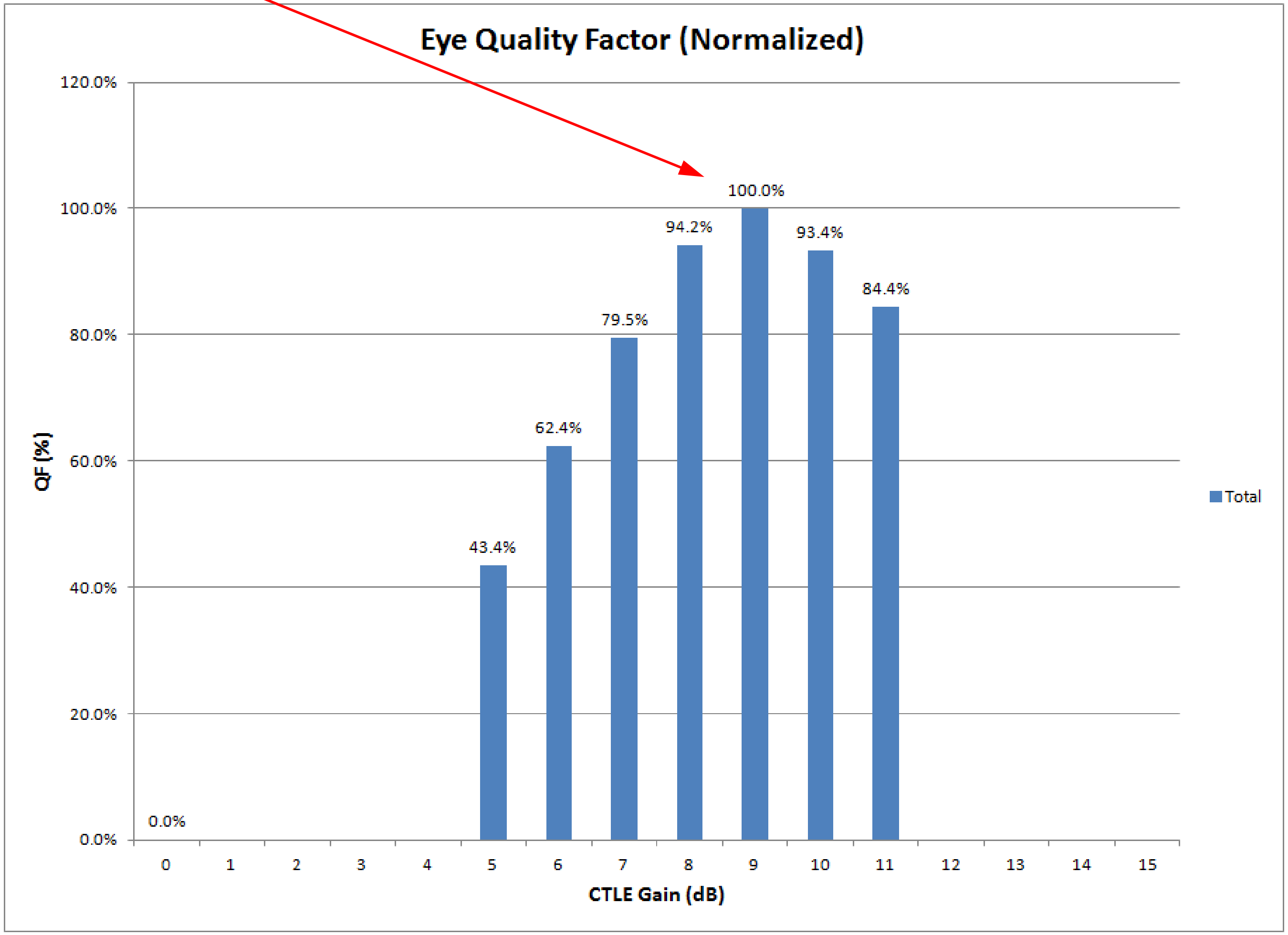
- Proposal in ghiasi_010713
  - OIF 28G-VSR and CAUI-4 chip to module define CTLE response from 1-9 dB
    - Additional CTLE filter 10-15 are provided for purpose of CAUI-4 C2C study
    - Assume we go with 15 dB then there is no reason to require more than 12 dB CTLE

http://www.ieee802.org/3/bm/public/tools/index.html

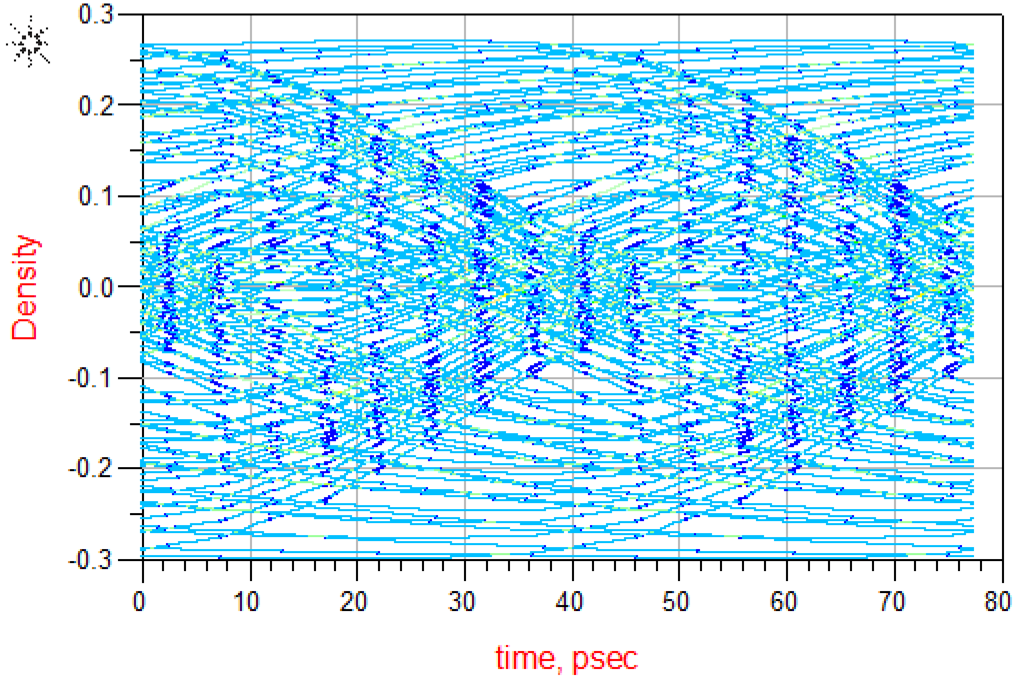



| Gain (dB) | G (Linear) | Z (GHz) | P1 (GHz) | P2 (GHz) |
|---|---|---|---|---|
| 1 | 0.89 | 7.1e9 | 1.86e10 | 1.41e10 |
| 2 | 0.795 | 7.1e9 | 1.86e10 | 1.41e10 |
| 3 | 0.795 | 7.1e9 | 1.56e10 | 1.41e10 |
| 4 | 0.633 | 4.98e9 | 1.56e10 | 1.41e10 |
| 5 | 0.563 | 4.35e9 | 1.56e10 | 1.41e10 |
| 6 | 0.5 | 3.82e9 | 1.56e10 | 1.41e10 |
| 7 | 0.446 | 3.4e9 | 1.56e10 | 1.41e10 |
| 8 | 0.398 | 3e9 | 1.56e10 | 1.41e10 |
| 9 | 0.3548 | 2.672e9 | 1.56e10 | 1.41e10 |
| 10 | 0.316 | 2.372e9 | 1.56e10 | 1.41e10 |
| 11 | 0.2818 | 2.11e9 | 1.56e10 | 1.41e10 |
| 12 | 0.2512 | 1.874e9 | 1.56e10 | 1.41e10 |
| 13 | 0.2239 | 1.67e9 | 1.56e10 | 1.41e10 |
| 14 | 0.1995 | 1.484e9 | 1.56e10 | 1.41e10 |
| 15 | 0.1778 | 1.325e9 | 1.56e10 | 1.41e10 |

9 dB CTLE is optimum

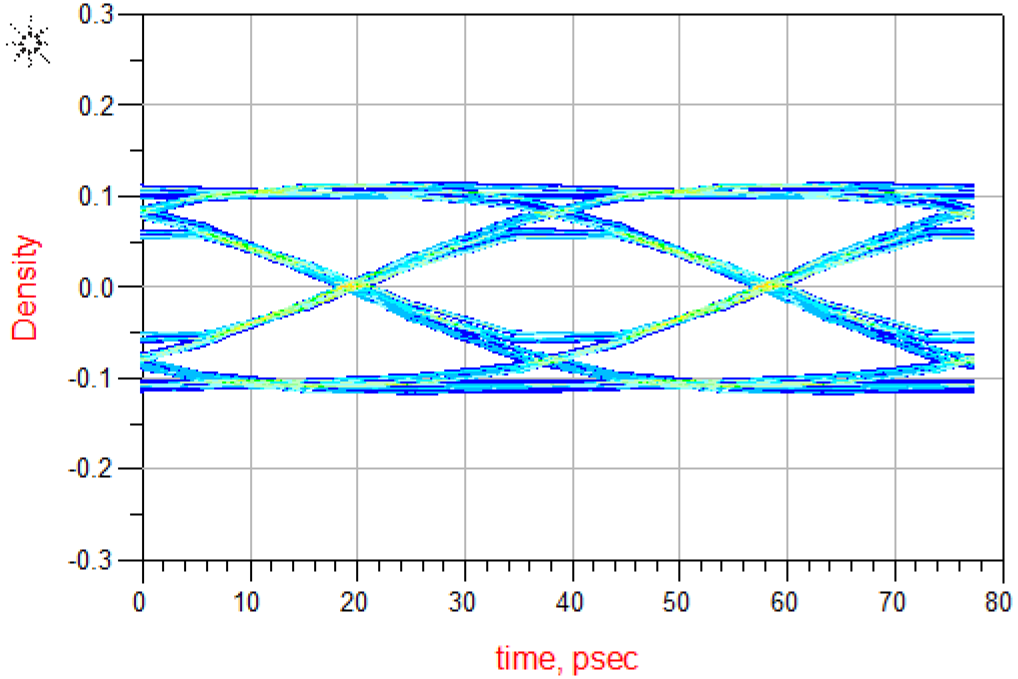


# Channel only




| index | permute(HeightAtBER) | permute(WidthAtBER) |
|---|---|---|
| 0.000 | -0.052 | 0.000 |

# 9 dB CTLE




| index | permute(HeightAtBER) | permute(WidthAtBER) |
|---|---|---|
| 0.000 | 0.103 | 3.549E-11 |

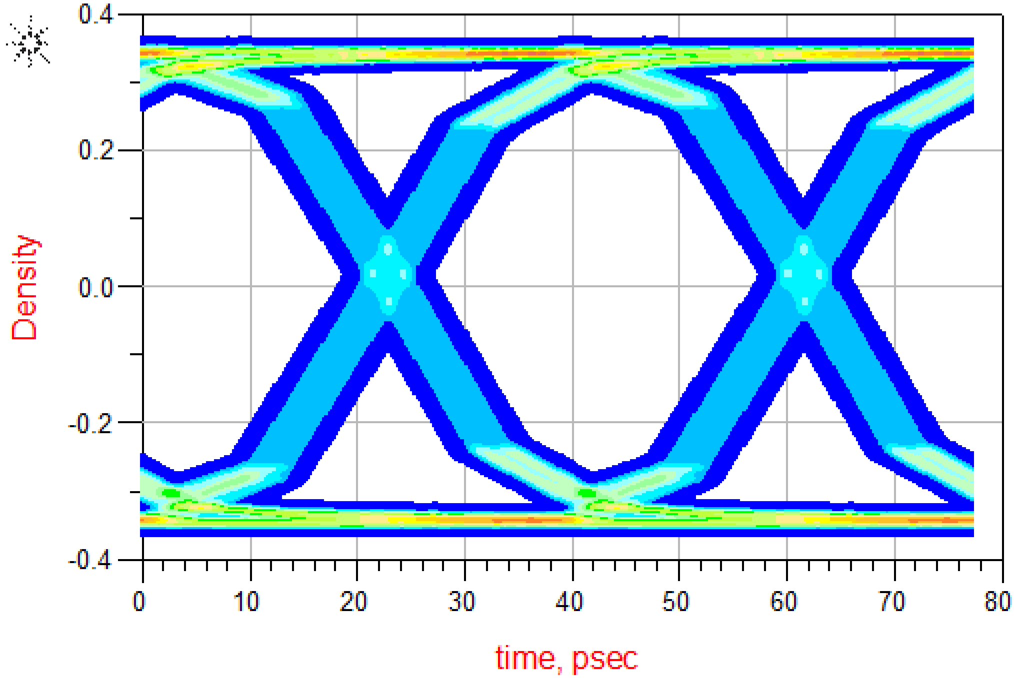
# Phase 2

(Stressed Eye)

# Tx Assumptions

- Tx swing 0.7 Vppd
- Tx DCD 0.035 UI
- Tx SJ 1.94 ps (0.05 UI)
- Tx SJ freq 100 MHz
- Tx RJ 0.012 UI rms
- Tx rise time ~19 ps, 0-100%

# Transmitter Eye statistical



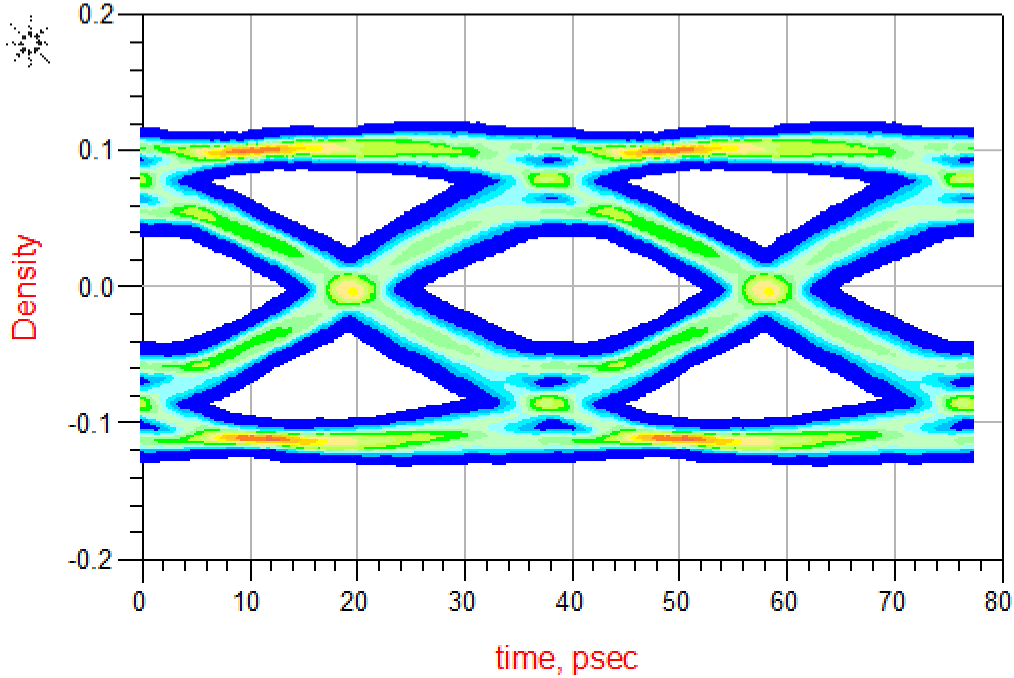

0.7 Vppd

| index | permute(HeightAtBER) | permute(WidthAtBER) |
|---|---|---|
| 0.000 | 0.515 | 2.657E-11 |

# Rx Assumptions

- Rx RJ 0.003 UI rms
- Rx Vn is to be determined

# Receiver Output Eye (statistical)

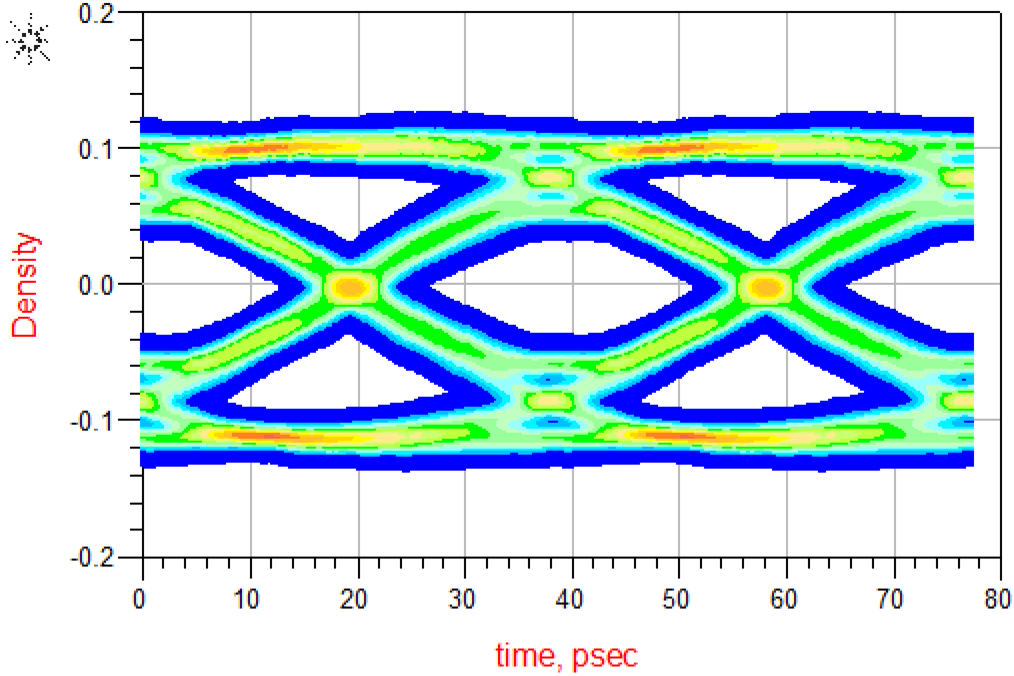



0.7 Vppd Tx
Vn = 0

| index | permute(HeightAtBER) | permute(WidthAtBER) |
|---|---|---|
| 0.000 | 0.060 | 2.153E-11 |

*20 mV margin* *0.103 UI margin*

# Receiver Output Eye (statistical)




0.7 Vppd Tx
Vn = 3 mVrms

| index | permute(HeightAtBER) | permute(WidthAtBER) |
|---|---|---|
| 0.000 | 0.040 | 1.707E-11 |

***~0 mV margin*** ***~0 UI margin***

Table 83D–3—Receiver interference tolerance parameters

| Parameter | Test Value | Units |
|---|---|---|
| Maximum BER[a] | $10^{-15}$ | |
| Applied peak-to-peak sinusoidal jitter | Table 88-13 | UI |
| Applied broad band noise | 1 | mVrms |
| Applied peak-to-peak random jitter | 0.091 | UI rms |
| Minimum eye height after reference CTLE | 40 (TBC) | mV |
| Minimum eye width after reference CTLE | 0.45 (TBC) | UI |
| Channel insertion loss at 12.89 GHz | TBD | |
| COM of ISI channel | TBD | |

[a]Maximum BER assumes errors are not correlated to ensure a sufficiently high mean time to false packet acceptance (MTTFPA) assuming 64B/66B coding. Actual implementation of the receiver is beyond the scope of this standard

work on these next

Change:
Broadband noise is added via the interference generator and is added such that the eye open-ing using the reference receiver and optimal CTLE setting is 40 mV (TBC) eye height and 0.45 UI (TBC) eye width.
To:
Pattern generator amplitude is adjusted and broadband noise is added (via interference generator) such that the eye opening using the reference receiver and optimal CTLE setting is 40 mV (TBC) eye height and 0.45 UI (TBC) eye width.

Change figure 83D-12 “frequency dependent attenuator” to “ISI channel”, change “Channel insertion loss…” to “ISI channel insertion loss”
Change figure 83D-12 to add random jitter box as an input to the pattern generator

# COM

- Summary from moore_01_073013:
  - DFE needed for some implementations
  - If we remove Rx package assumptions, COM>4dB
- Consider COM which removes Rx package assumption
  - Allows for implementation trade-offs
  - This will be most similar to interference tolerance test with reference receiver

## Results suggest DFE is required

| 15 dB Meg6_LowSR board model ( vias, etc) Thru, 3 FEXT, 4 NEXT, packages at Tx and Rx | | |
|---|---|---|
| DFE | Z_p (package Length) | COM / VEO |
| 0 | 12 | 0.99 dB / 10mV |
| 0 | 30 | 0.43dB / 2.5mV |
| 5 | 0 | 3.9db / 28mV |
| 5 | 30 | 5.2dB / 48mV |

Results suggest no DFE into and instrument would look OK

| 15 dB Meg6_LowSR board model ( vias, etc) Ideal Instrument Rx Termination, package at Tx only. | | |
|---|---|---|
| DFE | Z_p (package Length) | COM VEO |
| 0 | 12 | 4.38dB / 36mv |
| 0 | 30 | 4.01dB / 34mV |

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# Previously discussed topics

# Transmit equalizer characterization (In CL93)

- The transmitter output waveform is characterized using the procedure described in 85.8.3.3. The parameters of the linear pulse fit and equalizer are summarized in Table 93–5.

Table 93–5—Linear fit pulse and equalizer parameters

| Description | Symbol | Value | Units |
|---|---|---|---|
| Linear fit pulse length | $N_p$ | 8 | UI |
| Linear fit pulse delay | $D_p$ | 2 | UI |
| Equalizer length | $N_w$ | 8 | UI |
| Equalizer delay | $D_w$ | 2 | UI |

**Steady-state voltage and linear fit pulse peak**

The steady-state voltage *vf is defined to be the sum of the linear fit pulse p(k) divided by M (refer to 85.8.3.3* step 3). The steady-state voltage shall be greater than or equal to 0.4 V and less than or equal to 0.6 V after the transmit equalizer coefficients have been set to the values used for transmit wave form evaluation. The peak value of *p(k) shall be greater than 0.8 × vf after the transmit equalizer coefficients have been set to* the values used for transmit wave form evaluation .

**Linear fit error**

For any configuration of the transmit equalizer, the RMS value of the error between the linear fit and the measured waveform, *e(k), normalized to the peak value of the linear fit pulse, p(k), shall be less than or* equal to 0.037.

# Transmit wave form

Table 83D–1—CAUI-4 transmitter characteristics at TP0a§

| Parameter§ | Subclause Reference§ | Value§ | Units§ |
|---|---|---|---|
| Signaling rate per lane (range)§ | 83E.3.1.1§ | 25.78125 ± 100 ppm§ | GBd§ |
| Differential peak-to-peak output voltage (max)(<br>Transmitter disabled(<br>Transmitter enabled§ | 83D.3.1.1§ | (<br>30(<br>1200§ | mV§ |
| Common-mode voltage (max)§ | 83D.3.1.1§ | 1.9§ | V§ |
| Common-mode voltage (min)§ | 83D.3.1.1§ | 0§ | V§ |
| Common-mode AC output voltage (max, RMS)§ | 83D.3.1.1§ | 12§ | mV§ |
| Differential output return loss (min)§ | 83D.3.1.2§ | Equation (83D–2)§ | dB§ |
| Common-mode output return loss (min)§ | 83D.3.1.2§ | Equation (83D–3)§ | dB§ |
| Transition time (min, 20% to 80%)§ | 83D.3.1.3§ | 8§ | ps§ |
| Output Jitter (max)(<br>Random jitter(<br>Deterministic jitter(<br>Total jitter§ | 83D.3.1.4§ | (<br>0.15(<br>0.15(<br>0.28§ | UI§ |
| Transmitter eye mask definition X1§ | 83D.3.1.5§ | 0.14§ | UI§ |
| Transmitter eye mask definition X2§ | 83D.3.1.5§ | 0.4§ | UI§ |
| Transmitter eye mask definition Y1§ | 83D.3.1.5§ | 200§ | mV§ |
| Transmitter eye mask definition Y2§ | 83D.3.1.5§ | 600§ | mV§ |
| Minimum de-emphasis[a](<br>Post Cursor(<br>Pre Cursor§ | 83D.3.1.6§ | (<br>TBD(<br>TBD§ | dB§ |

[a]Independent of optimal setting used for transmitter jitter and output waveform measurements.§

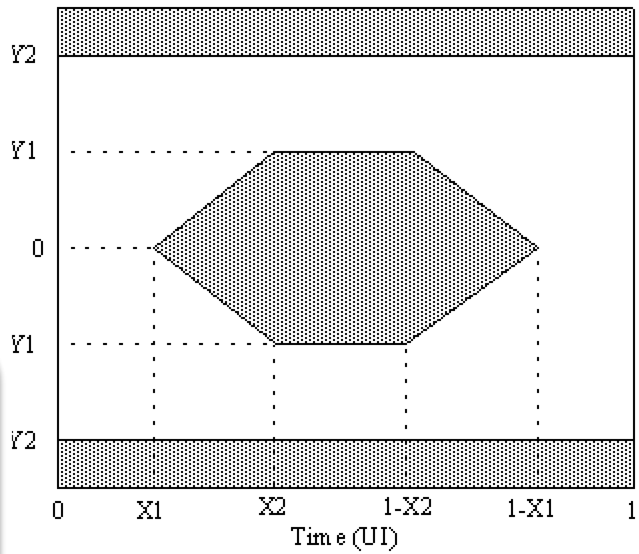


Figure 83D–7—Transmitter eye mask§

# Measurement of Transmit Jitter

**Transmitter output jitter**

- The components of the transmitter output jitter is defined in this subclause: total jitter (TJ), deterministic jitter (DJ), and random jitter (RJ).
- Transmitter output is measured at TP0a as defined in . All co-propagating and counter propagating CAUI-4 lanes are active during transmitter output jitter testing. Counter propagating lanes have a target differential peak-to-peak amplitude of 800 mV and transition time of 8 ps. All counter-propagating signals shall be asynchronous to the co-propagating signals using pattern 5 (with or without FEC encoding) pattern 3 or a valid 100GBASE-R signal. For the case of pattern 3, with at least 31 UI delay between the PRBS31 patterns on one lane and any other lane.
- The effect of a single-pole high-pass filter with 3 dB frequency of 10 MHz is applied to the jitter. The test pattern for jitter measurements is PRBS31. The voltage threshold for the measurement of BER or crossing times is the mid-point (0 V) of the AC-coupled differential signal.

**Total jitter**

- The total jitter (TJ) of a signal is defined as the range (the difference between the lowest and highest values) of sampling times around the signal transitions for which the BER at these sampling times is greater than or equal to $10^{-15}$.
- Total jitter for a CAUI-4 chip-to-chip transmitter is than or equal to 0.28 UI and is measured with optimal transmit equalizer setting.

**Deterministic and random jitter**

- The random jitter (RJ) of a signal is defined to be the difference between the TJ and DJ. DJ is derived from measured jitter distribution as follows
    - Measure the jitter Jn which is defined to be the interval that includes all but $10^{-n}$ of the jitter distribution. If measured by plotting BER vs. decision time, it is the time interval between the two points with BER of $10^{-n}/4$. Measure two values: J9 and J5
    - For each Jn determine the associated Qn from the inverse normal cumulative probability distribution adjusted for an assumed transition density of 0.5. Q9 is 5.998 and Q5 is 4.265
    - Calculate the effective DJ as shown in
- Deterministic jitter is less than or equal to 0.15 UI. Random jitter is less than or equal to 0.15 UI.

# Measurement Methodology for Eye Mask – Leverage 83E

**Transmitter output waveform**

- The eye mask show in is defined at a BER of $10^{-15}$, using the methodology described in TBD. Transmitter equalizer may be adjusted for optimum mask results.

TBD section:

- Transmit output waveform in CAUI-4 chip-to-chip are measured using a fourth-order Bessel-Thomson low-pass filter response with 33 GHz 3 dB bandwidth. X1 is measured using the methodology described in 83D.3.1.4 where X1 = TJ/2. Y2 is measured using the methodology described in 83D.3.1.1 . Y1 is measured using the following procedure using a PRBS9 waveform:
  - Capture the PRBS9 pattern using a clock recovery unit with 3 dB tracking bandwidth of 10 MHz and maximum peaking of 0.1 dB and a minimum sampling rate of 3 samples per bit. Collect sufficient samples equivalent to at least 4 million bits to allow for construction of a normalized cumulative distribution function (CDF) to a probability of $10^{-6}$ without extrapolation.
  - Use the differential signal from step 1 to construct the CDF of the signal amplitude at X2, midpoint (0.5) and 1-X2, for both logic 1 (CDF1) and logic 0 (CDF0), as a distance from the center of the eye. Calculate the eye height for each point (EH6) as the difference in amplitude between CDF1 and CDF0 with a value of $10^{-6}$. CDF0 and CDF1 are calculated as the cumulative sum of histograms of the amplitude at the top and bottom of the eye normalized by the total number of sampled bits. For a well balanced number of ones and zeros the maximum value for CDF0 and CDF1 will be 0.5.
  - Apply the Dual-Dirac and tail fitting techniques to CDF1 and CDF0 to estimate the noise at X2, 0.5 and 1-X2 points. Calculate the best linear fit in Q-scale over the range of probabilities of $10^{-4}$ and $10^{-6}$ of CDF1 and CDF0 to yield relative noise one (RN1) and relative noise zero (RN0). The eye height for plotting against the eye mask at X2, 0.5, and 1-X2 is then given by
  - EH15 = EH6 -3.19 x (RN0 + RN)
- where
  - *EH15 peak is the eye height extrapolated to $10^{-15}$ probability*
  - *EH6 is the eye height at $10^{-6}$ probability*
  - *RN1 is the RMS value of the noise estimated from CDF1*
  - *RN0 is the RMS value of the noise estimated from CDF0*