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CDAUI-8 PAM4 C2M Channel Investigations

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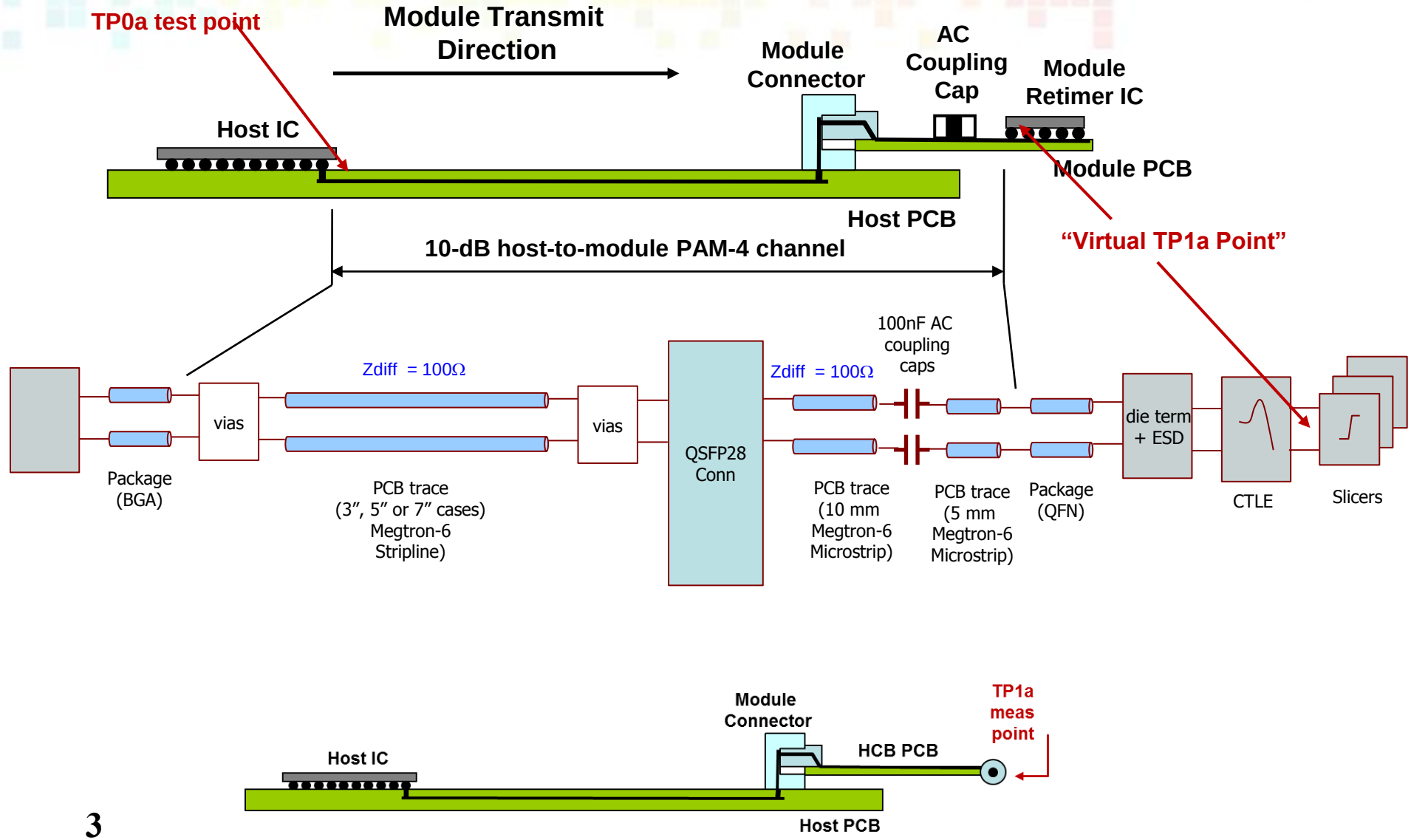
Introduction

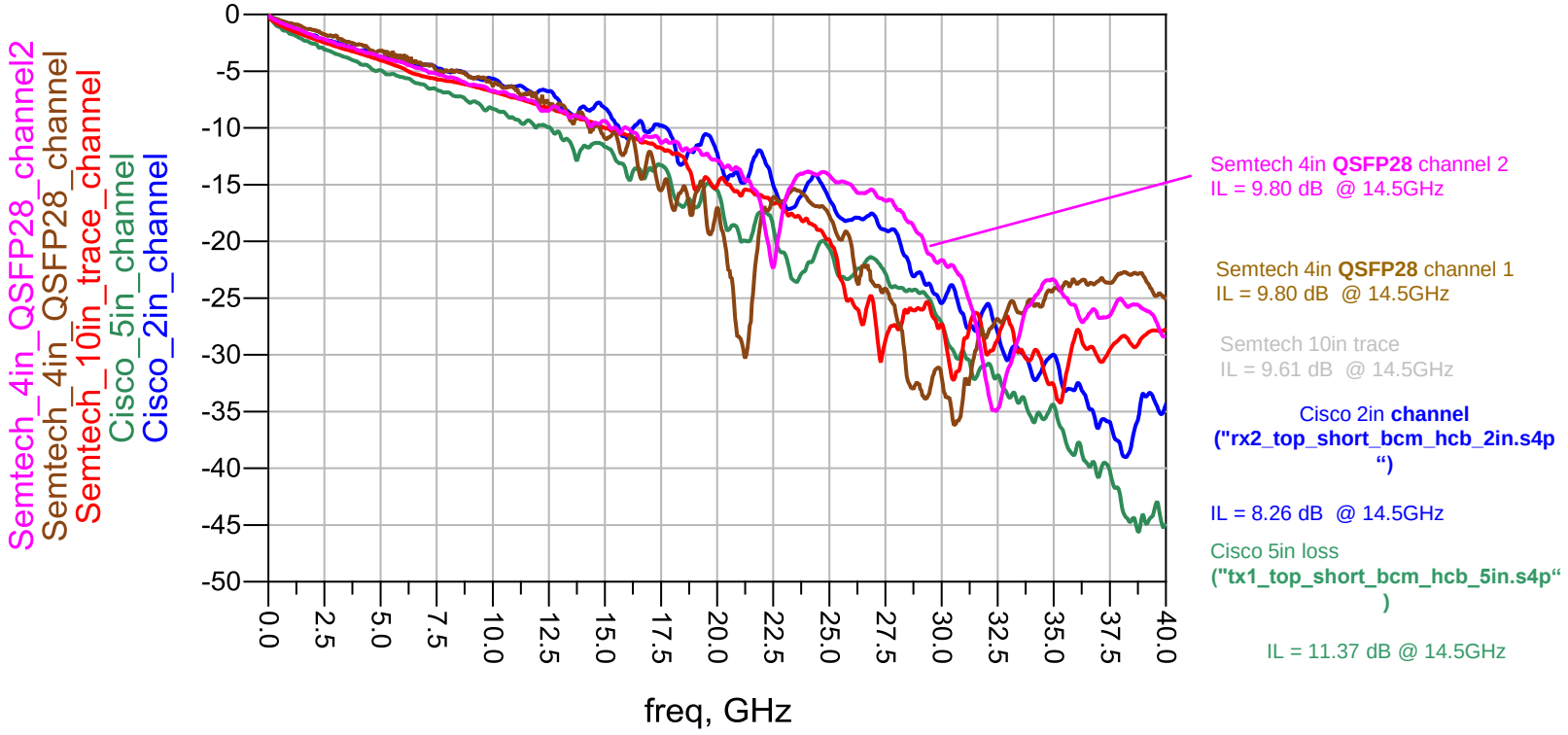
- **Five channels were investigated**
  - three Semtech channels – a 10in stripline Meg6 trace and two 4in QSFP28 VSR channels
  - two Cisco channels - one of Cisco 2in and 5in channels each

- **Various equalization approaches were studied including the standard 1z/2p CTLE as well as various 2z/3p CTLEs and a 3-tap FIR**

VSR-PAM4 Channel and Test Points

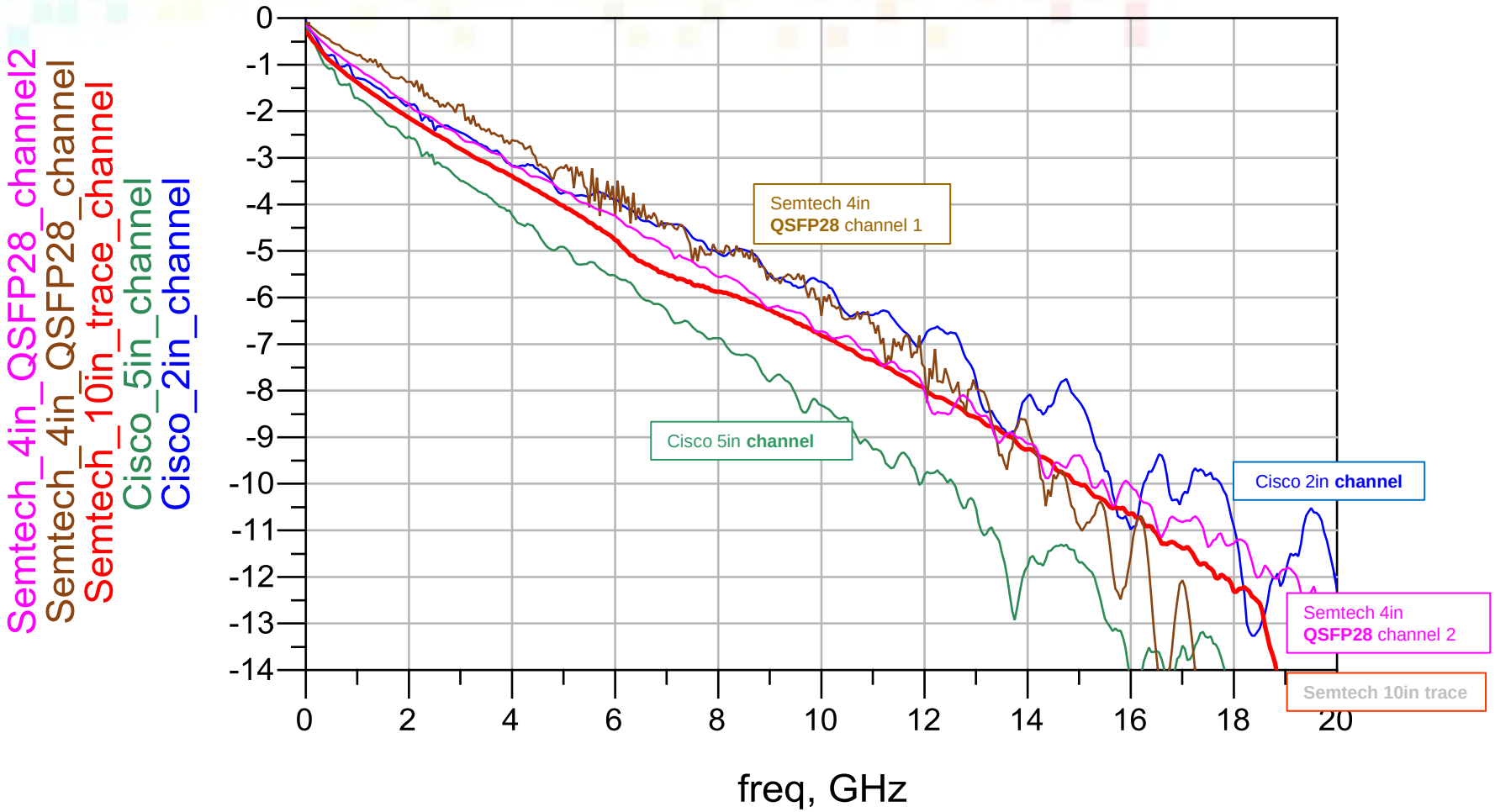


Investigated channel loss characteristics



- **Investigated channels included two Semtech QSFP28 channels and two Cisco VSR QSFP28 channels**

Zooming in

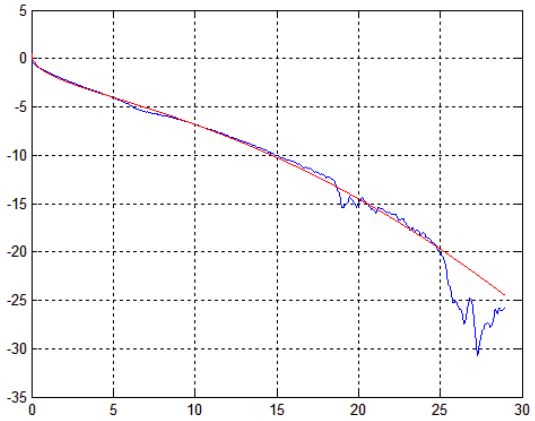


- **Semtech 4in-channel2 performance appears equivalent to 10in stripline trace!**

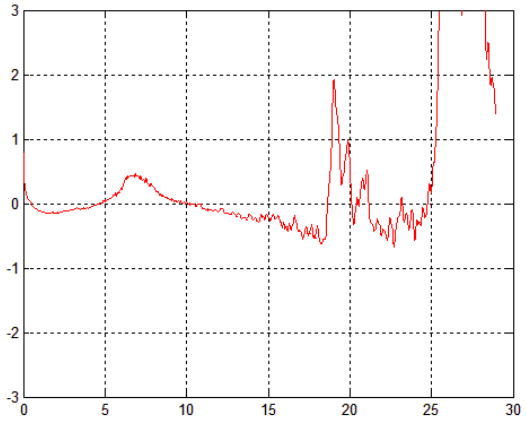
Channel ILD and FOM_{ILD} (1/3)

Semtech 10in stripline trace:

Curve fit



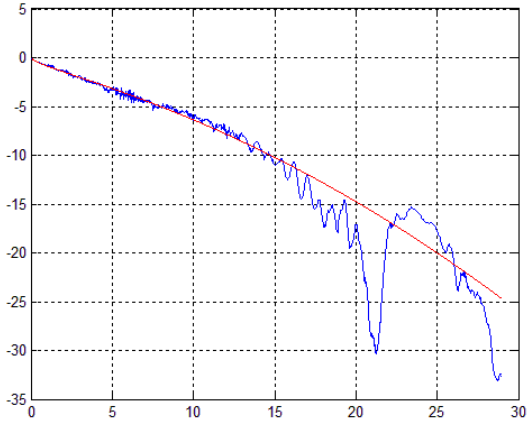
ILD (dB)



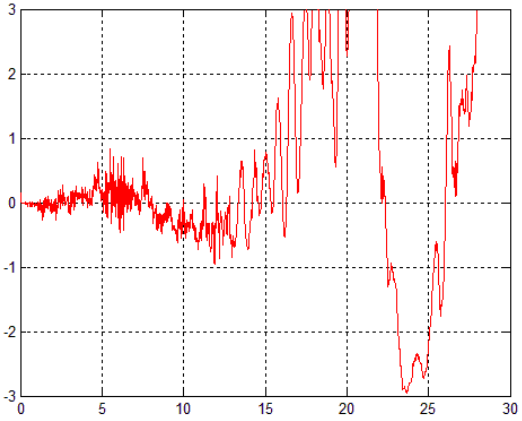
Semtech 10in trace
FOM_{ILD} = 0.14 dBrms

Semtech 4in QSFP28 channel 1:

Curve fit



ILD (dB)



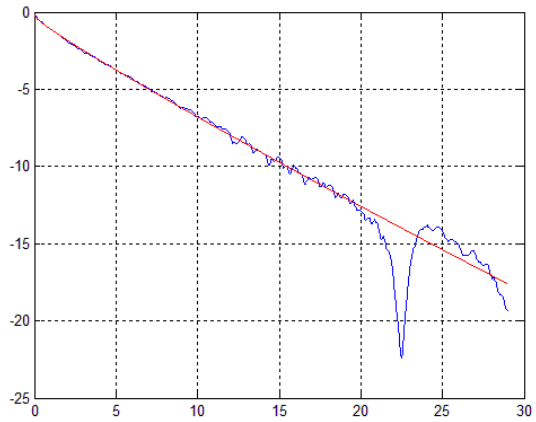
Semtech 4in QSFP28 channel
FOM_{ILD} = 0.70 dBrms

- **Semtech 4in channel1 suckout at 21 GHz is due to reflections at connector**

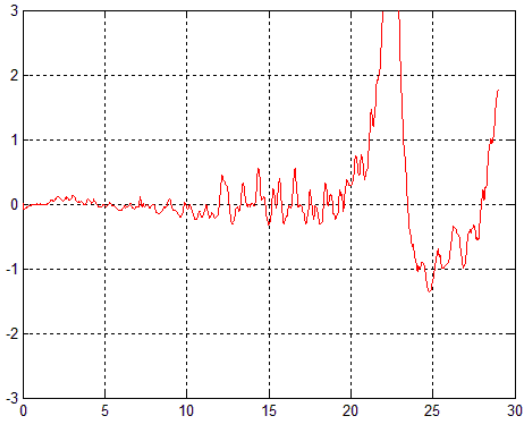
Channel ILD and FOM_{ILD} (2/3)

Semtech 4in QSFP28 channel2 :

Curve fit



ILD (dB)



Semtech 4in QSFP28 channel
FOM_{ILD} = 0.11 dBrms

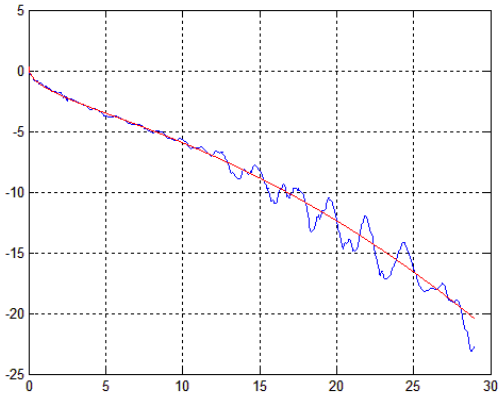
- **Semtech 4in channel2 nearly better than10in trace from an FOM_{ILD} perspective!**

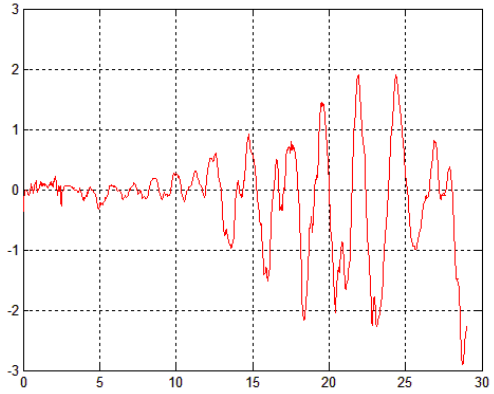
Channel ILD and FOM_{ILD} (3/3)

Curve fit

ILD (dB)

Cisco 2in channel:



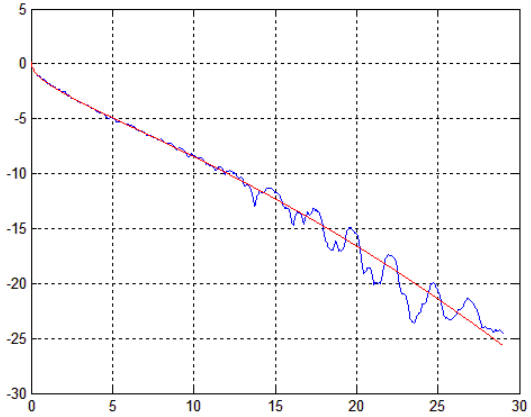


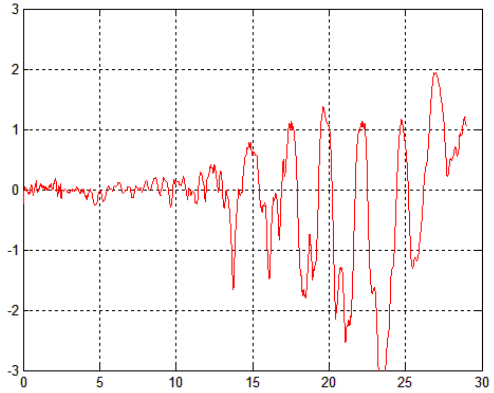
Cisco 2in channel
FOM_{ILD} = 0.24 dBrms

Curve fit

ILD (dB)

Cisco 5in channel:

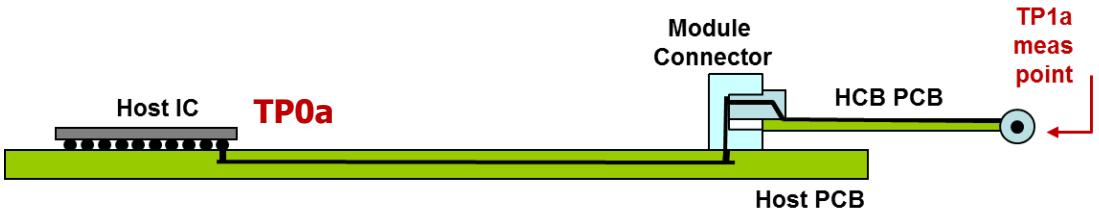




Cisco 5in channel
FOM_{ILD} = 0.24 dBrms

- **Both Cisco channels demonstrate the same FOM**

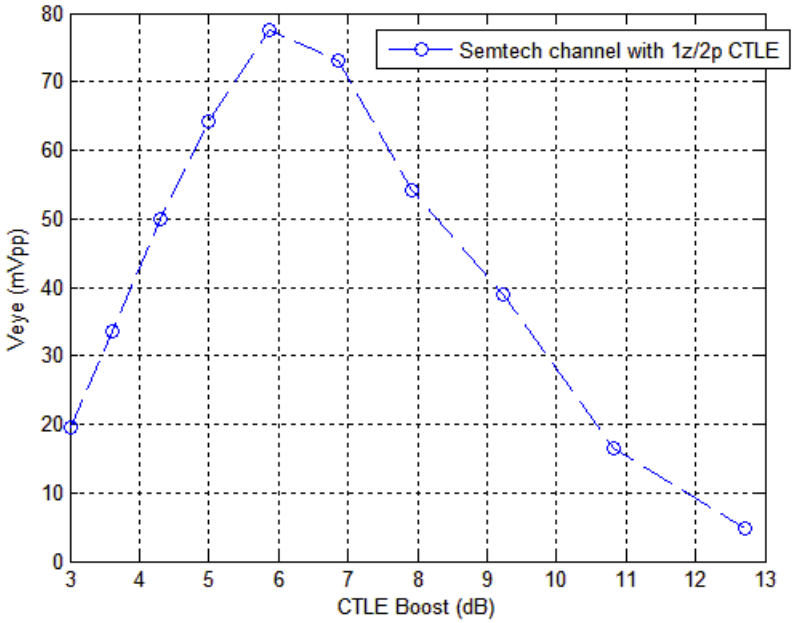
TP0a simulation parameters

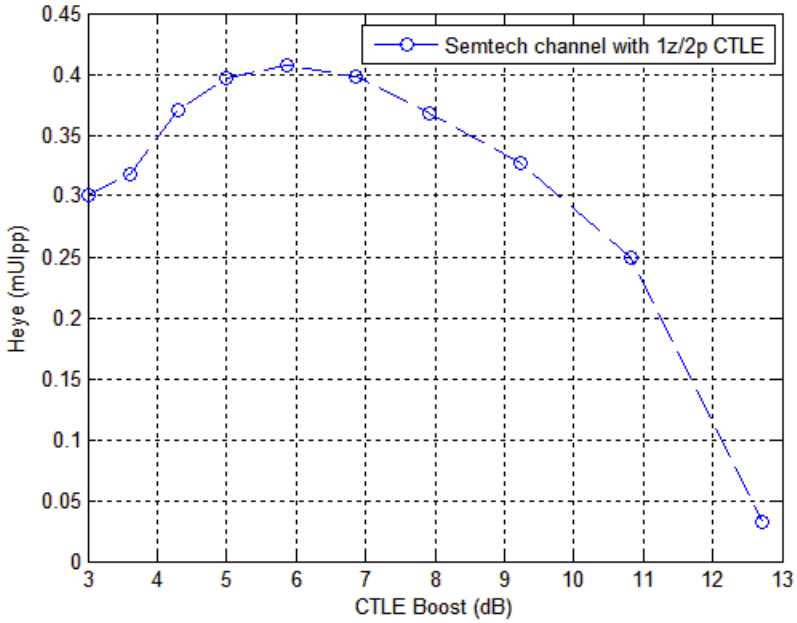


Simulation Parameter	Value
Tx Diff Volt	800 mVpp
PAM4 baud rate	29.0 GBd
Data pattern	PRBS15
EOJ	0.005 UIpp
Tx BUJ	0.05 UIpp
Random jitter	0.005 UIrms
Tx SNDR	29 dB

Semtech's 10in trace eye metrics vs 1z/2p CTLE boost with 1-dB pre-cursor Tx

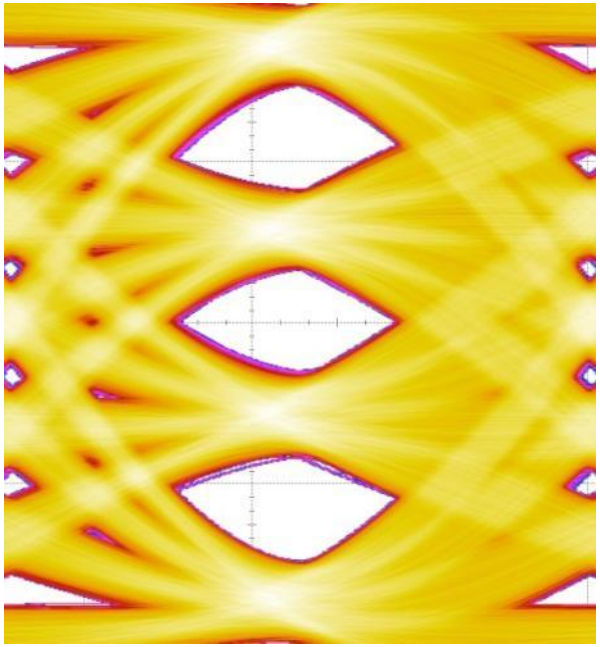
- Results based on 25K symbol pattern length





- CTLE having 6dB boost is optimal for the Semtech 10in trace channel

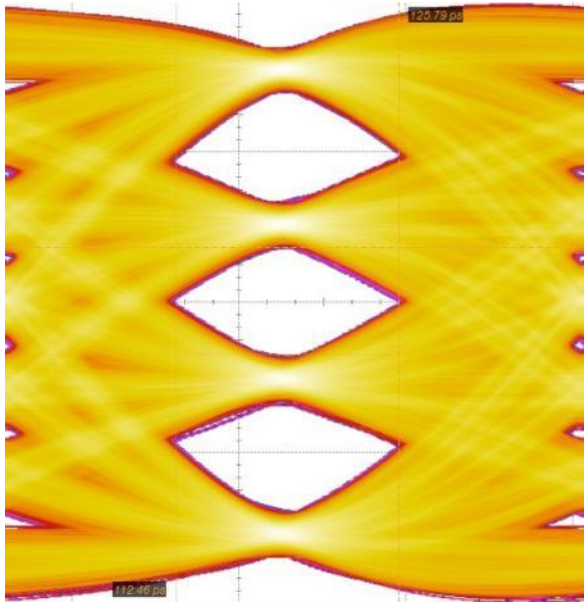
Semtech 10in trace eye with no Tx FIR



- **Tx FIR: None**
- **Rx CTLE:**
  - 5.87dB boost
  - 1Z: 4.5 GHz
  - 2P: 15.0, 20.0 GHz
- **13M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	58.5	10.9	0.316
Middle eye	56.8	12.7	0.368
Lower eye	58.5	11.1	0.322

Semtech 10in trace with a small Tx FIR pre-cursor



- **Tx FIR: [-0.05 0.95]**
- **Rx CTLE:**
  - 5.87dB boost
  - 1Z: 4.5 GHz
  - 2P: 15.0, 20.0 GHz
- **>4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	72.7	12.1	0.351
Middle eye	71.6	13.3	0.386
Lower eye	70.1	11.6	0.336

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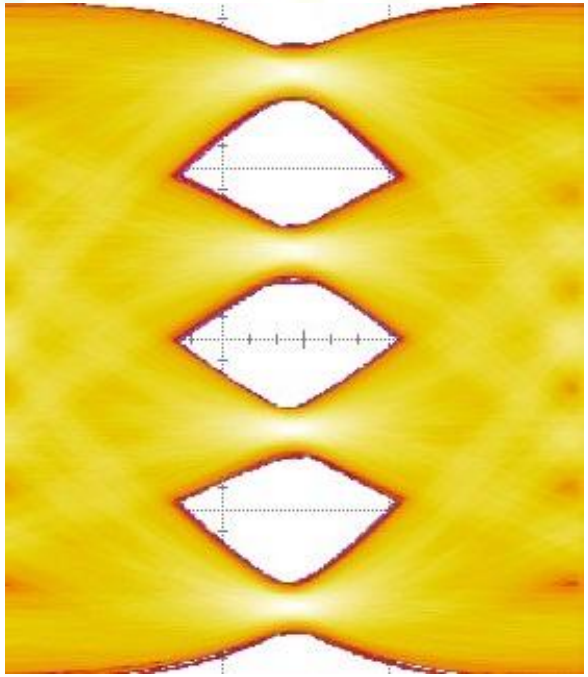
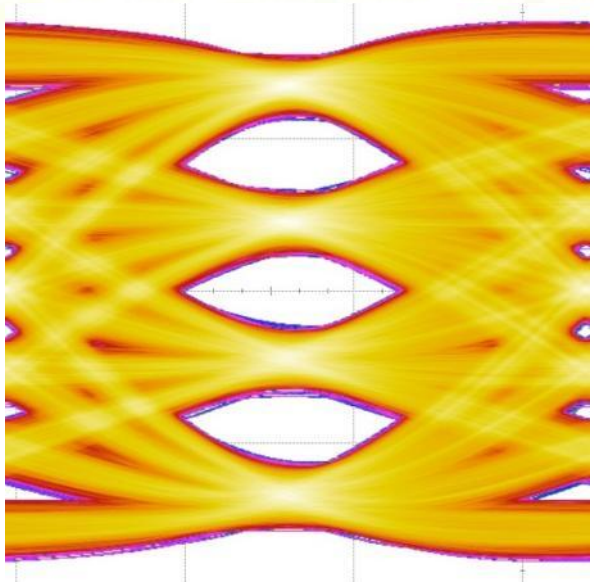
Semtech 10in trace eye with higher Tx de-Emphasis



- **Tx FIR: [-0.10 0.90]**
- **Rx CTLE:**
  - 5.87dB boost
  - 1Z: 4.5 GHz
  - 2P: 15.0, 20.0 GHz
- **1.4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	69.9	11.9	0.345
Middle eye	69.4	13.4	0.389
Lower eye	69.4	10.6	0.307

Semtech 10in trace eye with a 2z/3p CTLE

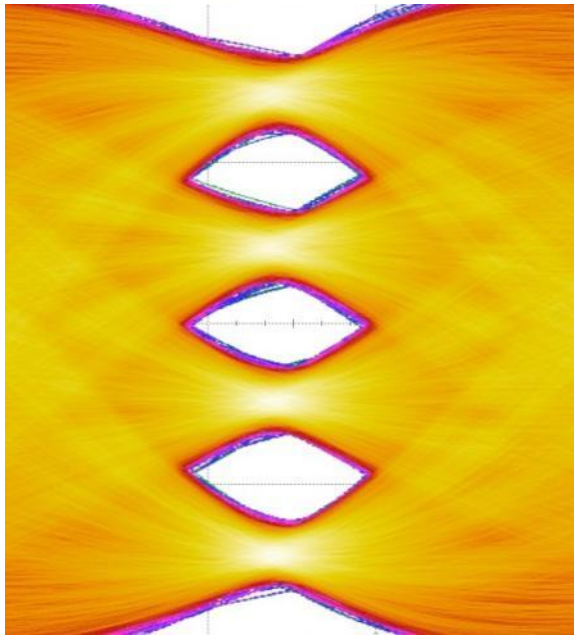


- Tx FIR: [-0.05 0.95]
- Rx CTLE:
  - 6.86dB boost
  - 2Z: 4.5, 15.0 GHz
  - 3P: 12.0, 23.0, 25.0 GHz
- 1.5M Samples
- No crosstalk

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	65.9	12.3	0.357
Middle eye	67.1	14.4	0.417
Lower eye	64.8	12.1	0.360

- 2z/3p CTLE better matched to channel provides some improvement in horizontal eye opening

Semtech 4in-9.6dB VSR channel 1 TP1a eye with a standard 6dB CTLE

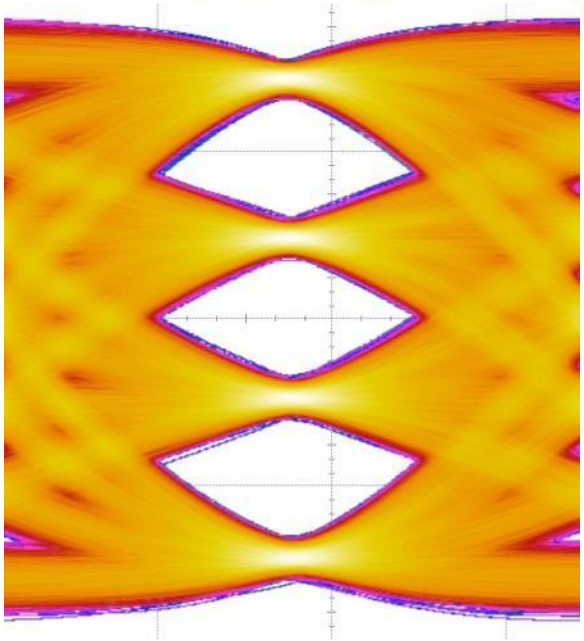


- **Tx FIR: [-0.05 0.95]**
- **Rx CTLE:**
  - 5.87dB boost
  - 1Z: 4.5 GHz
  - 2P: 15.0, 20.0 GHz
- **> 4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	48.3	8.77	0.254
Middle eye	51.0	10.12	0.294
Lower eye	53.7	8.95	0.260

- **Typical QSFP28 crosstalk must be budgeted though is not seen to drastically close the PAM4 eyes**

Semtech 4in-9.6dB VSR channel 2 TP1a eye with a standard 6dB CTLE

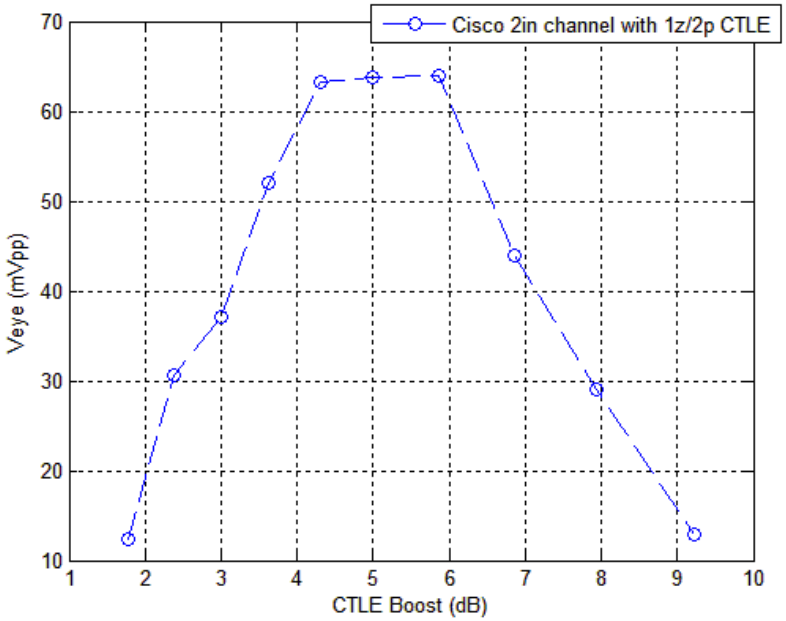


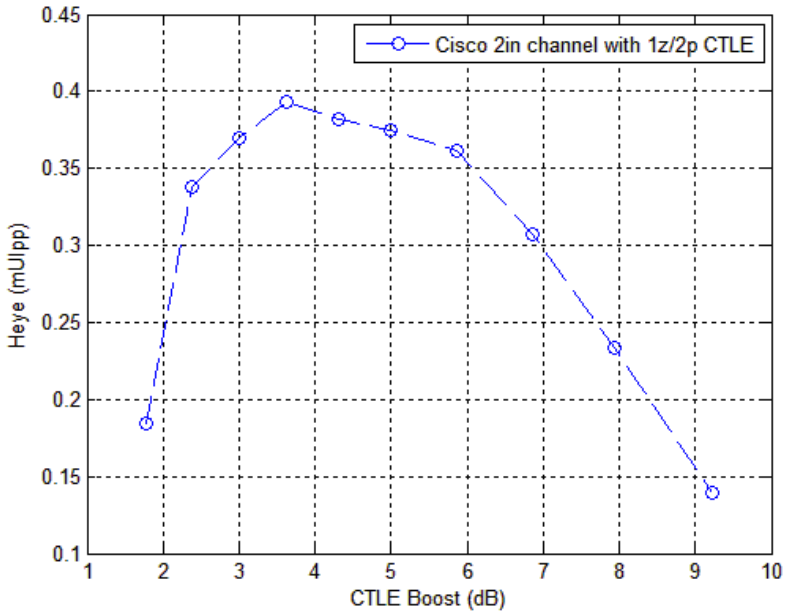
- **Tx FIR: [-0.05 0.95]**
- **Rx CTLE:**
  - 5.87dB boost
  - 1Z: 4.5 GHz
  - 2P: 15.0, 20.0 GHz
- **> 4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	75.1	11.3	0.328
Middle eye	77.8	14.1	0.409
Lower eye	75.8	11.3	0.328

Cisco 2in VSR channel TP1a eye metrics vs 1z/2p CTLE boost with 1-dB pre-cursor Tx

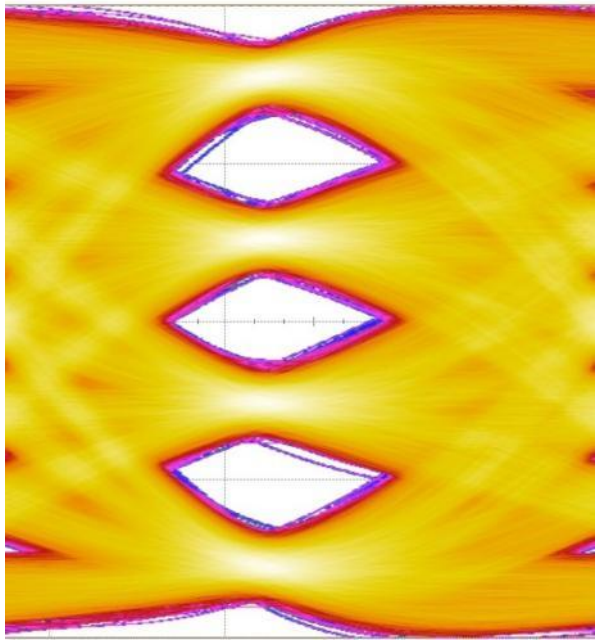
- Results based on 25K symbol pattern length





- CTLE having 4-6dB boost is optimal for the Cisco 2in channel

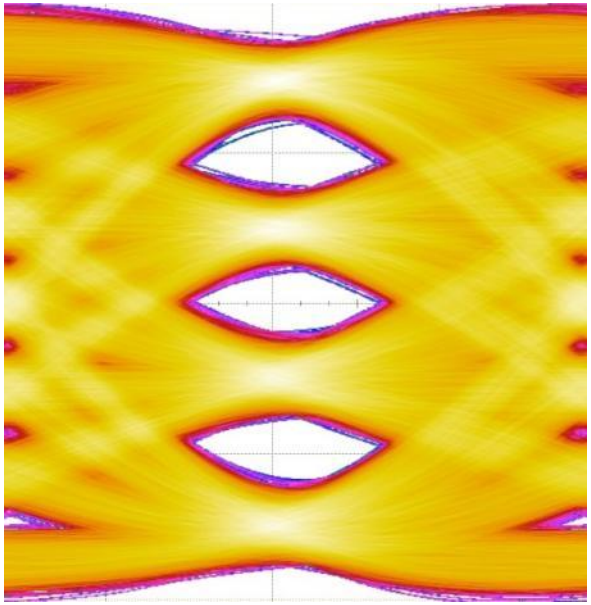
Cisco 2in-8.5dB VSR channel TP1a eye with a standard 5dB CTLE



- **Tx FIR: [-0.00 1.00]**
- **Rx CTLE:**
  - 5.00dB boost
  - 1Z: 5.0 GHz
  - 2P: 15.0, 20.0 GHz
- **>4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	59.9	9.30	0.270
Middle eye	60.7	11.6	0.336
Lower eye	56.3	9.42	0.273

Cisco 2in-8.5dB VSR channel TP1a eye with a 2z/3p CTLE

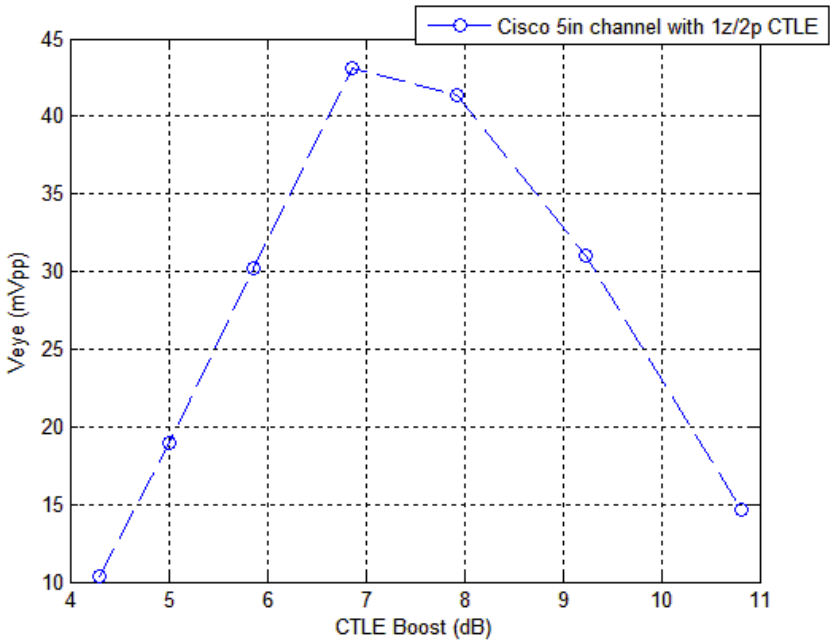


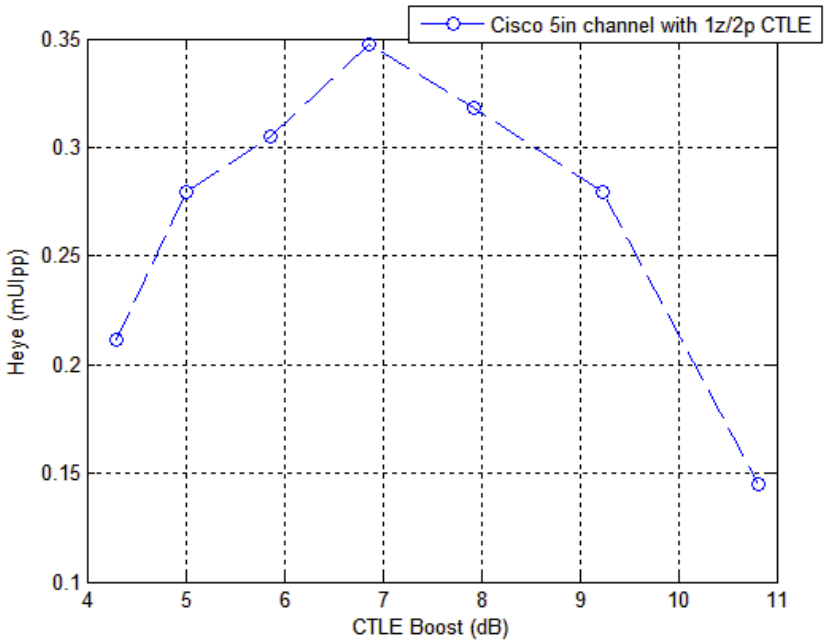
- **Tx FIR: [-0.05 0.95]**
- **Rx CTLE:**
  - 5.39dB boost
  - 2Z: 8.75, 8.75 GHz
  - 3P: 15. Results based on 25K symbol pattern length
  - 20,0 20.0, 20.0 GHz
- **>4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	45.2	10.1	0.293
Middle eye	47.0	11.3	0.328
Lower eye	47.6	10.6	0.307

Cisco 5in VSR channel TP1a eye metrics vs 1z/2p CTLE boost with 1-dB pre-cursor Tx

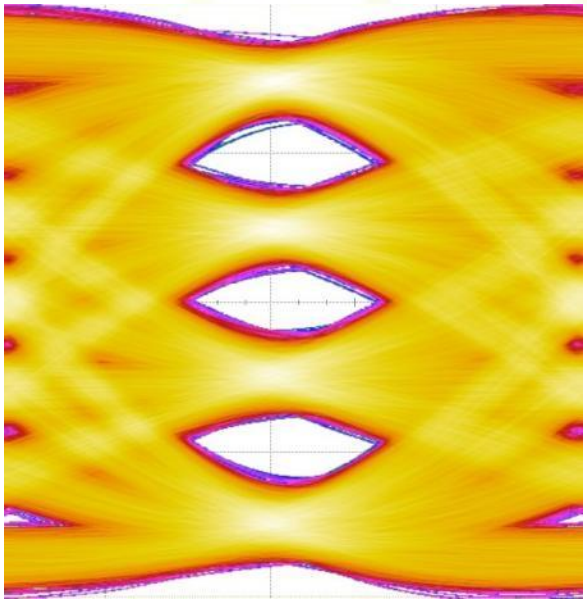
- Results based on 25K symbol pattern length





- CTLE having 7dB boost is optimal for the Cisco 5in channel
- This channel has higher ILD than the Semtech channel and fails the TP1a eye height even at 7dB boost

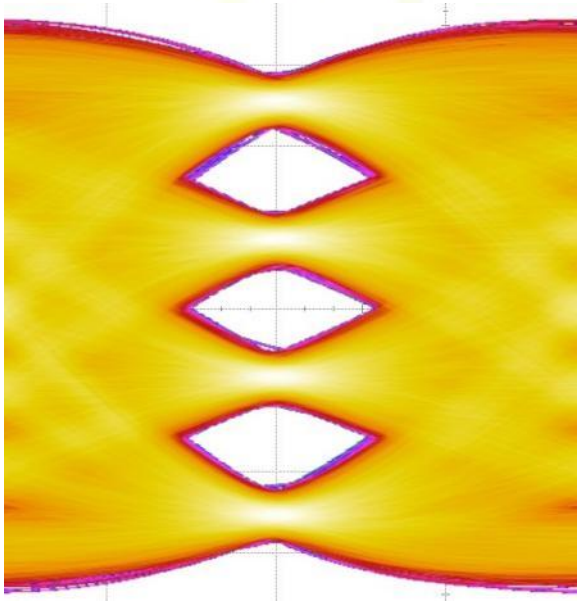
Cisco 5in-11.5dB VSR channel TP1a eye with a standard 7dB CTLE



- **Tx FIR: [-0.05 0.95]**
- **Rx CTLE:**
  - 6.86dB boost
  - 1Z: 4.0 GHz
  - 2P: 15.0, 20.0 GHz
- **>4M Samples**
- **No crosstalk**

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	34.6	9.06	0.263
Middle eye	36.6	11.40	0.330
Lower eye	34.6	10.41	0.302

System based upon a 3-tap FIR-only approach for Cisco 5in channel



- Tx FIR: [-0.08 0.68 -0.24]
- Rx CTLE: None

- 4M Samples
- No crosstalk

PAM-4 Eye	1E-6 Veye (mVpp)	1E-6 Heye (ps)	1E-6 Heye (mUIpp)
Upper eye	46.4	9.30	0.270
Middle eye	47.0	12.57	0.365
Lower eye	45.3	9.30	0.270

- Although the 3-tap FIR-only approach could potentially provide better performance than a CTLE based approach it still seems very challenging for this channel

Summary of Simulation Results

Case - channel	Tx FIR	Rx CTLE	Cross talk	Veye (mVpp)	Heye (UIpp)
Semtech 10in trace	None	1z (4.5GHz), 2p (15.0, 20. GHz)	No	56.8	0.316
Semtech 10in trace	[-0.05 0.95]	1z (4.5GHz), 2p (15.0, 20. GHz)	No	70.1	0.336
Semtech 10in trace	[-0.10 0.90]	1z (4.5GHz), 2p (15.0, 20. GHz)	No	69.4	0.307
Semtech 10in trace	[-0.05 0.95]	2z (4.5 15.0 GHz) 3p (12.0 23.0 25.0 GHz)	No	64.8	0.360
Cisco 2in chan	None	1z (5.0GHz), 2p (15.0, 20. GHz)	No	56.3	0.270
Cisco 2in chan	[-0.05 0.95]	2z (8.75 8.75GHz) 3p (15.0 20.0 20.0 GHz)	No	**45.2**	0.293
Cisco 5in chan	[-0.10 0.90]	1z (4.0GHz), 2p (15.0, 20. GHz)	No	**34.6**	0.263
Cisco 5in chan	[-0.08 0.68 -0.24]	None	No	**45.3**	0.270
Semtech 4in chan 1	[-0.07 0.93]	1z (4.5GHz), 2p (15.0, 20. GHz)	No	**48.3**	0.254
Semtech 4in chan 2	[-0.07 0.93]	1z (4.5GHz), 2p (15.0, 20. GHz)	No	75.1	0.328

- **Cisco 5in and Semtech 4in channel-1 were the most challenging – highest loss and Semtech 4in had huge ILD for f>20 GHz**
- **All of the channel appear capable of meeting PAM4 Heye requirements**
- **Semtech chan2 was the highest performing**

Summary

- **A standard 1z/2p CTLE should be adequate for most expected VSR channels in the host-to-module direction**
  - A 2-tap FIR in the host with some small pre-cursor de-emphasis can help to provide additional system margin
- **A channel at maximum VSR loss with higher ILD may require one of:**
  - Multi-tap FIR
    - This should not be mandatory for 56G-VSR-PAM4 as it is not the only option and forces too narrow a solution space
  - Higher performance reference CTLE
    - This needs further study but is likely the preferable solution to minimize module power
  - Note: The challenges of a host ASIC and a module retimer IC are fundamentally different. This drives different optimized solutions for each end the link

Recommendations

- Develop an agreed ILD mask for the channel
- Using the newly developed ILD mask, identify the worst-case channel(s)
- Repeat the analysis on equalization needs, using an agreed set of metrics
- Update reference receiver definition, if required