100G PAM PMD Observations

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Outline

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- PAM & LR4 Cost Comparison
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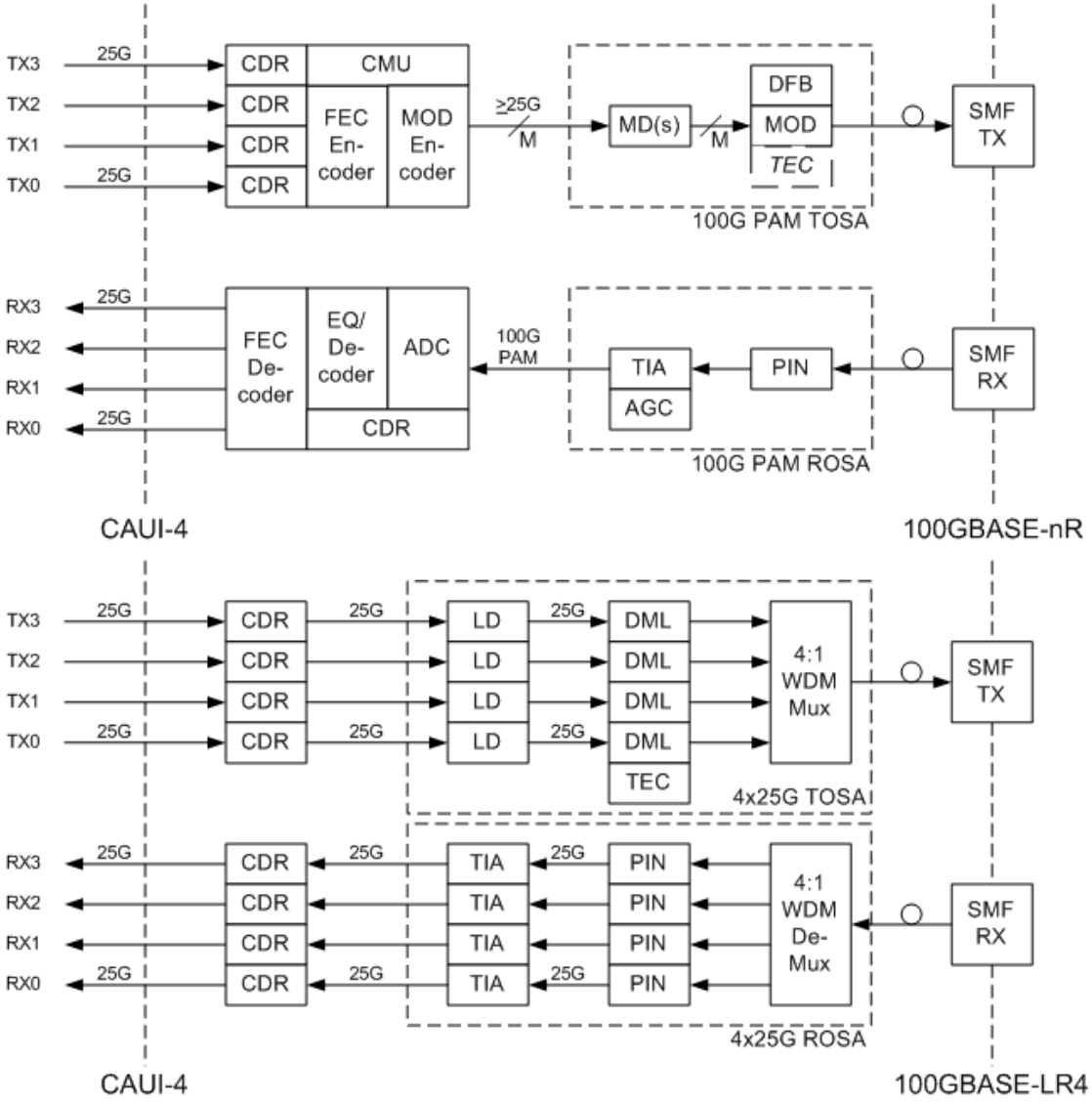
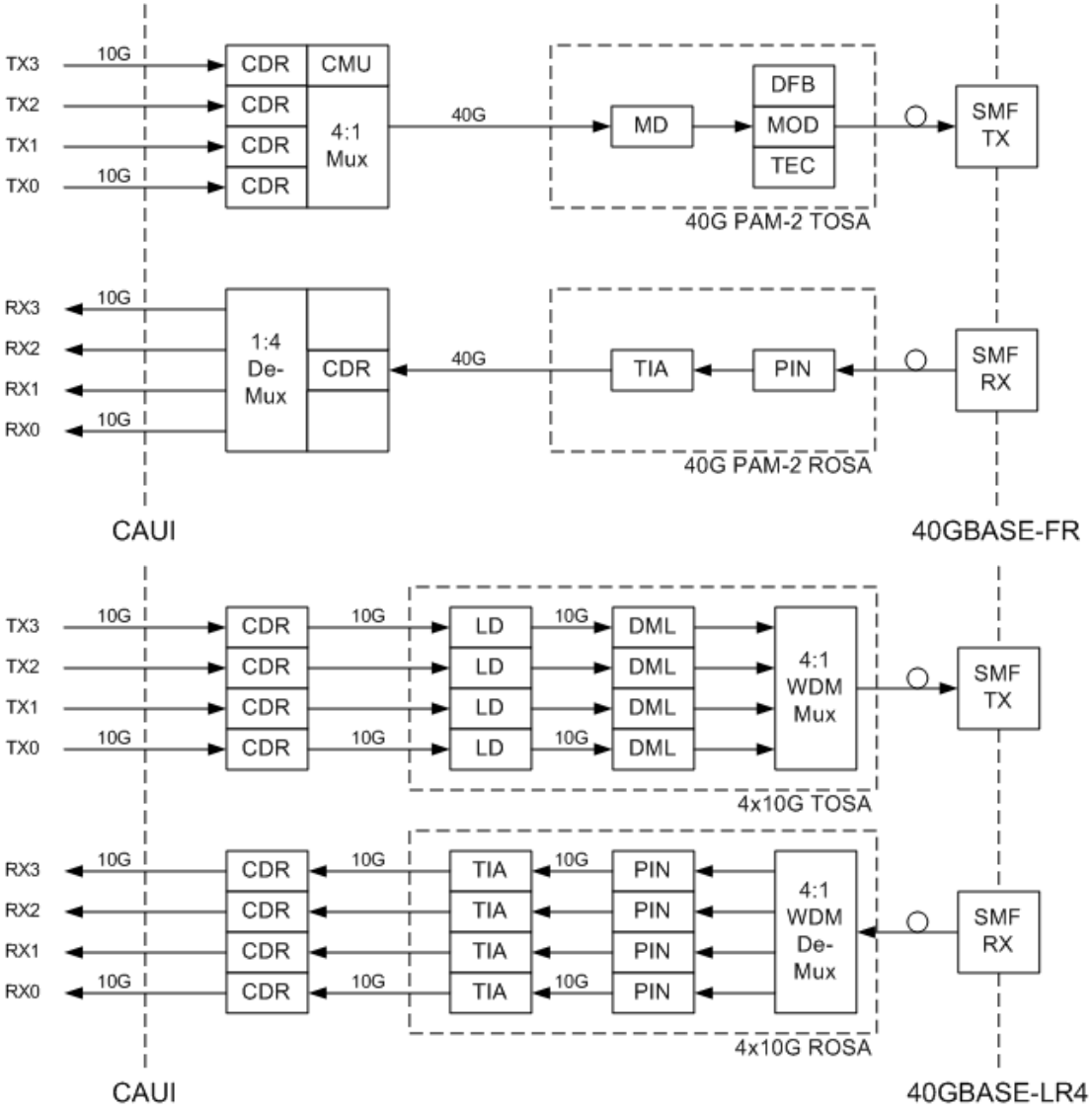
100G PAM & LR4 Block Diagrams



100G PAM & LR4 Cost Comparison

- Gavrilovic, Nicholl, Nowell, Traverso (nicholl_01_0112, p.5) 100G PAM to LR4 cost ratio: **0.5x** to **0.3x**
- No objective 100G PAM costs have been presented making independent verification impossible
  - No comparable production 100G TOSA or ROSA exists
  - No Si Mod based transceiver at any rate deployed
- Is there an objective PAM & LR4 cost comparison that can be independently verified?
- Yes! 40G PAM-2 (NRZ) to LR4 transceiver cost comparison
  - Multiple transceiver and component suppliers exist
  - IEEE 802.3 and ITU-T standards exist
  - Multiple transceivers deployed in volume

40G PAM & LR4 Block Diagrams



40G PAM & LR4 Observations

- Comparison is more favorable to PAM at 40G than at 100G
  - 40G LR4 is modestly simpler than 100G LR4
  - 40G PAM-2 is greatly simpler than 100G PAM-8/16
- 40G PAM is in production in the 300-pin SFF form factor (CFP ~size) and is transitioning to CFP
- Planned 40G PAM development efforts will result in significant future cost reduction
- 40G LR4 is in production in the CFP form factor and is transitioning to QSFP+
- Planned 40G LR4 development efforts will result in significant future cost reduction

40G PAM PMD Broad Market Potential

Supporters (and contributors*)

40GE SMF PMD CFI Nov. 2009

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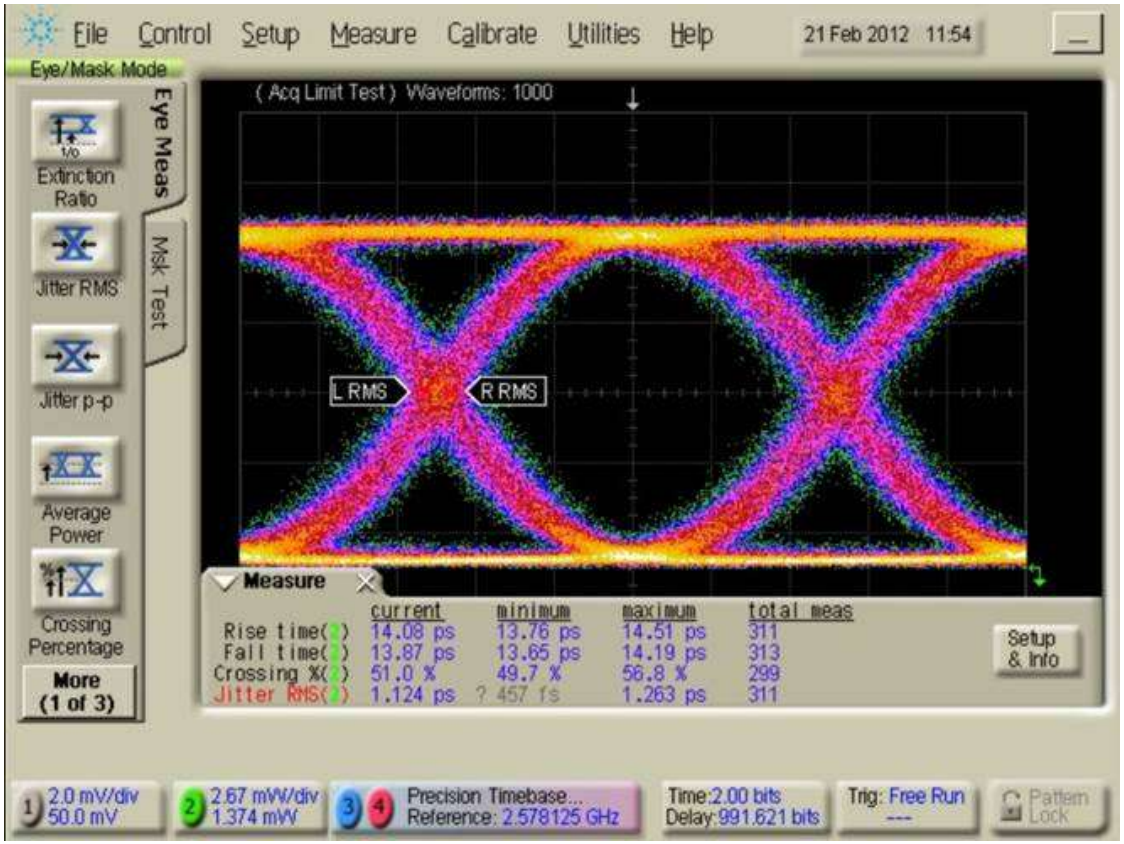
40G PAM Mod Trise/fall Requirements

PAM-2 (NRZ) Eye Trise/fall = 14ps (from CFP 40GE-FR DCA eye below)



PAM-8 Eye Trise/fall = 7ps (bhoja_01_0112, p.10, heaton_01_0312, p.11)

PAM-16 Eye Trise/fall = 12ps (bhoja_01_0112, p.22, dama_01_0312, p. 4)

40G PAM & LR4 Observations cont.

- 40G PAM transceiver observations
  - Broad market exists
  - Standards based specifications exist
  - PAM-2 TOSAs & ROSAs exist
  - PAM-2 SerDes exist
  - Form factors (CFP, QSFP+) exist
  - Proposed 100G PAM-8/16 Si Mods have the required Trise/fall for 40G PAM-2
  - If 40G PAM to LR4 cost ratio was **0.5x** to **0.3x,** this would result in PAM dominating the 40G client market
- So why is the market not dominated by 40G PAM Si Mod based CFP or QSFP+ transceivers?
- Even with best case assumptions about Si Mod cost, 40G PAM transceiver cost is greater than LR4 cost

PAM & LR4 Cost Comparison

100G CFP2 Blocks	LR4 Cost	PAM Cost
TX (TOSA)	0.32	0.02 - 0.18
RX (ROSA)	1	0.35
SerDes		
Misc. (mechanics)		
Assembly/ Test		
TOTAL	0.46	0.13 - 0.23

100G module cost analysis: nicholl_01_0112, page 5

40G CFP Blocks	LR4 Cost	PAM-2 Cost
TX (TOSA)	1x	3x
RX (ROSA)	1x	2x
SerDes	1x	14x
Misc. (mechanics)	1x	1x
Assembly/ Test	1x	1x
TOTAL	1x	3x

40G module cost analysis: blended cost of multiple real 40G components

PAM & LR4 Cost Comparison cont.

Historical 40G PAM-2 to LR4 cost comparisons

- Traverso, Mar'08→July'08, projected 2012 ratio: **1x→0.6x** **(**ba/…/traverso_04_0308, traverso_02_0708)
- Cole, Sept'08, projected 2012 ratio: **4x**

  (ba/…/cole_02_0908)

Current 40G PAM-2 to LR4 cost comparisons

- Cole Mar'12 (previous page) calculated 2012 ratio: **3x**
- LightCounting, Dec'11, projected 2012 ratio: **3.3x**

Current 100G PAM-8/16 to LR4 cost comparisons

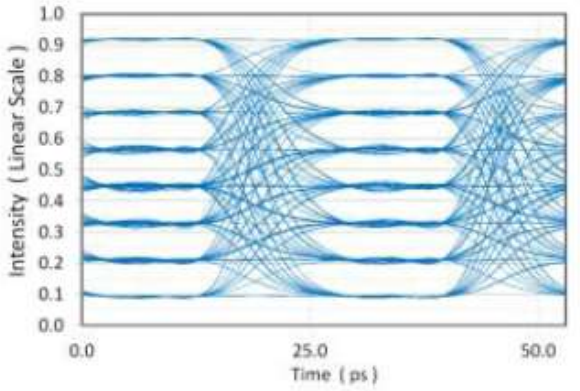
- Nicholl, Traverso, et al., Jan'12, projected ratio: **0.5x** to **0.3x**
- 40G to 100G **10x** drop of PAM to LR4 ratio is just as improbable as was the **10x** in 2 yrs. drop of 40G PAM cost projected in July'08 by PAM proponents

10x drop

Conclusions

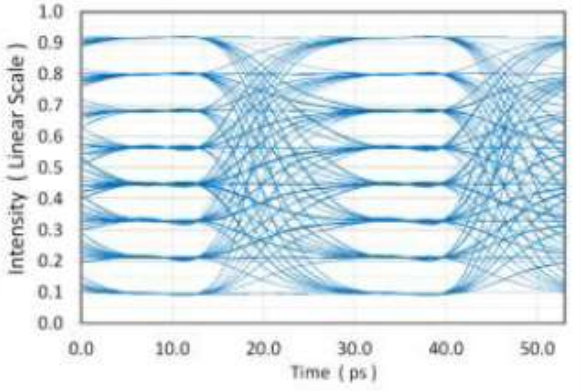
- 100G Si Mod based PAM transceiver cost advantage claims have no verifiable cost data behind them
- 100G Si Mod based PAM transceiver cost advantage claims are not credible as shown by independently verifiable 40G cost data
- 100G PAM cost advantage claims do not justify adopting a new 100G SMF PMD objective
- 40G & 100G DML PIC based LR4 transceivers are the lowest cost solutions for duplex SMF data center applications

Appendix: PAM-8 Eyes vs. Trise/fall



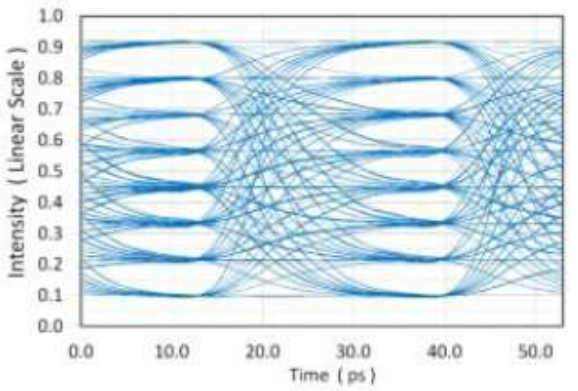
37 GHz 3dB *(6.3ps)*

(using cole_03_0112: 6.5ps)

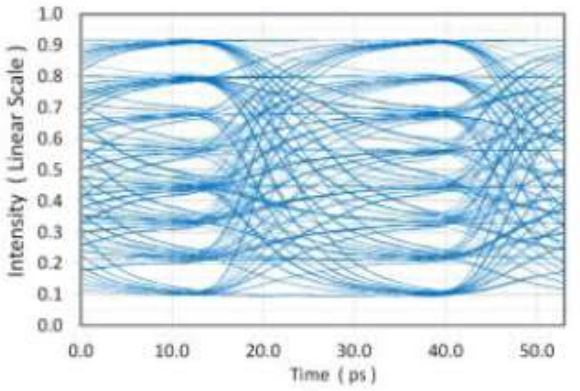


32 GHz 3dB *(7.3ps)*

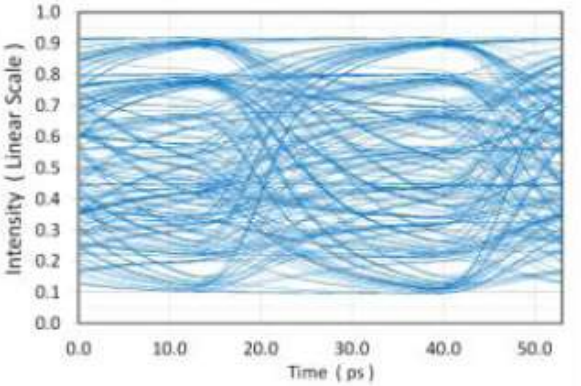
(using cole_03_0112: 7.5ps)



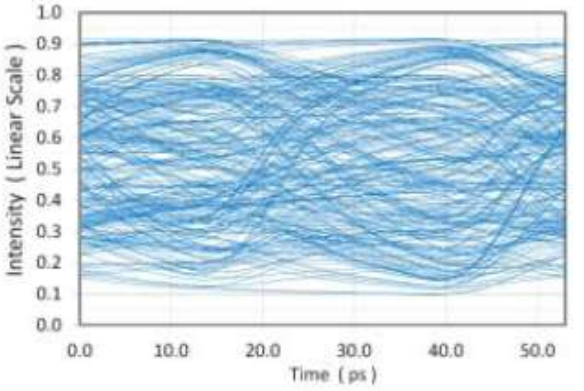
25 GHz 3dB *(9.3ps)*



20 GHz 3dB *(12ps)*



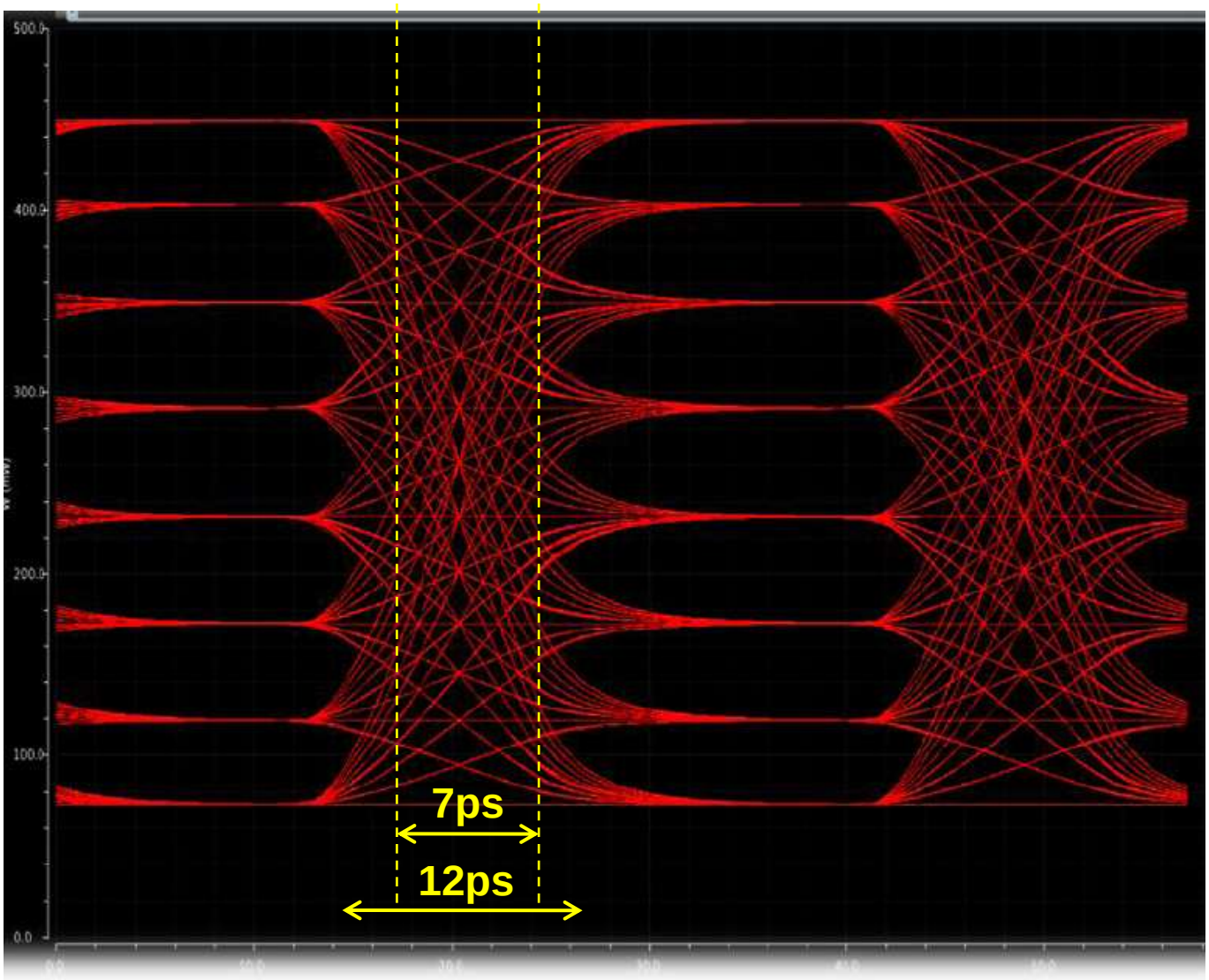
15 GHz 3dB *(16ps)*



10 GHz 3dB *(23ps)*

heaton_01_0312 p.11 *(20-80% Trise/fall = .233 / BW)*

Appendix: PAM-8 Eyes Trise/fall Analysis



PAM-8 eye: bhoja_01_0112 p.10

Yellow cursors superimposed on the eye to show Trise/fall

This page was added post-presentation to document Q&A discussion