simDM ACT & TDD Simulation

Contribution to 802.3dm Task Force

January 20, 2025

Ragnar Jonsson - Marvell

Supporters

- Kresimir Mirosavljevic – Cariad
- Thomas Hogenmueller – Bosch
- Rich Boyer – Aptive
- Ram Ganapathi – Nvidia
- Sanjeev Jain – Nvidia
- Amir Bar-Niv – Marvell
- Heath Stewart – ADI
- Hossein Sedarat – Ethernovia
- Jay Cordaro – ADI
- Ky-Anh Tran – Aeonsemi
- Yunteng Huang – Aeonsemi
- William Lo – Axonne

Introduction

- This presentation evaluates the performance of an ACT in various operating environments
- TDD simulation is presented for comparison
- The simulations are done for 2.5Gbps and 10Gbps
- For 2.5Gbps, both PAM2 and PAM4 are simulated for comparison
- The simulation is based on simulation framework presented in a separate presentation (jonsson_3dm_01_12_19_24.pdf), and the simulation code is provided for reference and to allow more thorough review
- The simulation uses the good and bad 15m cables from jonsson_3dm_02_09_15_24.pdf

Simulation Details

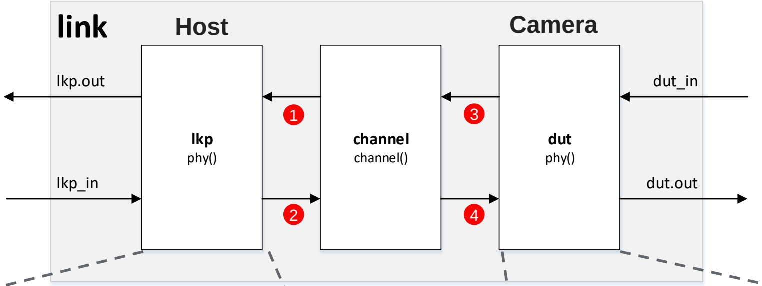
- The simulation uses a 22.5GHz sampling rate to represent analog signals, and analog signal levels are represented in Volts
- No quantization is done at the ADC (only down-sampling), to minimize ambiguity due to signal quantization
- The hybrid is simulated as simple passive hybrid
  - See slide 4 of jonsson_3dm_02a_12_19_24.pdf

Simulation of Equalizer and Echo Cancelation

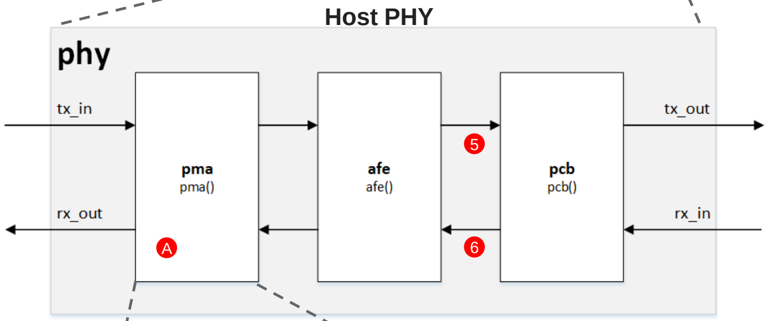
- **No echo cancelation** is used for either high or low data rate signals
- **No equalization** is used for the 100Mbps DME signal
- T/2-spaced equalizers are used for the high data rate signals, to minimize ambiguity due to sampling phase at the ADC
- The equalizer has 30 FFE taps and 10 DFE taps
- Equalizer coefficients for high data rate signals are calculated using line probing signals and closed form minimum mean square equalizer algorithm from [1]
  - The noise estimate is set to zero, so this becomes zero-forcing equalizer solution

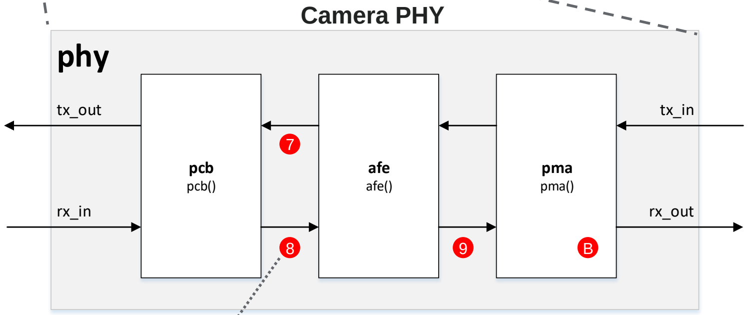
[1] R. H. Jonsson, "DSL Channel Equalization" in *Fundamentals of DSL Technology* P. Golden, H. Dedieu, and K. S. Jacobsen, Eds. CRC Press, 2005, pp. 299-350.

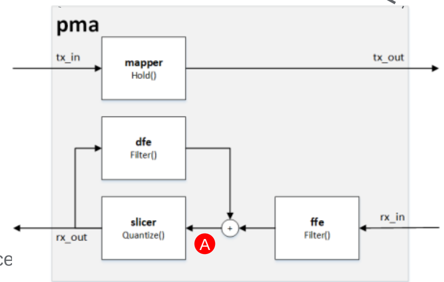
Signal Path & Probe Points



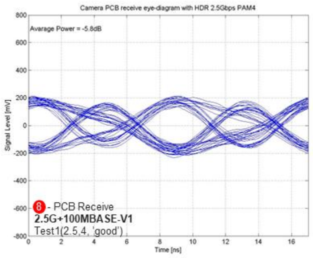
1 Host MDI Receive
2 Host MDI Transmit
3 Camera MDI Transmit
4 Camera MDI Receive







5 Host AFE Transmit
6 Host PCB Receive
A Host Slicer Input



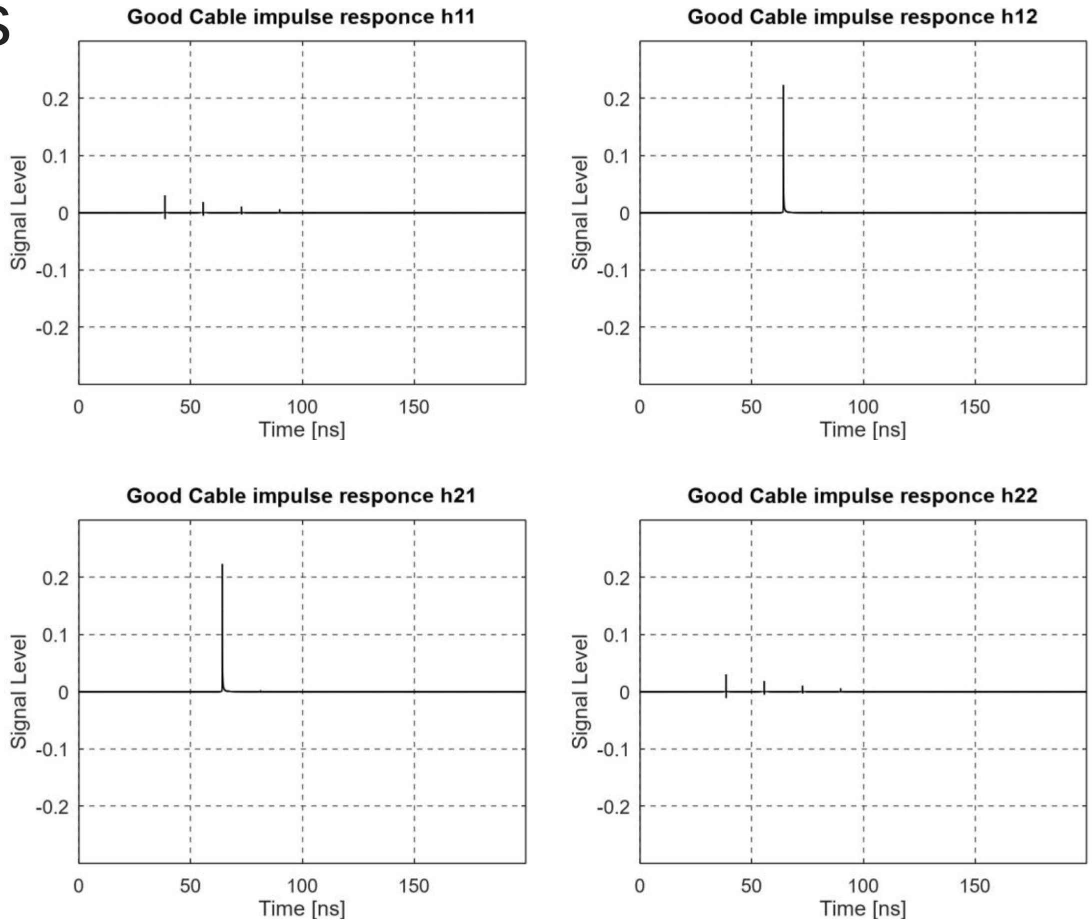
7 Camera AFE Transmit
8 Camera PCB Receive
9 Camera AFE Receive
B Camera Slicer Input (TDD only)

Cable Characteristics

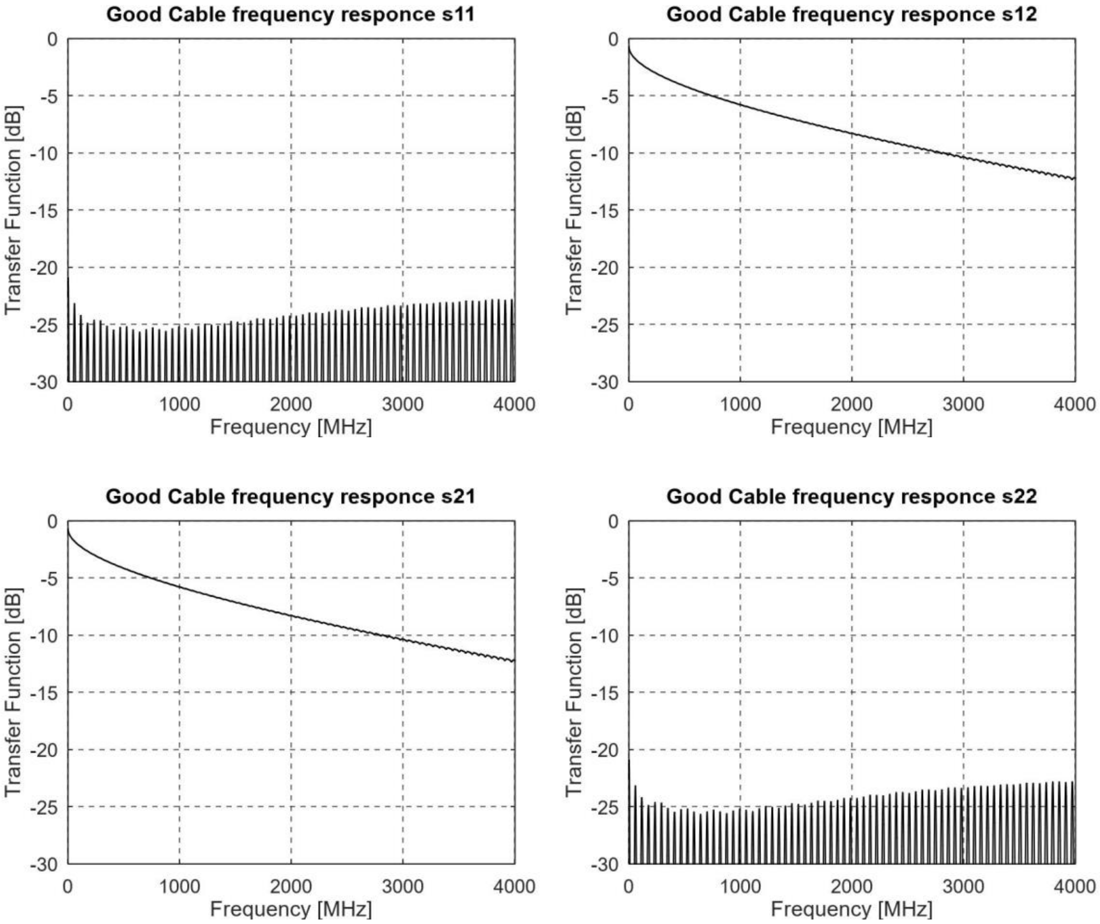
Simulated Cables

- The cables simulated in this presentation are taken from jonsson_3dm_02_09_15_24.pdf
- The s-parameters for these cables have been shared with the task force
- Both the good and the bad cable harnesses are based on RTK044 cable with four inline connectors: 4.5m+2m+ 2m+ 2m+4.5m
- The difference between them is that the bad cable harness has very bad simulated inline connectors
- The following slides show the impulse response, and the frequency transfer functions for the good and the bad cable harnesses
- Simulations have been run for number of other cables, and they have shown similar results to what is presented here

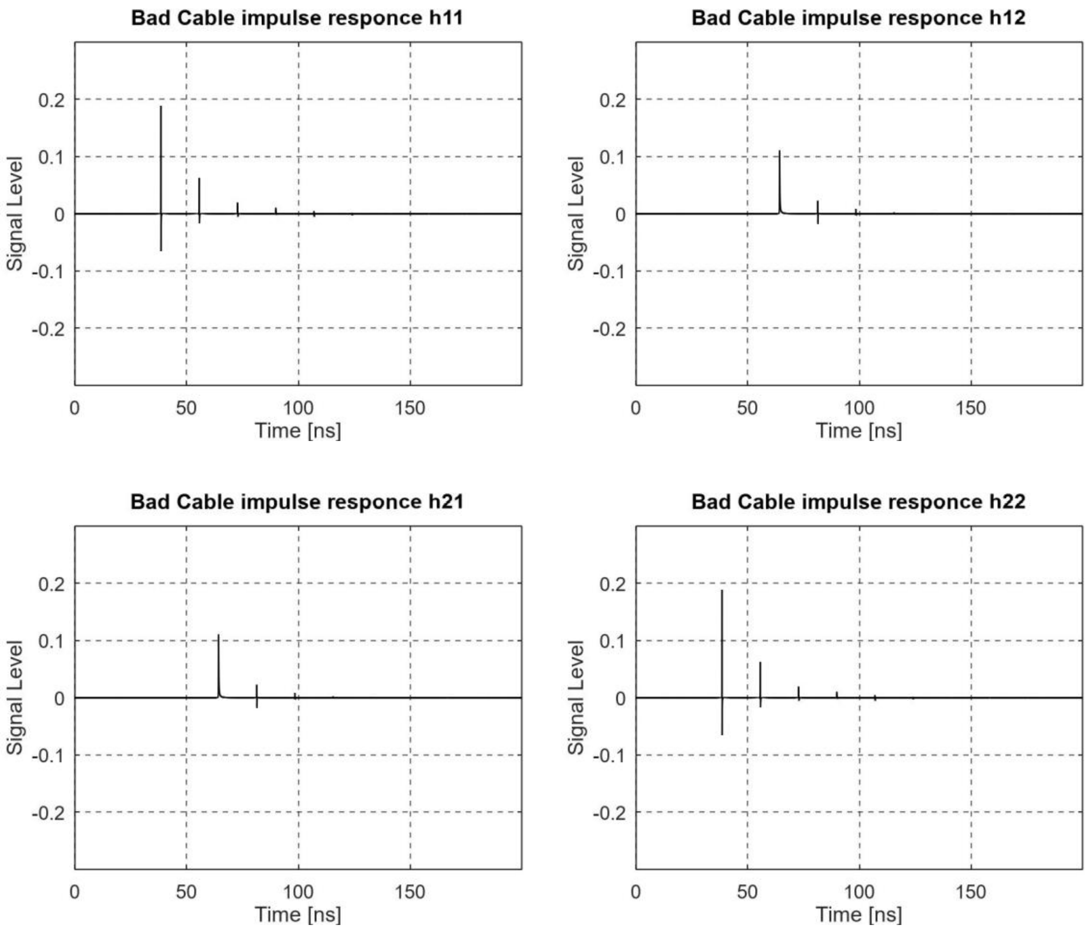
Good Cable Harness Impulse Responses



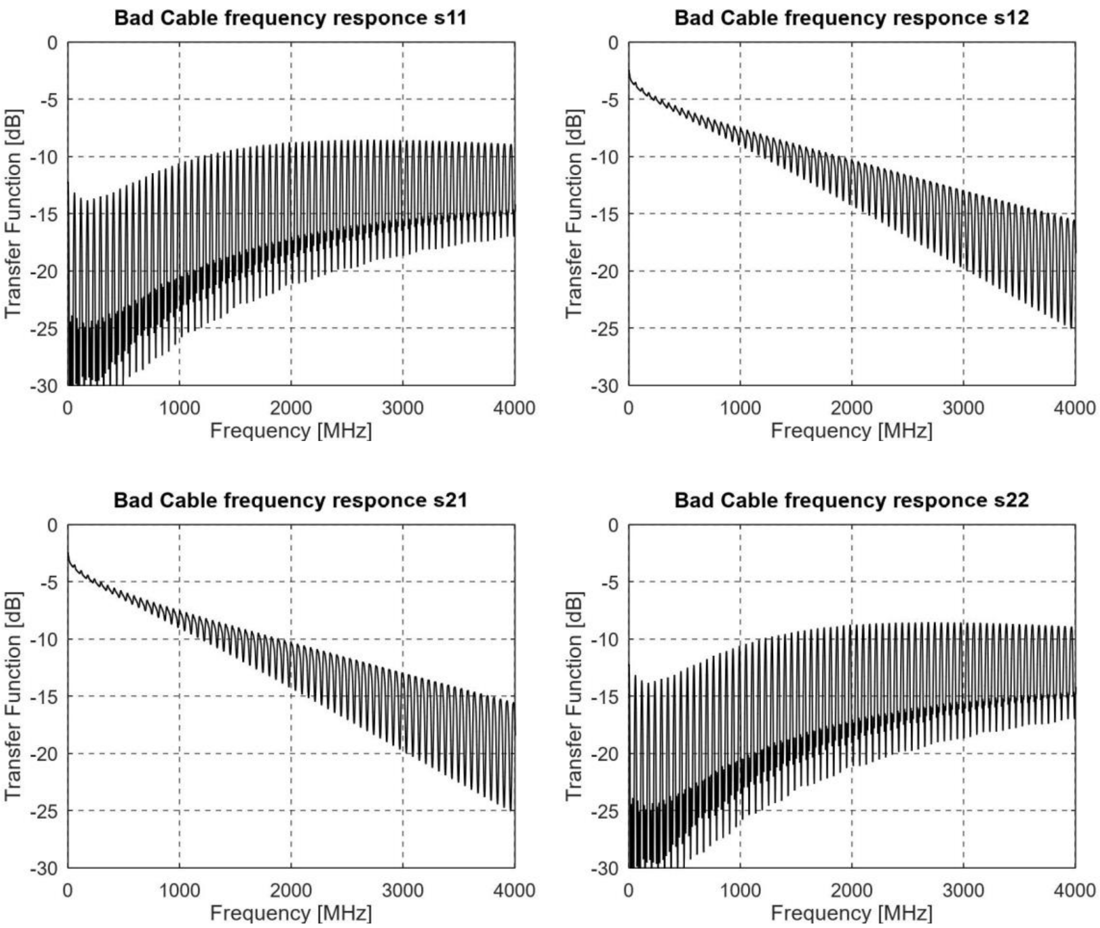
Good Cable Harness Transfer Functions



Bad Cable Harness Impulse Responses



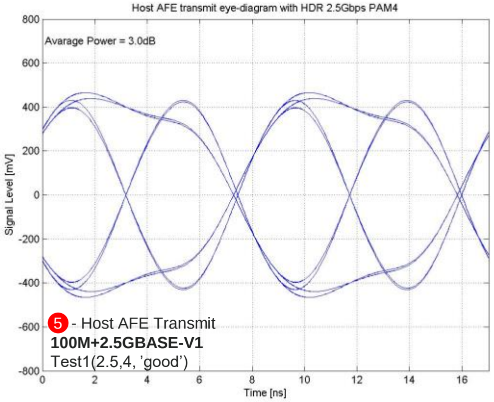
Bad Cable Harness Transfer Functions

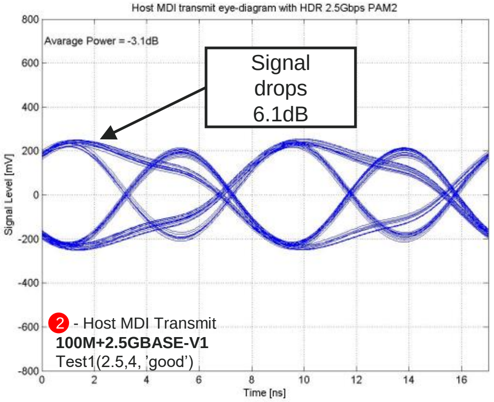


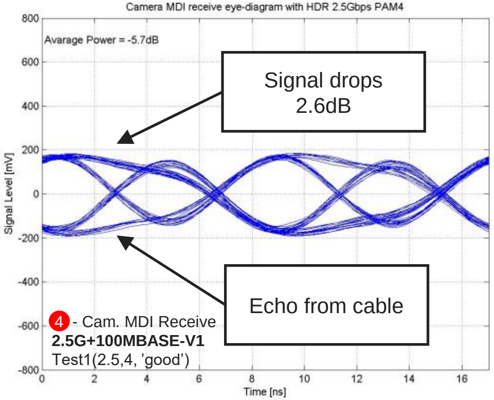
Signal Path on Good Cable

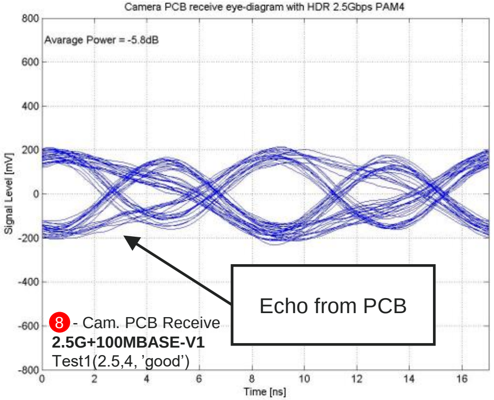
100M+2.5GBASE-V1 DME Signaling

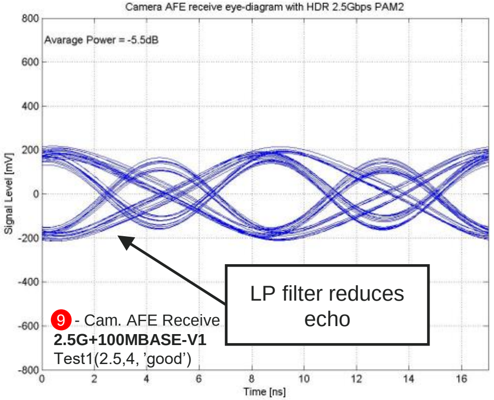
- The eye is open without any equalization





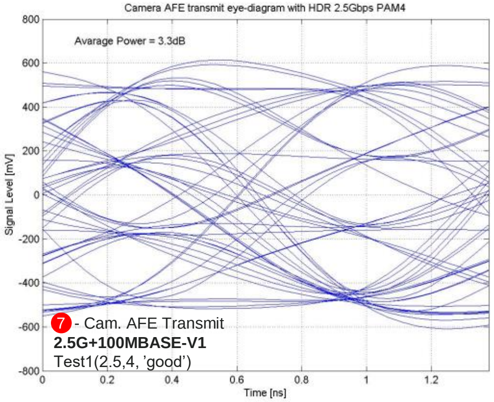


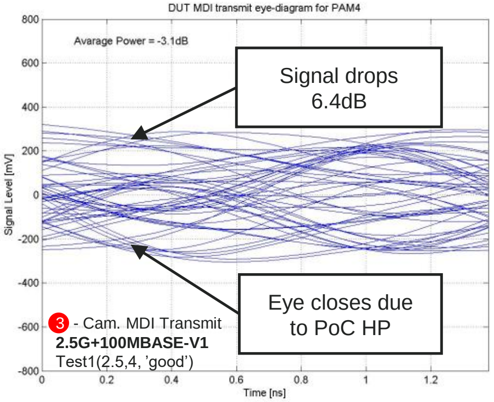


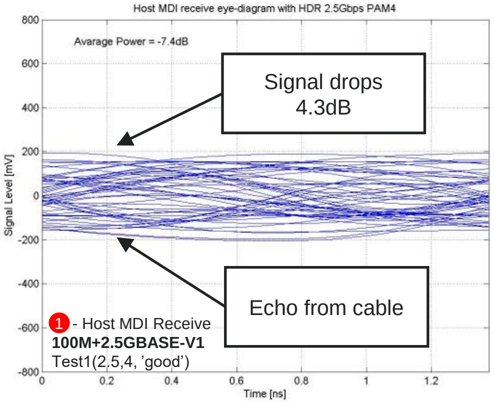


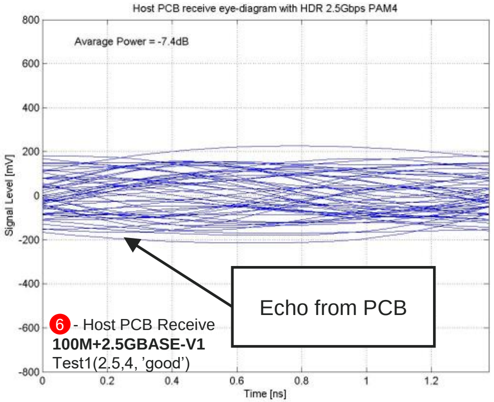
2.5G+100MBASE-V1 PAM4 Signaling

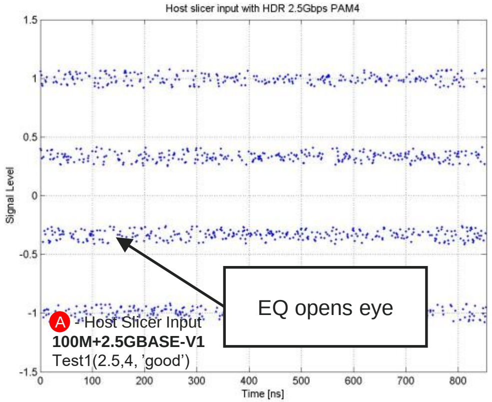
- The eye is closed without equalization





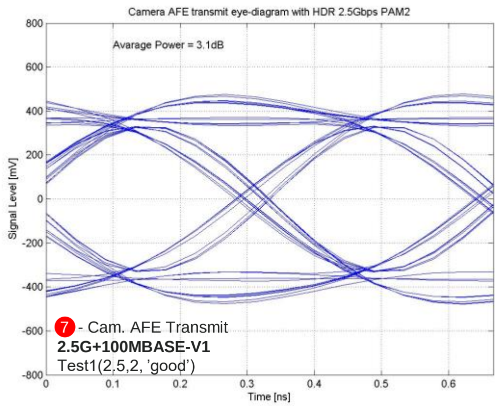


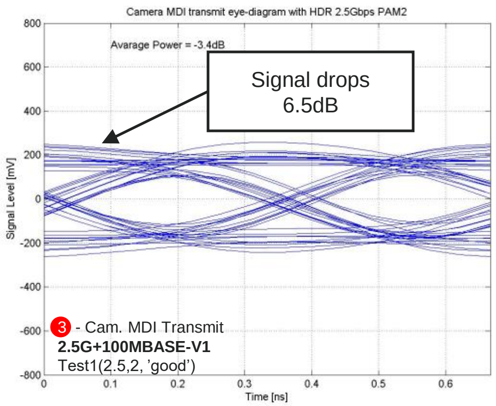


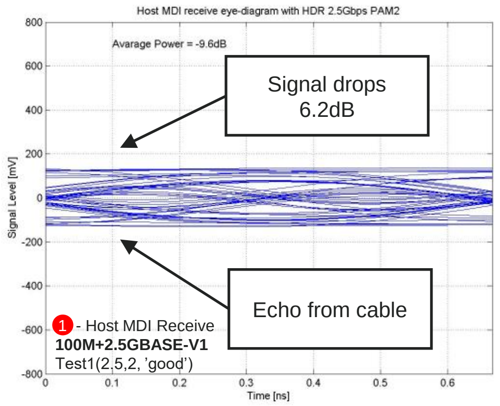


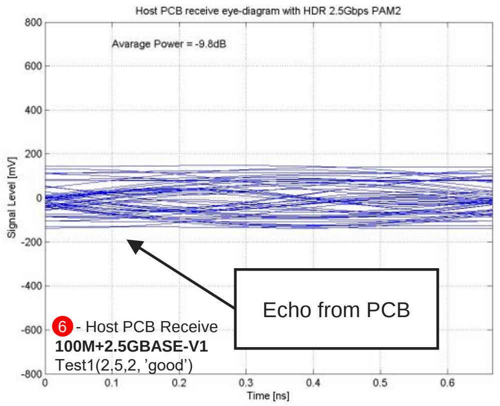
2.5G+100MBASE-V1 PAM2 Signaling

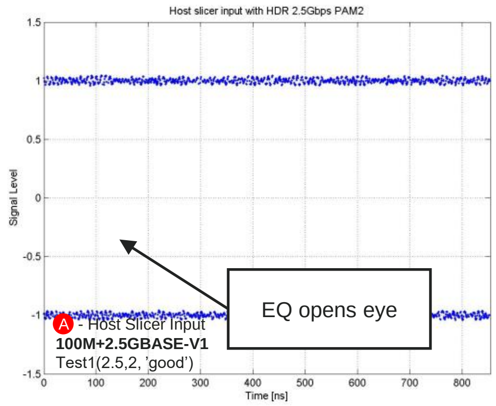
- The eye is closed without equalization





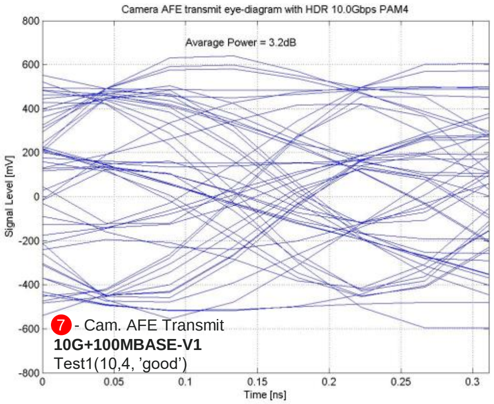


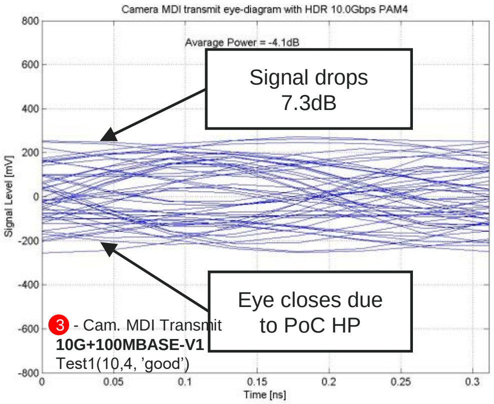


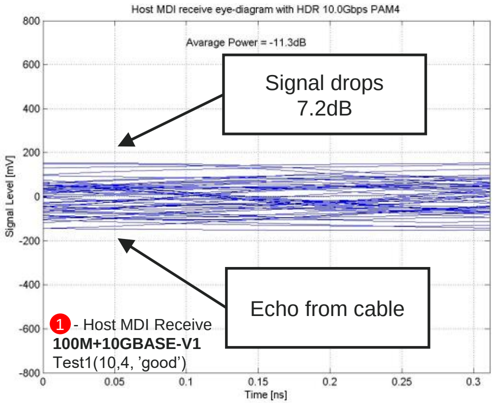


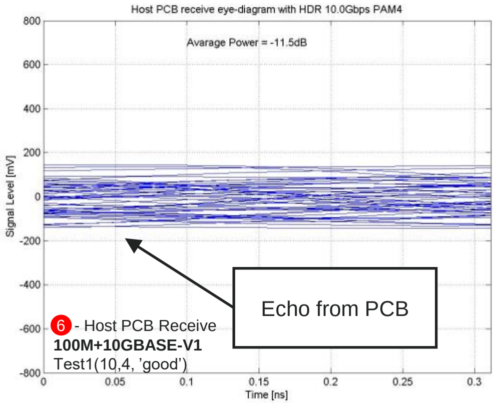
10G+100MBASE-V1 PAM4 Signaling

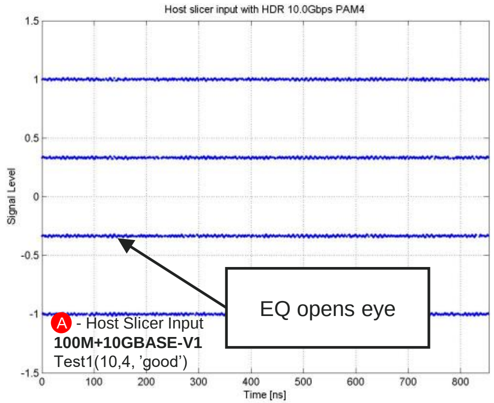
- The eye is closed without equalization









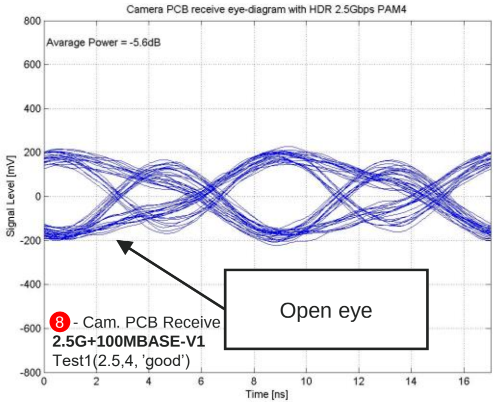


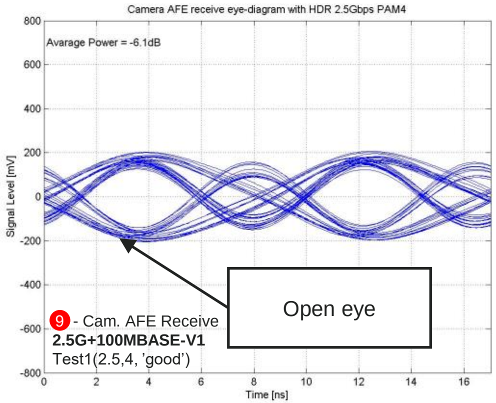
Good vs Bad Cable

100M+2.5GBASE-V1 DME Signaling

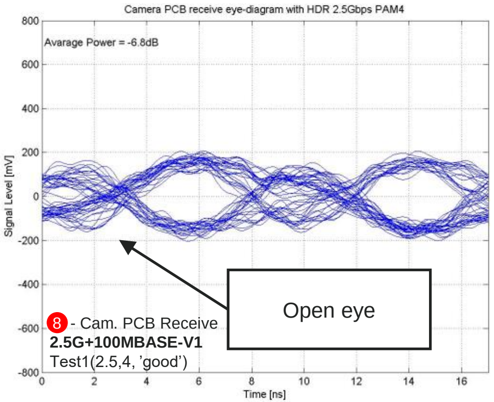
- The bad cable attenuates the signal more and introduces secondary reflections
- The bad cable introduces much more echo
- No echo cancelation or equalization is required

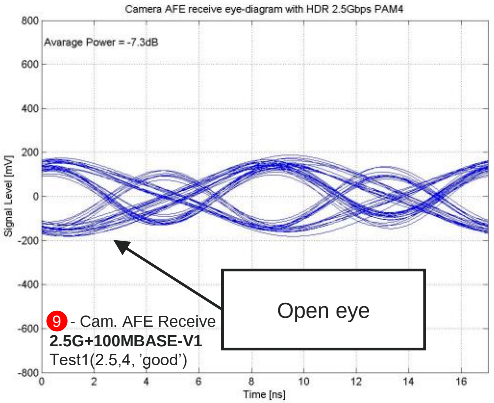
Good Cable





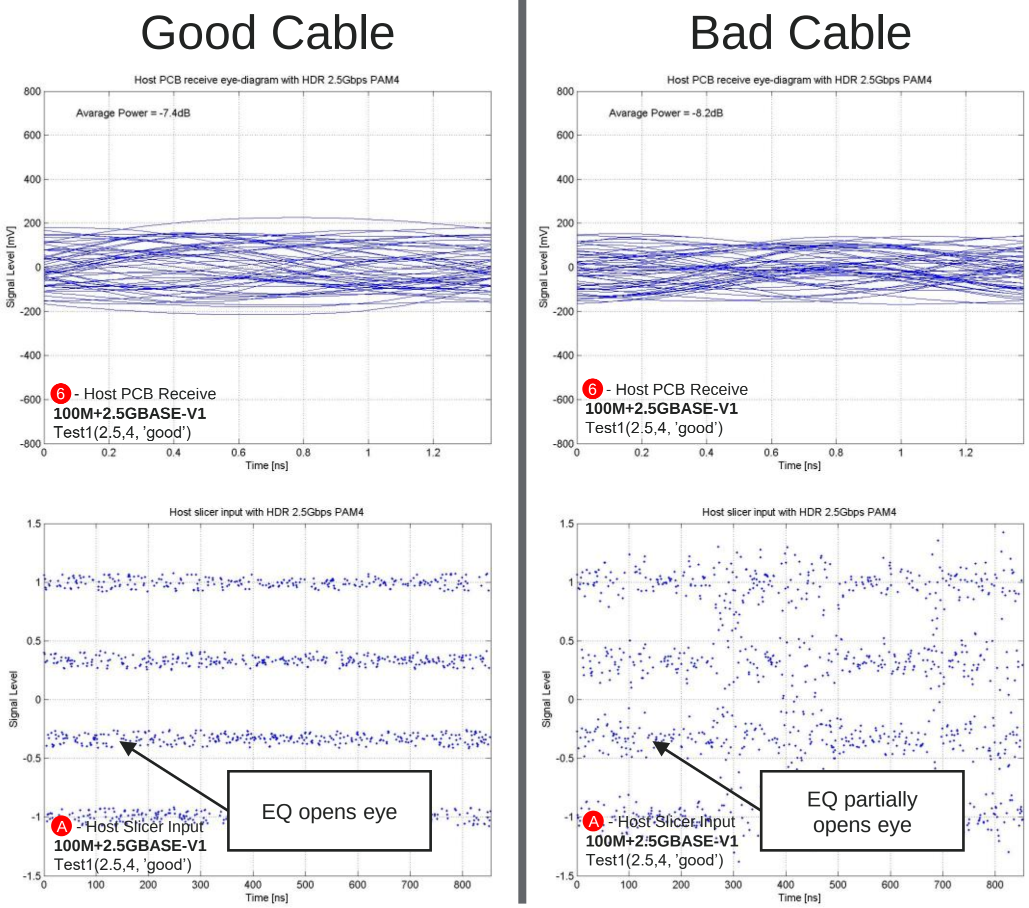
Bad Cable





2.5G+100MBASE-V1 PAM4 Signaling

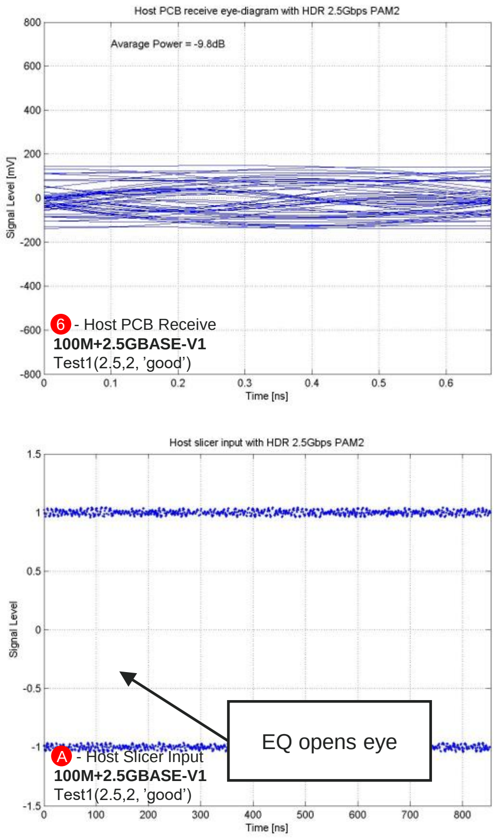
- The bad cable attenuates the signal more and introduces secondary reflections
- The bad cable introduces much more echo
- The equalizer in this experiment can only partially open the eye for the bad cable



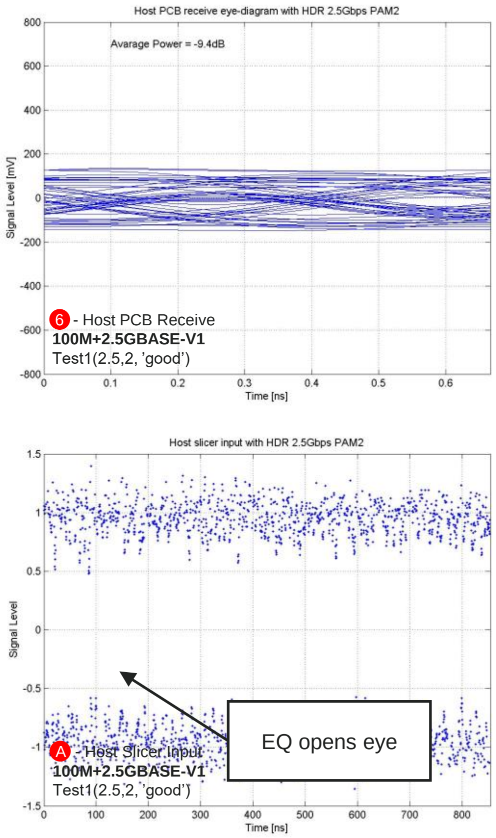
2.5Gbps PAM2 Transmit Signals

- The equalizer in this experiment can open the eye for the bad cable
- For the bad cable, the PAM2 modulation is performing better than the PAM4 modulation on previous slide

Good Cable



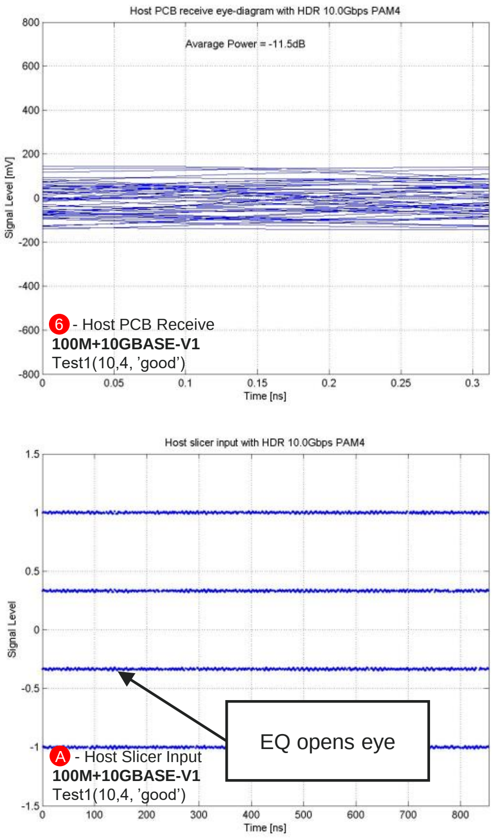
Bad Cable



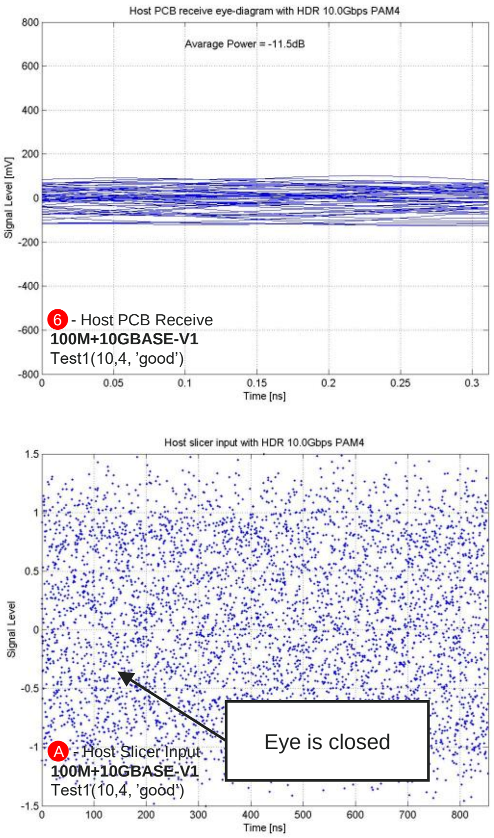
10G+100MBASE-V1 PAM4 Signaling

- The equalizer in this experiment can not open the eye for the bad cable

Good Cable



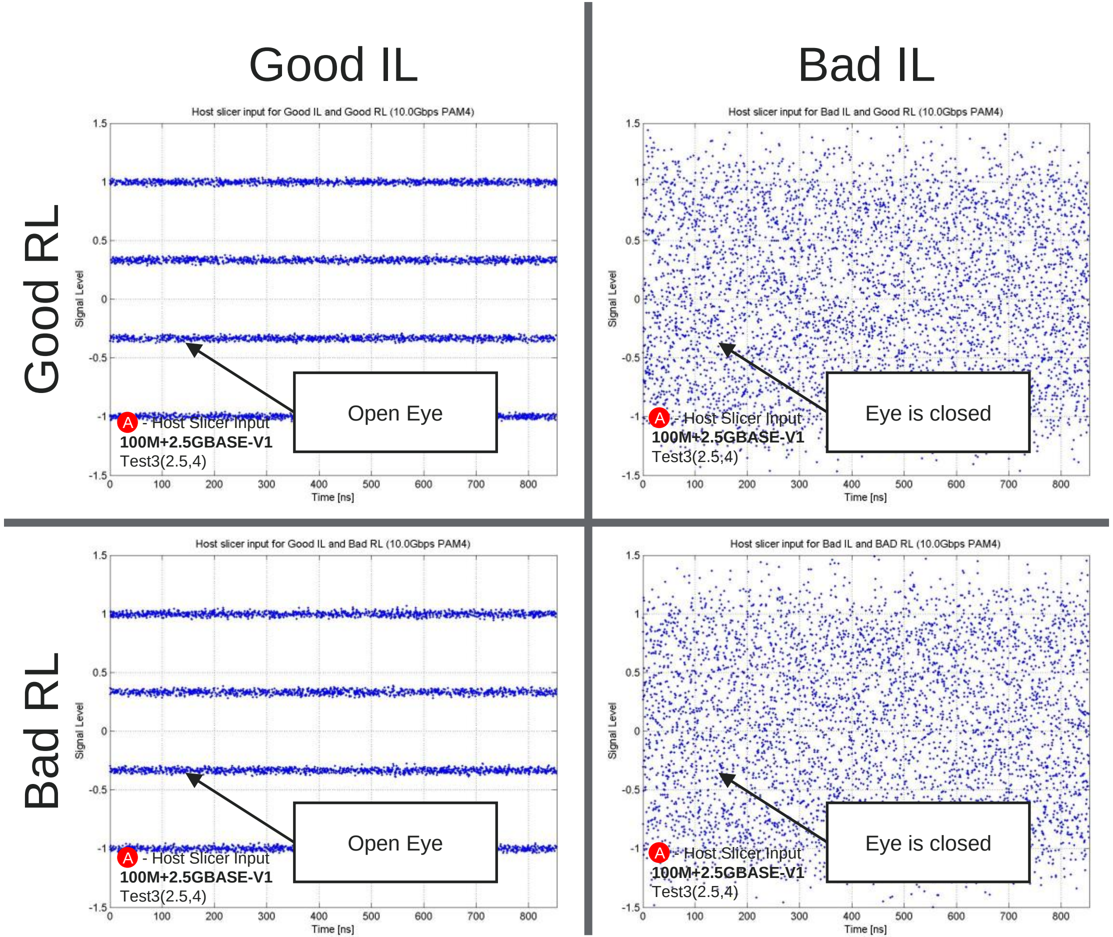
Bad Cable



Bad IL vs Bad RL

10G+100MBASE-V1 PAM4 Signaling

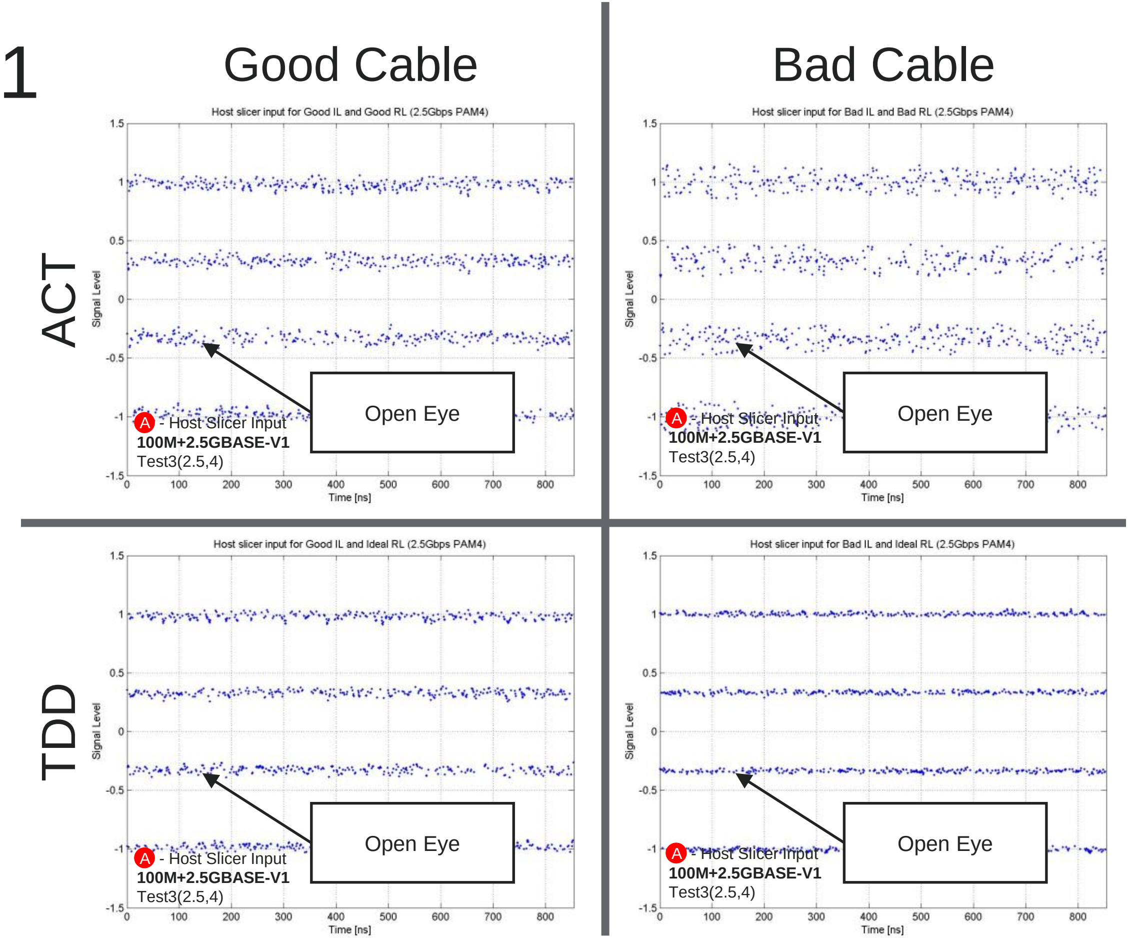
- The plots on the right compare the effect of insertion loss (IL) and return loss (RL) on the failed link for 10Gbps PAM4 on bad cable
- The plot shows that the failure is due to the bad IL, not the bad RL



ACT vs TDD

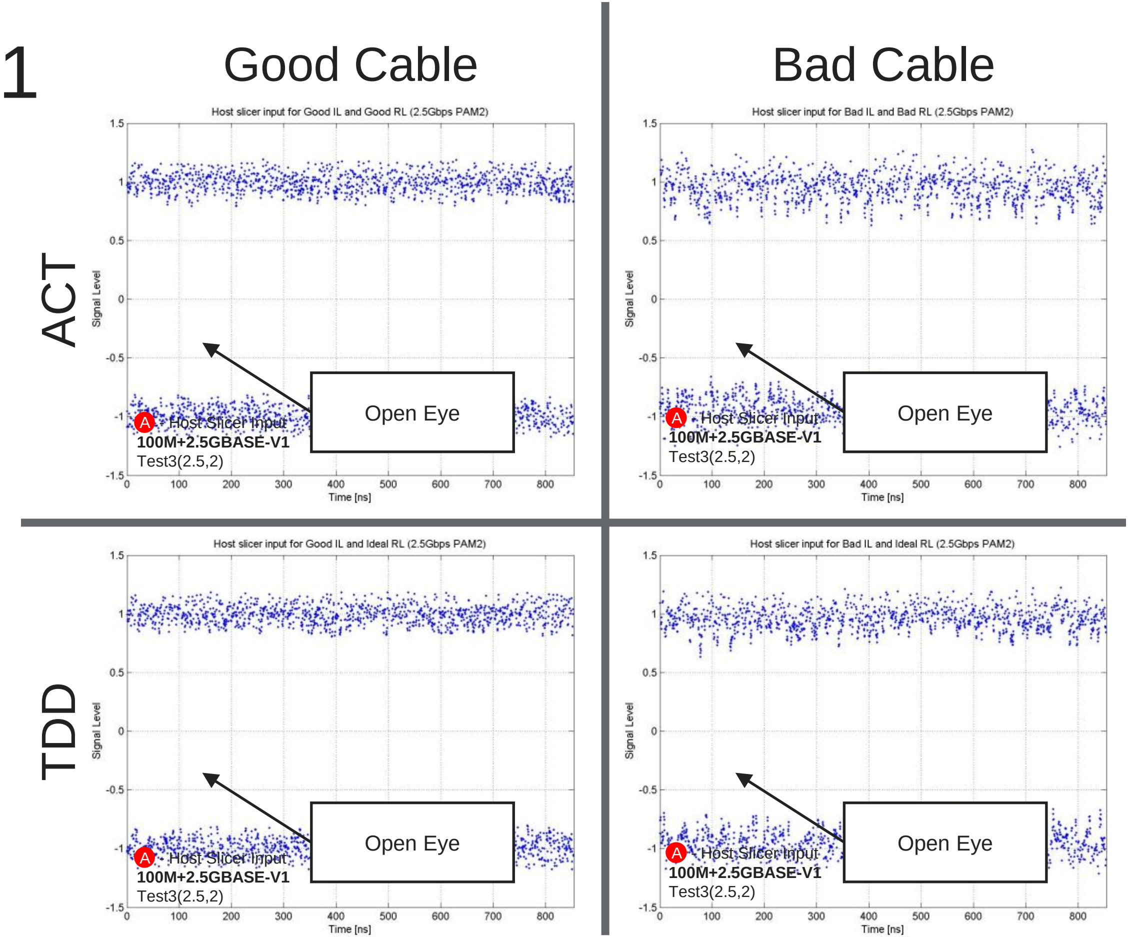
2.5G+100MBASE-V1 PAM4 Signaling

- The plots on the right compare ACT (top row) to TDD (bottom row)
- TDD is emulated by using ideal RL (no echo)
- For more direct comparison, the TDD uses the same modulation as ACT high data rate
- The plot shows that the echo has little impact on the ACT receiver



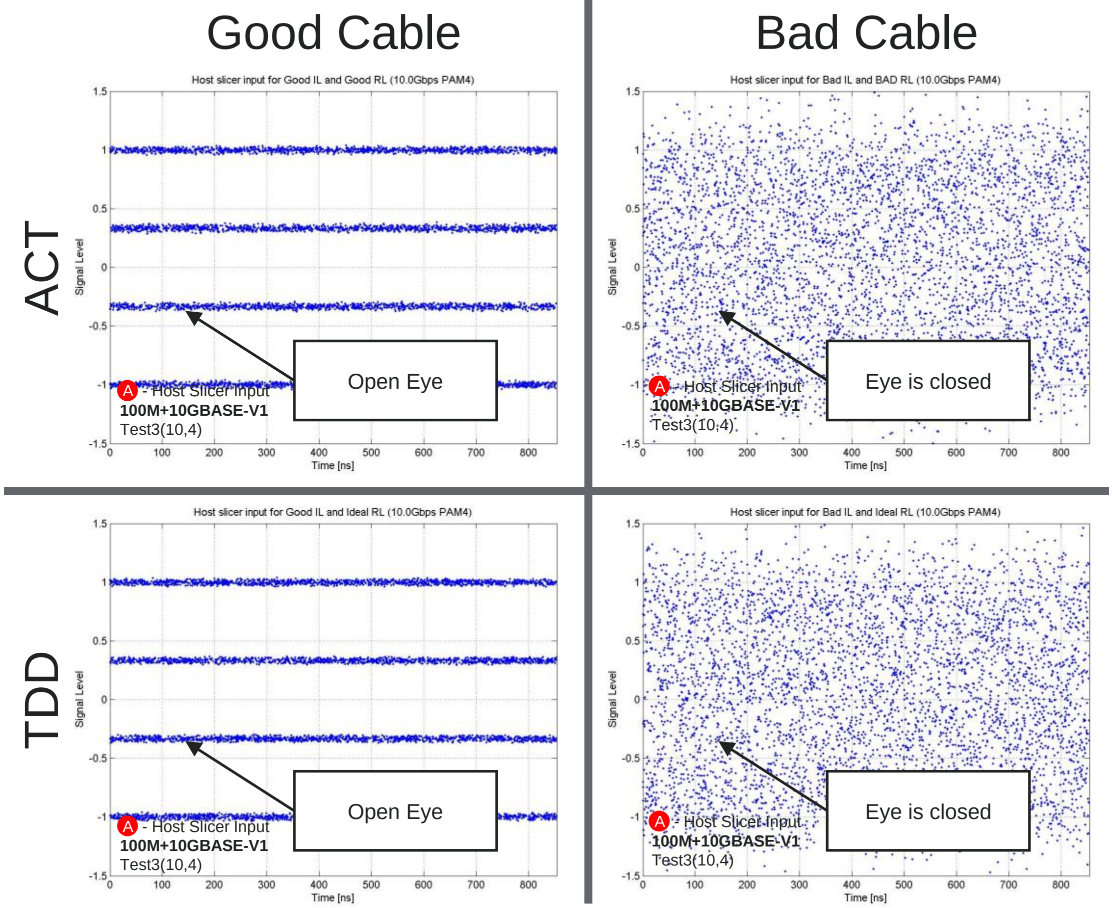
2.5G+100MBASE-V1 PAM2 Signaling

- The plots on the right compare ACT (top row) to TDD (bottom row)
- TDD is emulated by using ideal RL (no echo)
- For more direct comparison, the TDD uses the same modulation as ACT high data rate
- The plot shows that the echo has little impact on the ACT receiver



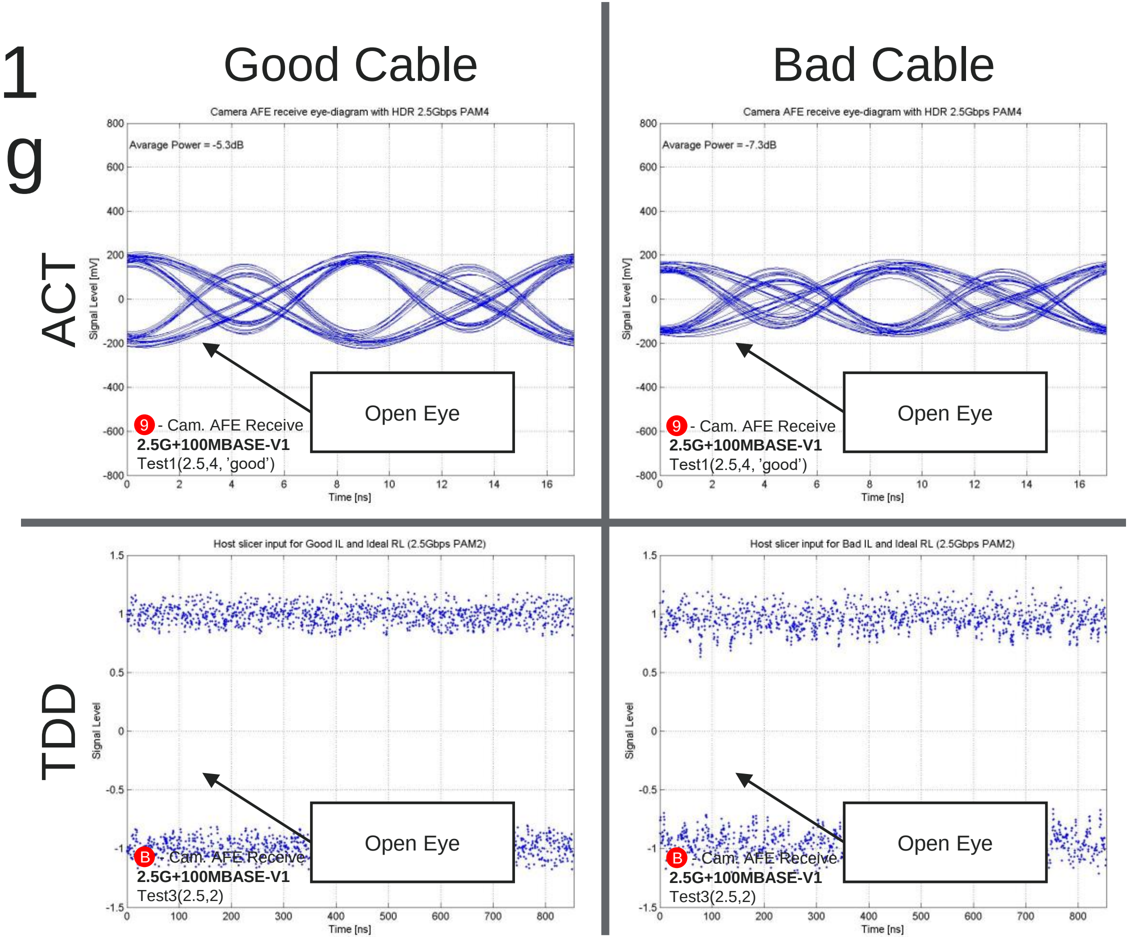
10G+100MBASE-V1 PAM4 Signaling

- The plots on the right compare ACT (top row) to TDD (bottom row)
- TDD is emulated by using ideal RL (no echo)
- The plot shows that the echo has minimal impact on the ACT receiver
- At high symbol rate both ACT and TDD fail on the bad cable due to secondary reflections



100M+2.5GBASE-V1 DME/PAM2 Signaling

- The plots on the right compare low data rate ACT (top row) to TDD (bottom row)
- TDD is emulated by using ideal RL (no echo)
- ACT uses the low rate DME for the 100Mbps
- 100Mbps TDD is simulated using 2.5Gbps data rate PAM2 for the 100Mbps
- The plot shows that the echo has little impact on the ACT DME receiver



Summary

- The simulations shows that the ACT can operate over good and bad cables without echo cancelation and without equalization in the camera
- The simulations shows that even in the presence of severe echo, the ACT degradation is very limited
- The simulations show that the absence of echo is not a significant benefit for TDD over ACT
- The simulations show that comparison of PAM2 and PAM4 deserves a closer look
- The simulations show that the camera receiver is much simpler for ACT, compared to TDD

The higher complexity of the TDD (compared to ACT) is not justified

MARVELL™

Essential technology, done right™