KEYSIGHT

Hybrid IBIS Summit at IEEE WAI2025

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Conquer MIPI C-PHY Simulation Challenge

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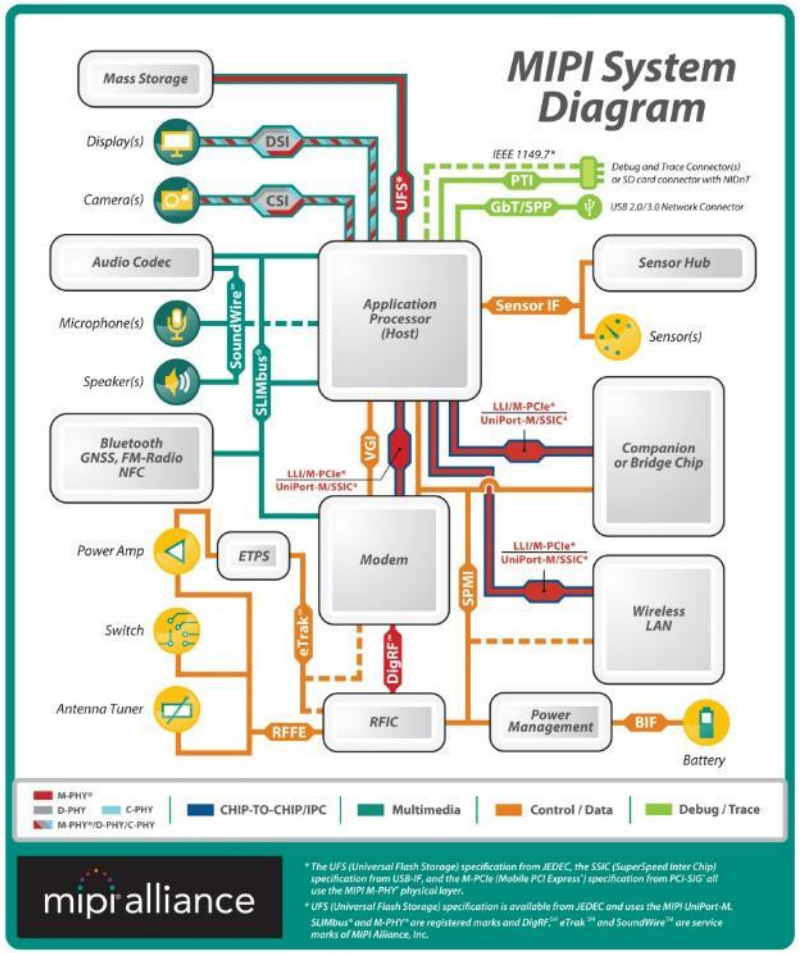
Agenda

- MIPI and C-PHY Background
- C-PHY Simulation Challenge
- C-PHY Simulation Traditional Solution
- Innovative Simulation for C-PHY and Case Study
- Summary



Background

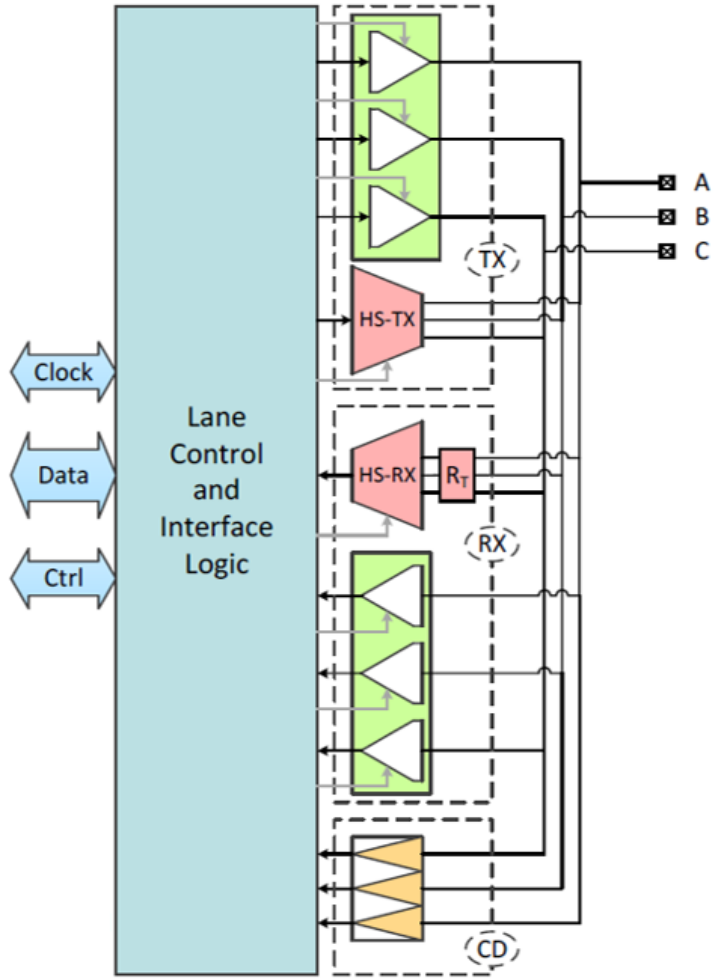
MIPI C-PHY leads Camera interface

- More cameras have been integrated into mobile devices, including VR/AR headsets
- High-speed data transmission is essential for ADAS, autonomous vehicles, and in-vehicle infotainment systems
- Adopting more MIPI C-PHY reduces harness weight and enables the transmission of more high-speed data

Image source: tesla.com

MIPI C-PHY Introduction

- Lane consisting of 3 wires, A, B, C
- TXs and RXs: Bidirectional
- Contention detection (LP only)
- Two set‘s of TXs / RXs (HS & LP)
- LP-mode:
  - Large amplitude (~ 1V), unterminated
  - Data format: “RZ“
  - Signaling: non-differential
- HS-mode:
  - Small amplitude (~ 200mV,pp)
  - Termination 50 W - “star-type“ (encircled)
  - Data format: 3-phase / 3-level
  - Signaling: 3 single ended wires forming a HS-lane,
  - Encoding:16 bits to 7 symbols with 5 values (0,1,2,3,4) => coding gain 2.28



MIPI C-PHY Simulation Challenges

C-PHY sources need to model true silicon behaviors

However,

- The generic C-PHY model has limitations due to its linear behavior
- The simulation results show discrepancies from actual measurements
- Designers have begun to seek an accurate simulation method down to the silicon level.

"There are differences between simulations vs. real silicon measurements."

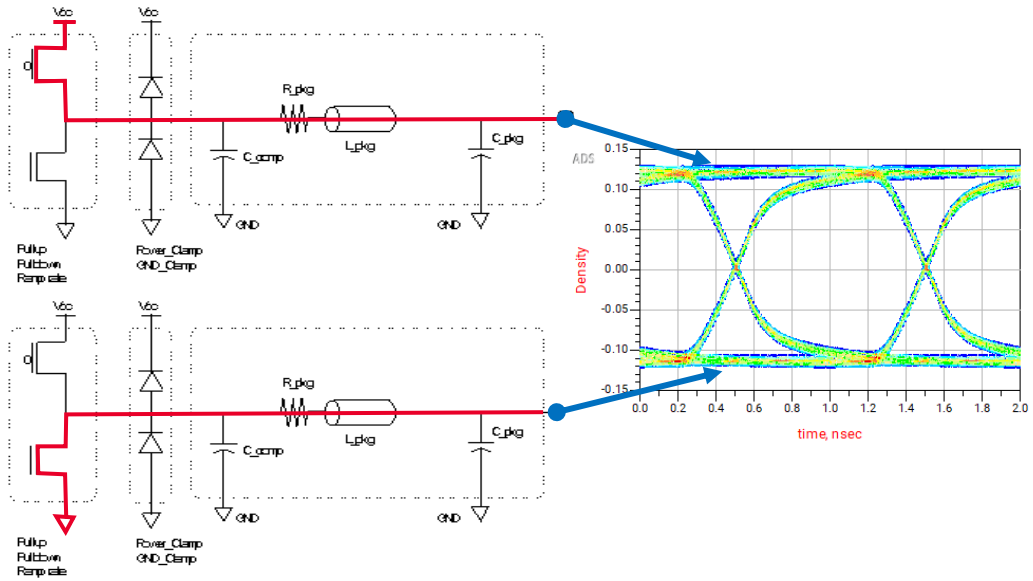
"Designers want to simulate C-PHY with true silicon-level chip behaviors.
How can we provide this model?"

How to simulate MIPI C-PHY with true silicon level behaviors?

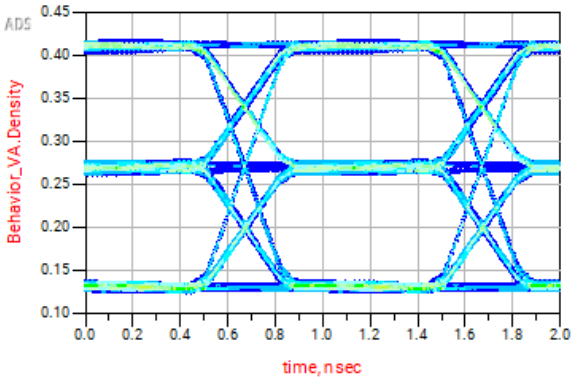
MIPI C-PHY Simulation Challenges I

Limitation with conventional IBIS models

- IBIS (Input/Output buffer information specification) model



The IBIS model is defined for two level transitions (Pull-up and Pull-down)

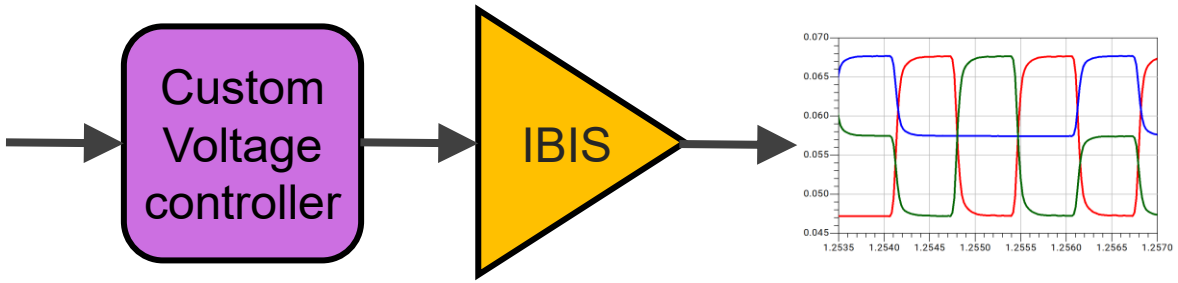


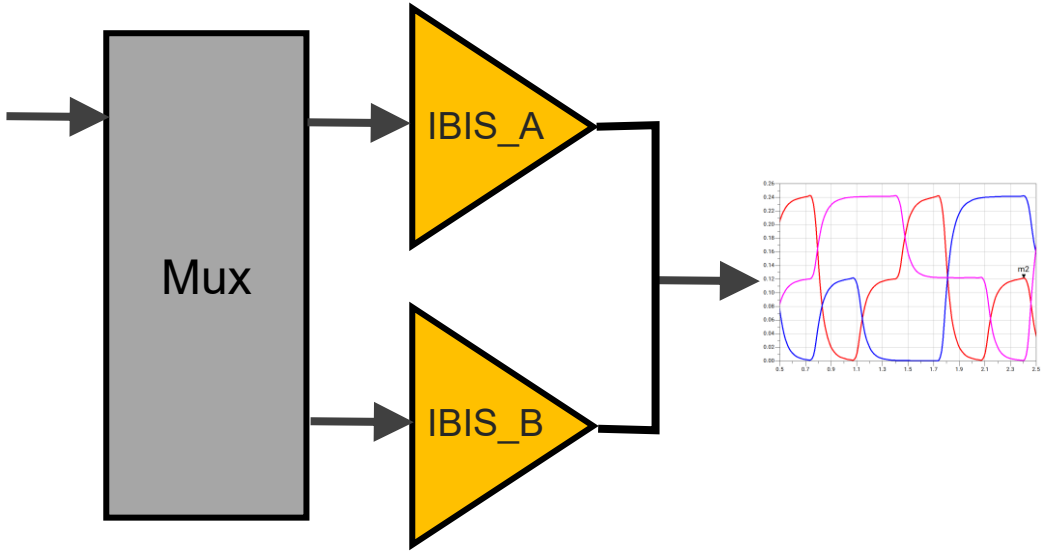
However, C-PHY uses PAM3-like signaling.

MIPI C-PHY Simulation Challenges II

Why conventional IBIS model can't deliver the right signaling?

- Modified IBIS model



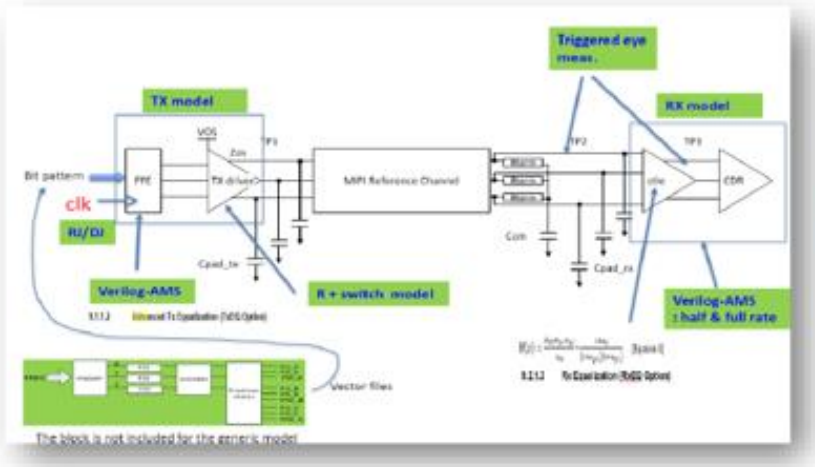


- 3 state level is not real chip behavior
- All rise/fall time has the same slew rate

- Mid-state level might be wrong due to impedance difference between IBIS files
- Low to High rise/fall time is not represented

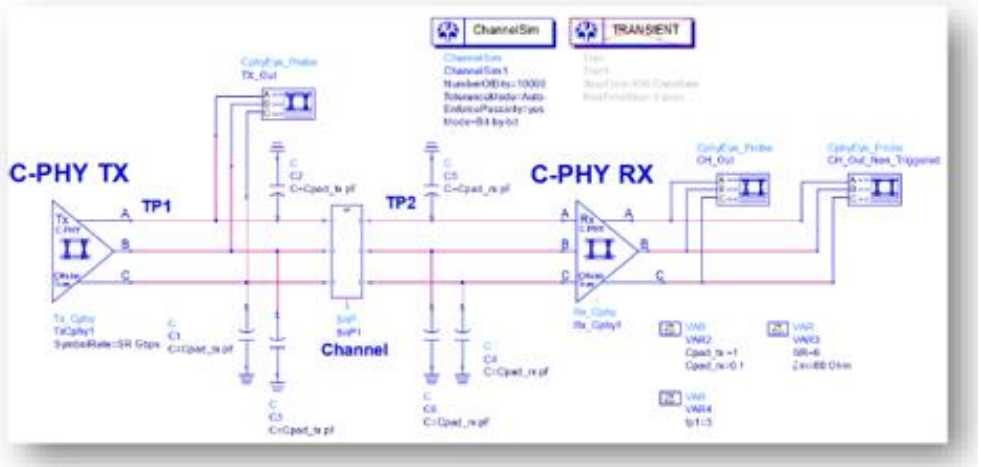
C-PHY Simulation Traditional Solution

- Special C-PHY Transmitter, Receiver and Trigger Eye-Probe
- Support Transient and Statistical simulation technology
- Support Tx/Rx equalization and RJ, PJ, DCD, and so on jitter model.



Note: Courtesy of Qualcomm

Today



EDA Tool

EDA Tool Challenges

Ensuring EDA Tool Compatibility

- High-speed data transmission is essential for ADAS, autonomous vehicles, and in-vehicle infotainment systems
- Adopting more MIPI C-PHY reduces harness weight and enables the transmission of more high-speed data

However,

- C-PHY is new to the automotive industry
- There is no clear direction on which tools to use.
- Existing simulation tools are commonly utilized.

"What criteria should be used to choose a MIPI C-PHY simulation tool?"

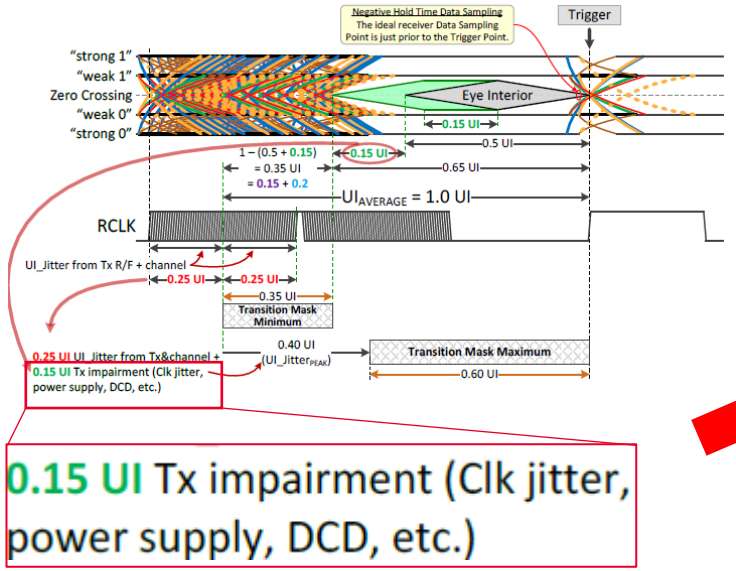
"C-PHY is new to me, so how can I design the circuit and perform simulations?"

How do I know my EDA tool complies with the C-PHY specification?

MIPI C-PHY Jitter Requirements

Ensure Accurate Jitter Simulation

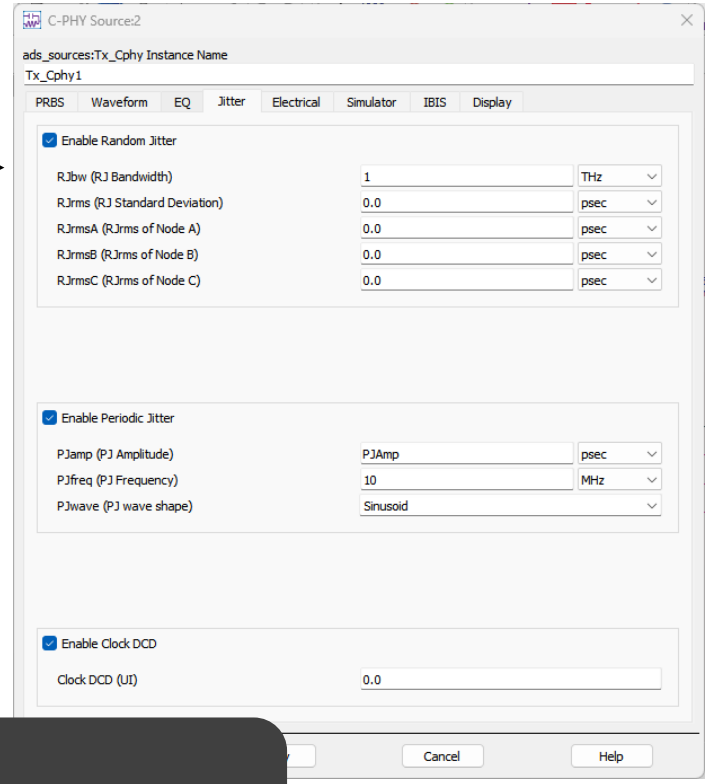
MIPI C-PHY Jitter definition



0.15 UI Tx impairment (Clk jitter, power supply, DCD, etc.)

Possible Tx jitter

- Power supply → RJ
- Clk_Jitter → Periodic
- DCD → Clock DCD



C-PHY source must support Tx jitter, ClockDCD, RJ, PJ

Complexity of C-PHY Signals

Mapping and Encoding the data

0x7290 =
0001110001111010

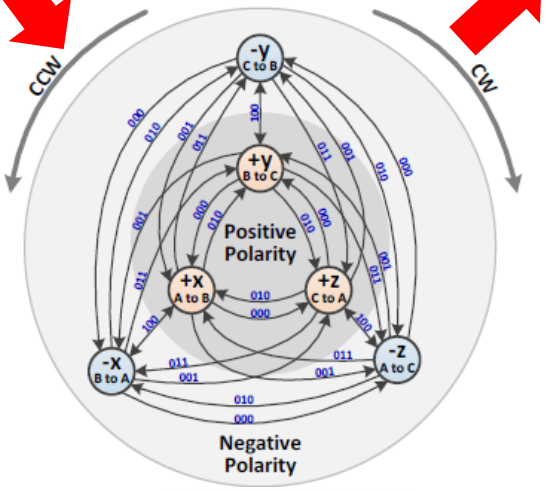
16 bits word

Mapping

Symbols

010
010
011
001
000
011
001

{1301322}



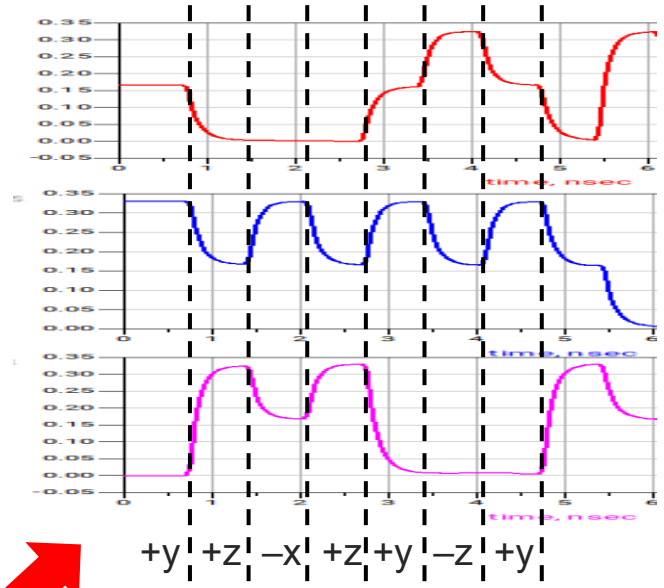
Encoding

Wire state name

+x
+y
+z
-x
+z
+y
-z
+y

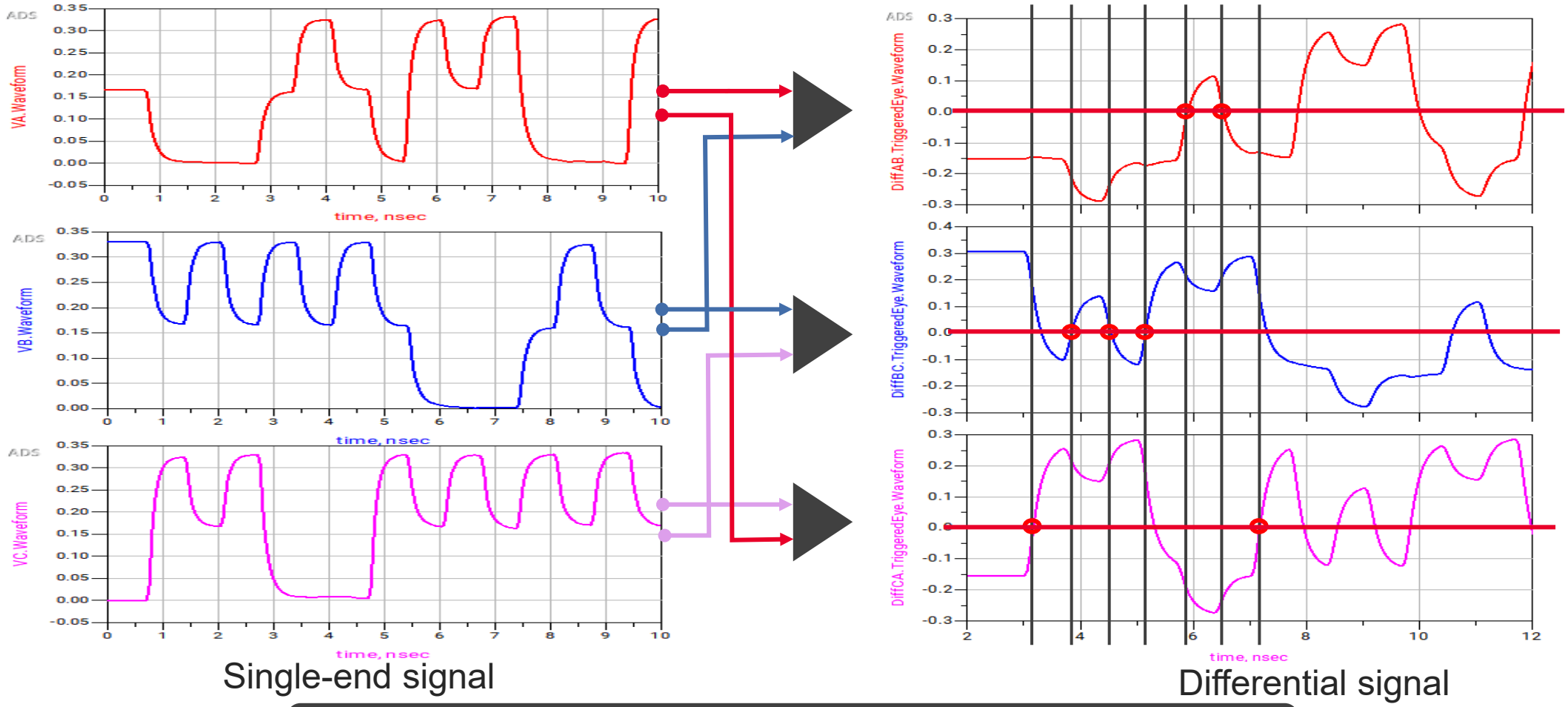
Wire State	VA	VB	VC
+x	¾ V	¼ V	½ V
-x	¼ V	¾ V	½ V
+y	½ V	¾ V	¼ V
-y	½ V	¼ V	¾ V
+z	¼ V	½ V	¾ V
-z	¾ V	½ V	¼ V

Wire State



Correct C-PHY Encoding

Coding ensures every UI has at least ONE 0V crossing for clock recovery



Single-end signal

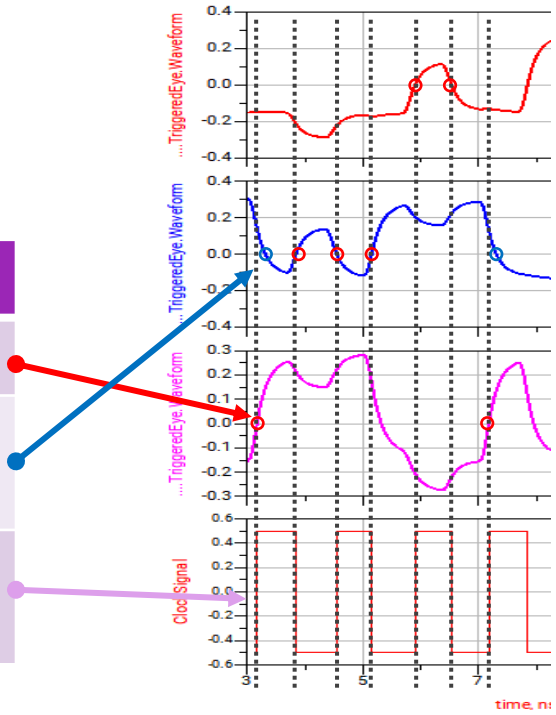
Differential signal

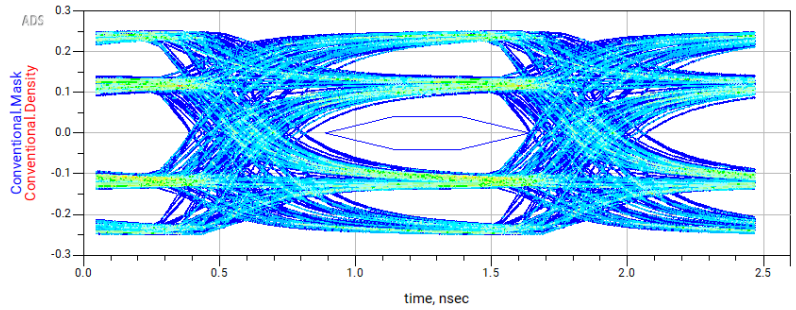
C-PHY source must have mapping and encoding

C-PHY Signal Quality Check with Eye Diagram

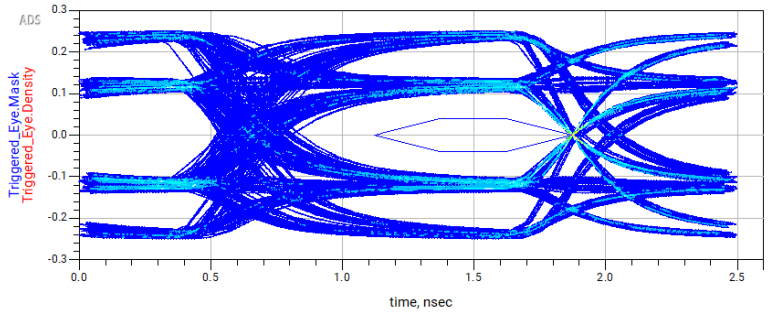
Non-triggered vs Triggered Eye

	Non-triggered	Triggered eye
Clock edge	Center of eye	At the first zero-crossing
Clock source	Single waveform	3 waveforms, ignore subsequent edges in the same UI
Data sample point	Center of eye	Prior to the trigger point





Non-triggered Eye



Triggered Eye

2Gsps, 100mUI, 100MHz PJ

Impact of Jitter on C-PHY Eye Diagrams

C-PHY's Jitter Resilience

- A triggered eye is resistant to jitter

Non-triggered eye | C-PHY triggered eye

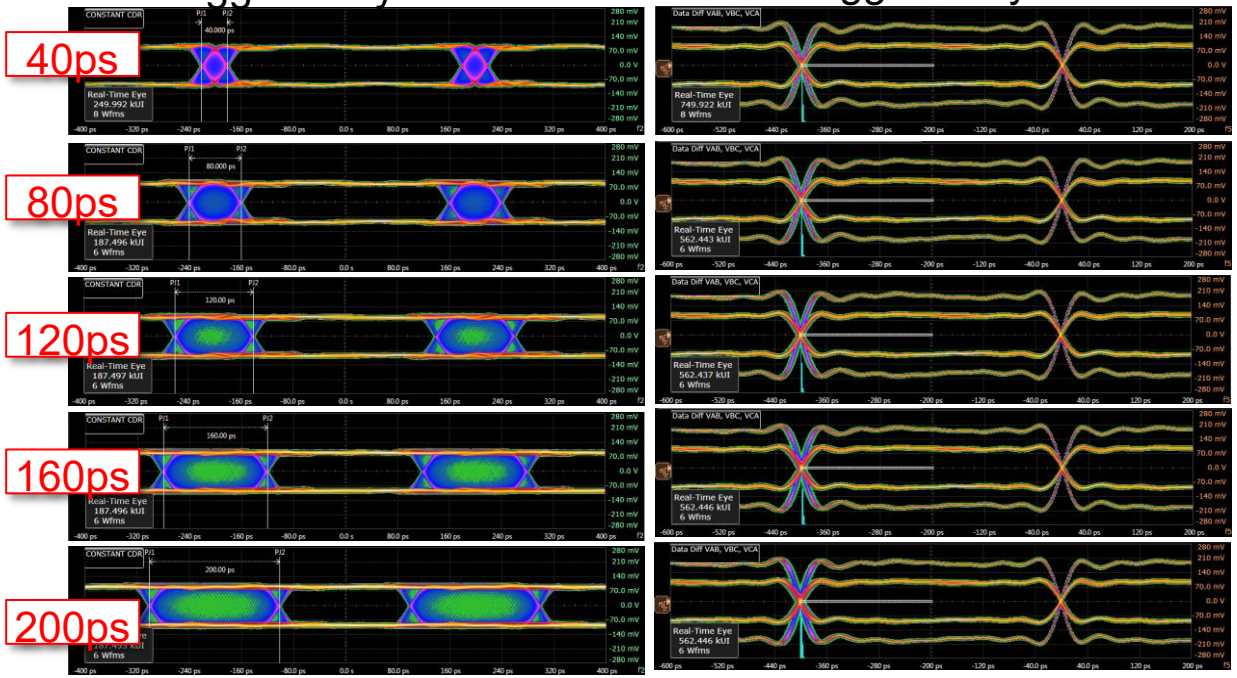
40ps

80ps

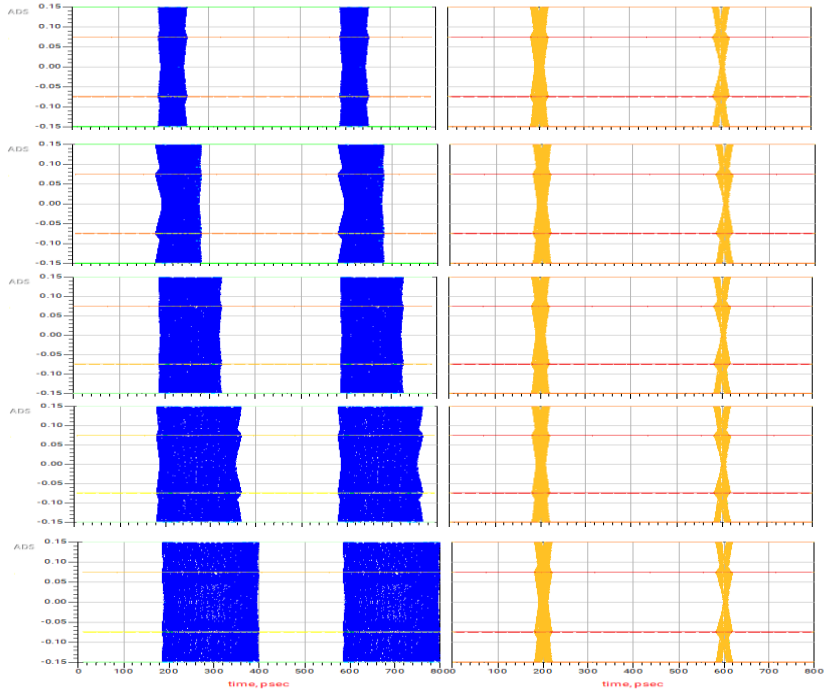
120ps

160ps

200ps



Non-triggered eye | C-PHY triggered eye



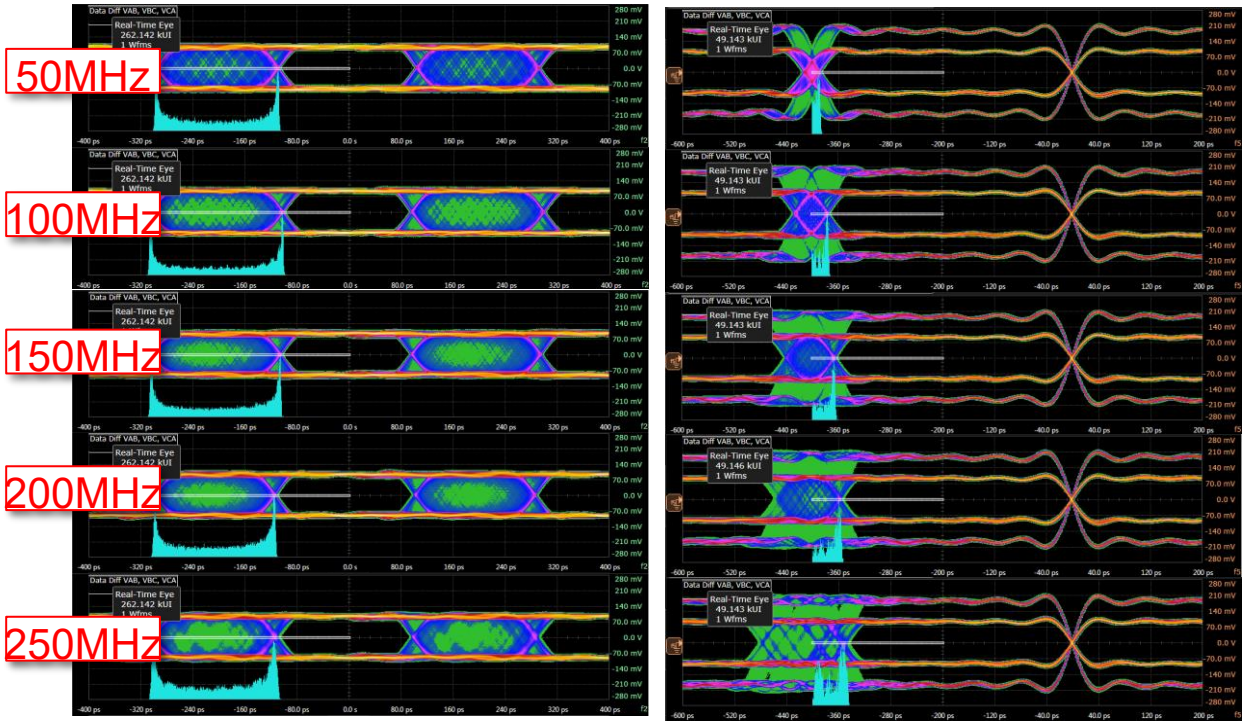
2.5Gsps, 10MHz PJ

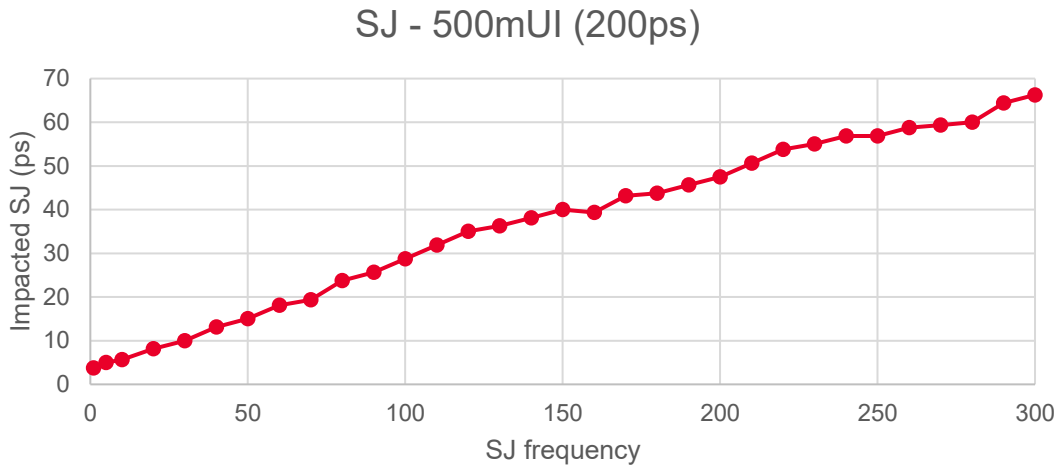
Importance of C-PHY Triggered Eye Support

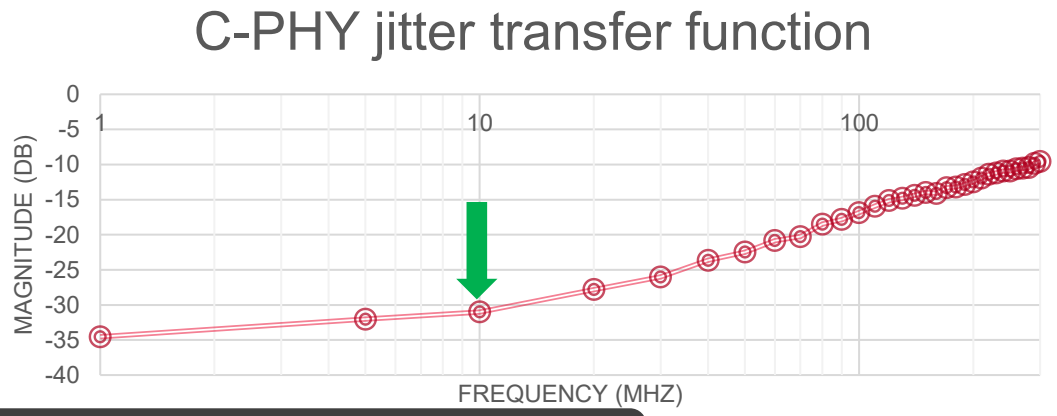
Only triggered eye shows the right behavior of the C-PHY eye diagram

Non-triggered eye

C-PHY triggered eye







C-PHY measurement must have Triggered eye

Utilization of C-PHY Equalization

Verifying CTLE Support in C-PHY Receivers

- From C-PHY v2.0 and on, Rx CTLE (Continuous Time Linear Equalization) is required.

f_Z (GHz)	f_{P1} (GHz)	f_{P1} / f_Z	f_{P2} (GHz)
1.0	2.0	2.0	10
1.0	2.2	2.2	10
1.0	2.4	2.4	10
1.0	2.6	2.6	10
1.0	2.8	2.8	10
1.0	3.0	3.0	10

Reference CTLE for standard channel

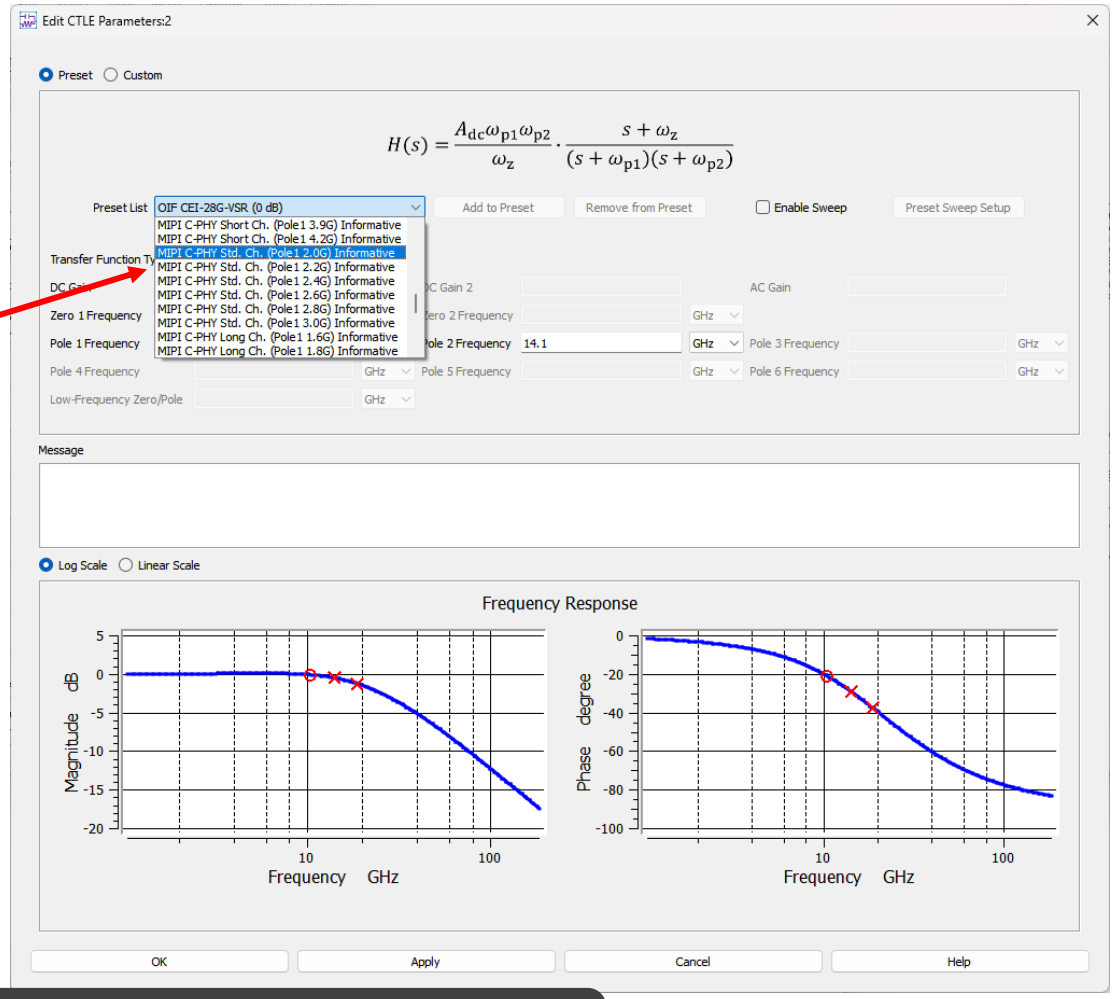
$$H(s) = \frac{A_{DC}\omega_{P1}\omega_{P2}}{\omega_Z} \cdot \frac{s+\omega_Z}{(s+\omega_{P1})(s+\omega_{P2})} \quad \text{[Equation 1]}$$

Where: A_{DC} is the DC gain,

$\omega_{P1} = 2\pi f_{P1}$ f_{P1} is the first pole frequency

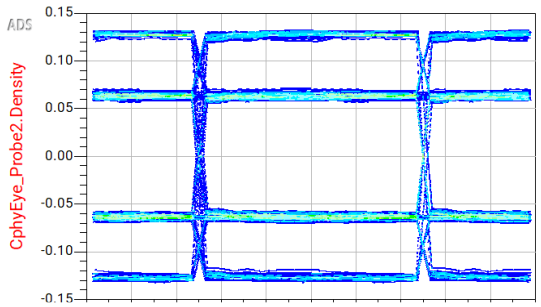
$\omega_{p2} = 2\pi f_{P2}$ f_{P2} is the second pole frequency

$\omega_Z = 2\pi f_Z$ f_Z is the zero frequency

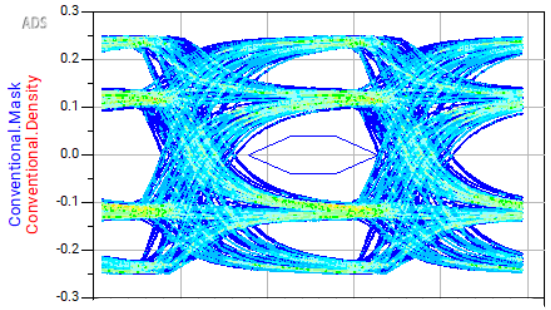


C-PHY receiver must support Equalization

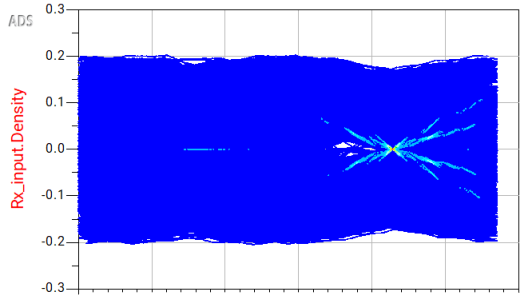
Summary



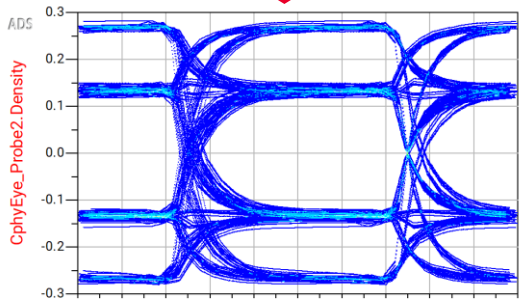
Behavior model



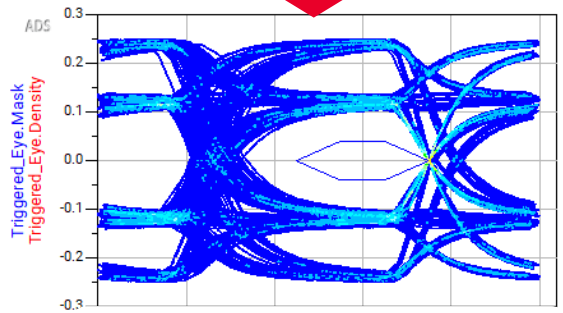
Non-triggered Eye



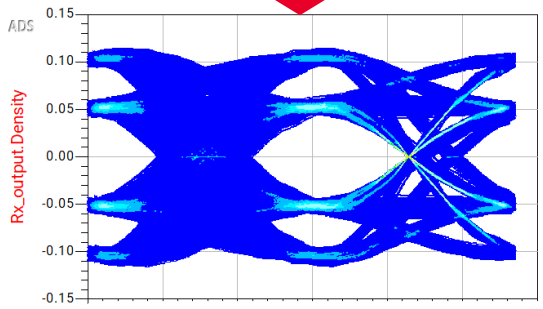
No Equalization



C-PHY Waveform source



Triggered Eye



Receiver CTLE

Deliver Accurate Results

Comply with the Specification

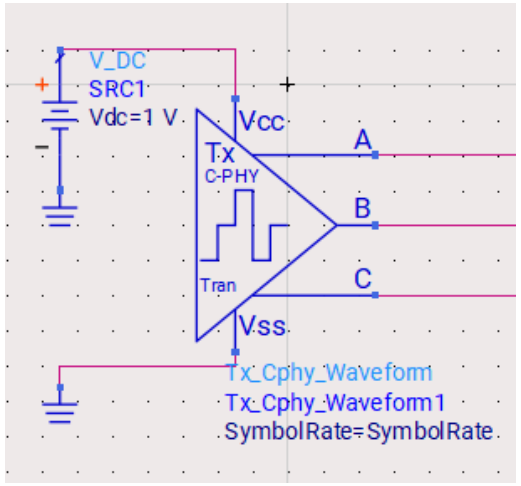
Ensure Rx Accuracy

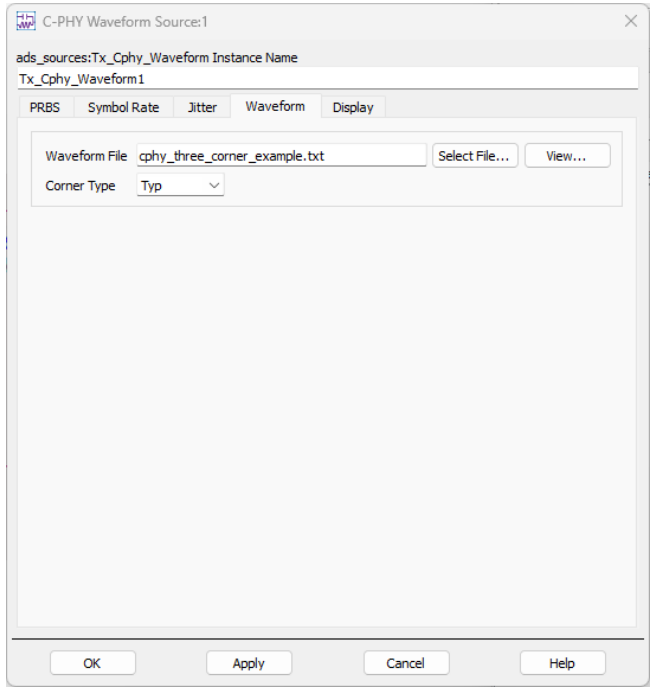
KEYSIGHT

Innovative C-PHY Waveform Source

New, Innovative C-PHY Waveform Source

Beyond the limits of IBIS





Highlights:

- Industry-unique solution
- Measured waveform-based model
- 3 different corner cases: Typical, Min, Max

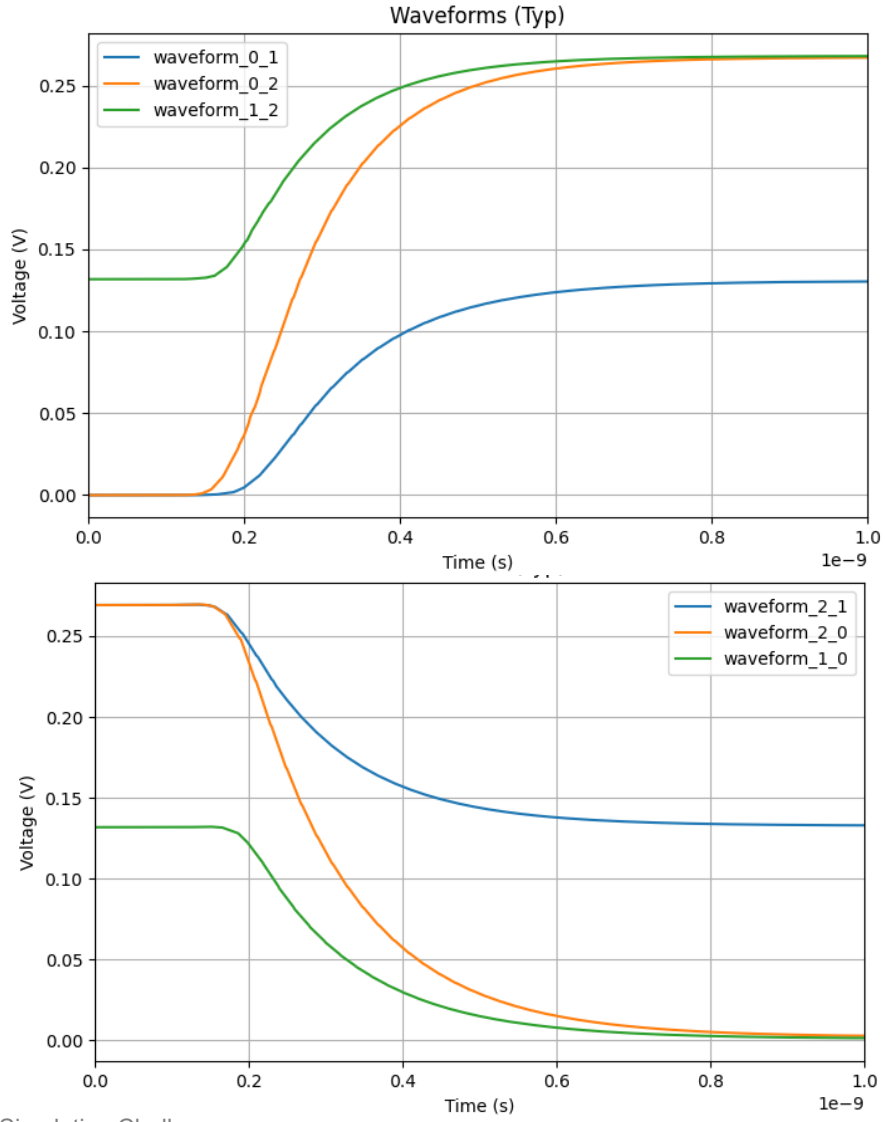
Advantage I with New C-PHY Waveform Source

Accurate silicon behavior from measured waveform

```
[Waveform_1_0]
R_fixture=50
V_fixture=0.0
|time        V(typ)
|
0.0000E+00
2.0000E-12
4.0000E-12
6.0000E-12
1.0000E-11
1.2000E-11
1.4000E-11
1.6000E-11
1.8000E-11
2.0000E-11
2.2000E-11
2.4000E-11
2.6000E-11
2.8000E-11
3.0000E-11
```

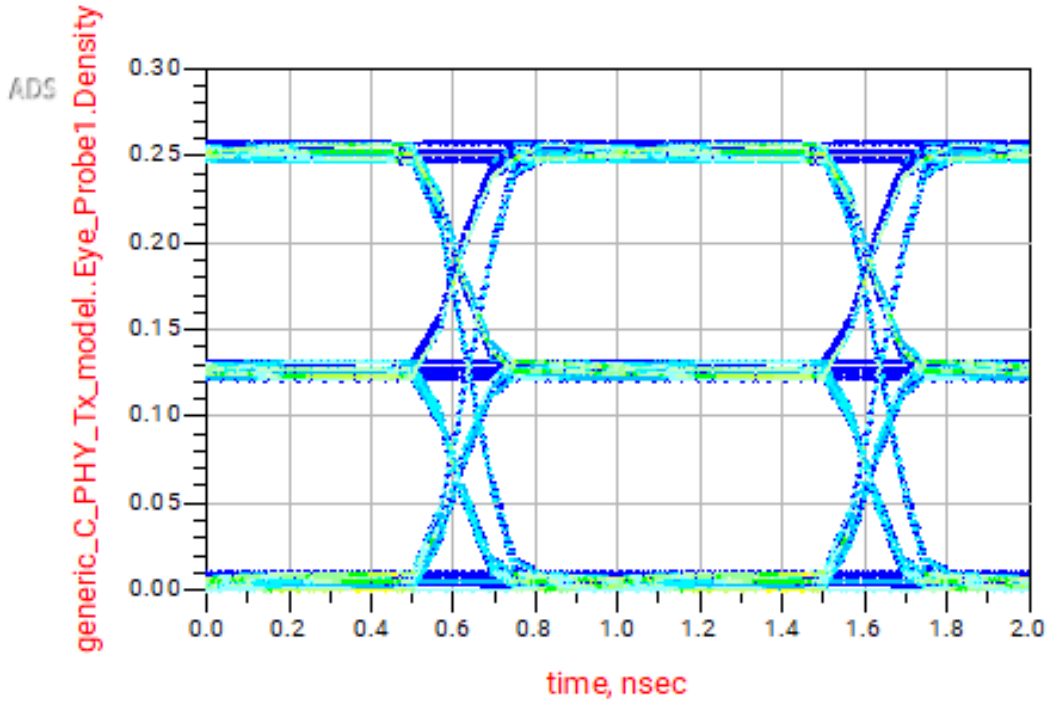
```
[Waveform_2_0]
R_fixture=50
V_fixture=0.0
|time        V(typ)
|
0.0000E+00
2.0000E-12
4.0000E-12
6.0000E-12
1.0000E-11
1.2000E-11
1.4000E-11
1.6000E-11
1.8000E-11
2.0000E-11
2.2000E-11
2.4000E-11
2.6000E-11
2.8000E-11
3.0000E-11
```

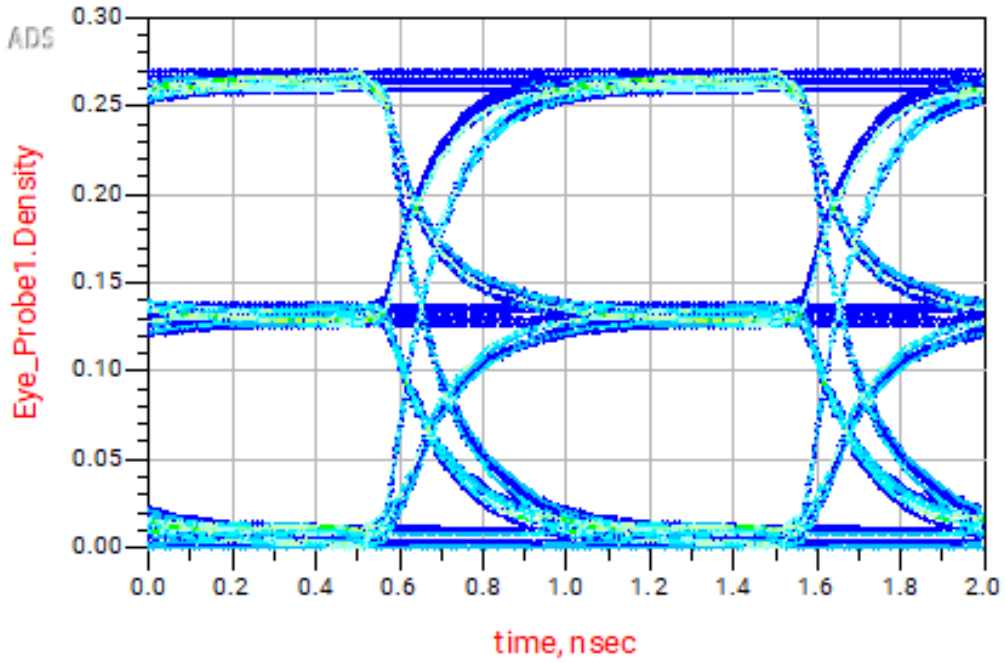
```
[Waveform_2_1]
R_fixture=50
V_fixture=0.0
|time        V(typ)
|
0.0000E+00          2.69201E-01
2.0000E-12          2.69201E-01
4.0000E-12          2.69201E-01
6.0000E-12          2.69201E-01
1.0000E-11          2.69201E-01
1.2000E-11          2.69201E-01
1.4000E-11          2.69202E-01
1.6000E-11          2.69202E-01
1.8000E-11          2.69202E-01
2.0000E-11          2.69202E-01
2.2000E-11          2.69202E-01
2.4000E-11          2.69202E-01
2.6000E-11          2.69202E-01
2.8000E-11          2.69201E-01
3.0000E-11          2.69201E-01
3.2000E-11          2.69200E-01
```



Advantage I with New C-PHY Waveform Source, cont...

Accurate Eye Diagram prediction



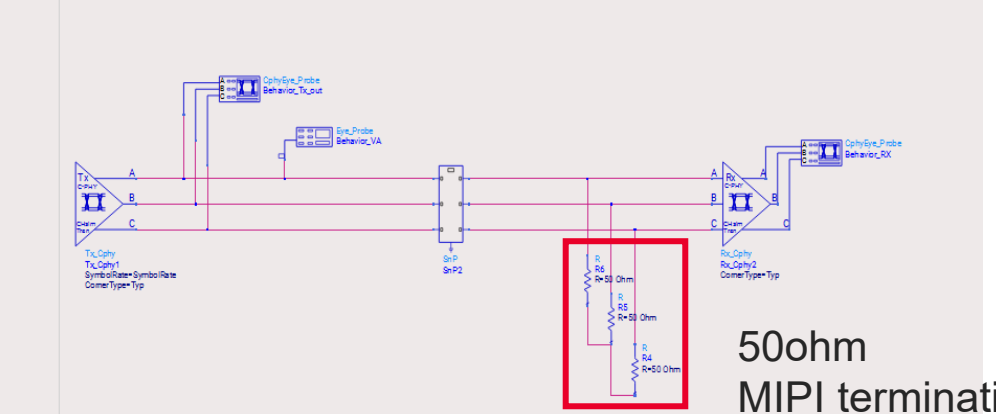


Represents true C-PHY transition behavior

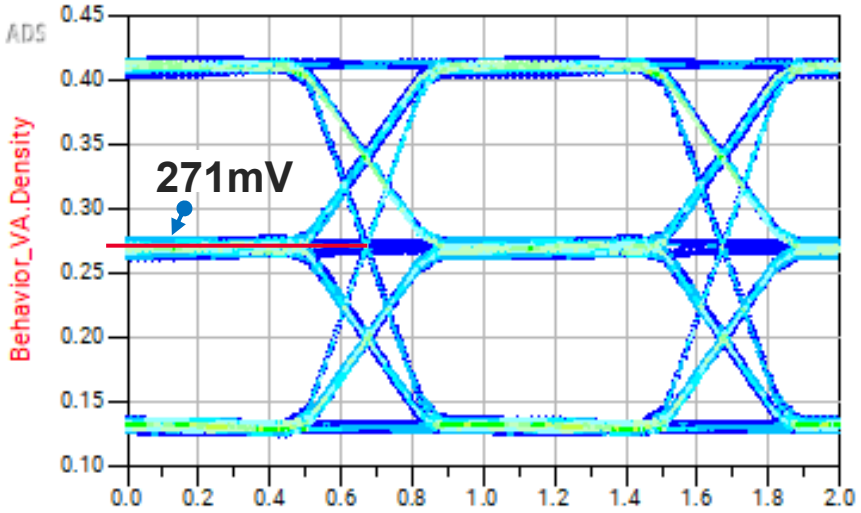
Advantage II with New C-PHY Waveform Source

Accurate non-linear DC offset behavior modeling

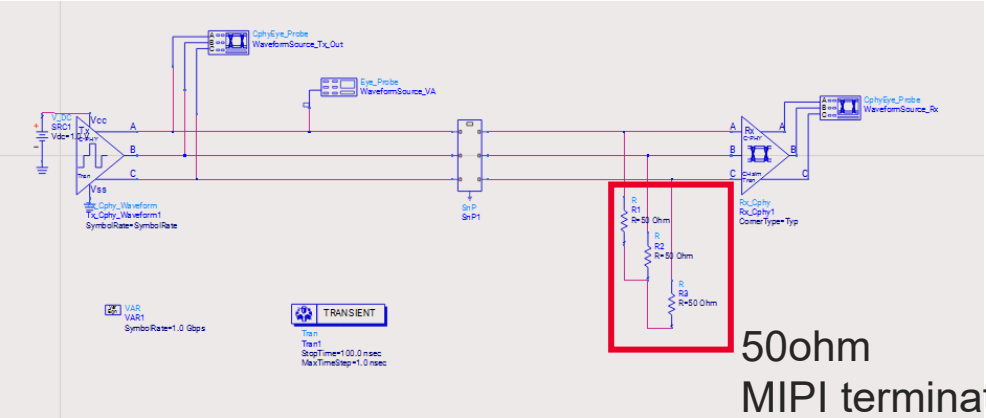
Behavior model



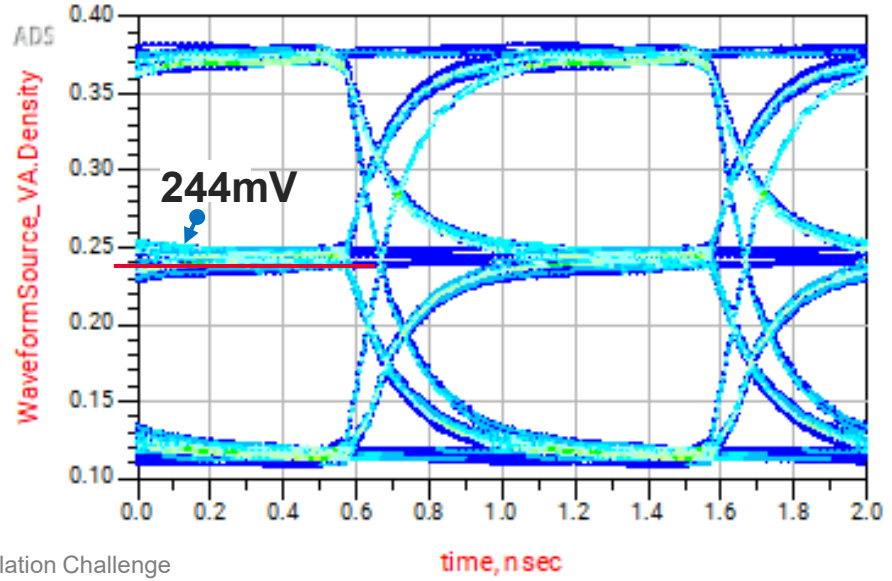
50ohm
MIPI termination



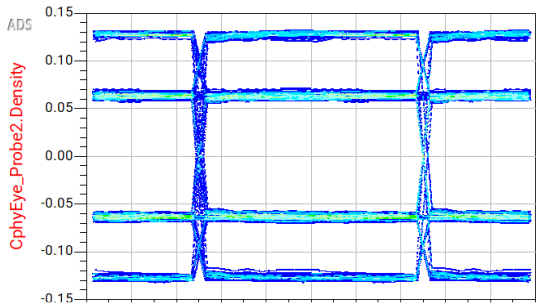
Waveform source



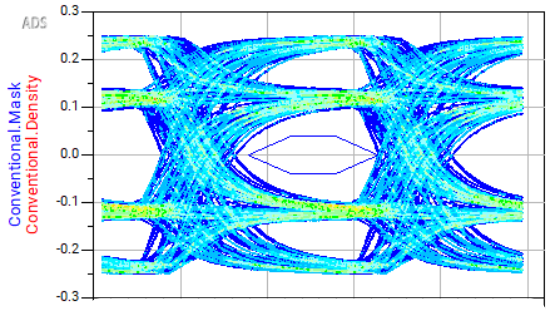
50ohm
MIPI termination



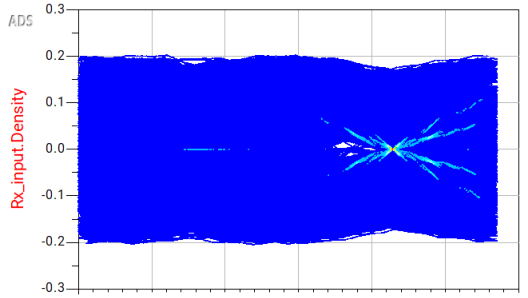
Summary



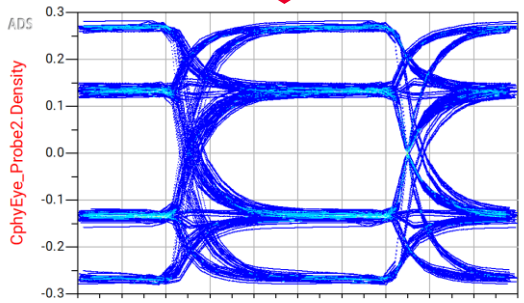
Behavior model



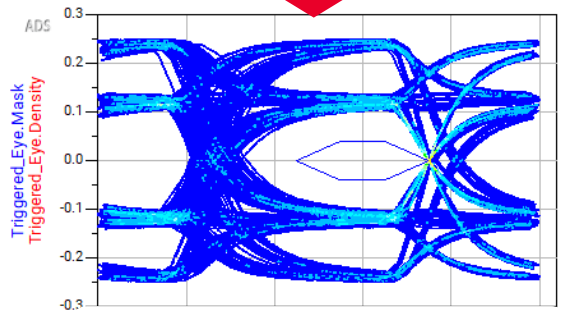
Non-triggered Eye



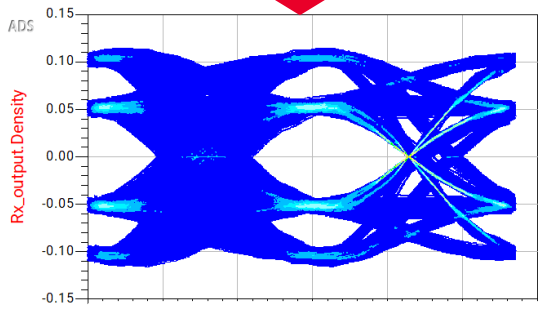
No Equalization



C-PHY Waveform source



Triggered Eye



Receiver CTLE

Deliver Accurate Results

Comply with the Specification

Ensure Rx Accuracy


KEYSIGHT