mipi®
DEVCON

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Study on the Influence of Random Jitter to the MIPI C-PHY℠ High Speed Timing Budget

MIPI ALLIANCE DEVELOPERS CONFERENCE
TAIPEI
18 OCTOBER 2019

Agenda

- RJ (Random Jitter) Impact on C-PHY Eye Diagram
- Tx Impairment Budget Case Study
- MIPI PHY Simulation Solution in ADS (Advance Design System)

C-PHY Physical Layer Overview

High Speed (HS) Mode

- **Signaling**
  - 3-phase signal
  - 3-wire group
- **Clocking**
  - Embedded clock
- **Data rate**

Short reference channel
- 2.5 Gsps
- 4.5 Gsps with TxEQ
- 8 Gsps with RxEQ

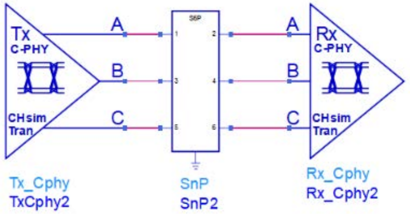
Standard reference channel
- 1.7 Gsps
- 3.5 Gsps with TxEQ
- 6 Gsps with RxEQ

Long reference channel
- 1.3 Gsps
- 2.3 Gsps with TxEQ
- 4 Gsps with RxEQ

- **Channel compensation**
  - Advanced TxEQ (Tx Equlization)
  - Rx CTLE (Continuous Time Linear Equalizer)

Current version v2.0

Minimum configuration:
- 1 lane (trio)



The channel may consist of several cascaded transmission line segments, such as, **PCB**, **flex-foils**, and **cable connections**, that might also include **vias** and **connectors**.

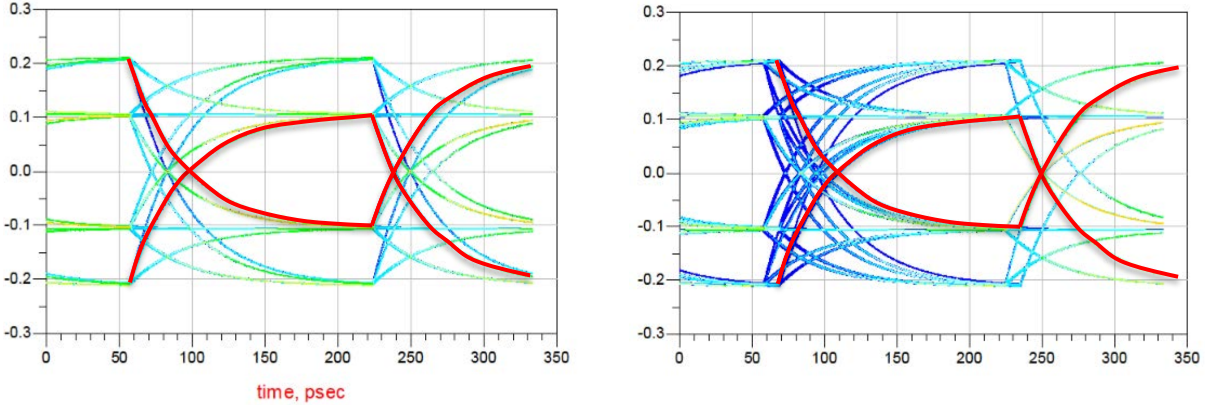
Jitter Types in a C-PHY Channel

- Random Jitter (RJ)
- Deterministic Jitter (DJ)
  - Encoding Jitter
  - Inter-symbol Interference (ISI)
  - Periodic Jitter (PJ)
  - Clock Duty Cycle Distortion (DCD)
  - etc.

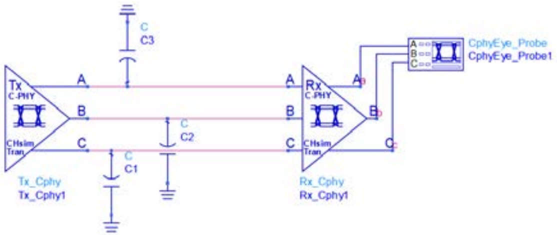
Trigger and Non-Triggered Eye with No RJ

- We first look at RJ on two transitions
  - Strong 0 -> Weak 1 -> Strong 0
  - Strong 1 -> Weak 0 -> Strong 1

Non-triggered and triggered eye diagrams without RJ



Speed = 6 Gsps
C = 1.5 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ OFF



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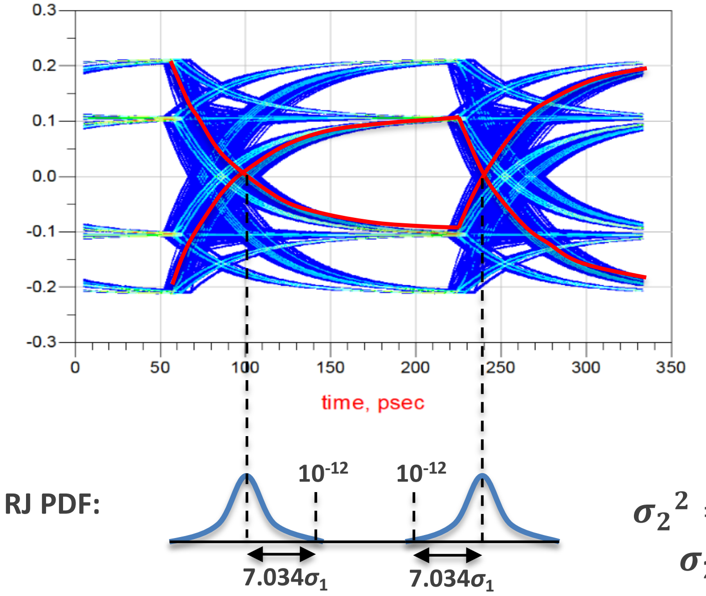
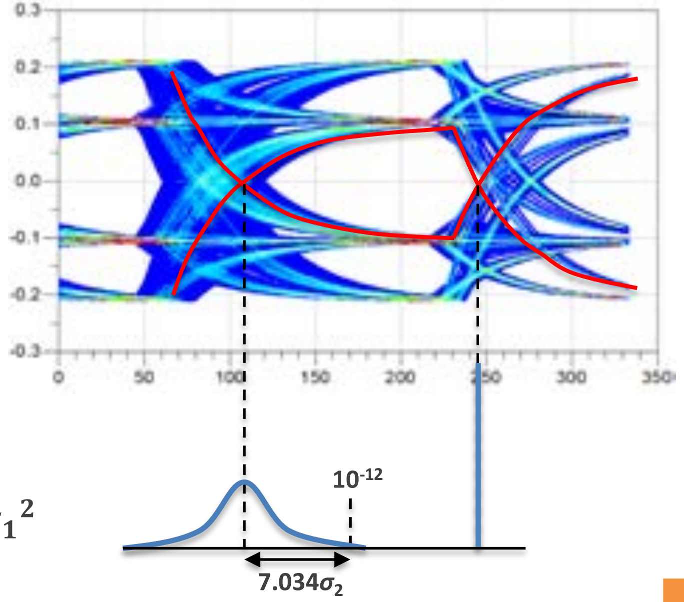
Trigger and Non-Triggered Eye with RJ = 2ps

Non-triggered and triggered eye diagrams with RJ (σ = 2 ps)



$$\sigma_2{}^2 = \sigma_1{}^2 + \sigma_1{}^2$$
$$\sigma_2 = \sqrt{2}\sigma_1$$



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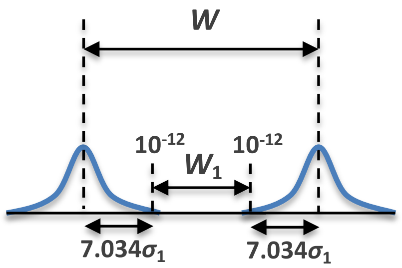
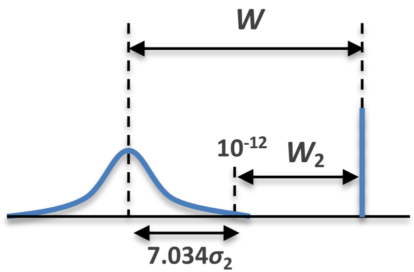
RJ Tolerance: Trigger and Non-Triggered Eye





- RJ Impairment on non-triggered eye

$$W - W_1 = 14.068\sigma_1$$

- RJ Impairment on triggered eye

$$W - W_2 = 7.034\sigma_2 \approx 9.948\sigma_1$$

- C-PHY triggered eye width has better tolerance on RJ

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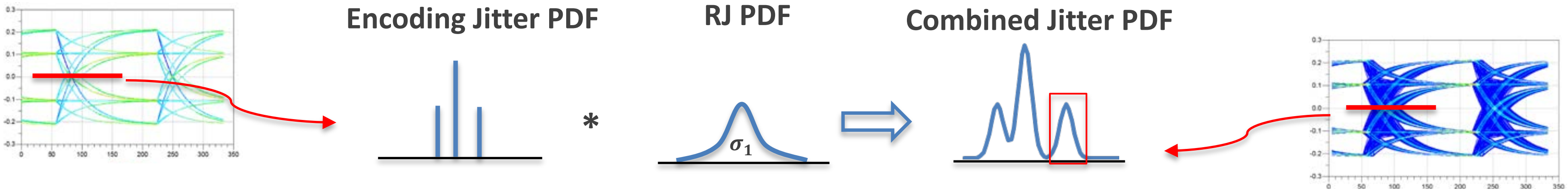
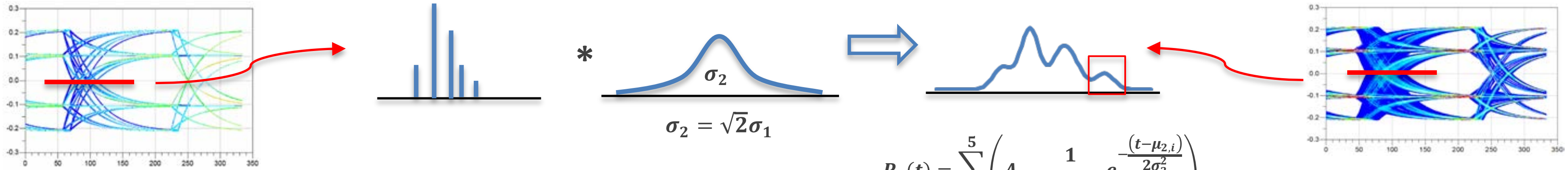
Combined PDF for RJ + Encoding Jitter



$$P_1(t) = \sum_{i=1}^{3} \left(A_{1,i} \frac{1}{\sqrt{2\pi\sigma_1^2}} e^{-\frac{(t-\mu_{1i})}{2\sigma_1^2}} \right)$$

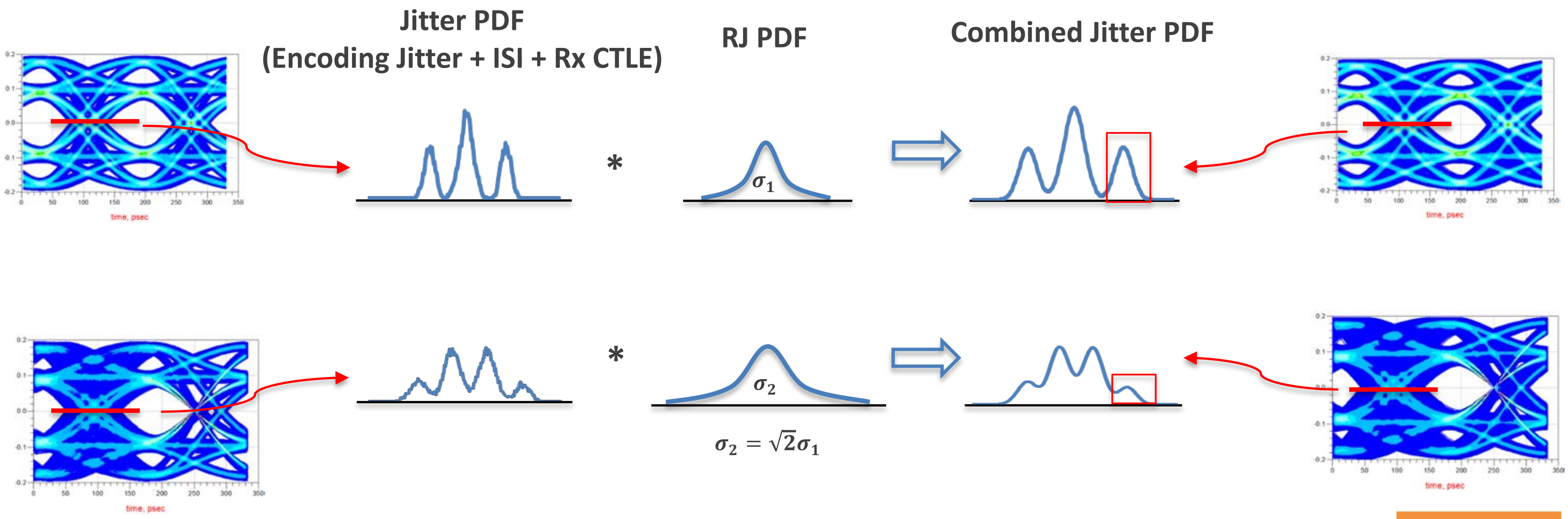


$$\sigma_2 = \sqrt{2}\sigma_1$$

$$P_2(t) = \sum_{i=1}^{5} \left(A_{2,i} \frac{1}{\sqrt{2\pi\sigma_2^2}} e^{-\frac{(t-\mu_{2,i})}{2\sigma_2^2}} \right)$$

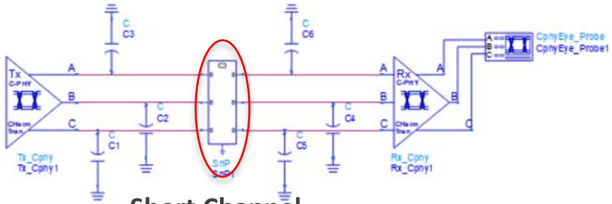
KEYSIGHT TECHNOLOGIES

Combined PDF for RJ + Encoding Jitter + ISI + Rx CTLE



Simulation Results (Short Channel)

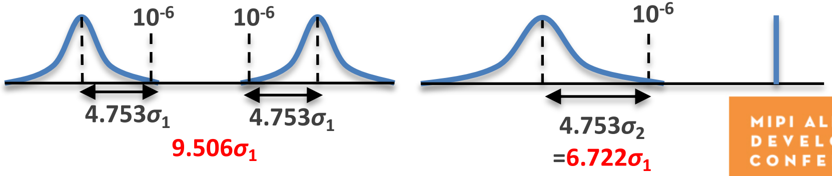
Speed = 8 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1.4 GHz, Pole1 = 4.2 GHz, Pole2 = 14 GHz, DC Gain = 1)



Short Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Non-triggered Eye		Triggered Eye	
	Width, ps	RJ Impairment,	Width, ps	RJ Impairment,
0	77.5	0 σ	85.7	0 σ
1	72.3	5.2 σ	82.1	3.6 σ
2	67.4	5.1 σ	78.0	3.9 σ
3	60.3	5.7 σ	74.7	3.7 σ
4	54.7	5.7 σ	71.0	3.7 σ
5	49.6	5.6 σ	67.0	3.7 σ
6	40.3	6.2 σ	58.6	4.5 σ
7	31.8	6.5 σ	54.6	4.4 σ



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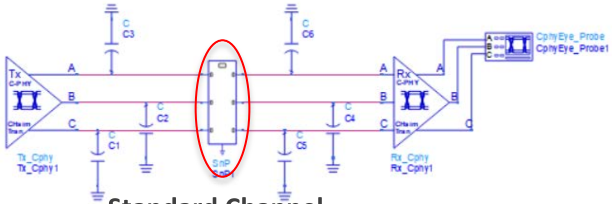
Simulation Results (Standard Ch)

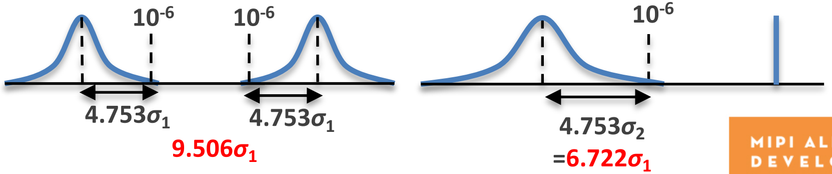
Speed = 6 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1 GHz, Pole1 = 3 GHz, Pole2 = 10 GHz, DC Gain = 1)



Standard Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Non-triggered Eye		Triggered Eye	
	Width, ps	RJ Impairment,	Width, ps	RJ Impairment,
0	106.6	0 σ	114.7	0 σ
1	100.8	5.8 σ	109.7	5.0 σ
2	94.9	5.9 σ	106.2	4.3 σ
3	89.7	5.6 σ	101.5	4.4 σ
4	85.4	5.3 σ	97.7	4.3 σ
5	76.9	5.9 σ	92.6	4.4 σ
6	69.1	6.3 σ	86.4	4.7 σ
7	61.4	6.5 σ	79.4	5.0 σ



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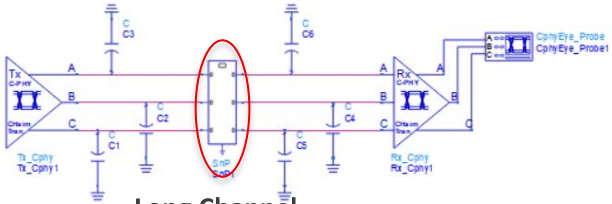
Simulation Results (Long Ch)

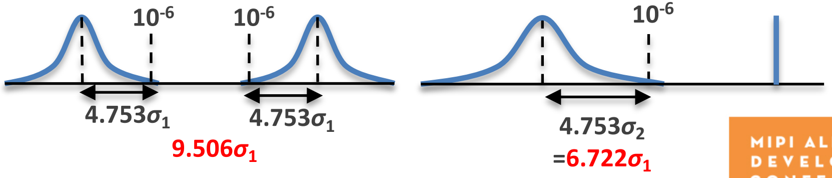
Speed = 4 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 0.8 GHz, Pole1 = 2.4 GHz, Pole2 = 10 GHz, DC Gain = 1)



Long Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Non-triggered Eye		Triggered Eye	
	Width, ps	RJ Impairment,	Width, ps	RJ Impairment,
0	166	0 σ	170.9	0 σ
1	158.3	7.7 σ	163.0	7.9 σ
2	156.6	4.7 σ	162.7	4.1 σ
3	149.4	5.5 σ	158.7	4.1 σ
4	145.6	5.1 σ	156.6	3.6 σ
5	137.4	5.7 σ	152.3	3.7 σ
6	129.7	6.1 σ	145.6	4.2 σ
7	125.1	5.8 σ	138.9	4.6 σ



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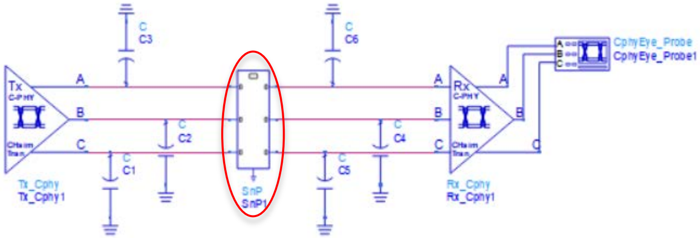
Agenda

- RJ (Random Jitter) Impact on C-PHY Eye Diagram
- Tx Impairment Budget Case Study
- MIPI PHY Simulation Solution in ADS (Advance Design System)

TX Impairment for Short Channel + RJ

Speed = 8 Gsps

C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1.4 GHz, Pole1 = 4.2 GHz, Pole2 = 14 GHz, DC Gain = 1)

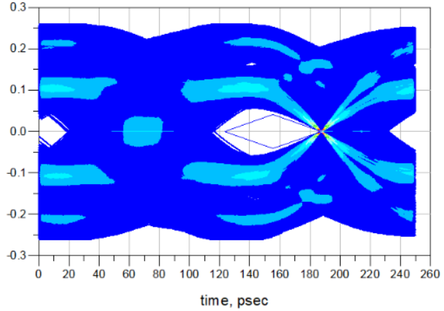


Short Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	87.5	0 UI
1	82.1	0.029 UI
2	78.0	0.062 UI
3	74.7	0.09 UI
4	71.0	0.12 UI
5	67.0	0.15 UI

Triggered eye with prorated eye mask



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TX Impairment for Short Channel + RJ + 0.05 UI DCD

DCD=0.05 UI

Speed = 8 Gsps

C_{PADTX} = 1.5 pF

C_{PADRX} = 1 pF

V_{DD} = 425 mV

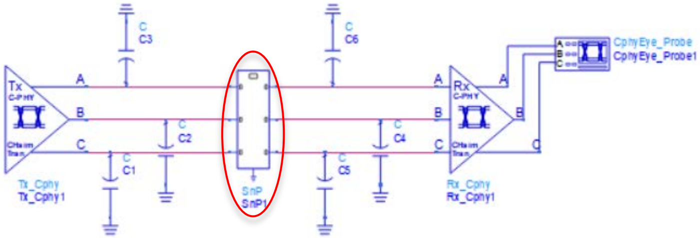
Z_{OS} = 50 ohm

Z_{ID} = 100 ohm

TxEQ OFF

RxEQ ON

(Zero1 = 1.4 GHz, Pole1 = 4.2 GHz, Pole2 = 14 GHz, DC Gain = 1)

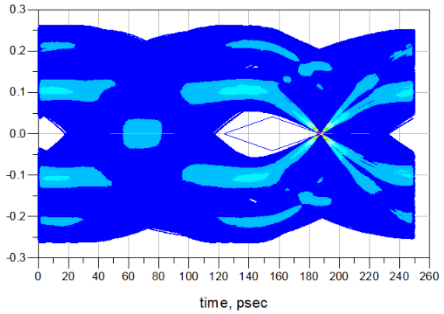


Short Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	82.0	0.03 UI
1	76.4	0.07 UI
2	71.5	0.11 UI
3	69.9	0.13 UI
4	65.9	0.16 UI

Triggered eye with prorated eye mask



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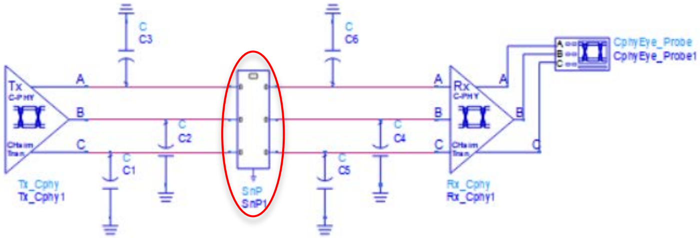
TX Impairment for Short Channel + RJ + 0.1 UI DCD

DCD=0.1 UI
Speed = 8 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1.4 GHz, Pole1 = 4.2 GHz, Pole2 = 14 GHz, DC Gain = 1)

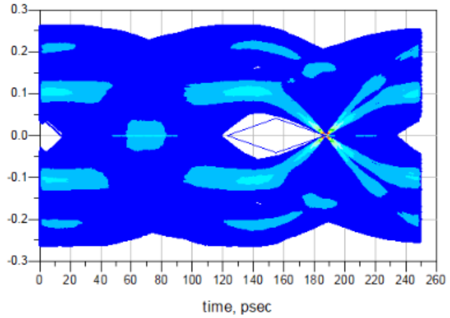


Short Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	74.5	0.09 UI
1	71.1	0.12 UI
2	67.8	0.14 UI
3	65.2	0.16 UI
4	61.3	0.20 UI

Triggered eye with prorated eye mask



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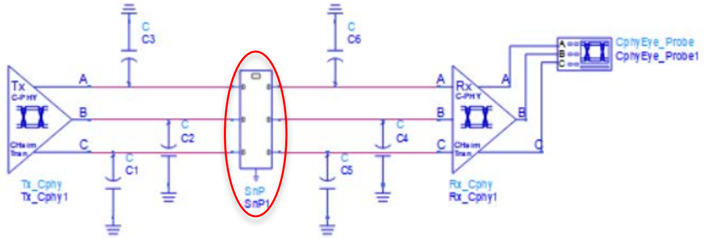
TX Impairment for Standard Channel + RJ

Speed = 6 Gsps

C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1 GHz, Pole1 = 3 GHz, Pole2 = 10 GHz, DC Gain = 1)

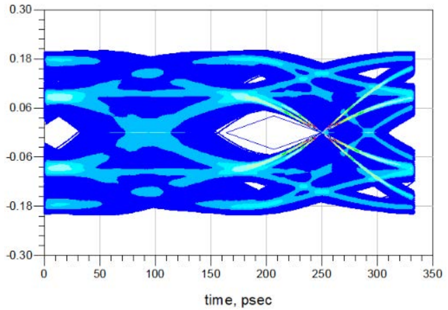


Standard Channel

ADS (Advanced Design System) (1M Bits)

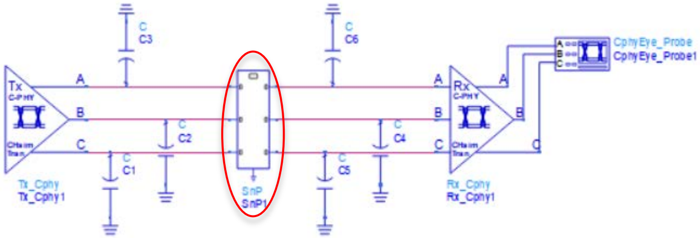
RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	114.7	0 UI
1	109.7	0.03 UI
2	106.2	0.05 UI
3	101.5	0.08 UI
4	97.7	0.10 UI
5	92.6	0.13 UI
6	86.4	0.17 UI

Triggered eye with prorated eye mask



TX Impairment for Standard Channel + RJ + 0.05 UI DCD

DCD = 0.05 UI
Speed = 6 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1 GHz, Pole1 = 3 GHz, Pole2 = 10 GHz, DC Gain = 1)

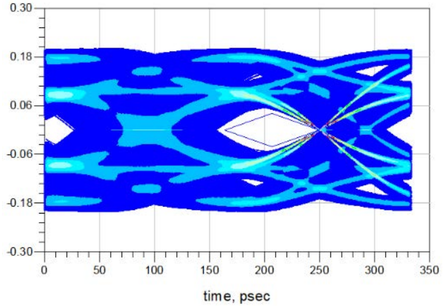


Standard Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	108.3	0.04 UI
1	100.9	0.08 UI
2	98.8	0.10 UI
3	96.5	0.11 UI
4	94.0	0.12 UI
5	85.9	0.17 UI

Triggered eye with prorated eye mask



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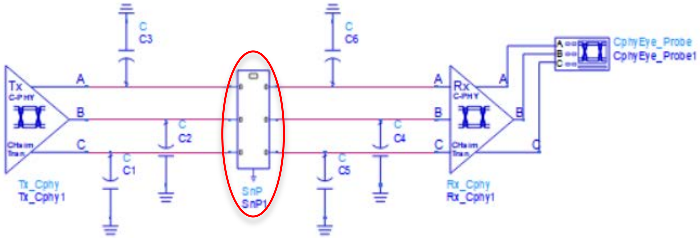
TX Impairment for Standard Channel + RJ + 0.1 UI DCD

DCD = 0.1 UI
Speed = 6 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 1 GHz, Pole1 = 3 GHz, Pole2 = 10 GHz, DC Gain = 1)

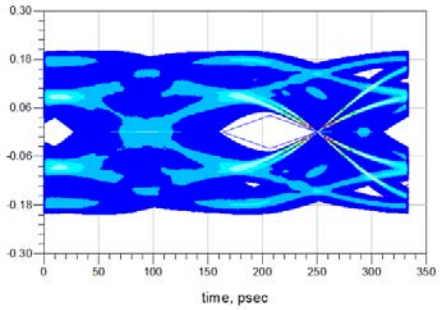


Standard Channel

ADS (Advanced Design System) (1M Bits)

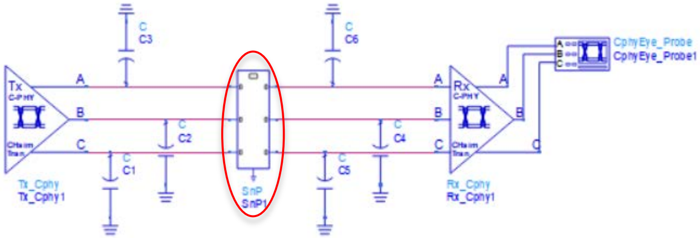
RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	98.7	0.10 UI
1	95.0	0.12 UI
2	91.1	0.14 UI
3	86.3	0.17 UI
4	81.0	0.20 UI

Triggered eye with prorated eye mask



TX Impairment for Long Channel + RJ

Speed = 4 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 0.8 GHz, Pole1 = 2.4 GHz, Pole2 = 10 GHz, DC Gain = 1)

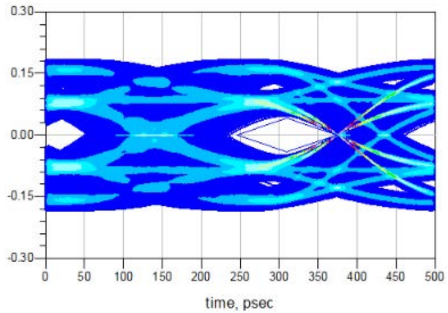


Long Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	170.9	0 UI
1	163.0	0.03 UI
2	162.7	0.03 UI
3	158.7	0.05 UI
4	156.6	0.06 UI
5	152.3	0.07 UI
6	145.6	0.10 UI
7	138.9	0.13 UI

Triggered eye with prorated eye mask



KEYSIGHT TECHNOLOGIES

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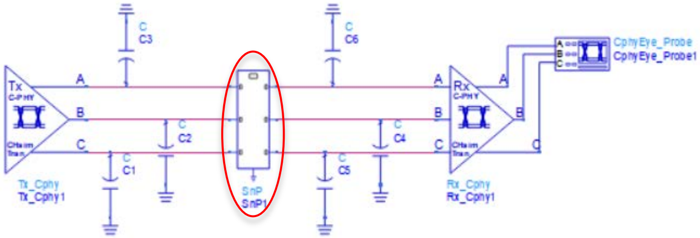
TX Impairment for Long Channel + RJ + 0.05 UI DCD

DCD = 0.05 UI
Speed = 4 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 0.8 GHz, Pole1 = 2.4 GHz, Pole2 = 10 GHz, DC Gain = 1)

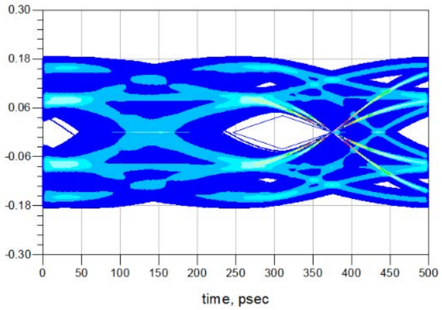


Long Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	160.5	0.04 UI
1	154.0	0.07 UI
2	147.6	0.09 UI
3	146.5	0.10 UI
4	143.5	0.11 UI
5	134.9	0.14 UI
6	125.8	0.18 UI

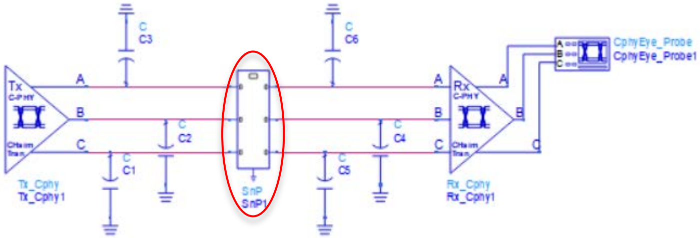
Triggered eye with prorated eye mask



KEYSIGHT TECHNOLOGIES

TX Impairment for Long Channel + RJ + 0.1 UI DCD

DCD = 0.1 UI
Speed = 4 Gsps
C_{PADTX} = 1.5 pF
C_{PADRX} = 1 pF
V_{DD} = 425 mV
Z_{OS} = 50 ohm
Z_{ID} = 100 ohm
TxEQ OFF
RxEQ ON
(Zero1 = 0.8 GHz, Pole1 = 2.4 GHz, Pole2 = 10 GHz, DC Gain = 1)

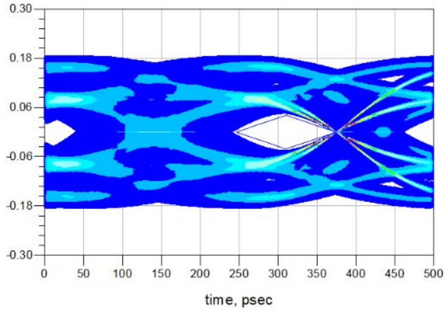


Long Channel

ADS (Advanced Design System) (1M Bits)

RJ_{rms} (σ), ps	Triggered Eye	
	Width, ps	Tx Impairment,
0	143.5	0.11 UI
1	139.9	0.12 UI
2	136	0.14 UI
3	134.8	0.14 UI
4	129.6	0.17 UI

Triggered eye with prorated eye mask



KEYSIGHT TECHNOLOGIES

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Agenda

- RJ (Random Jitter) Impact on C-PHY Eye Diagram
- Tx Impairment Budget Case Study
- MIPI PHY Simulation Solution in ADS (Advance Design System)

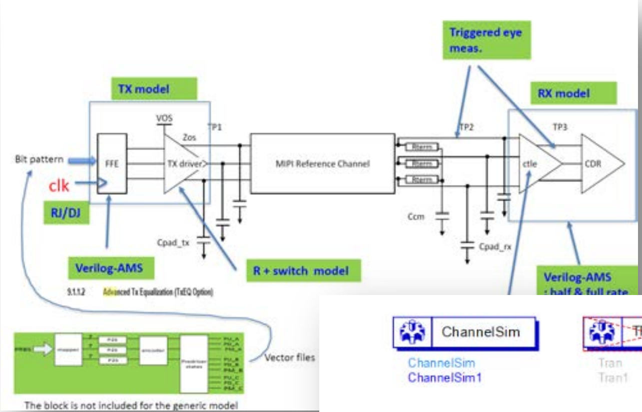
C-PHY Physical Layer Simulation Challenges

- Complicated transmitter and receiver modeling process including equalizations
  - Need simple transmitter and receiver models
- No single platform solution but using multiple tools such as Verilog-A, meaning lots of customization required
  - Need just simple one platform solution
- Limited jitter analysis
  - Need full support of RJ, PJ (Periodic Jitter) and DCD (Duty Cycle Distortion)
- SPICE-alike simulations result in long simulation time and limit number of bits that can be simulated
  - Need channel simulation technology for faster simulation with millions of bits
- Non-triggered eye plot
  - Need triggered eye plot to support MIPI C-PHY specification

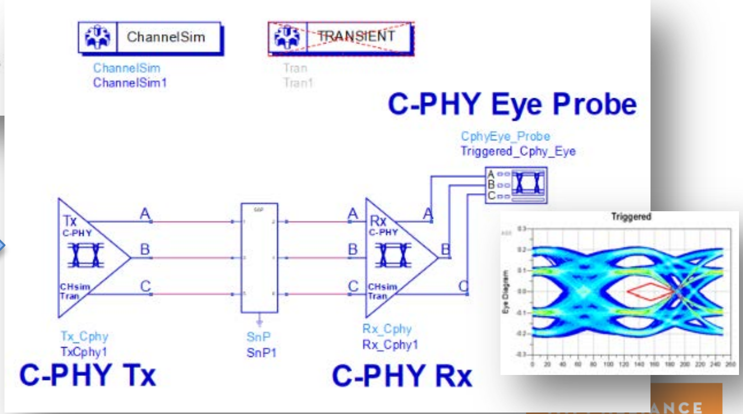
C-PHY Simulation Solution in ADS

- Dedicated C-PHY transmitter, receiver, and eye probe with triggered eye
- Supports both transient and channel simulation technologies
- Supports Tx equalization, Rx CTLE (Continuous Time Linear Equalizer), and jitter models such as RJ, PJ, and clock DCD

Before



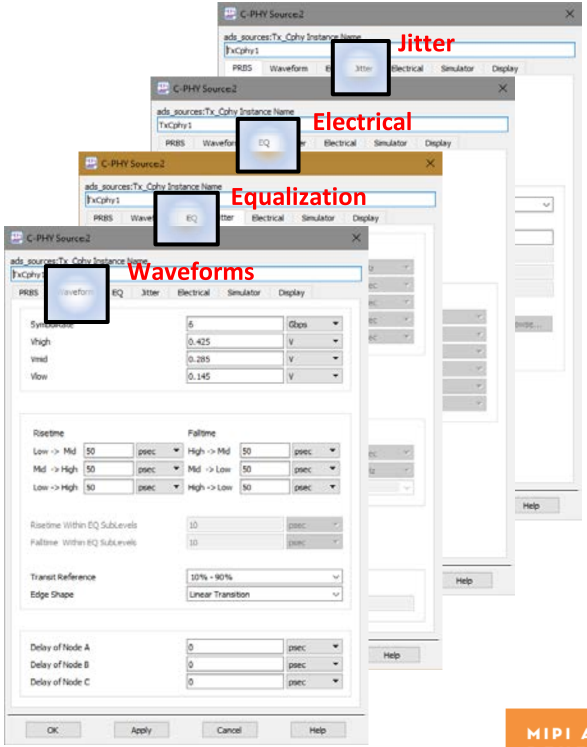
After



C-PHY Simulation Solution in ADS

Details on C-PHY Tx:

- PRBS (Pseudo Random Bit Sequence) generation
  - Maximal length LFSR, User defined LFSR, etc.
- C-PHY encoding and mapping
- Waveform parameters adjustment
  - V_{high}, V_{mid}, V_{low}, rise/fall time, edge shape, delay, etc.
- Advanced TxEQ
- Jitters
  - Random jitter, periodic jitter, Clock DCD, etc.
- Output resistance adjustment



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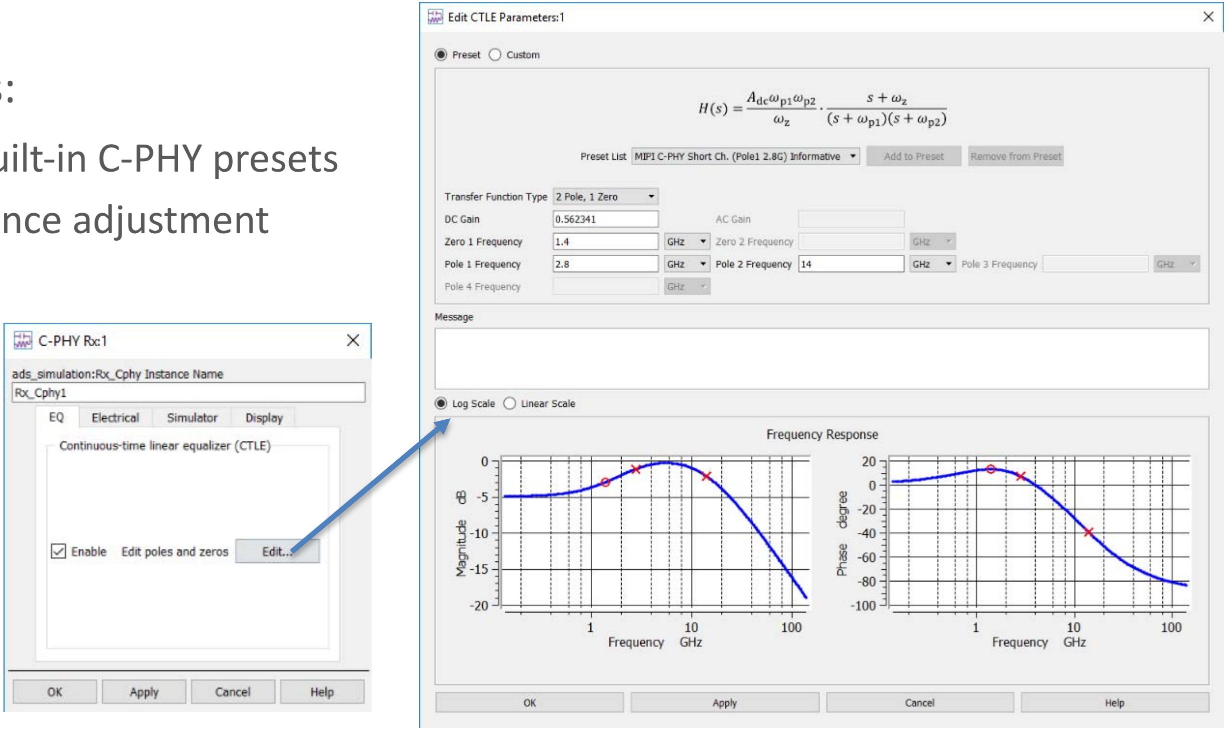
C-PHY Simulation Solution in ADS

C-PHY Rx supports:

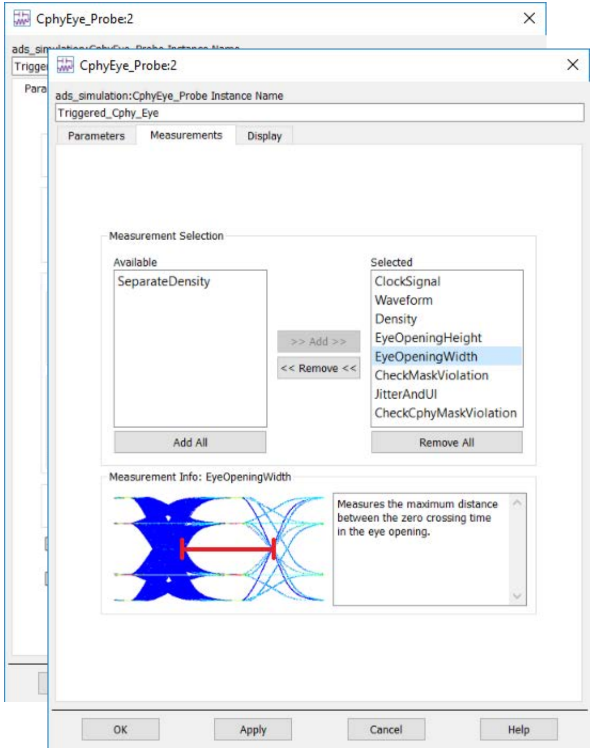
- CTLE with built-in C-PHY presets
- Input resistance adjustment



C-PHY Simulation Solution in ADS

C-PHY Eye Probe supports:

- C-PHY eye mask
- Triggered/non-triggered eye diagram
- Eye height/width
- UI jitter, average UI, minimum UI
- Mask violation
- Recovered clock



KEYSIGHT TECHNOLOGIES

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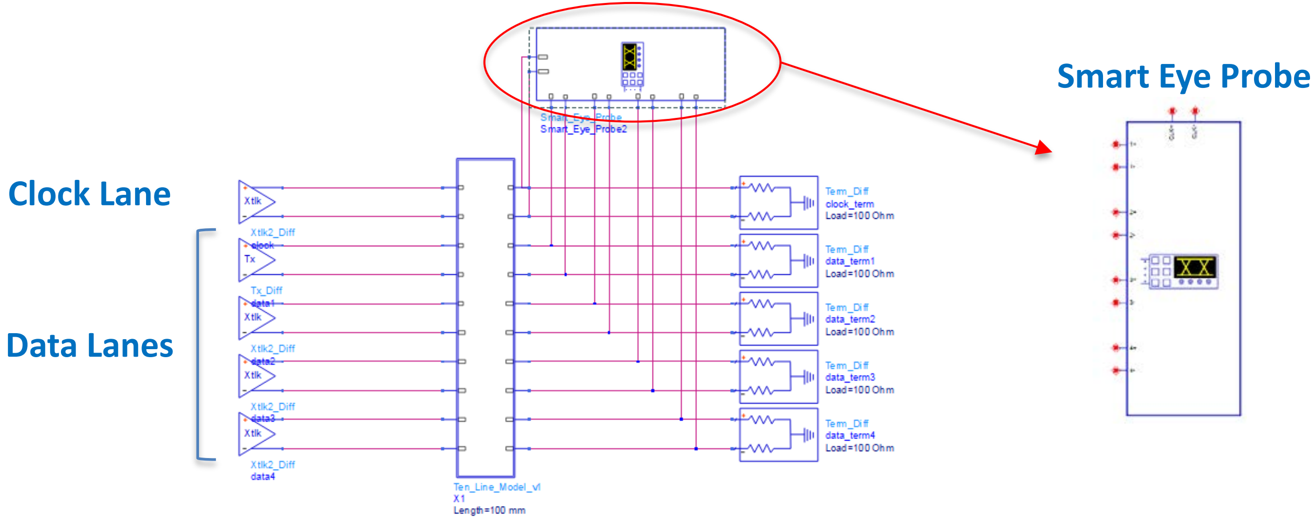
MIPI D-PHY^{SM} Simulation Solution in ADS

- Features in ADS to support MIPI D-PHY signal integrity simulations
  - Smart eye probe with triggered eye function, multi-lane, single ended and differential signal support
  - 8B9B encoder, EQ (de-emphasis), jitter (Random jitter, periodic jitter, DCD) in Tx



Summary

- C-PHY triggered eye diagram has good tolerance on random jitter
- The Impact of RJ on triggered eye width tends to reduce when combined with encoding jitter and ISI
- The 0.15 UI Tx impairment budget could be reduced

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THANK YOU

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