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Study on the Influence of Random Jitter to the MIPI C-PHYSM 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)

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C-PHY Physical Layer Overview

High Speed (HS) Mode

- Signaling
 - 3-phase signal
 - 3-wire group
- Clocking ٠
 - Embedded clock

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Data rate

Short reference channel

- 2.5 Gsps ٠
- 4.5 Gsps with TxEQ ٠
- 8 Gsps with RxEQ ٠
- Standard reference channel 1.7 Gsps

3.5 Gsps with TxEQ

6 Gsps with RxEQ

- 2.3 Gsps with TxEQ
- 4 Gsps with RxEQ

Channel compensation ٠

- Advanced TxEQ (Tx Equization)
- Rx CTLE (Continuous Time Linear Equalizer) ٠

Current version v2.0

1.3 Gsps .

Long reference channel

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.



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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.



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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



Trigger and Non-Triggered Eye with RJ = 2ps

0.3 0.3 0.3 0.2 0.1 0.1-0.0 0.0 -0. -0.1 -0.2--0.2 -0.3--0.3 1 50 200 1250 300 350 100 150 200 time, psec **10**⁻¹² 10-12 10-12 $\sigma_2^2 = \sigma_1^2 + \sigma_1^2$ $\sigma_2 = \sqrt{2}\sigma_1$ **RJ PDF:** 7.034₀ **7.034**σ₁ **7.034**σ₁

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



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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







Combined PDF for RJ + Encoding Jitter







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





Simulation Results (Short Channel)

ADS (Advanced Design System) (1M Bits)

RJ _{rms}	Non-trigg	ered Eye	Triggered Eye			
(σ), ps	Width, ps	RJ Impairment,	Width, ps	RJ Impairmen	ıt,	
0	77.5	0σ	85.7	0σ		
1	72.3	5.2 σ	82.1	3.6 σ		
2	67.4	5.1 σ	78.0	3.9 <i>σ</i>		
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		
	10-6 10-6	\wedge	\wedge	10 ⁻⁶		
	4.753 <i>σ</i> ₁ 4.	753σ ₁	4.75	3 σ ₂		







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9.506*σ*1

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=6.722σ₁

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Simulation Results (Standard Ch) ADS (Advanced Design System) (1M Bits)

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



RJ _{rms}	Non-trigge	ered Eye	Triggered Eye		
(0), ps	Width <i>,</i> 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

 $C_{PADRX} = 1 pF$ $V_{DD} = 425 mV$

 $Z_{OS} = 50 \text{ ohm}$ $Z_{ID} = 100 \text{ ohm}$

> TxEQ OFF RxEQ ON

(Zero1 = 0.8 GHz, Pole1 = 2.4 GHz, Pole2 = 10 GHz, DC Gain = 1)

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Rx_Cphy Rx Cphy1 CphyEye_Probe

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C2

Long Channel

ADS (Advanced Design System) (1M Bits)

	RJ _{rms}	Non-trigge	ered Eye	Triggered Eye		
ps		Width <i>,</i> ps	RJ Impairment,	Width, ps	RJ Impairment,	
	0	166	0σ	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 <i>σ</i>	
	3	149.4	5.5 σ	158.7	4.1 <i>σ</i>	
	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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Tx_Cphy Tx_Cphy1

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TX Impairment for Short Channel + RJ

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





ADS (Advanced Design System) (1M Bits)

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 $C_{PADTX} = 1.5 \text{ pF}$ $C_{PADRX} = 1 \text{ pF}$ $V_{DD} = 425 \text{ mV}$ $Z_{OS} = 50 \text{ ohm}$ $Z_{ID} = 100 \text{ ohm}$ TxEQ OFFRxEQ ON





RJ _{rms}	Trigger	red Eye	
(σ), ps	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	

ADS (Advanced Design System) (1M Bits)

Triggered eye with prorated eye mask









TX Impairment for Short Channel + RJ + 0.1 UI DCD

CphyEye_Probe CphyEye Probe



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Rx_Cphy Rx Cphy1

ADS (Advanced Design System) (1M Bits)

RJ _{rms}	Triggered Eye				
(σ), ps	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_Cphy TX_Cphy1 0

C1

C2

Short Channel



TX Impairment for Standard Channel + RJ

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





ADS (Advanced Design System) (1M Bits)

Triggered eye with prorated eye mask









TX Impairment for Standard Channel + RJ + 0.05 UI DCD



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Rx_Cphy Rx Cphy1

ADS (Advanced Design System) (1M Bits)



Triggered eye with prorated eye mask





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TX_Cphy TX_Cphy1



0

C1

C2

Standard Channel

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CphyEye_Probe CohvEve_Probe

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TX Impairment for Standard Channel + RJ + 0.1 UI DCD

CphyEye_Probe CohvEve_Probe

DCD = 0.1 UI Speed = 6 Gsps $C_{PADTX} = 1.5 \text{ pF}$ $C_{PADRX} = 1 \text{ pF}$ $V_{DD} = 425 \text{ mV}$ $Z_{OS} = 50 \text{ ohm}$ $Z_{ID} = 100 \text{ ohm}$ TxEQ OFFRxEQ ON

(Zero1 = 1 GHz, Pole1 = 3 GHz, Pole2 = 10 GHz, DC Gain = 1)

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Rx_Cphy Rx Cphy1

ADS (Advanced Design System) (1M Bits)



Triggered eye with prorated eye mask







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TX_Cphy TX_Cphy1 0

C1

C2

Standard Channel



TX Impairment for Long Channel + RJ

CphyEye_Probe ColwEve Probe

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

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Rx_Cphy Rx Cphy1

ADS (Advanced Design System) (1M Bits)



Triggered eye with prorated eye mask







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TX_Cphy TX_Cphy1



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Long Channel



TX Impairment for Long Channel + RJ + 0.05 UI DCD

CphyEye_Probe

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

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Rx_Cphy Rx Cphy1

ADS (Advanced Design System) (1M Bits)



Triggered eye with prorated eye mask







C-PHY

TX_Cphy TX_Cphy1 0

C1

C2

Long Channel



TX Impairment for Long Channel + RJ + 0.1 UI DCD

CphyEye_Probe CohvEve_Probe

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

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C4

Rx_Cphy Rx Cphy1 ADS (Advanced Design System) (1M Bits)

RJ _{rms}	Trigger	red Eye	
(0), ps	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







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TX_Cphy TX_Cphy1 0

C1

C2

Long Channel





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









E R S N C E

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-PF

> C-PHY Rx:1 ads simulation:Rx Cphy Insta

> > OK

Rx_Cphy1

Input resistance adjust •

	Edit CTLE Parameter	rs:1				>
	Preset Custom					
			$H(s) = \frac{A_{\rm dc}\omega_{\rm p1}}{\omega_{\rm z}}$	$\frac{\omega_{\rm p2}}{(s+\omega_{\rm p1})(s+\omega_{\rm p2})}$	$\frac{t}{t}$ + ω_{p2})	
in C-PHY presets		Preset List MIPI C-	PHY Short Ch. (Pole1 2.8G) Ir	nformative Add	to Preset Remove from	n Preset
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	Pole 1 Frequency	2.8	GHz Pole 2 Frequency	14	GHz Pole 3 Frequent	GHz 👻
	Pole 4 Frequency		GHz *			
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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

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Available		Selected
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MIPI D-PHYSM Simulation Solution in ADS

- Features in ADS to support MIPI D-PHY signal integrity simulations ۰
 - 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



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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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