A SerDes Balancing Act:
Co-Optimizing Tx and Rx Equalization Settings to Maximize Margin

Todd Westerhoff, VP SiSoft
Donald Telian, Owner SiGuys

SI GUYS

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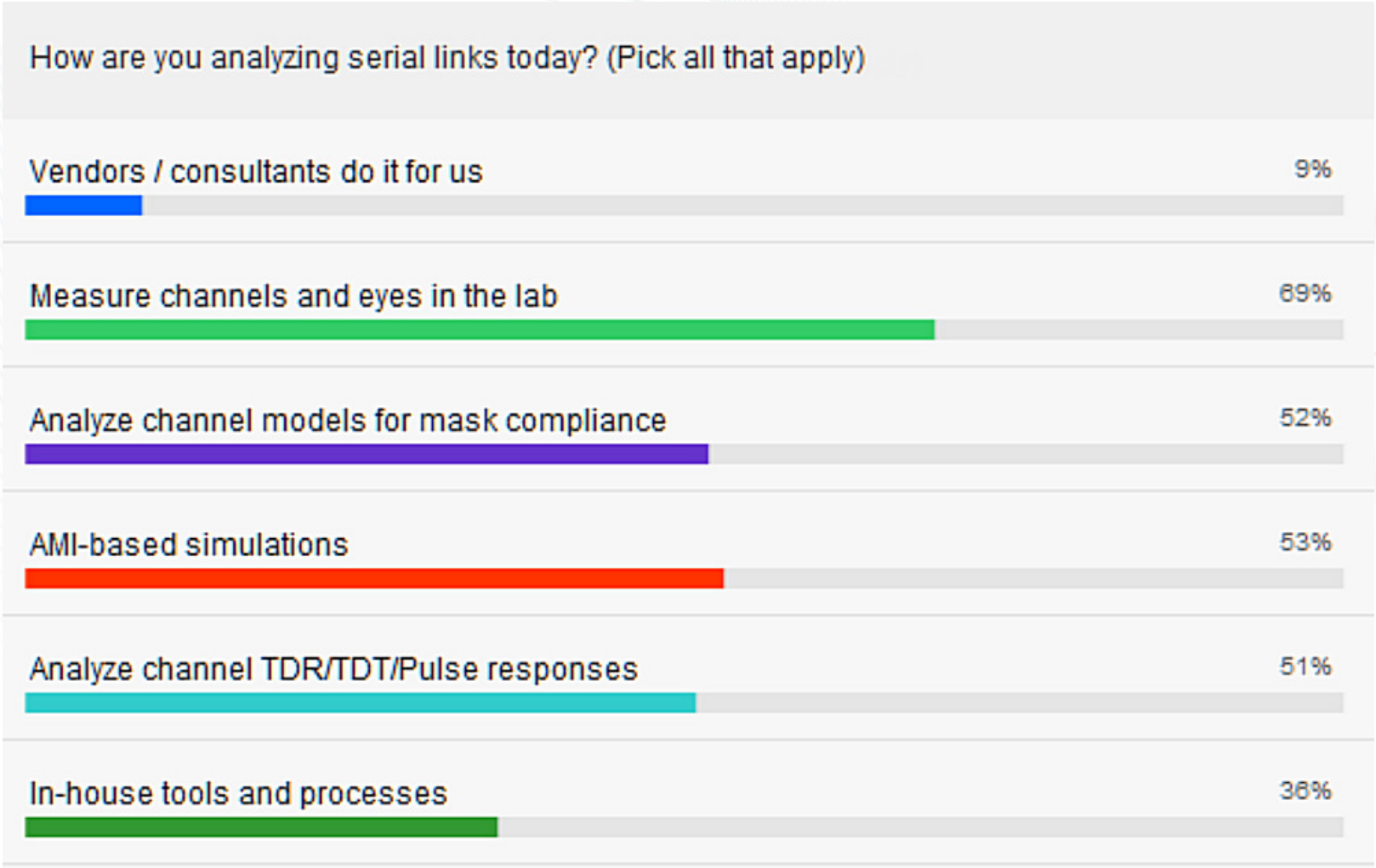
Poll Results: Analyzing Serial Links



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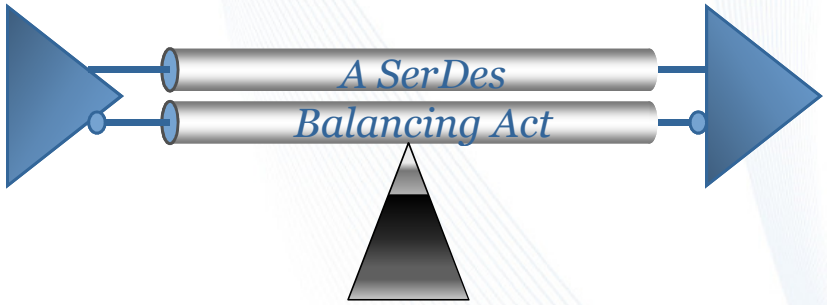
AGENDA

- Introduction to Co-Optimization
- Co-Optimization Examples
- How to Co-Optimize
- Summary



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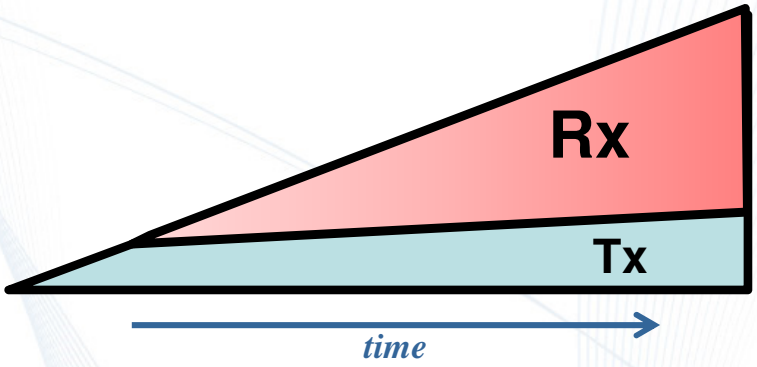
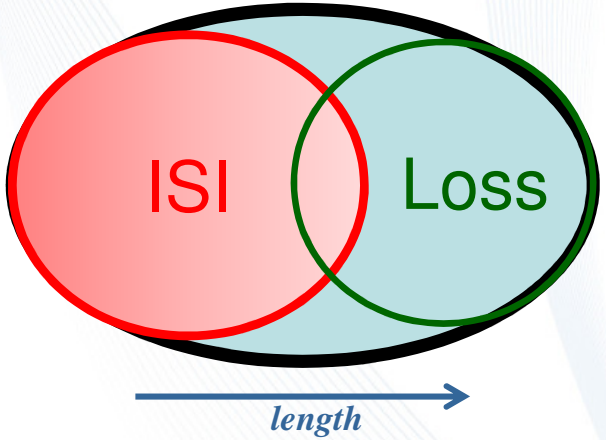
Why Co-Optimization?

- Increasing #links, data rates, and protocols
- EQ complexity / importance
  - PAM4, decreasing margin
  - Must balance Tx with Rx



- "Auto-Negotiation/Training" often isn't
  - Good goal, will take time to achieve
- Problems not only loss
  - Traditional EQ targets loss
- Optimal settings: SW-only fix
  - Rescues failing links



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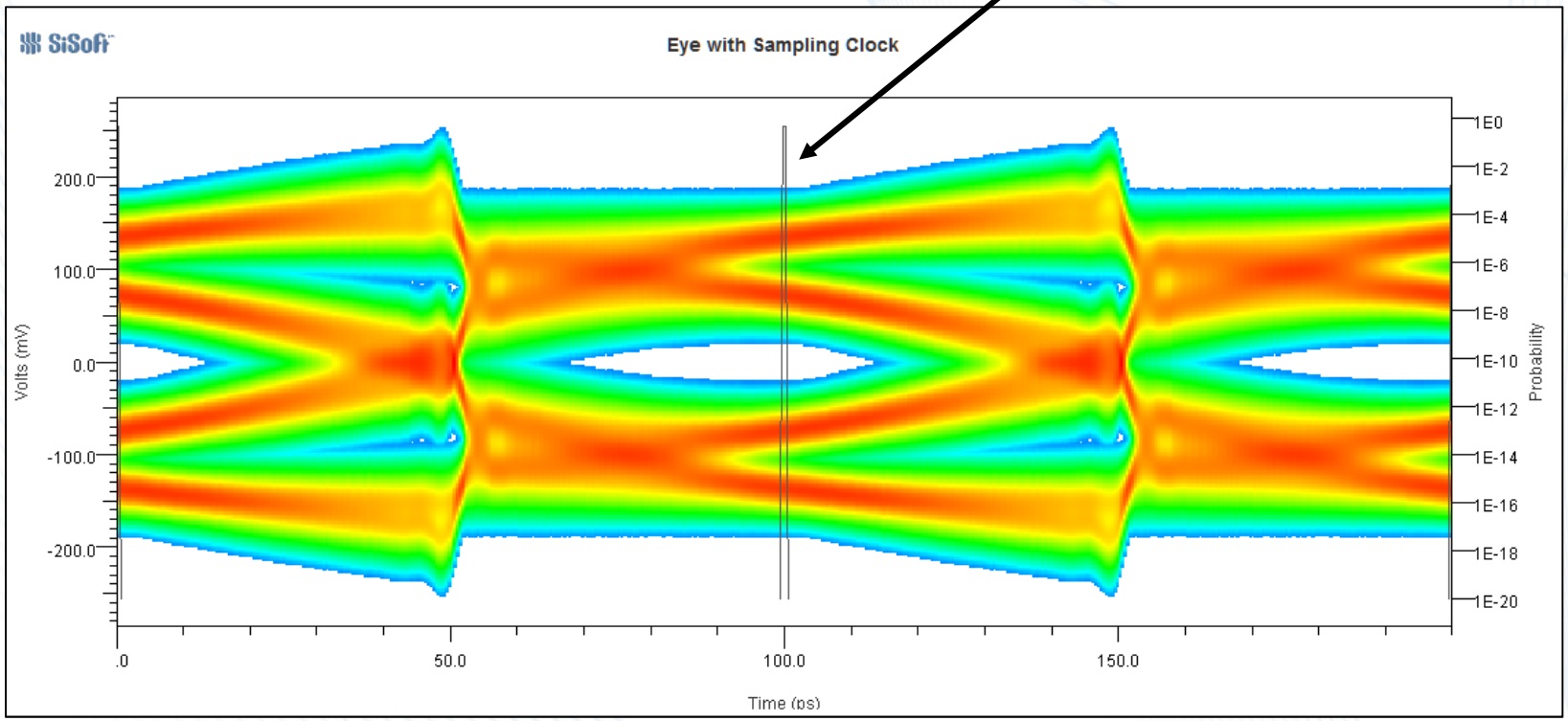
The Goal

Maximize eye height
where data is sampled



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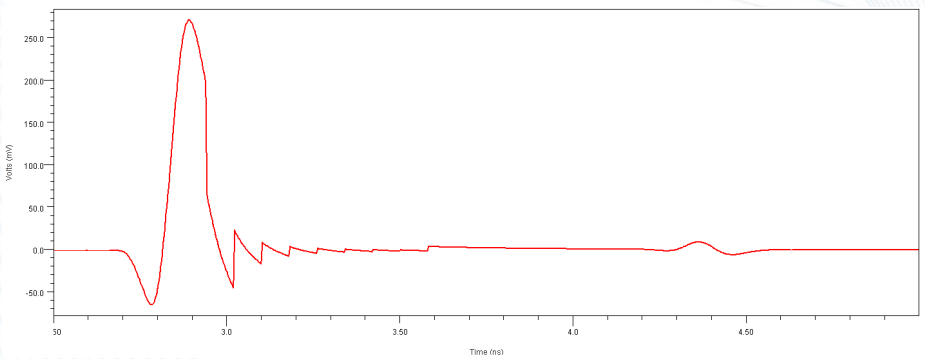
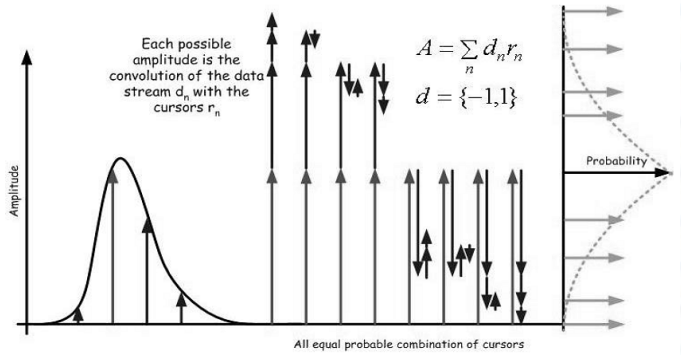
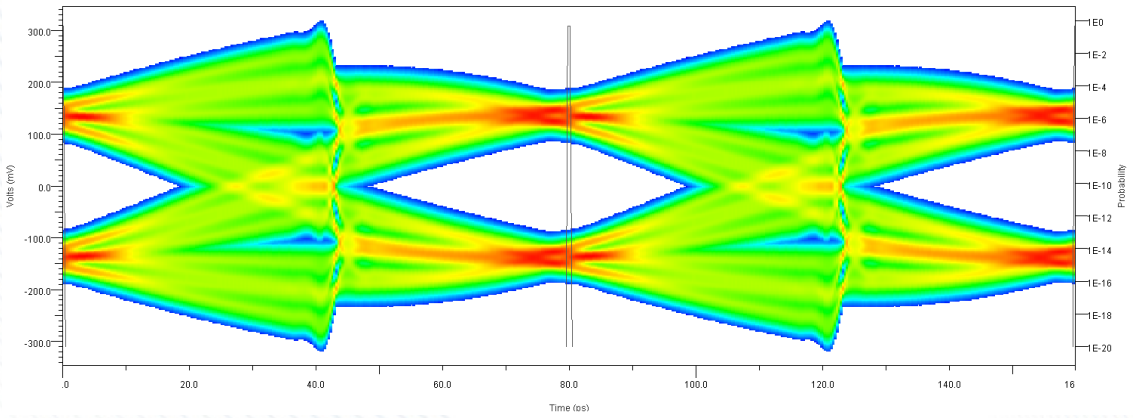
Pulse Response Analysis







"Channel Compliance Testing Utilizing Novel Statistical Eye Methodology", Anthony Sanders, DesignCon 2004

- Eye diagram derived from pulse response through recursive convolution

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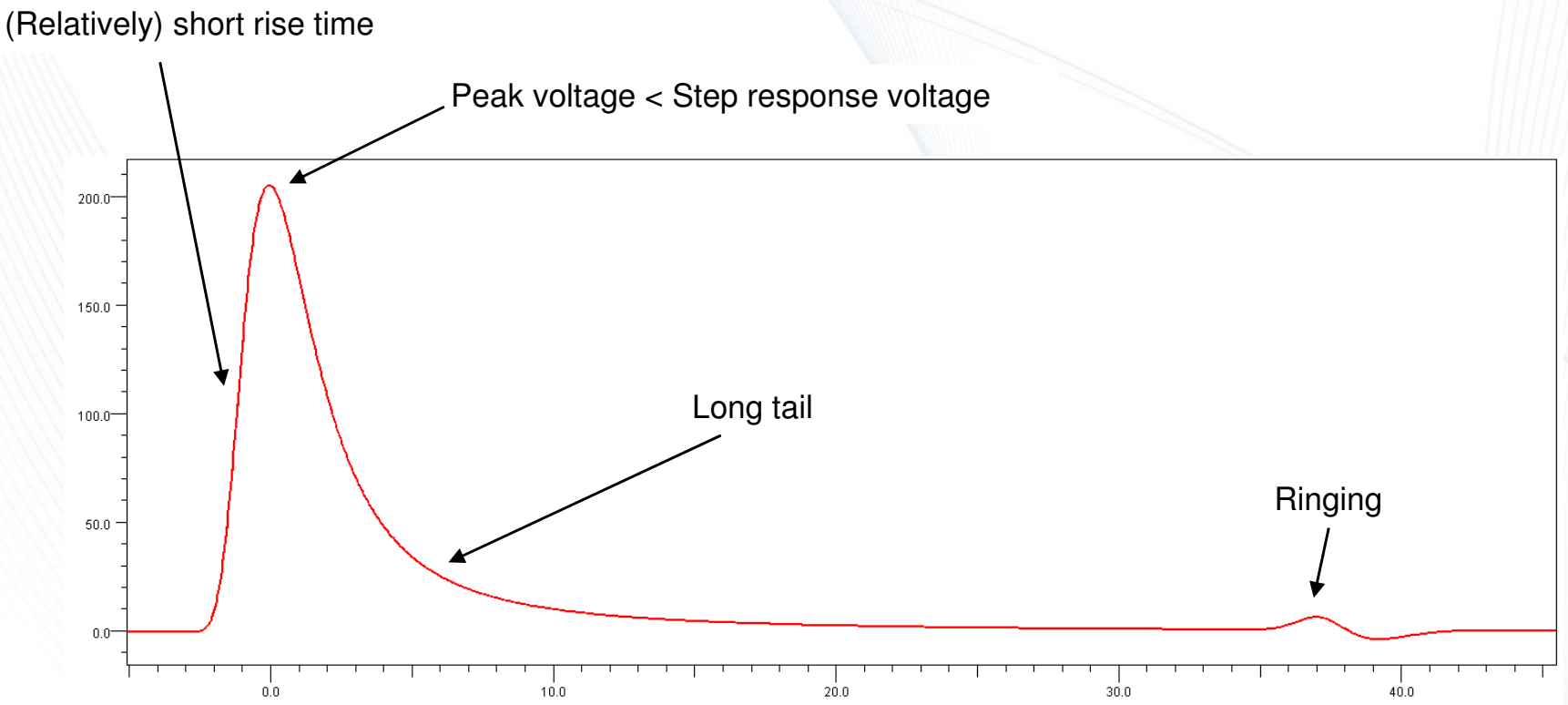
Unequalized Pulse Response
(a.k.a. the Channel Response)



- Requires accurate Tx/Rx analog models to correctly predict ringing due to reflections

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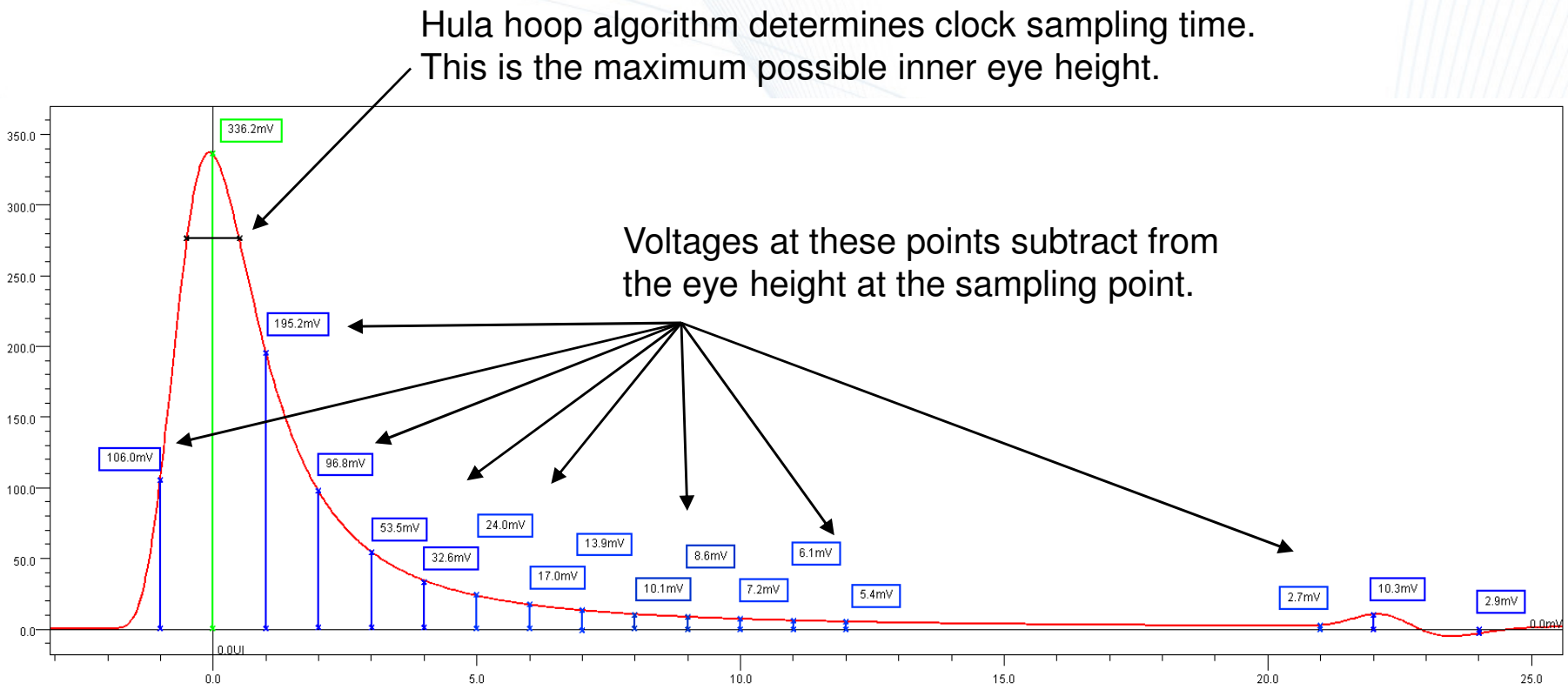
The ISI Pulse Response



- Voltage and time scales show ISI contributions
- Useful in evaluating EQ & predicting eye opening

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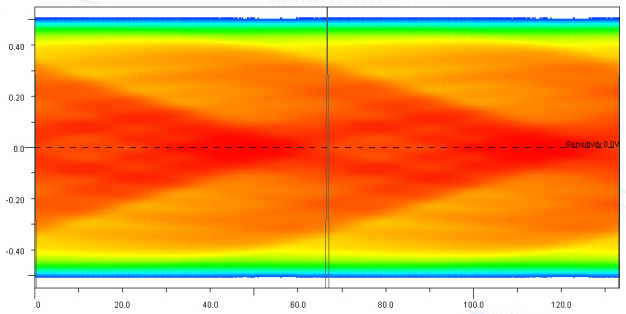
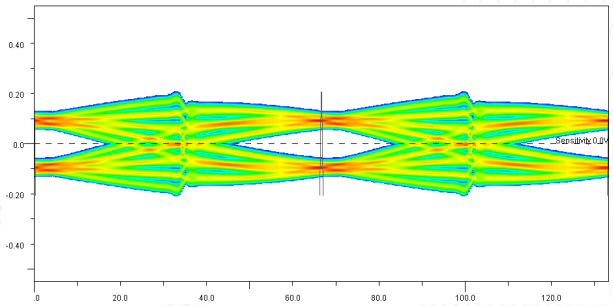
Equalization & the Pulse Response

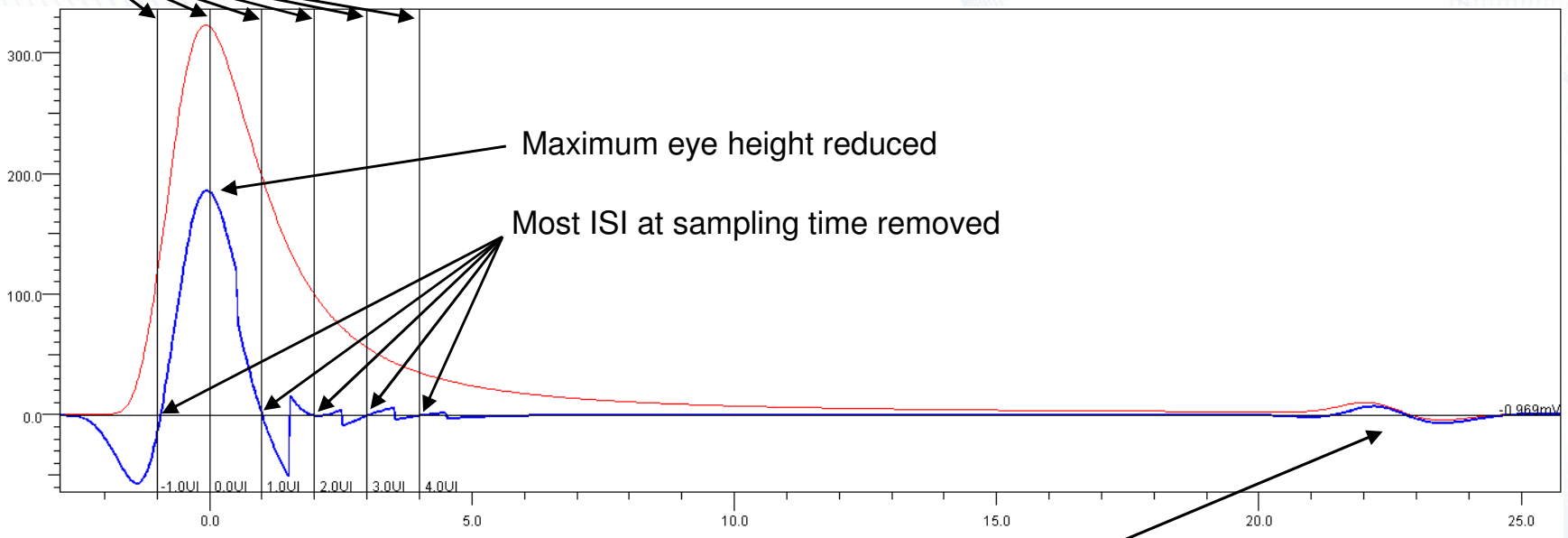


Unequalized



Equalized

Tx & Rx taps affect the signal here



Maximum eye height reduced

Most ISI at sampling time removed

Some ISI cannot be removed

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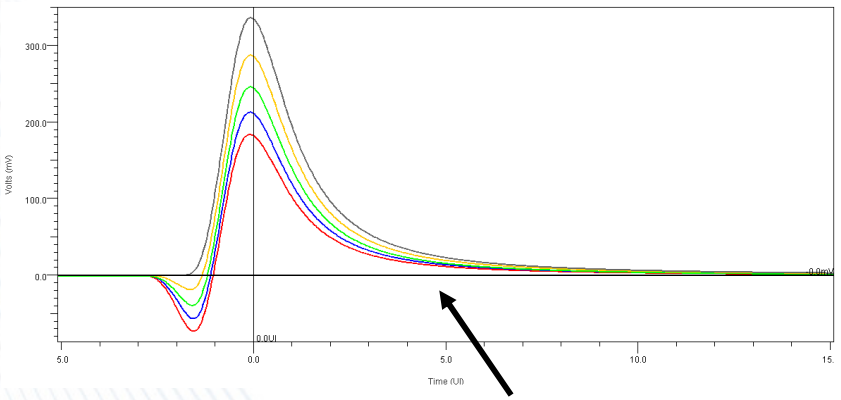
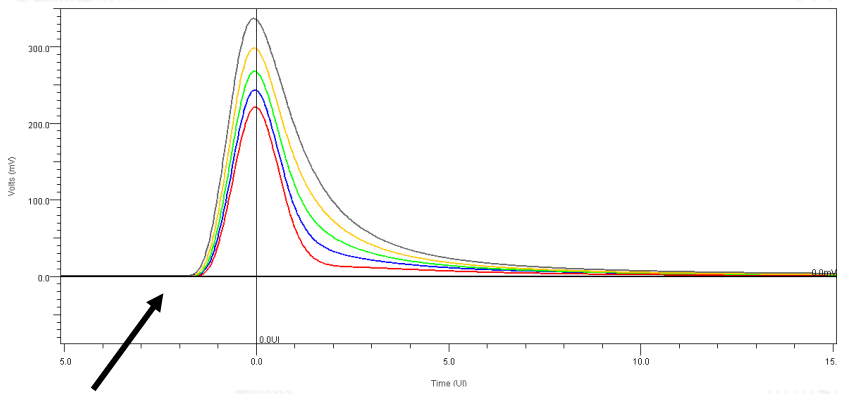
Types of Equalization

Tx Pre-Cursor

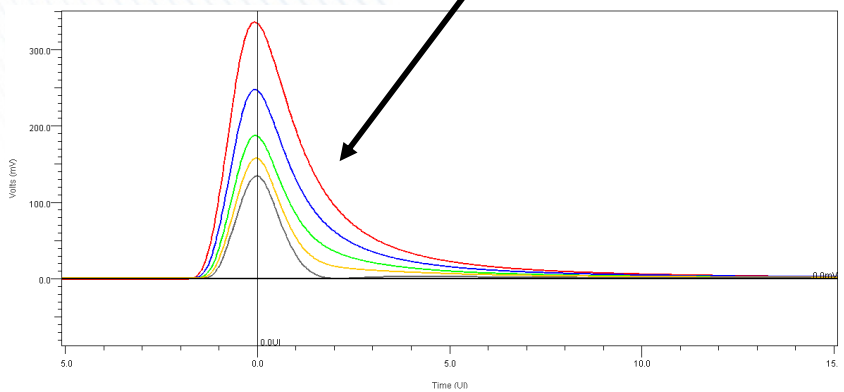


Tx Post-Cursor

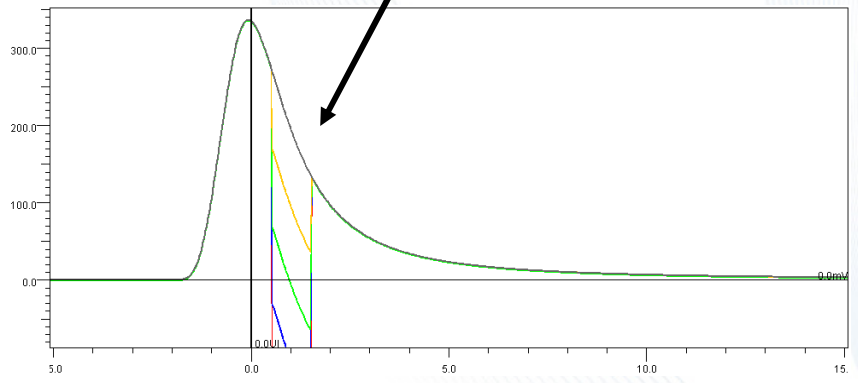


Multiple bit times affected

Single bit time affected



Rx CTLE



Rx DFE (Tap 1)

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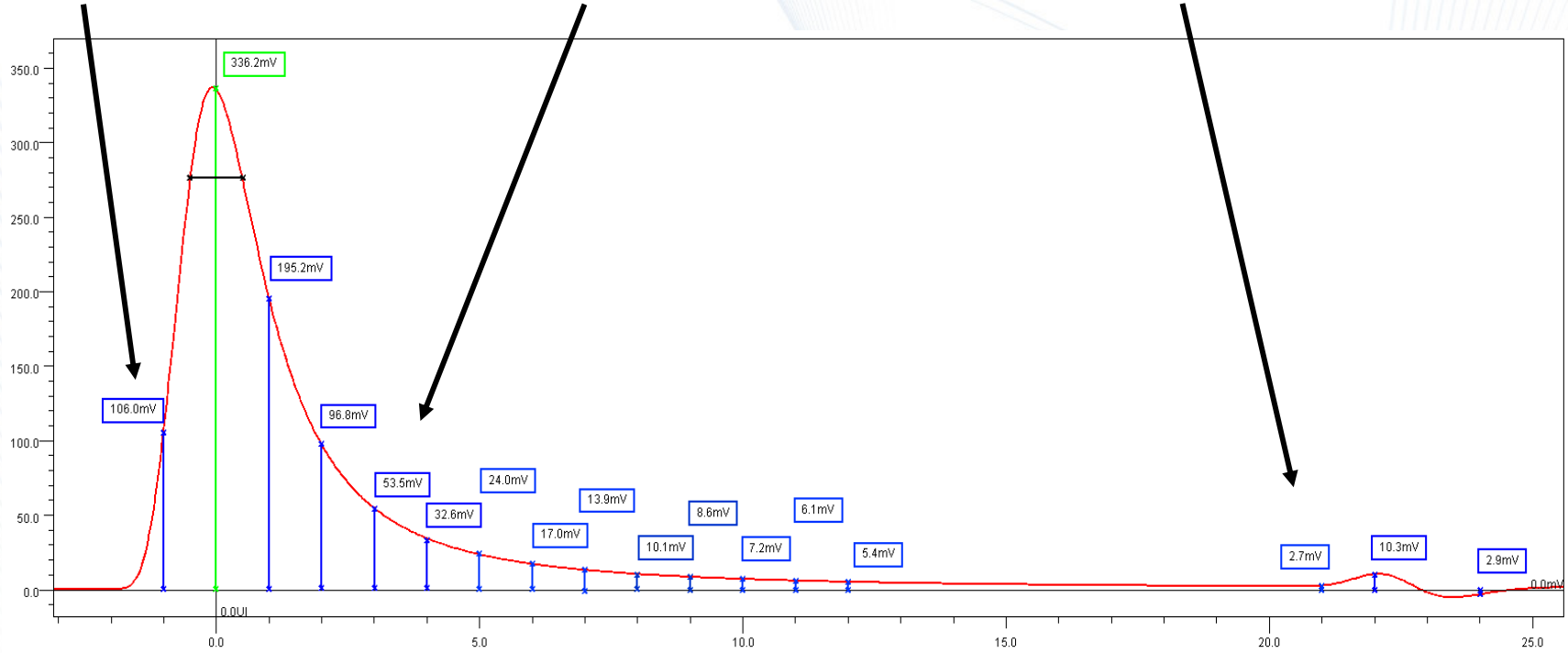
Equalizing Pulse Responses

Pre-cursor ISI
Tx pre-cursor is most effective
RX CTLE can help
RX DFE doesn't help at all

Long tails
Tx post cursor is effective
RX CTLE is sometimes better
RX DFE has limited range

Ringing
Tx and RX CTLE not much help
RX DFE floating taps may help
Bigger issue with short channels



- Long channels: pre-cursor & tail ISI is usually the challenge
- Short channels: ringing is usually the challenge

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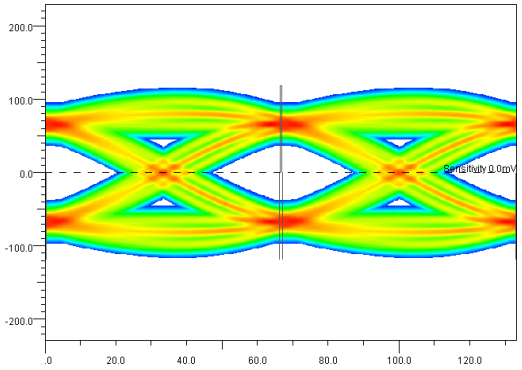
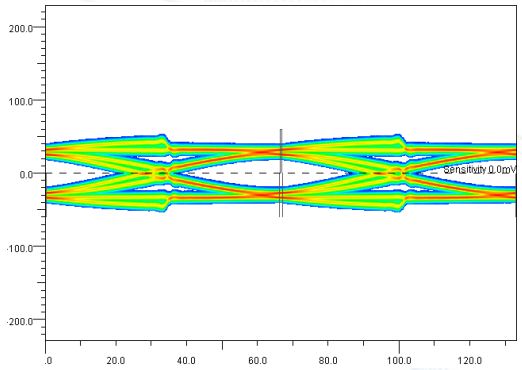
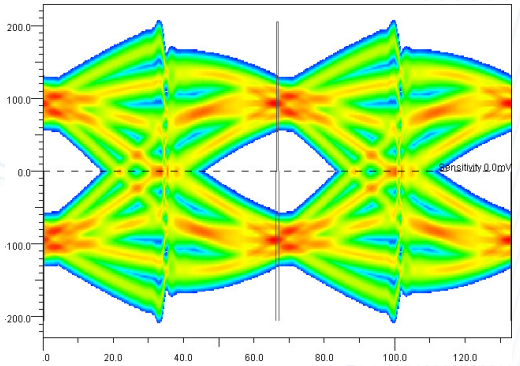
Evaluating EQ Tradeoffs



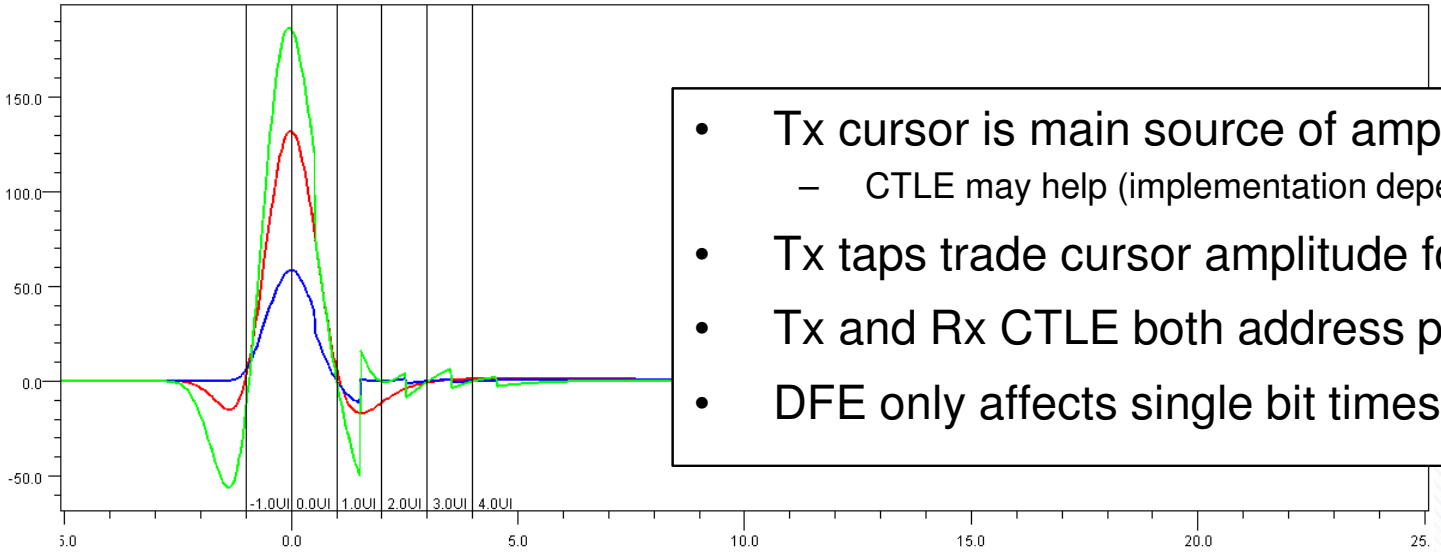
TX Only



RX Only



Tx & Rx



- Tx cursor is main source of amplitude
  - CTLE may help (implementation dependent)
- Tx taps trade cursor amplitude for reduced ISI
- Tx and Rx CTLE both address post-cursor EQ
- DFE only affects single bit times

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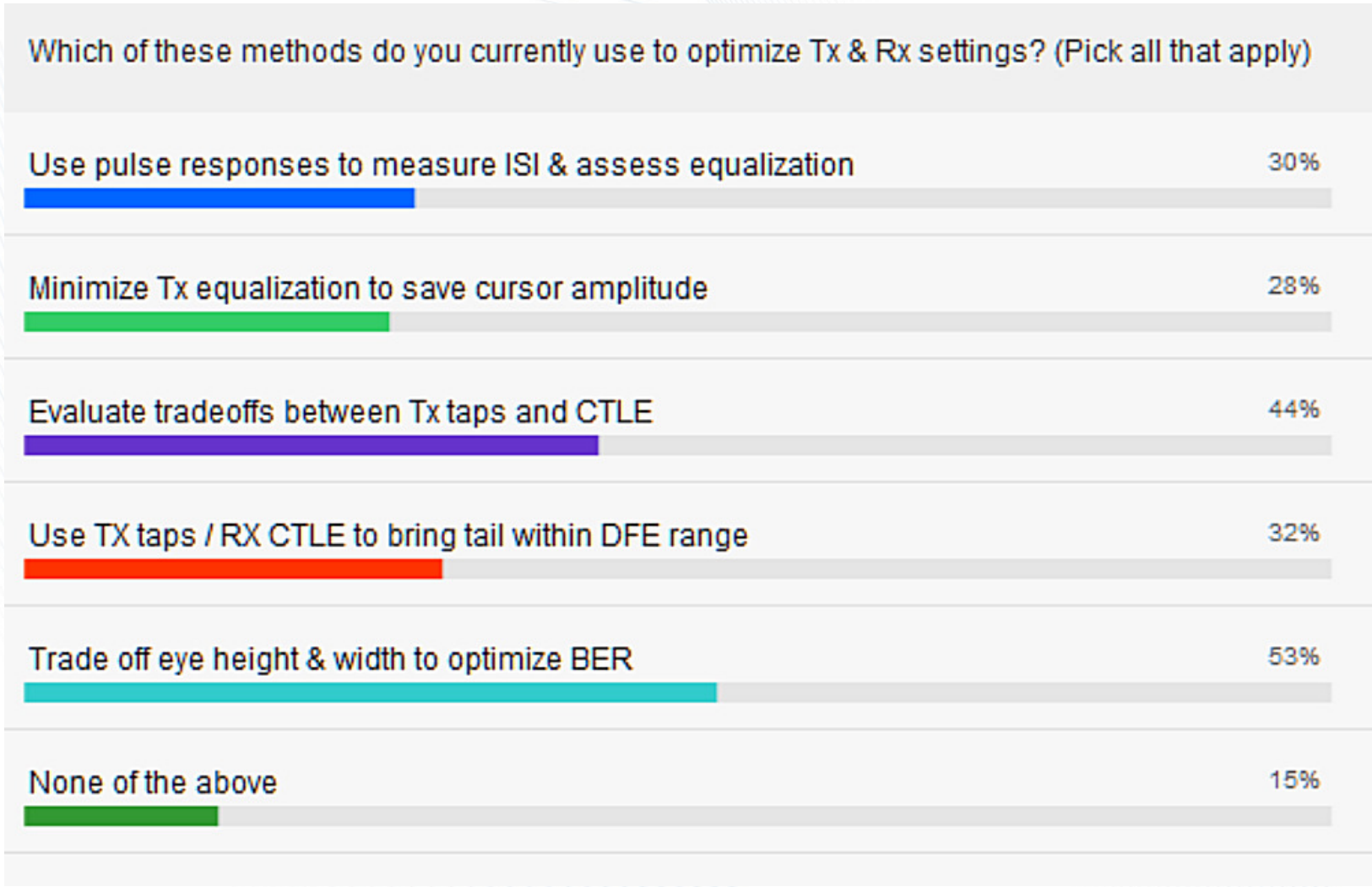
Poll Results: Analysis Methods



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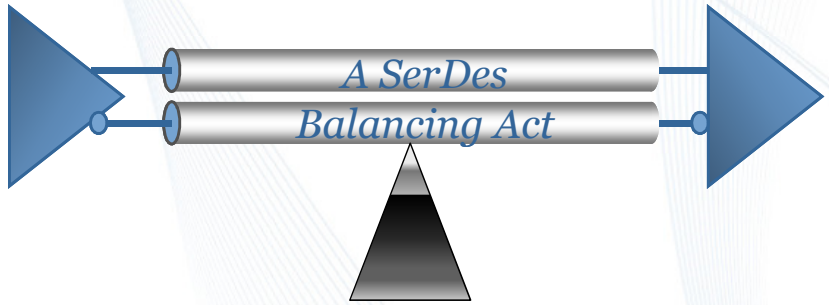
AGENDA

- Introduction to Co-Optimization
- Co-Optimization Examples
  - Industry Case Study
  - S-Parameter
  - Circuit-based
  - PAM4
- How to Co-Optimize
- Summary



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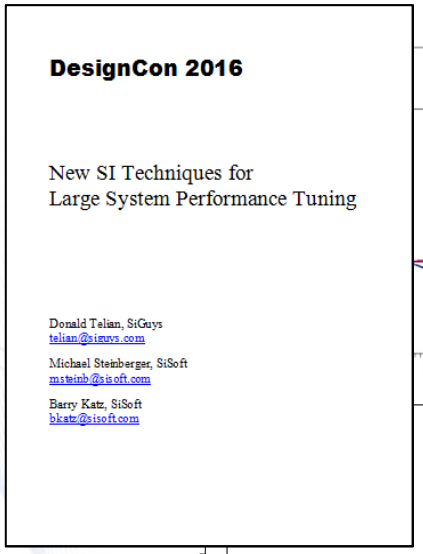
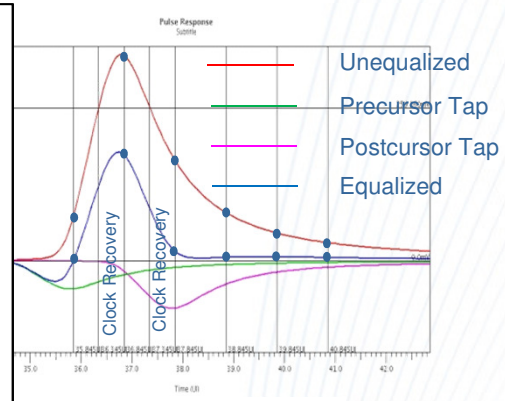
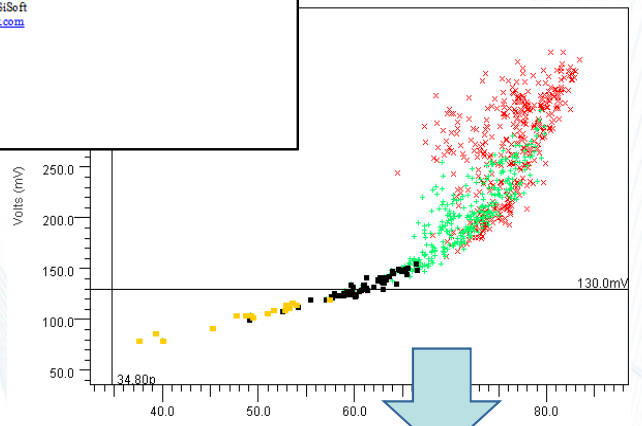
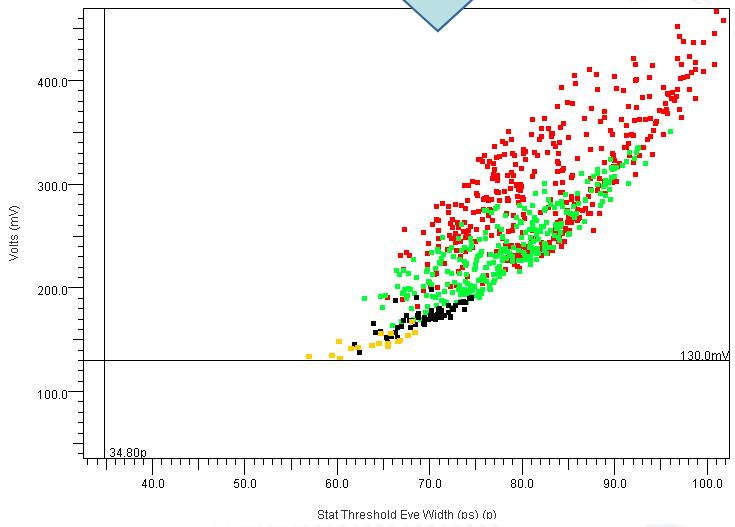
Industry Paper

- Co-Optimization case study
  - 60%+ performance gains
  - Allowed 25% longer links
    - Compared with best-known EQ
  - Removed dozens of components
- Detail on Co-Optimization concepts and techniques
  - Hula-hoop algorithm
  - Equations for reducing ISI
  - System-level Tx/Rx EQ tradeoffs









This presentation illustrates Co-Optimization on a wider array of channels

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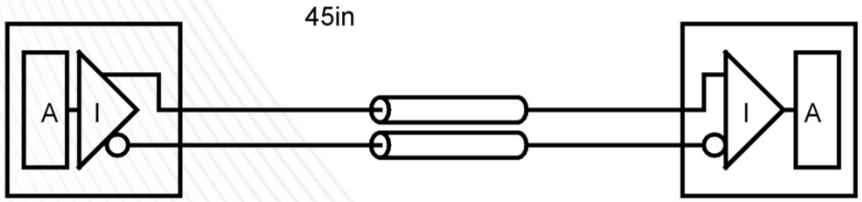
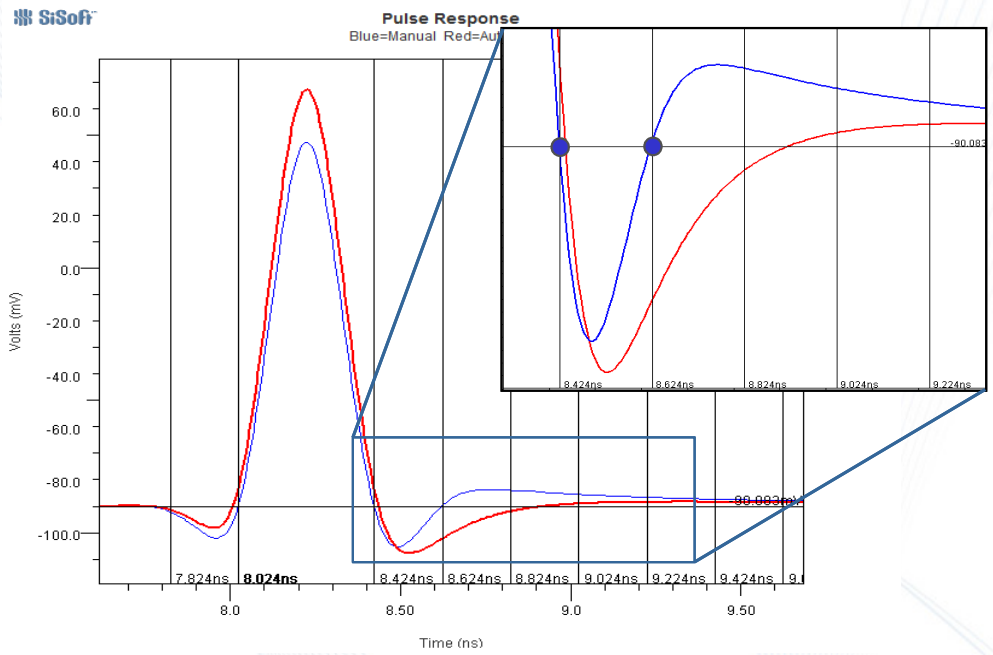
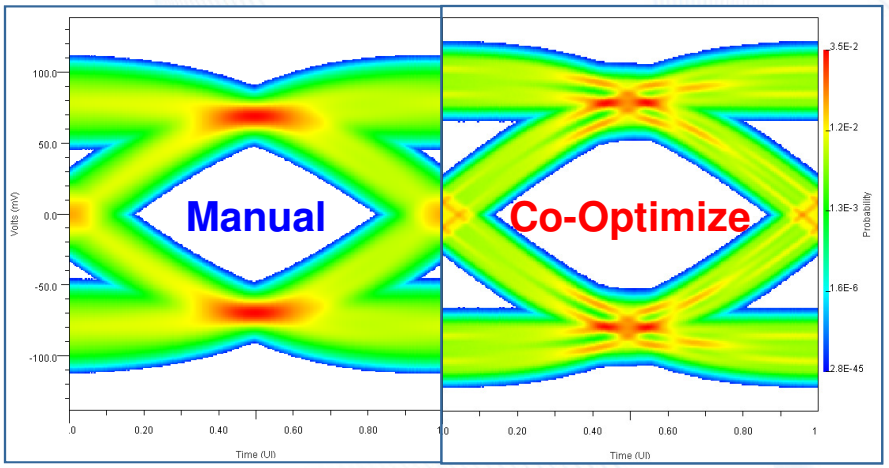
Paper: Equations vs Co-Optimization

- Problem:
  - Long/lossy channel
  - 4-tap Tx (1pre, 2post)
  - No Rx EQ



- Hand Calculation (blue)
  - Force zero in all taps
  - 1 hour/tap to solve/iterate
- Co-Optimization (red)
  - Trade amplitude for ISI
  - 15% better eye





Better Result

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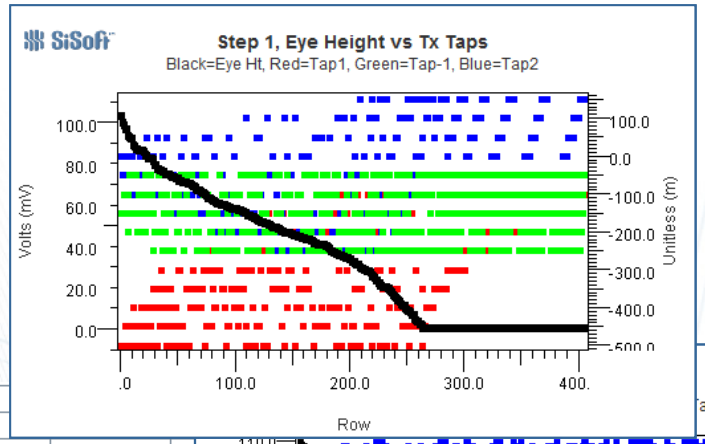
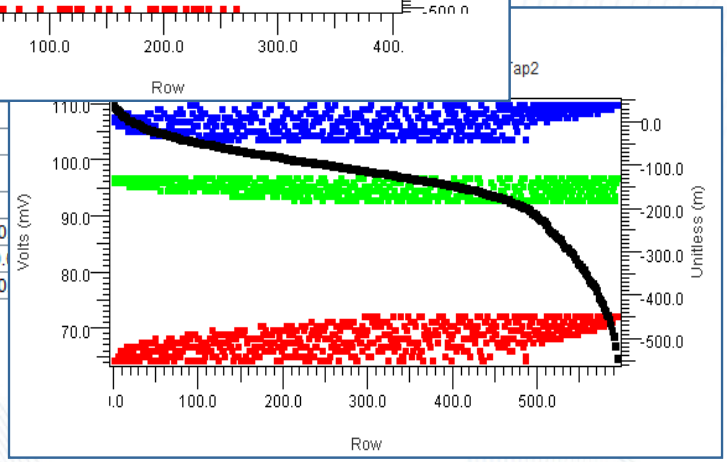
Blind Sweep

- 2-step sweep of Tx taps





TX1:tap_filter.0	Tap	AMI Range	<none>	1.0				
TX1:tap_fi...	Tap	AMI Range	<none>	-0.5	-0.45	-0.4	-0.35	
TX1:tap_fi...	Tap	AMI Range	<none>	-0.3	-0.25	-0.2	-0.15	-0.05	0
TX1:tap_filter.-1	Tap	AMI Range	<none>	-0.25	-0.2	-0.15	-0.1	-0.05	

1 coarse, ~500 runs, Statistical

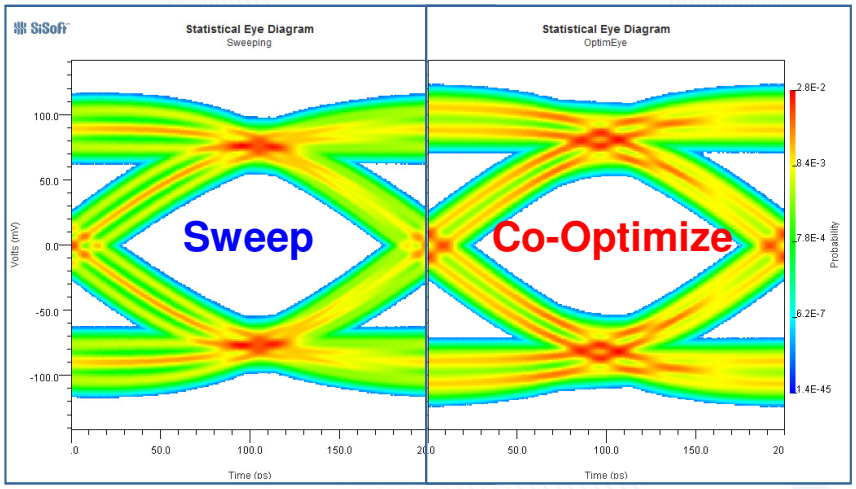
TX1:tap_filter.0	Tap	AMI Range	<none>	1.0					
TX1:tap_f...	Tap	AMI Range	<none>	-0.55	-0.54	-0.53	-0.52	-0.51	-0
TX1:tap_f...	Tap	AMI Range	<none>	-0.03	-0.02	-0.01	-0.01	0.0	0.
TX1:tap_filter.-1	Tap	AMI Range	<none>	-0.18	-0.17	-0.16	-0.15	-0.14	-0

2 fine, ~500 runs, Statistical

- 1 hour, closer result
  - Co-Optimization is 5% wider
- Results:

	Tap-1	Tap0	Tap1	Tap2	Eye	Time
Hand_Calc	-0.07	0.54	-0.34	0.05	-15%	**3 hours**
Sweep	-0.08	0.59	-0.33	0.00	-5%	**1 hour**
Co-Optimize	-0.04	0.61	-0.35	0.00	Best	**< 1 sec**

- If Rx EQ added
  - complex, less convergence



Faster

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Co-Optimization Cockpit

- You can fly this plane
  - Examples that follow will be available as SiSoft QCD Project
- Co-Optimization = SiSoft OptimEye™ Technology
- All variables adaptable
  - UI, EQ (FFE, DFE, CTLE), PCB Parameters, Jitter, Clock Recovery, etc.

Details later in presentation…

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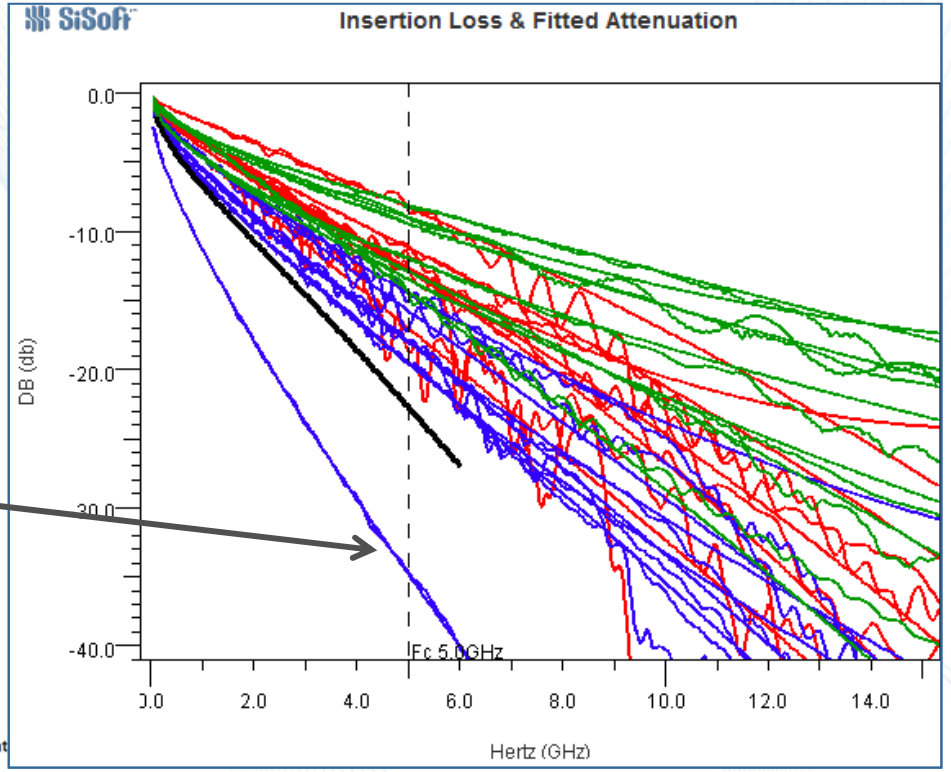
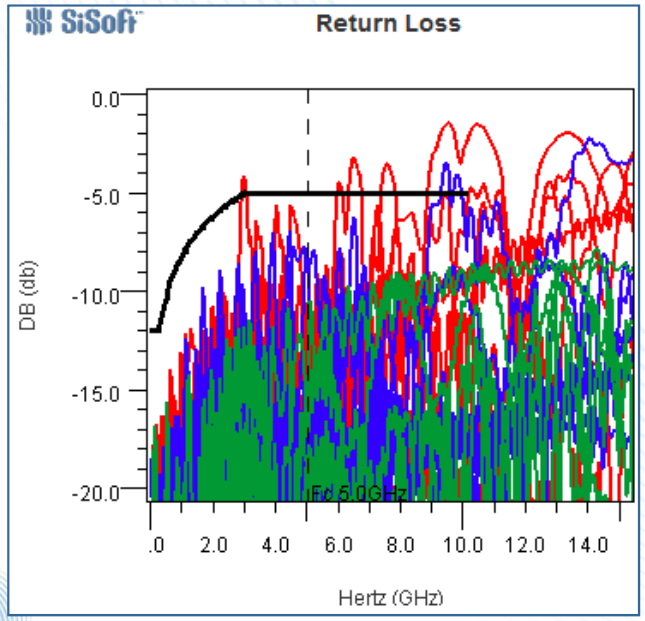
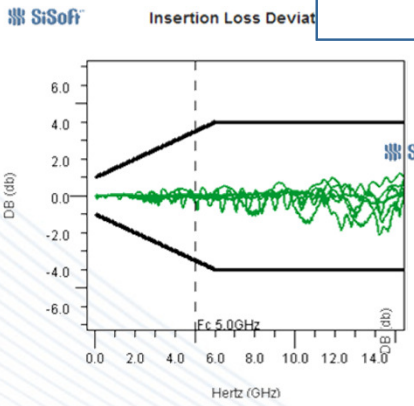
S-Parameter Channels

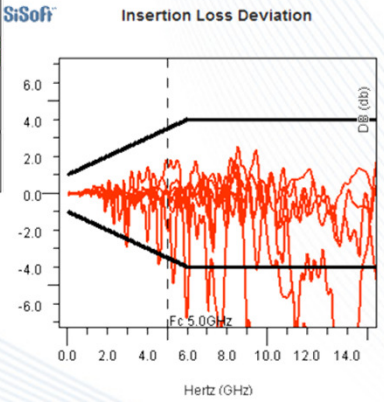
Range of characteristics

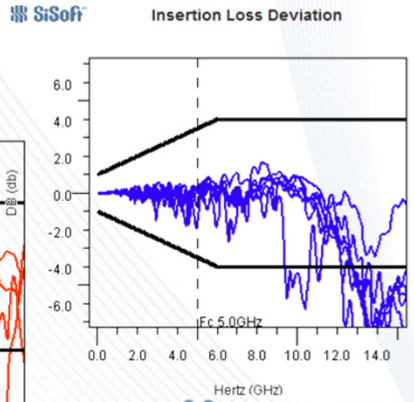
- 7 Industry Channels
- 6 ISI Channels
- 6 Loss Channels
- 1 Failing Channel











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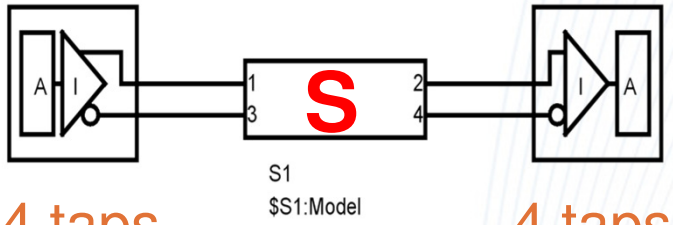
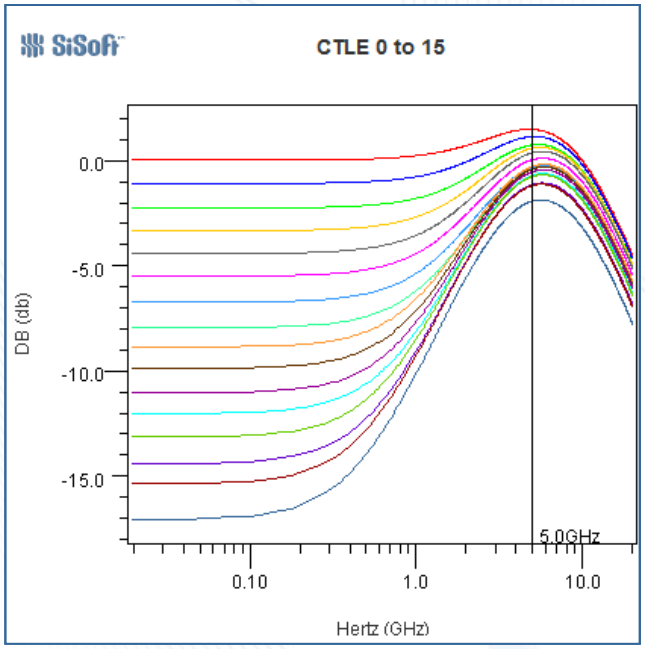
Analysis Setup

- Circuit
  - s4p channels, 10 Gbps
  - Advanced Tx/Rx w/ Dj, Rj, DCD
- SerDes EQ
  - 4-taps in Tx FFE and Rx DFE
  - Rx CTLE, 0-15, ~0-15dB boost
- EQ Preset Scenarios
  - 1: Tx taps ~half, CTLE=12
  - 2: Tx taps ~PCIe P7, CTLE=8
  - 3: OptimEye selects Tx / CTLE
  - Rx DFE always “auto”





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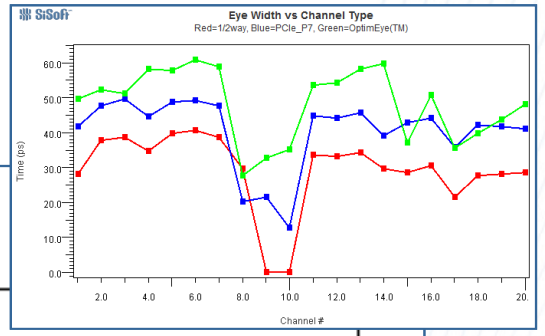
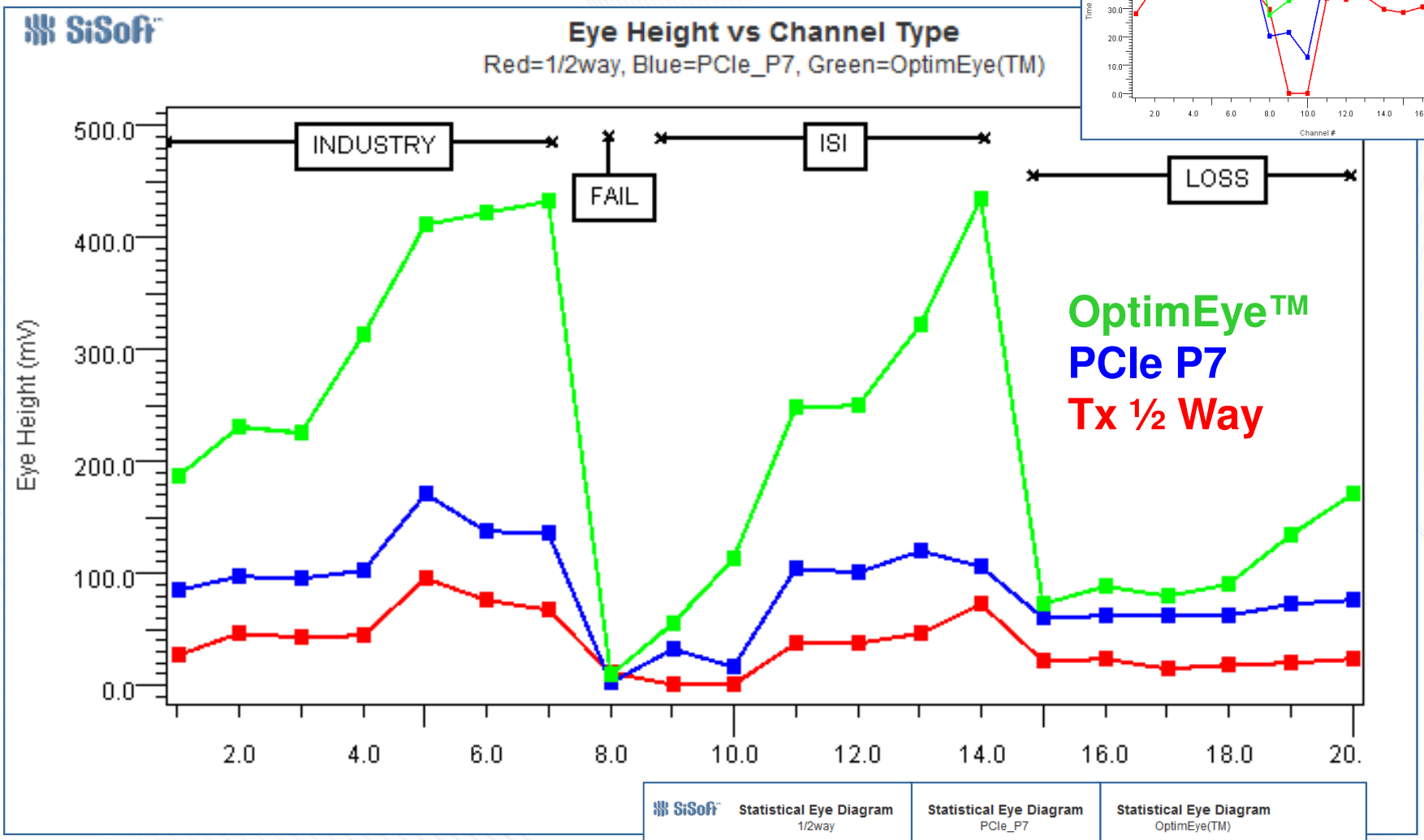
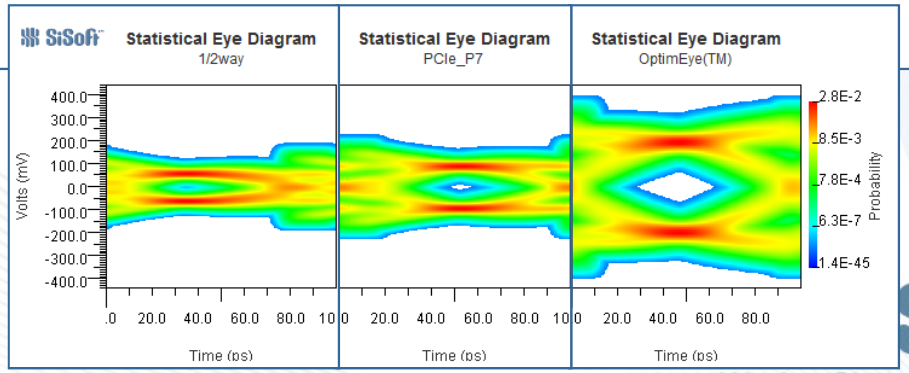
Eye Height Results

Widths:







- Typically 2x better
- Eyes for Channel 10:

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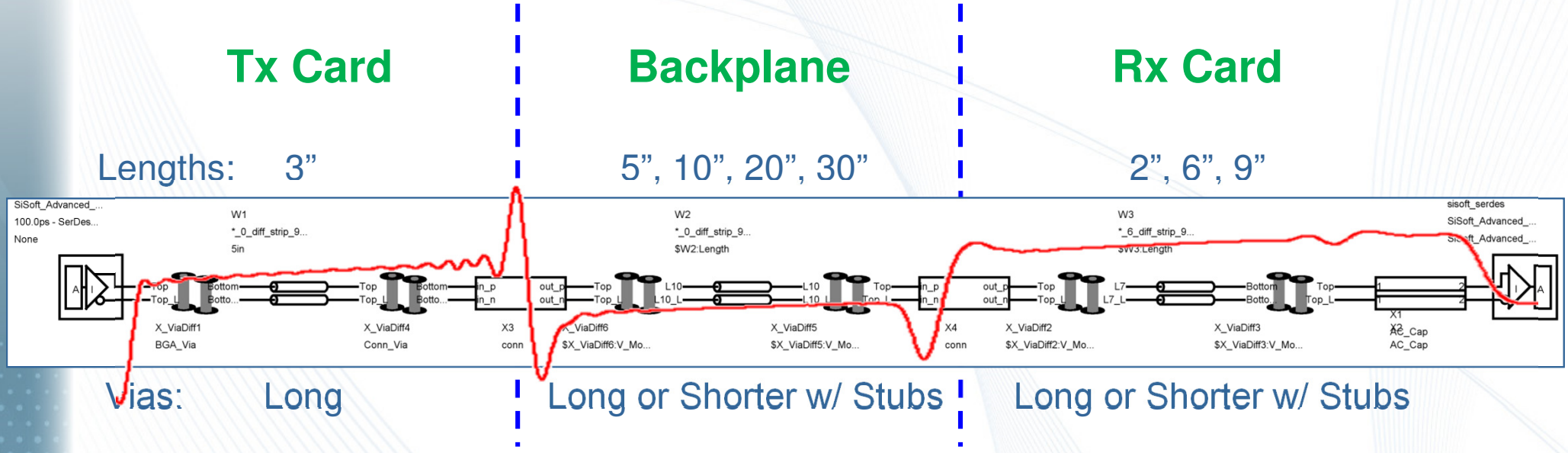
Circuit-based Channels



- 10 Gbps, same EQ options and jitter as S-param channels
- Length: 10” to 42”, Lt_cd/bp: 0.015/0.009, ISI & Loss channels
- Permutations: 4 bp_len * 3 rx_len * 2 bp_via * 2 rx_via = 48
- Total Simulations: 48 * 3 EQ options = 144
- Manufacturing tolerances

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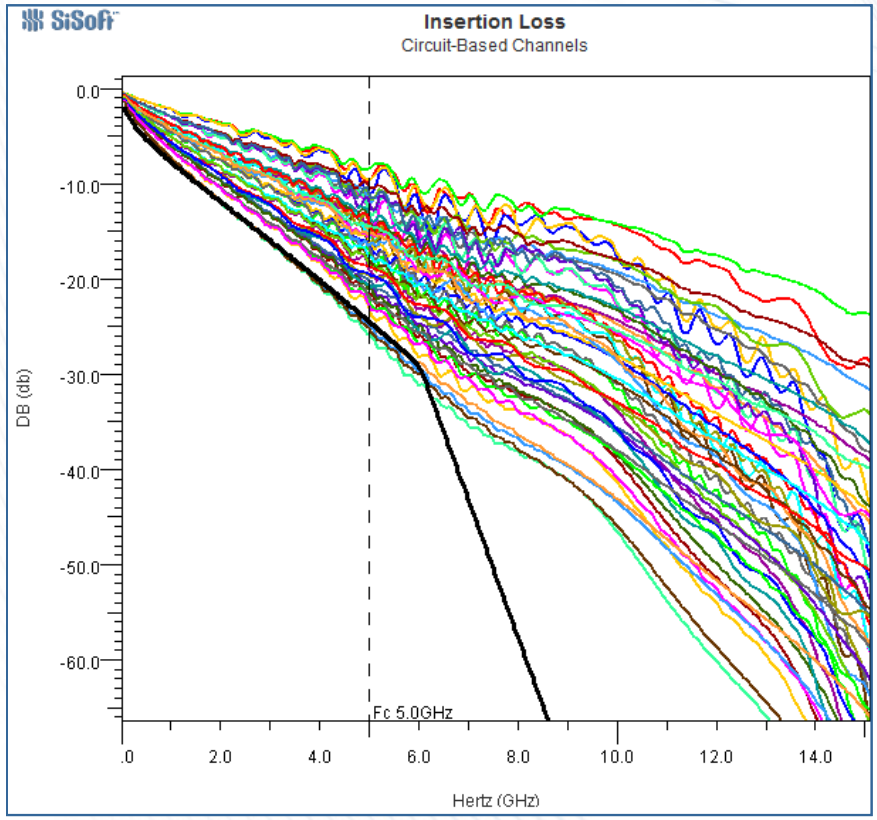
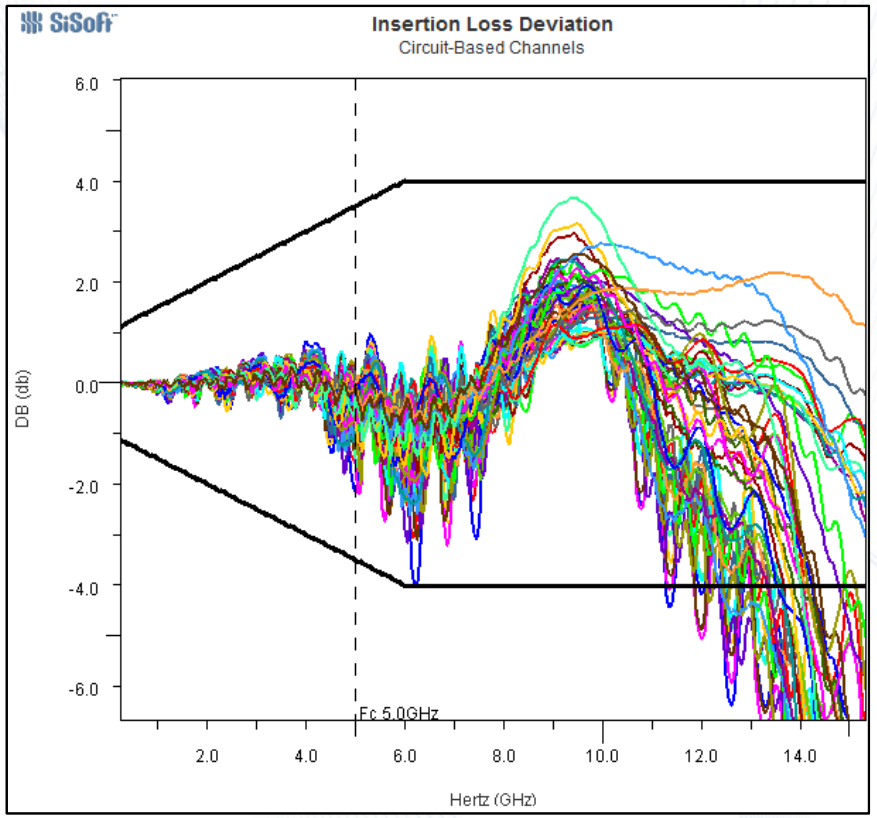
Passive Characteristics, 48 Channels





- Mix of ISI-Constrained & Loss-Dominated Channels
- 20 dB Insertion Loss variation at 5 GHz

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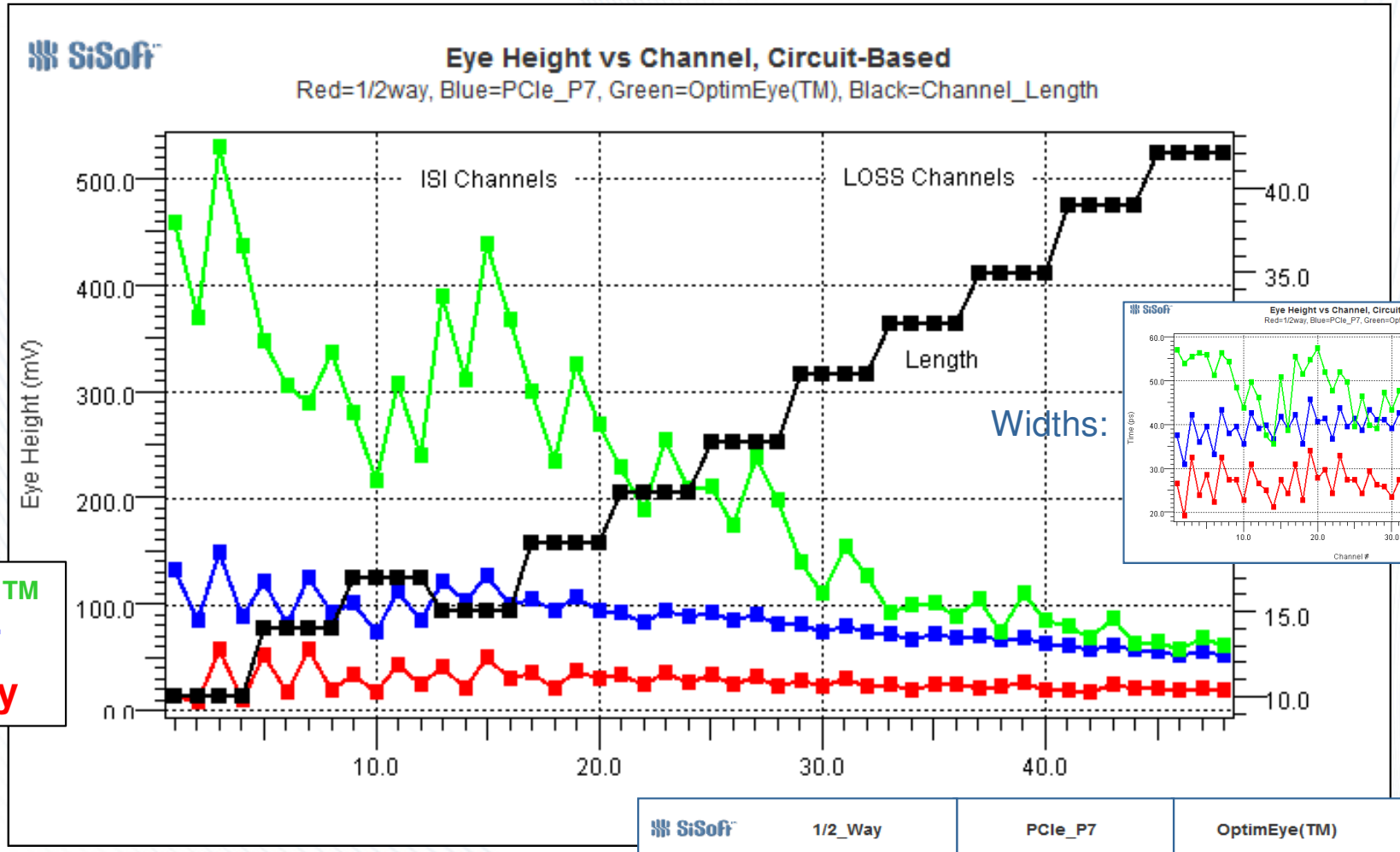
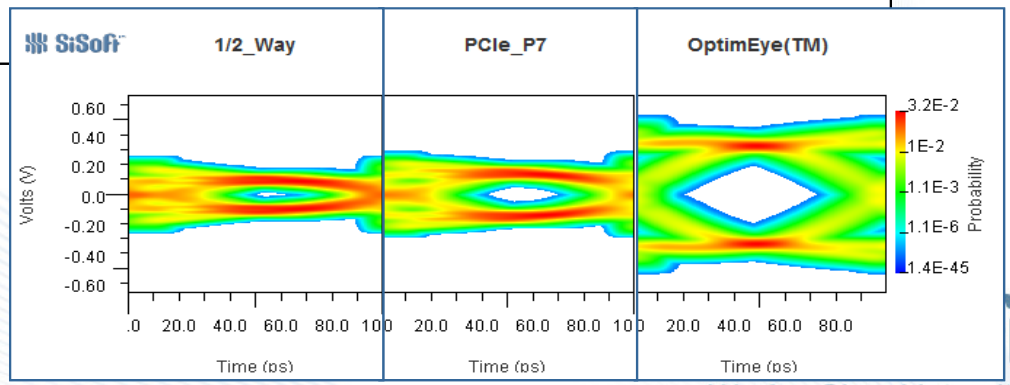
Eye Height Results



Widths:

OptimEye™
PCIe P7
Tx ½ Way

- Similar trends
- Eyes for Channel 2:



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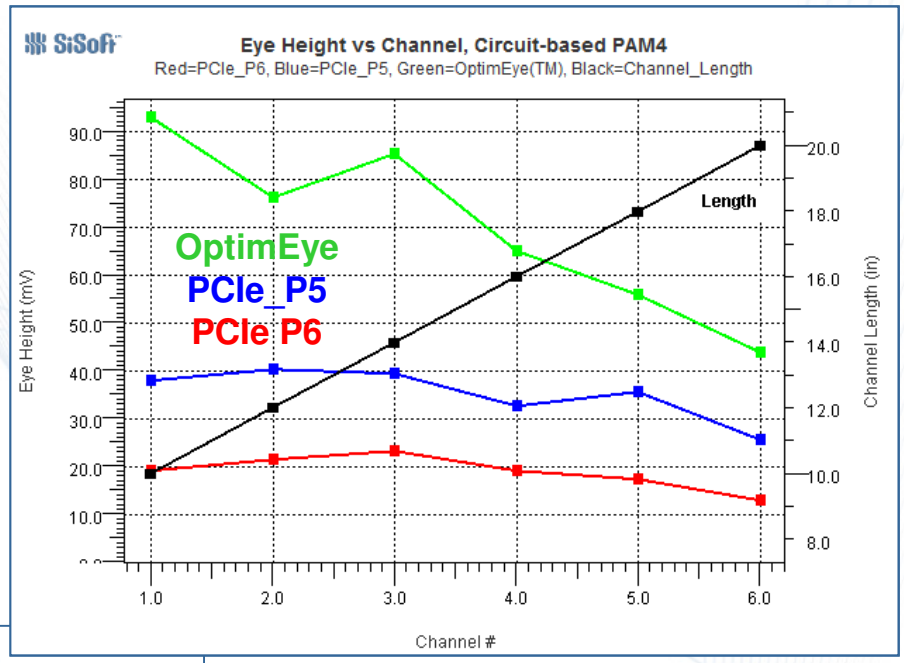
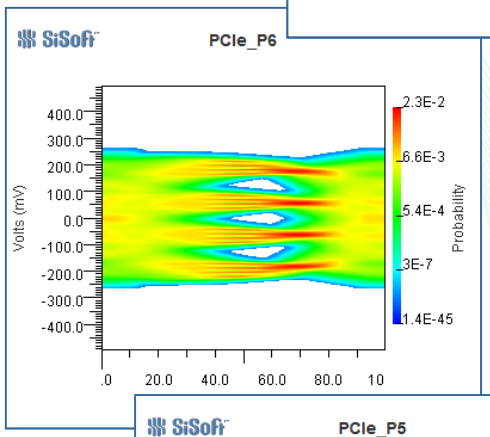
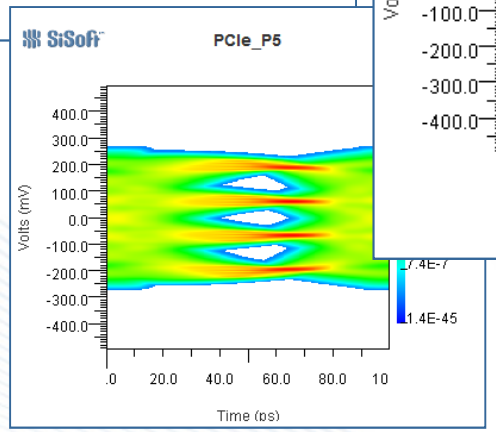
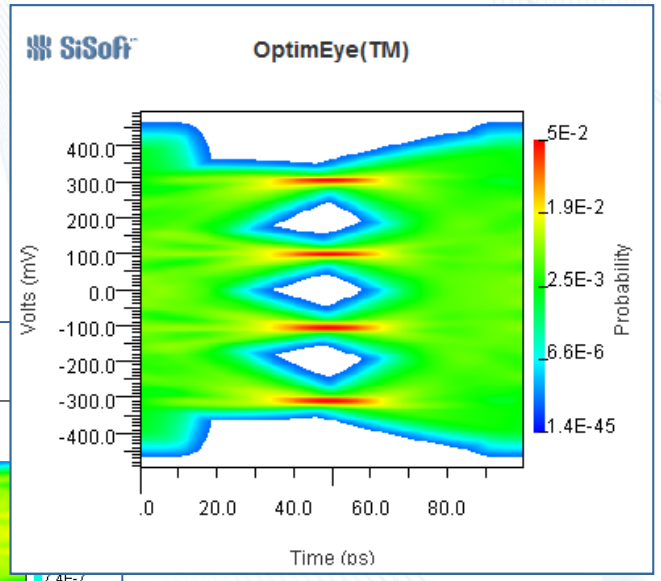
PAM4

- Co-Optimization goes center-stage
  - Same OptimEye technology
- Channels 10”-20”
- Eye Height vs EQ
  - PCIe_P6
  - PCIe_P5
  - OptimEye
- OptimEye ~2x improvement
  - Channel 3 eyes shown









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Overall Results

Channel Type	Average Improvement	Standard Deviation	Sample Size	Comparing
ISI	217%	97%	30	OptimEye vs P7
Loss	55%	41%	30	OptimEye vs P7
Industry	166%	42%	7	OptimEye vs P7
PAM4	97%	31%	6	OptimEye vs P5
All	140%	109%	73	OptimEye vs P7/5

- Baseline settings slanted towards loss equalization
  - Which is typical in today's systems
- In general, we expect
  - 100% improvement for ISI-dominated channels
  - 50% improvement for Loss-constrained channels

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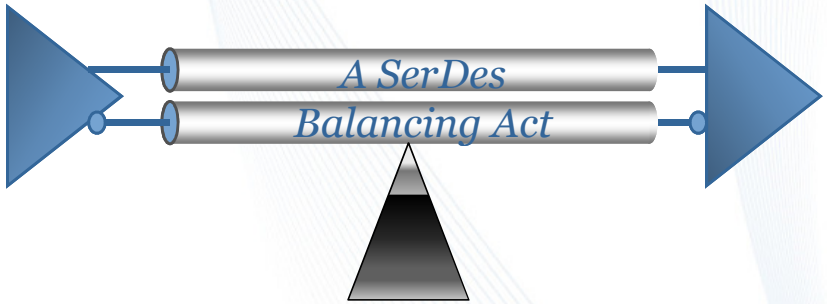
AGENDA

- Introduction to Co-Optimization
- Co-Optimization Examples
- Using OptimEye™
- Summary



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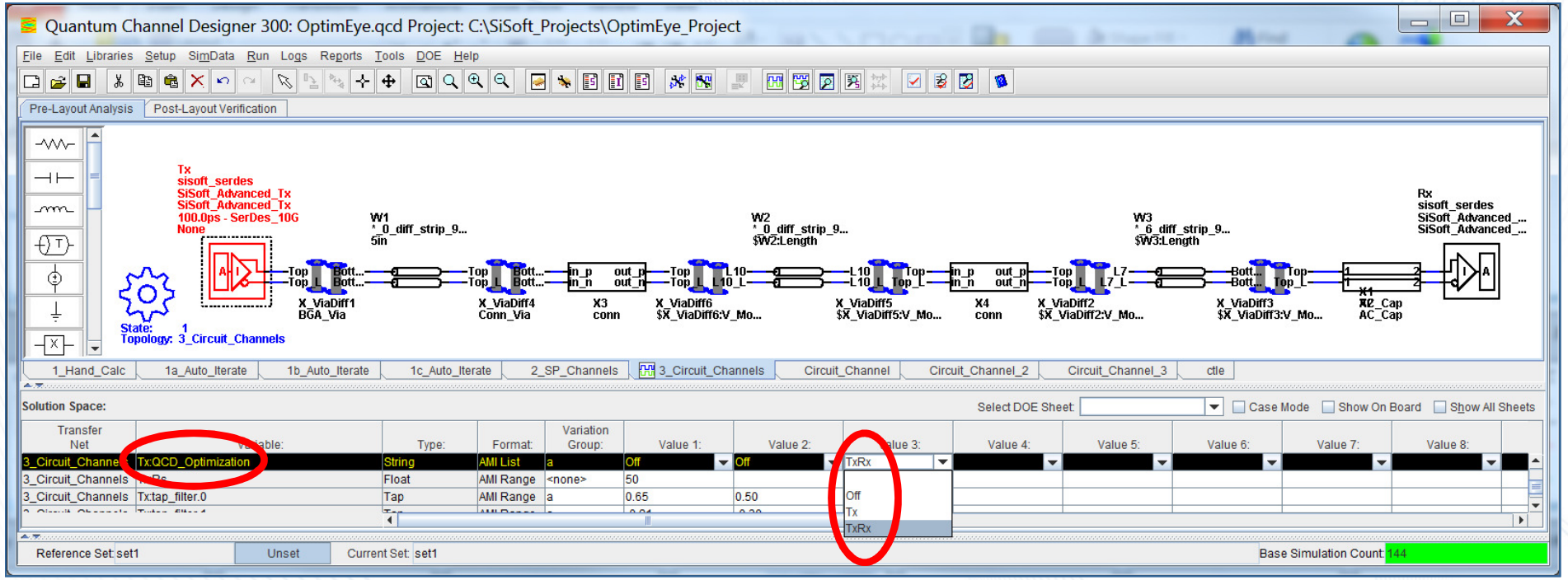
Using OptimEye



- "QCD Optimization" attribute on any enabled Tx
- 2 modes – Tx & TxRx
- Runtime is longer than normal simulation

Channels	Normal (s)	OptimEye™ (s)	x Longer
20 S-Parameter	38	62	1.6
48 Circuit-based	94	120	1.3
running TxRx mode, Statistical Analysis, Quad-core Laptop, Win7			

Answers in seconds instead of weeks

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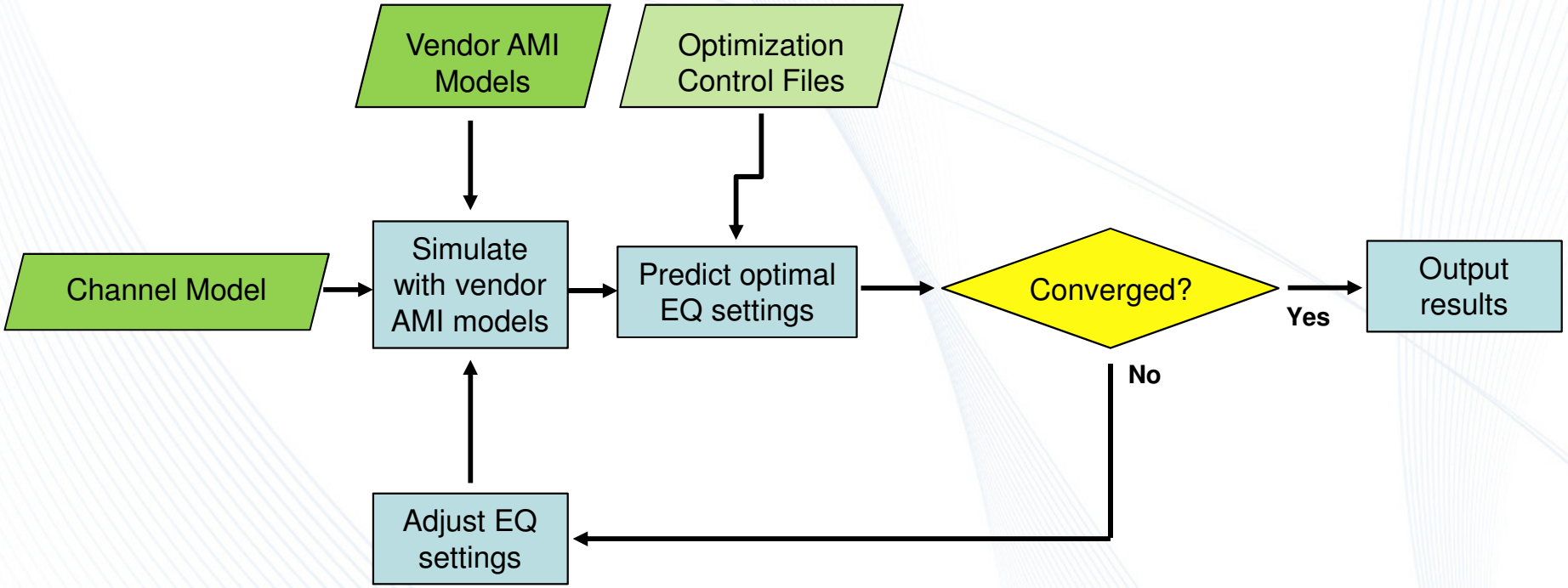
OptimEye and Vendor Models



- Optimization control files let OptimEye predict and verify model settings
- Support for SiSoft models built-in

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OptimEye Results

Opt ATX1.-1	-0.225961
Opt ATX1.0	0.590481
Opt ATX1.1	0
Opt ATX1.2	-0.183558
Opt ATX1.tx_swing	1
Opt ARX1.peaking_filter.config	0
Stat ATX1.tap_filter.-1	-0.225961
Stat ATX1.tap_filter.0	0.590481
Stat ATX1.tap_filter.1	0
Stat ATX1.tap_filter.2	-0.183558
Stat ATX1.tx_swing	1
Stat ATX1.normalize_taps	Y
Stat ATX1.number_tx_tap	4
Stat ATX1.number_precursor_tap	1
Stat ATX1.tap_max	
Stat ATX1.tap_min	
Stat ATX1.tap_step	
Stat ARX1.AGC.Mode	0
Stat ARX1.AGC.Level	0
Stat ARX1.peaking_filter.config	0
Stat ARX1.peaking_filter.mode	f
Stat ARX1.peaking_filter.use_new_pole_zero_defaults	N
Stat ARX1.peaking_filter.scale_by_design_data_rate	Y
Stat ARX1.peaking_filter.pole_zero_data_rate	6
Stat ARX1.peaking_filter.design_data_rate	1.406250E+10
Stat ARX1.dfe.number_rx_tap	4
Stat ARX1.dfe.taps.1	-0.068782
Stat ARX1.dfe.taps.2	0.022204
Stat ARX1.dfe.taps.3	0.011844
Stat ARX1.dfe.taps.4	0.002764
Stat ARX1.dfe.mode	auto

BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV
Stat ARx.SiSoft_ Optimizing _Rx.mod	Stat ARx.SiSoft_ Optimizing _Rx.tx_tap_ values	Stat ARx.SiSoft_ Optimizing _Rx.tx_ta	Stat ARx.Modul ation	Stat Eye Height[0.00 1] (V)	Stat Eye Height[1e- 006] (V	Stat Eye Height[1e- 009] (V	Stat Eye Height[1e- 012] (V	Stat Eye Width[0.00 1] (ps)	Stat Eye Width[1e- 006] (ps	Stat Eye Width[1e- 009] (ps	Stat Eye Width[1e- 012] (ps	Opt ATx.	Opt ATx.	Opt ATx.1	Opt ATx.2	Opt ARx.peakin g_filter.con fig
Off	1	0	NRZ	0.532533	0.474033	0.442577	0.421179	74.6094	64.0625	59.7656	57.0313	-0.0476998	0.948184	-0.00411652	0	0
Off	1	0	NRZ	0.460423	0.390103	0.354113	0.331334	73.8281	62.1094	57.4219	53.9063	-0.0818942	0.915814	-0.00229197	0	0
Off	1	0	NRZ	0.45555	0.416535	0.394462	0.380246	73.0469	62.5	58.2031	55.4688	-0.0281843	0.834636	0	-0.13718	1
Off	1	0	NRZ	0.499445	0.444192	0.415163	0.396053	74.2187	64.0625	59.375	56.25	-0.0640821	0.933004	-5.42101E-20	-0.00291357	0
Off	1	0	NRZ	0.434893	0.383424	0.355172	0.335223	74.2187	62.8906	58.5937	55.8594	-0.0819756	0.917761	-0.000263023	-4.33681E-19	0
Off	1	0	NRZ	0.389585	0.32891	0.296433	0.274523	71.0937	58.9844	53.9063	51.1719	-0.103678	0.891136	-0.00518587	-8.67362E-19	0
Off	1	0	NRZ	0.46732	0.424751	0.401923	0.385181	73.8281	63.2813	59.375	56.25	-0.0615739	0.936741	0.00168538	0	0
Off	1	0	NRZ	0.412755	0.361336	0.332669	0.312507	73.4375	62.5	57.8125	54.2969	-0.0976001	0.891354	-8.67362E-19	0.0110462	0
Off	1	0	NRZ	0.263167	0.216189	0.19284	0.176631	68.3594	56.25	51.5625	48.4375	-0.144352	0.849163	-0.00648496	0	0
Off	1	0	NRZ	0.221759	0.172705	0.149139	0.133	66.7969	53.9063	48.0469	43.75	-0.186514	0.8054	-0.0080858	0	0
Off	1	0	NRZ	0.274246	0.228107	0.204805	0.188174	69.9219	58.5937	53.5156	49.6094	-0.146933	0.848469	-0.00459776	1.73472E-18	0
Off	1	0	NRZ	0.247413	0.202678	0.179685	0.163731	67.5781	55.8594	50	46.0938	-0.166084	0.827227	-0.00668917	0	0
Off	1	0	NRZ	0.115594	0.0925684	0.0801188	0.0712205	55.8594	45.3125	40.625	37.5	-0.162573	0.610528	0	-0.226899	1
Off	1	0	NRZ	0.0960605	0.0754149	0.0646627	0.0570573	57.8125	43.3594	38.6719	35.5469	-0.166734	0.62837	0	-0.204896	4
Off	1	0	NRZ	0.129846	0.113873	0.105473	0.0995056	70.3125	58.5938	54.2969	50.7812	-0.132532	0.862265	0	-0.00520367	9
Off	1	0	NRZ	0.104849	0.0877173	0.0777613	0.0703553	60.9375	47.2656	41.7969	38.6719	-0.163027	0.673252	0	-0.163721	5
Off	1	0	NRZ	0.397121	0.34599	0.318113	0.298606	74.6094	62.8906	58.5938	55.4688	-0.0640421	0.895245	0	-0.0407134	0
Off	1	0	NRZ	0.27045	0.233186	0.212996	0.199847	73.4375	61.3281	55.0781	51.5625	-0.0861227	0.910919	-0.00295848	0	5
Off	1	0	NRZ	0.393657	0.352129	0.327848	0.310063	73.4375	61.7188	57.4219	54.6875	-0.0623177	0.836789	0	-0.100893	0
Off	1	0	NRZ	0.301033	0.263918	0.24396	0.230696	75.3906	65.2344	60.5469	57.4219	-0.0784638	0.919178	-0.00235777	0	4
Off	1	0	NRZ	0.320367	0.270395	0.243274	0.22422	71.0937	59.7656	55.4687	51.9531	-0.120524	0.874361	-0.00511474	0	0
Off	1	0	NRZ	0.284641	0.232517	0.204151	0.185074	68.3594	56.25	51.1719	47.6563	-0.14794	0.843623	-0.00843601	0	0
Off	1	0	NRZ	0.340023	0.294948	0.269354	0.25107	70.7031	59.7656	55.0781	51.9531	-0.108547	0.88707	-0.00438279	0	0

- Original and optimized settings reported for each Tx/Rx model parameter
- Post-process output to configure your entire system

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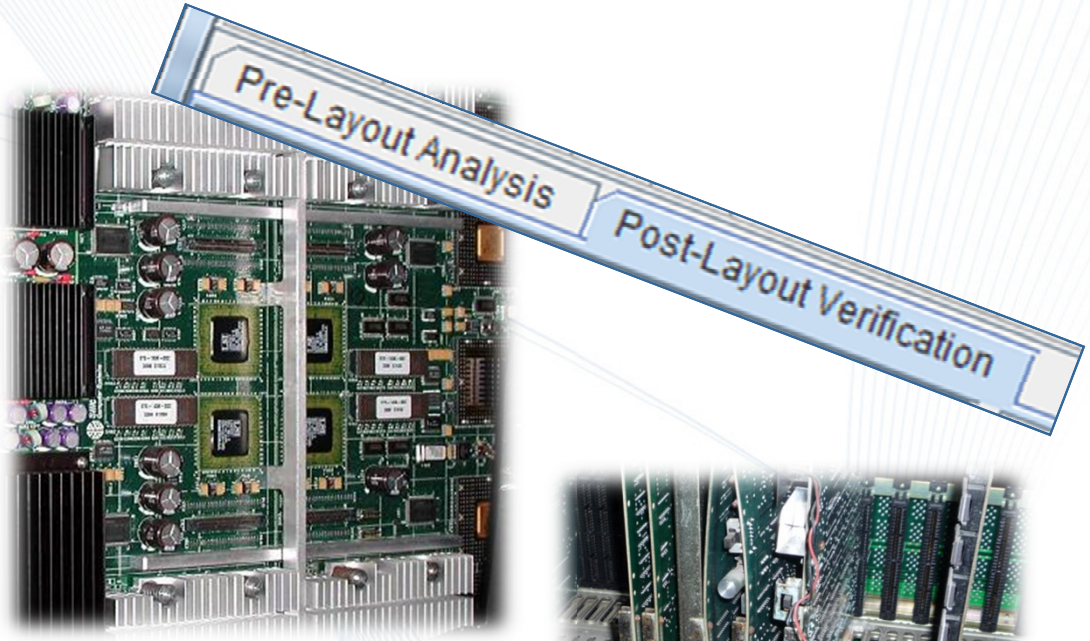
Optimize Routed & Built Systems

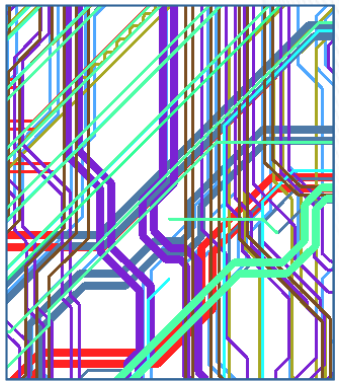
Design

- Use OptimEye™ Pre- or Post-Route
- Single-board, or System of PCBs
- Actual routes refine design space



Debug

- Import / analyze failing channels
- Derive optimal settings
- Software change only



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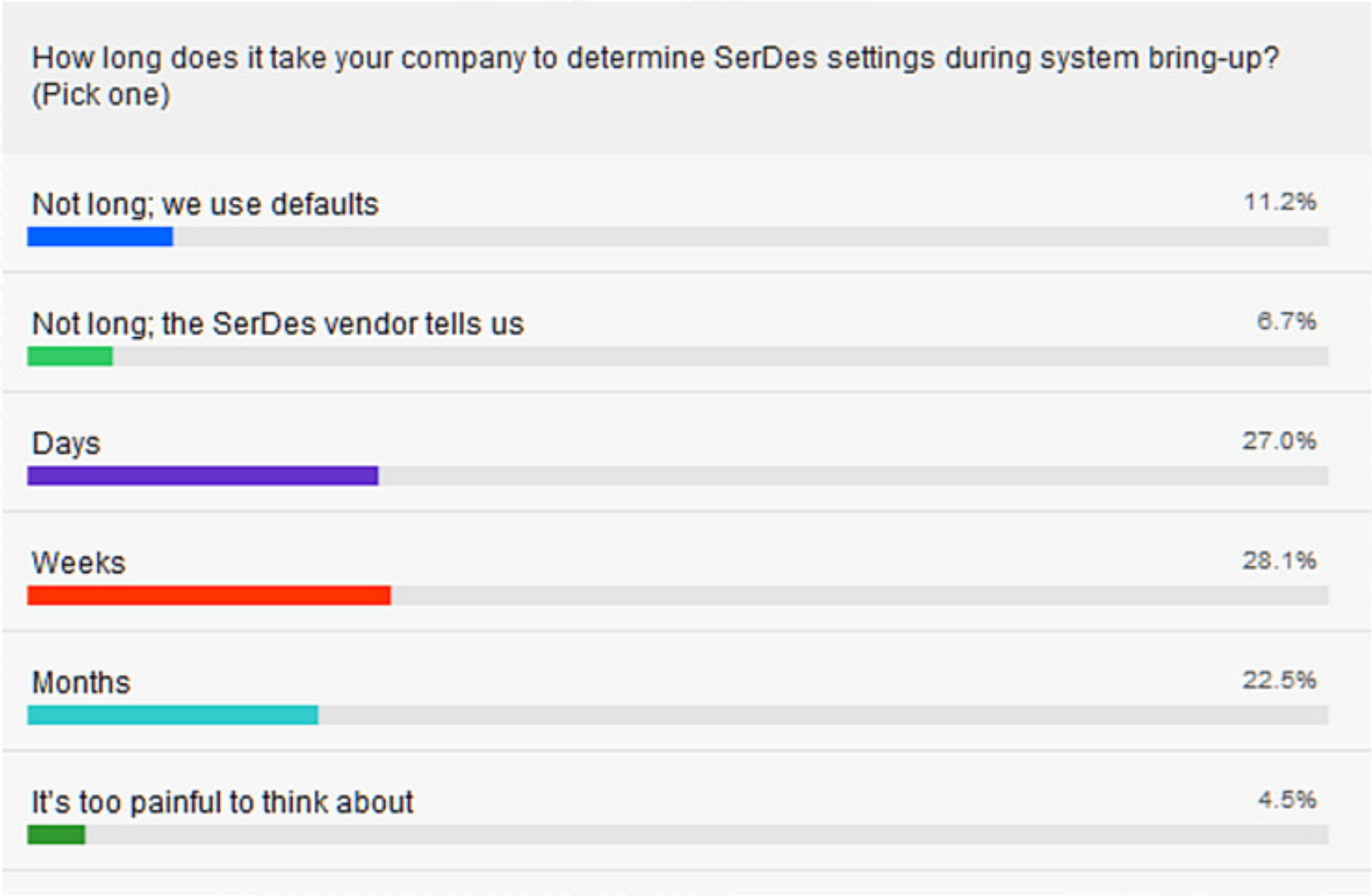
Poll Results: SerDes Settings



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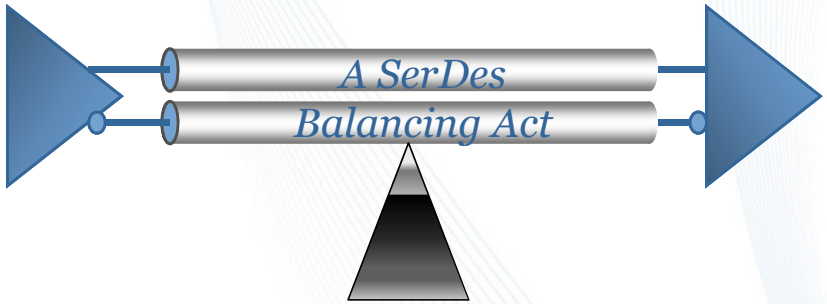

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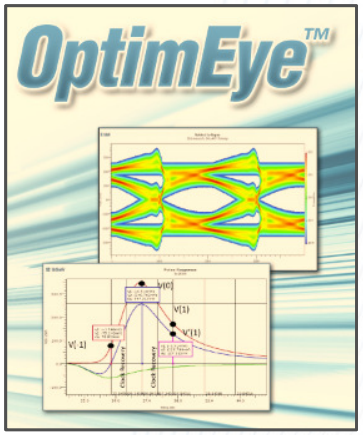
Summary



- Rx eye height should be optimized for the point where the recovered clock samples the data
- "Blind sweeps" consume time and brain cycles
- OptimEye is 3rd generation SiSoft technology
  - Maximizes eye height by co-optimizing Tx/RX settings
  - Does not require changes to vendor AMI models
- Per-channel optimization is now practical at the full system level

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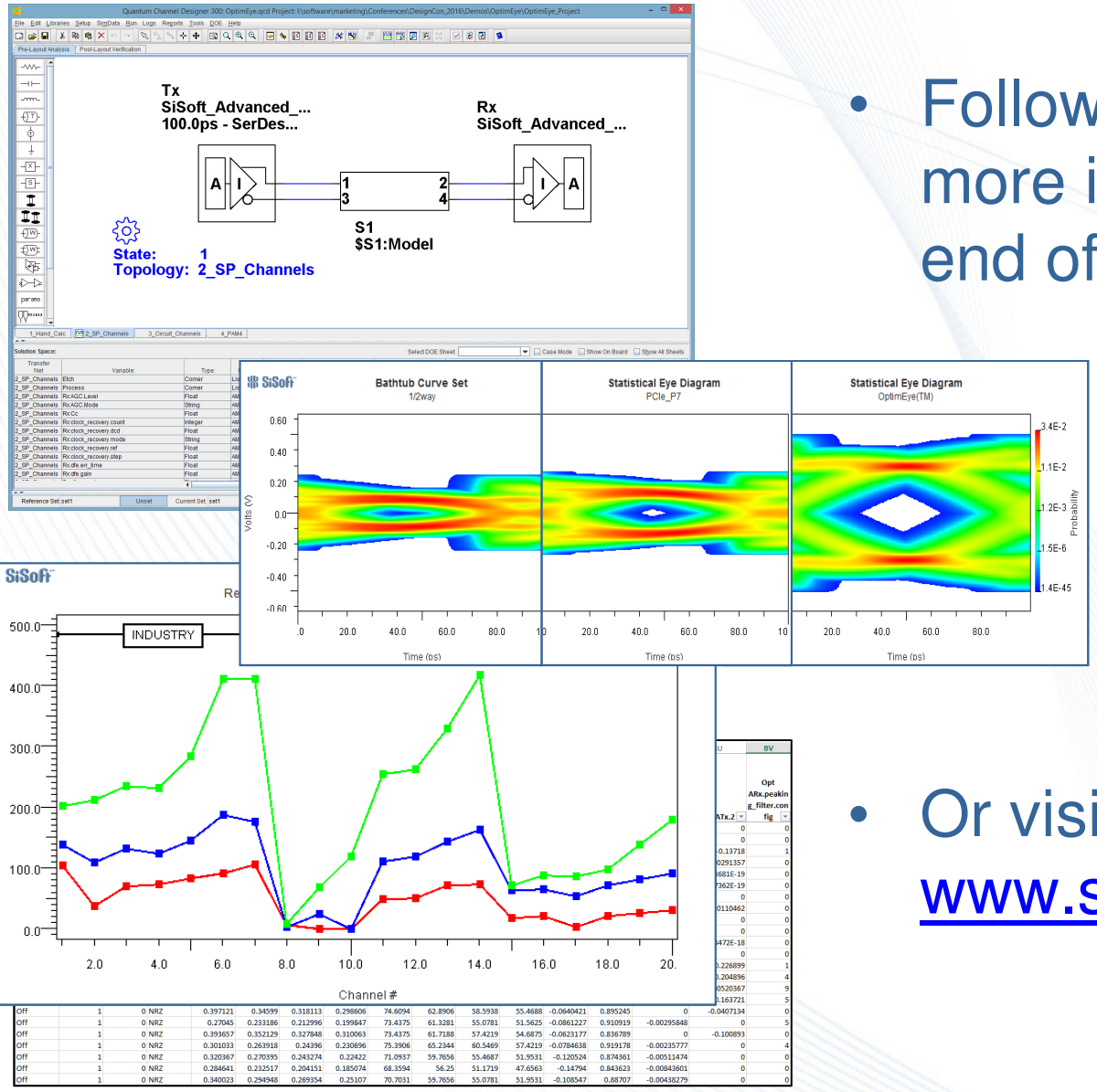
See How OptimEye Works for You!



- Follow link to “request more information” at the end of this webinar
- Or visit: www.sisoft.com/optimeye

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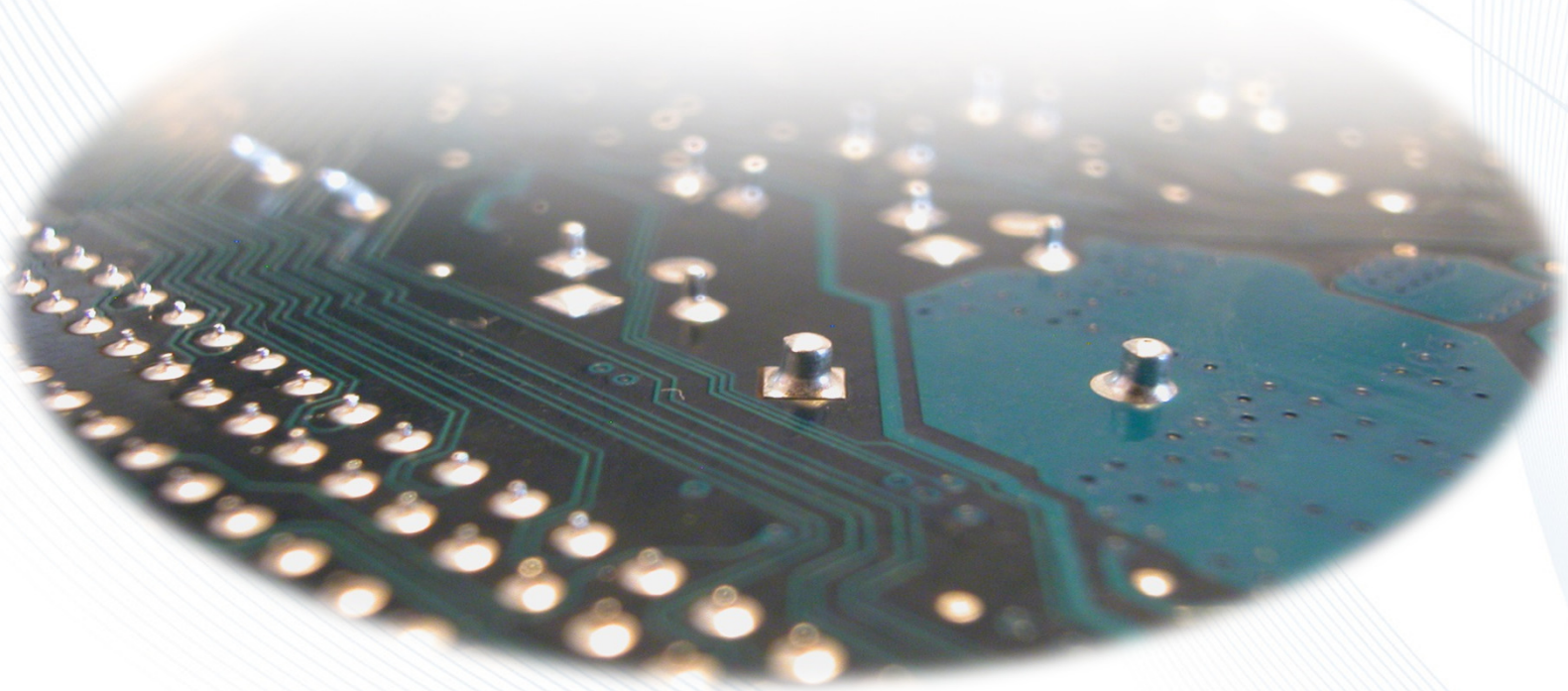
QUESTIONS ?



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THANK YOU

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