Channel Based Methods for Signal Integrity Evaluation

COMPAL ELECTRONICS, INC. Taipei Server Business

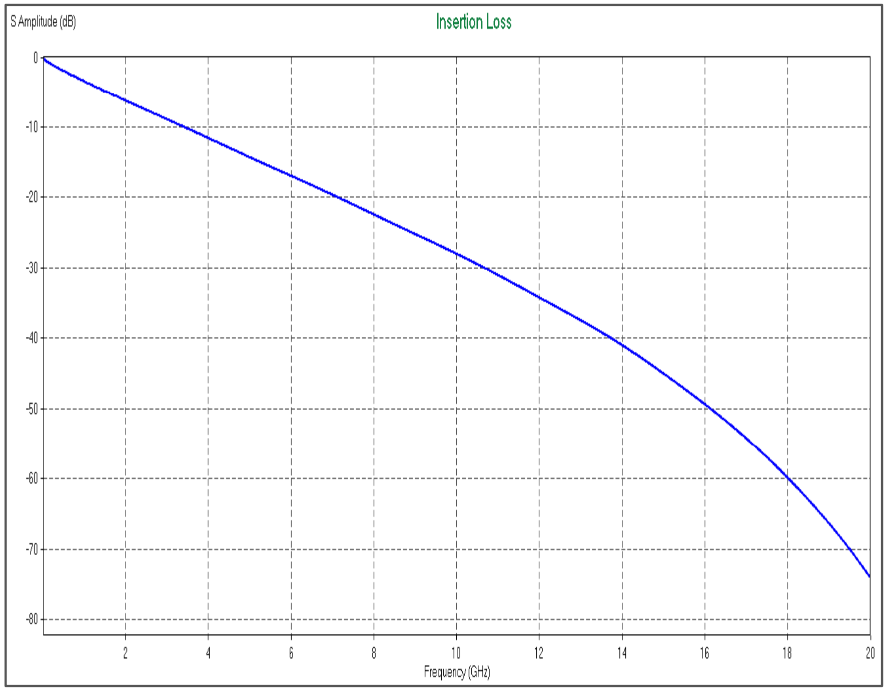
Aug 13, 2013

Agenda

- Evolution of Signal Integrity Evaluation
- Review of Industrial Specification
- Foundation of Channel Based Methods
- Impact of Channel Extraction Method
- Case Study
- Conclusion
- Reference

Evolution of Signal Integrity Evaluation (1/2)

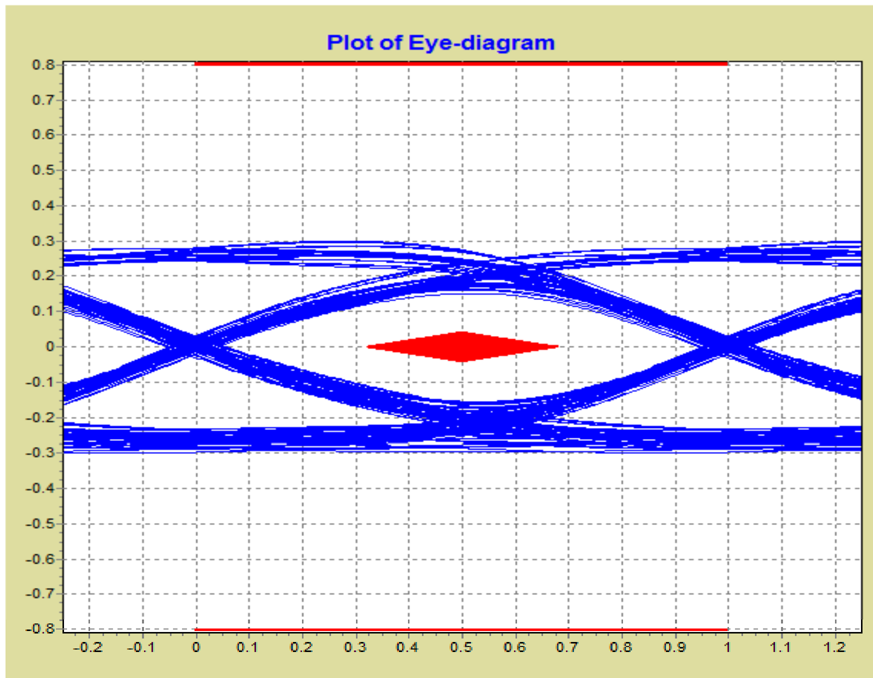
Loss evaluation



1.No reflection and crosstalk effect

2.Not visualizing evaluation method

Eye-diagram evaluation

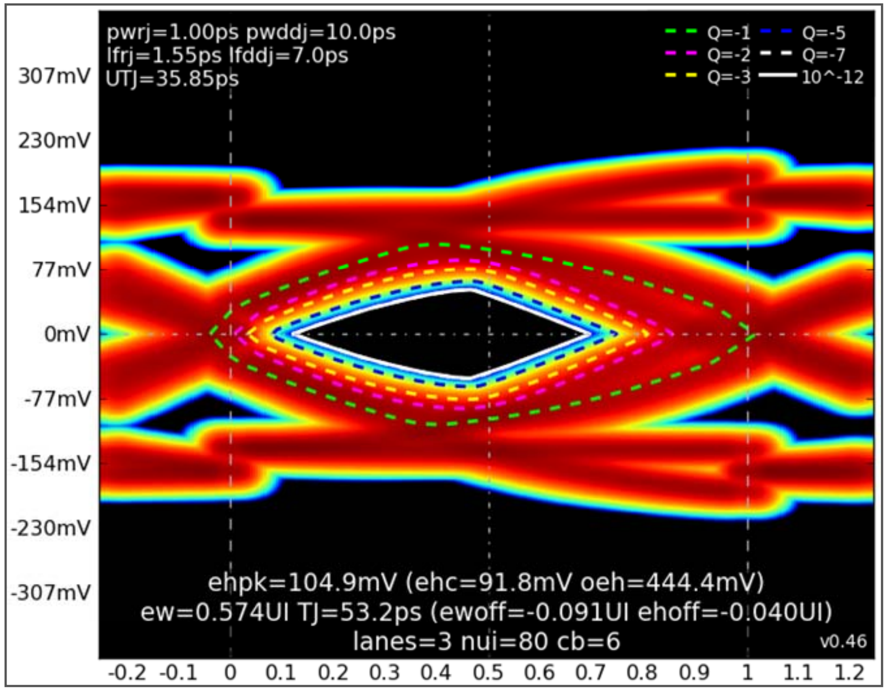


1.Probability factor is not taken into account

2.Not every equalizer effect could be considered

Evolution of Signal Integrity Evaluation (2/2)

Statistical Eye-contour evaluation



It seems good enough. But,...

New evaluation method

- Multi-level signaling?
- Multi-path crosstalk?
- Error Correction Code effect?

Review of Industrial Specification (1/5)

SAS6G Passive TxRx Connection Specification

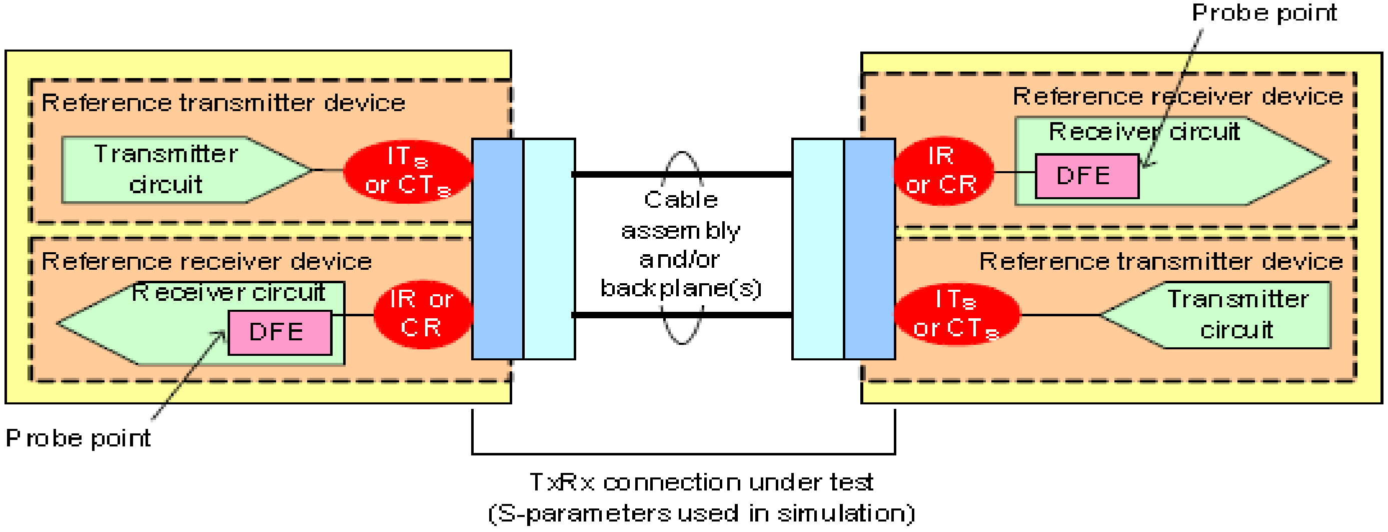


Figure 98 — Example passive TxRx connection compliance testing for trained 1.5 Gbps, 3 Gbps, and 6 Gbps

Table 27 defines the required passive TxRx connection characteristics.

Table 27 — Passive TxRx connection characteristics for trained 6 Gbps

Characteristic	Units	6 Gbps
Minimum voltage [a]	mV(P-P)	84
Maximum TJ [a]	UI	0.64

[a] As reported by simulation of the passive TxRx connection S-parameters with the reference transmitter device and the reference receiver device. Values are reported at a BER of 10^{-15} inside the reference receiver device after equalization at 6 Gbps. This standard does not define values for trained 3 Gbps and 1.5 Gbps. Passive TxRx connections that comply with the 6 Gbps characteristics are expected to operate correctly at slower physical link rates.

In general, most specification defines requirement of eye-diagram as table above

COMPAL

Review of Industrial Specification (2/5)

SAS12G Passive TxRx Connection Specification

T10/BSR INCITS 519 Revision 05b **22 May 2013**

labels beginning by <usage> indicate reference transfer functions. <usage> represents a prefix that is set according to the selected usage model (see D.2).

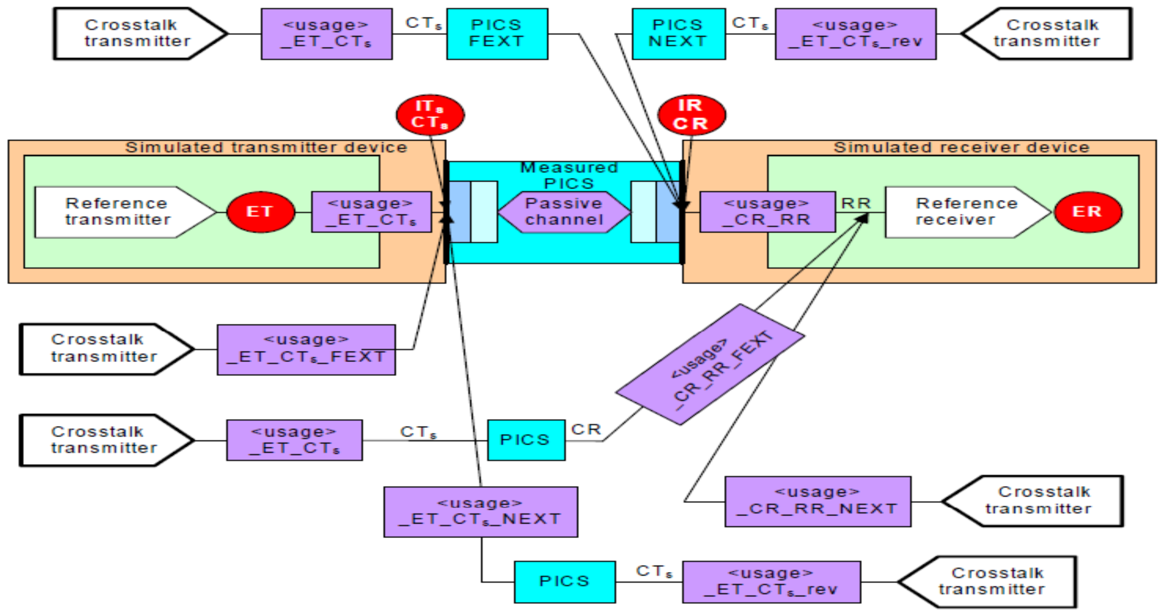


Figure 100 — Passive TxRx connection segment between CT_S and CR or IT_S and IR end to end simulation schematic for trained 12 Gbps

Table 28 — Passive TxRx connection charateristics for trained 12 Gbps at ET and ER

Characteristic	Units	Minimum	Maximum	Compliance point
Coefficient 1 (i.e., C1) [a b c]	V/V	-0.15	0	ET
VMA [d e]	mV(P-P)	80	-	ET
Coefficient 3 (i.e., C3) [a b f]	V/V	-0.3	0	ET
Reference pulse response cursor peak-to-peak amplitude [g]	mV(P-P)	85	-	ER
Vertical eye opening to reference pulse response cursor ratio [h i]	%	45	-	ER
DFE coefficient amplitude to reference pulse response cursor ratio [j]	%	-50	50	ER

1.Where is jitter requirement?

2.Why using these criteria?

Review of Industrial Specification (3/5)

CEI-6G and 11G LR Specification Defined in OIF

Table 9-1. CEI-11G-LR Receiver Equalization Output Eye Mask

Parameter	Symbol	Max	Units
Eye mask	R_X1	0.2625	UI
Eye mask	R_Y1	50	mV
Correlated Bounded High Probability Jitter, pre-equalizer	R_CBHPJ	0.40	UIpp
Correlated Bounded High Probability Jitter, post-equalizer	R_CBHPJ	0.10	UIpp
Uncorrelated Bounded High Probability Jitter	R_UBHPJ	0.15	UIpp
Uncorrelated Unbounded Gaussian Jitter	R_UUGJ	0.15	UIpp
Quality of signal (SNR in real number)	Q	7.94	

Table 7-10. CEI-6G-LR High Frequency Jitter Budget

CEI-6G-LR	Uncorrelated Jitter		Correlated Jitter		Total Jitter				Amplitude	
	Unbounded Gaussian	High Probability	Bounded Gaussian	Bounded High Probability	Gaussian	Sinusoidal	Bounded High Probability	Total		
Abbreviation	**UUGJ**	**UHPJ**	**CBGJ**	**CBHPJ**	**GJ**	**SJ**	**HPJ**	**TJ**	**k**	
Unit	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp	UIpp		mVppd
Transmitter	**0.150**	**0.150**			**0.150**		**0.150**	**0.300**		**800.0**
Channel			0.230	0.525						
Receiver Input	**0.150**	**0.150**	**0.230**	**0.525**	**0.275**		**0.675**	**0.950**	**0.00**	**0.0 See 2**
Equalizer				-0.350 See 1						
Post Equalization	**0.150**	**0.150**	**0.230**	**0.175**	**0.275**		**0.325**	**0.60**	**0.20**	**100.0**
DFE Penalties				0.100					-0.08	-45.0
Clock + Sampler	0.150	0.100		0.100						-45.0
Budget	**0.212**	**0.250**	**0.230**	**0.375**	**0.313**	**0.050**	**0.625**	**0.988**	**0.06**	**10.0**

NOTES:
1. Due to receiver equalization, it reduces the ISI as seen inside the receiver. Thus this number is negative.
2. It is assumed that the eye is closed at the receiver, hence receiver equalization is required as indicated below.

Review of Industrial Specification (4/5)

CEI-25G LR Specification Defined in OIF

Figure 11-1.CEI-25G-LR Reference Model

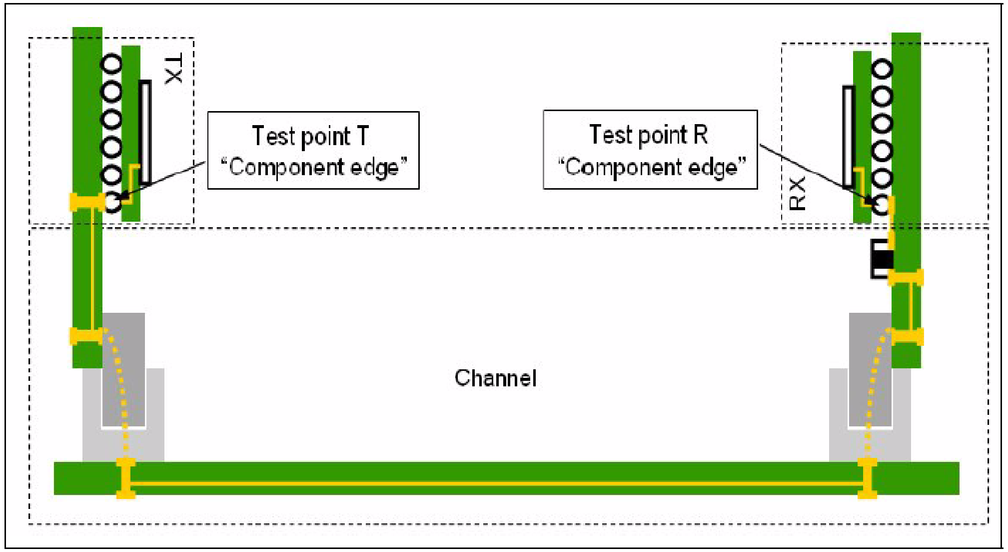


Table 11-12. Receiver Electrical Input Specifications

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Baud rate	R_Baud		19.90		25.80	GSym/s
Input Differential Voltage	R_Vdiff	Note 1			1200	mVppd
Differential Input Impedance	R_Rdin		80	100	120	Ω
Input Impedance Mismatch	R_Rm				10	%
Differential Input Return Loss	R_SDD11	See 11.3.2.3				
Common Mode Input Return Loss	R_SCC11	Below 10 GHz			-6	dB
		10GHz to baud rate			-4	dB
Input Common Mode Voltage	R_Vcm	Load Type 0 See Note 2	-200		1800	mV

NOTES:
1. The receiver shall have a differential input voltage range sufficient to accept a signal produced at point R by the combined transmitter and channel. The channel response shall include the worst case effects of the return losses at the transmitter and receiver.
2. Load Type 0 with min. T_Vdiff, AC-Coupling or floating load. For floating load, input resistance shall be ≥ 1kΩ

Table 11-13. Receiver Input Jitter Specification

Characteristic	Symbol	Condition	MIN.	TYP.	MAX.	UNIT
Sinusoidal Jitter, Maximum	R_SJ-max	See Section 2.5.4, note 1			5	Ulpp
Sinusoidal Jitter, High Frequency	R_SJ-hf	See Section 2.5.4, note 1			0.05	Ulpp

NOTES:
1. The Receiver shall tolerate the sum of these jitter contributions: Total transmitter jitter from Table 11-7;Sinusoidal jitter as defined in Table 11-13;The effects of a channel compliant to the Channel Characteristics (Section 11.2.6).

No Eye-diagram requirement for 25G

Review of Industrial Specification (5/5)

CEI-25G Channel Compliance Requirement Defined in OIF

Figure 11-2. CEI-25G-LR Normative Channel Insertion Loss at 25.80 Gsym/s.

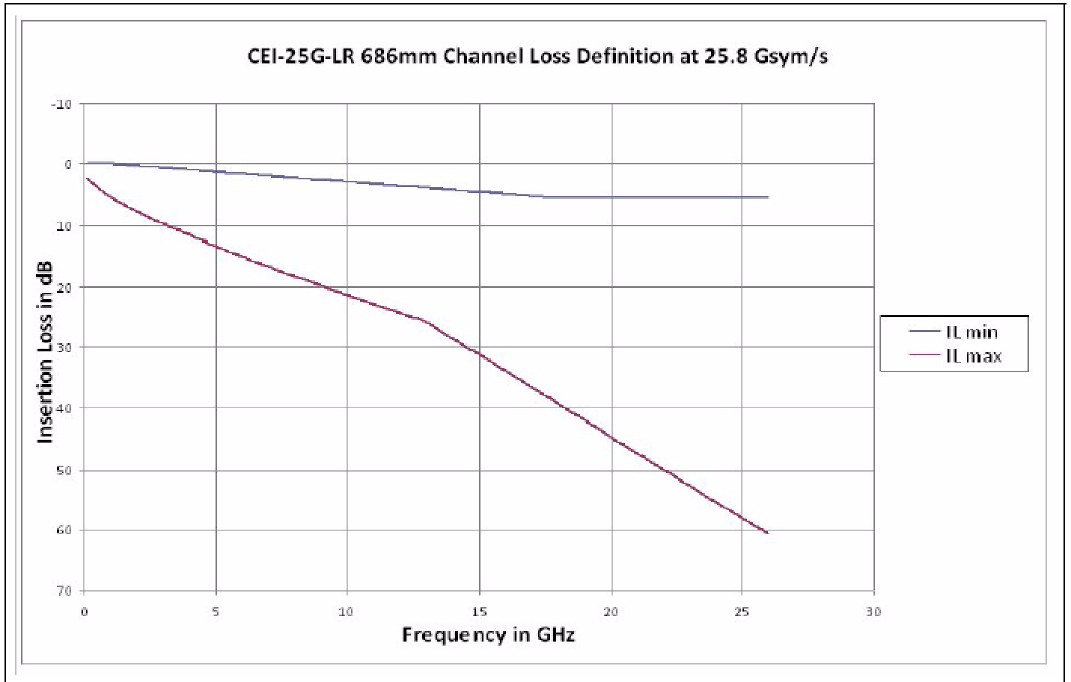
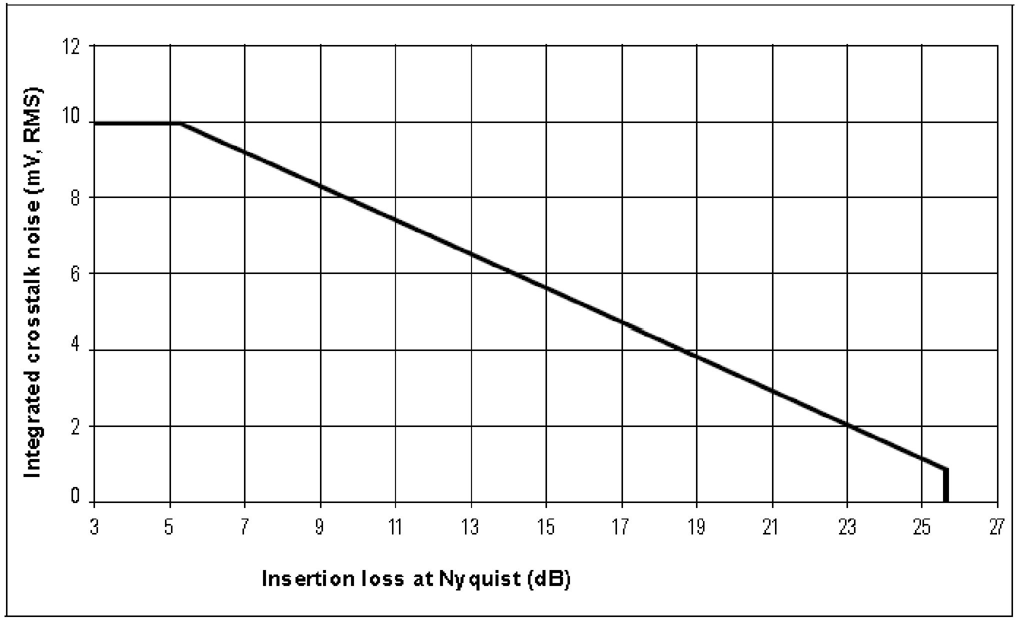


Figure 11-3. Illustration integrated crosstalk noise limits



$$ILD \geq ILD_{min} = \begin{cases} -1.0 - 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\ -4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax} \end{cases}$$

$$ILD \leq ILD_{max} = \begin{cases} 1.0 + 12.0(f/f_b) & f_{ILmin} \leq f < f_b/4 \\ 4.0 & f_b/4 \leq f \leq (3/4)f_{ILmax} \end{cases}$$

Short Conclusion: 1. Industrial specs starting to change focus of requirement

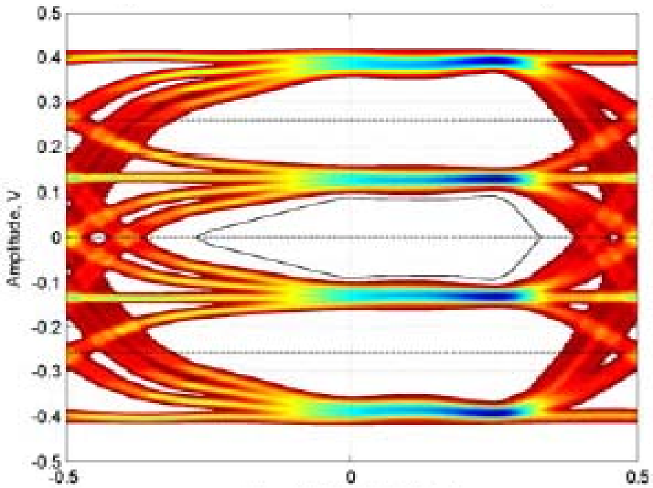
2. Channel discontinuity and crosstalk constraints become important in new specification

Foundation of Channel Based Methods (1/4)

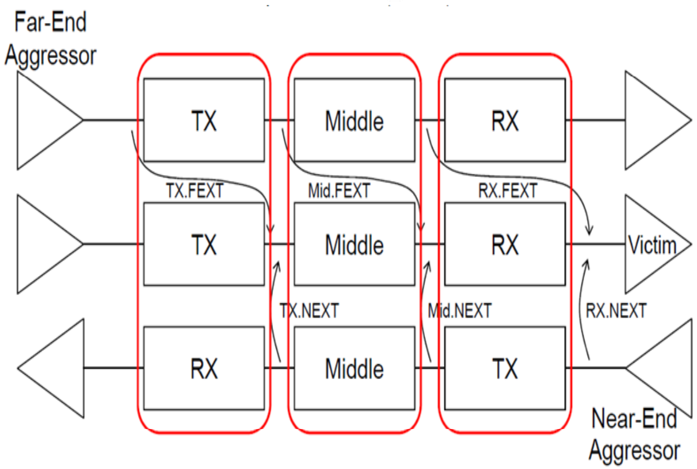
- **SNR is widely used metric in communication field**

$$BER < 10^{-15}$$

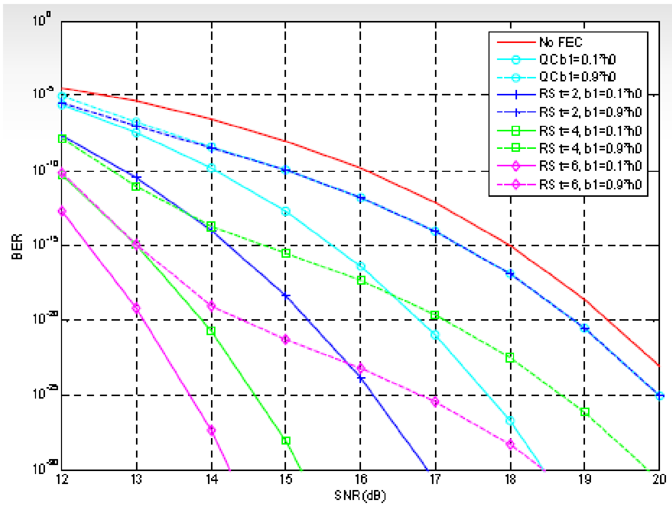
$$SNR_{dB} > 20 * \log 10\left(\sqrt{2} * erfcinv(2 * BER)\right) = 18dB$$



Multi-level signaling evaluation become practicable



Multi-path crosstalk could be simplified



Effect of Error Correction Code could be considered by coding gain

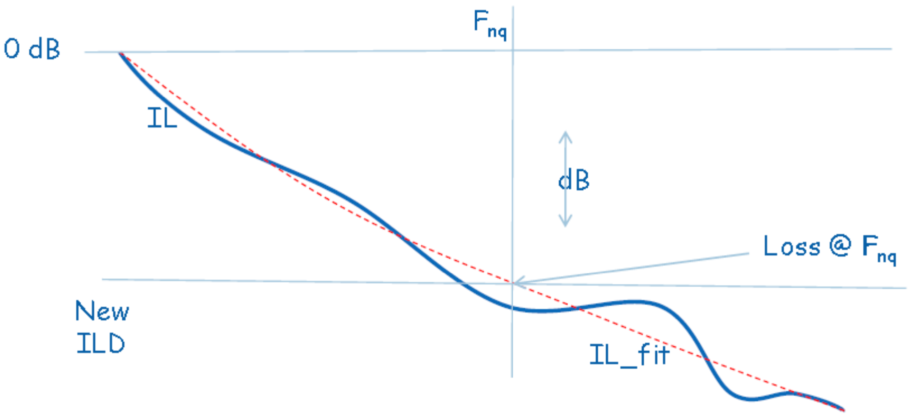
Foundation of Channel Based Methods (2/4)

- **Illustration of different methods**

Methods adopted by SAS_Chan2L and CCT

$$SNR = 20 \cdot \log\left(\frac{S_{avail\_channel} * Si_{eq\_gain} * Si_{Jitter\_penalty}}{\sqrt{\sigma_{icn}^2 + \sigma_{ii\ln}^2 + \sigma_{Si\_noise}}} \right)$$

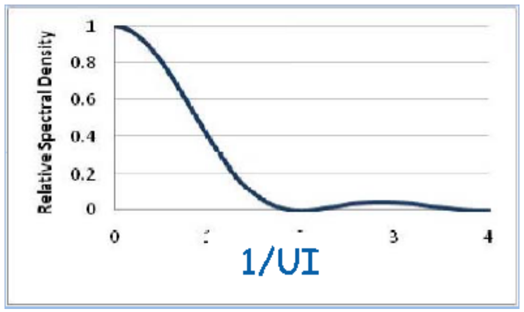
Insertion loss calculation



Noise calculation formula

$$\sigma = \sqrt{\frac{2 \cdot \Delta f \cdot \sum_n PWF(f_n) \cdot Quantity^2}{F2 - F1}}$$

PWF

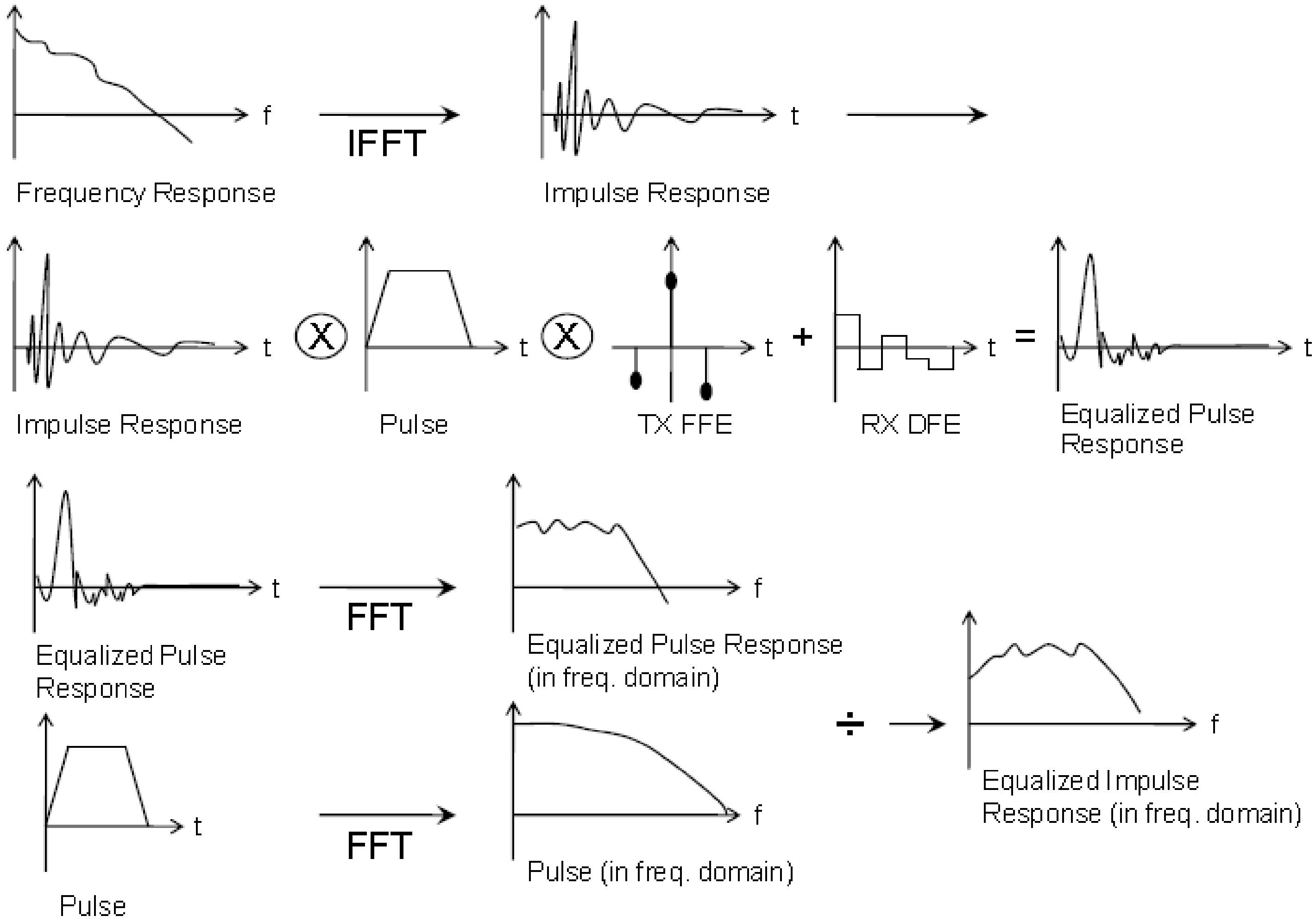


Drawback: Equalization effect didn't take into account

Foundation of Channel Based Methods (3/4)

- **Illustration of different methods**

Methods adopted by SAS3_EYEOPENING



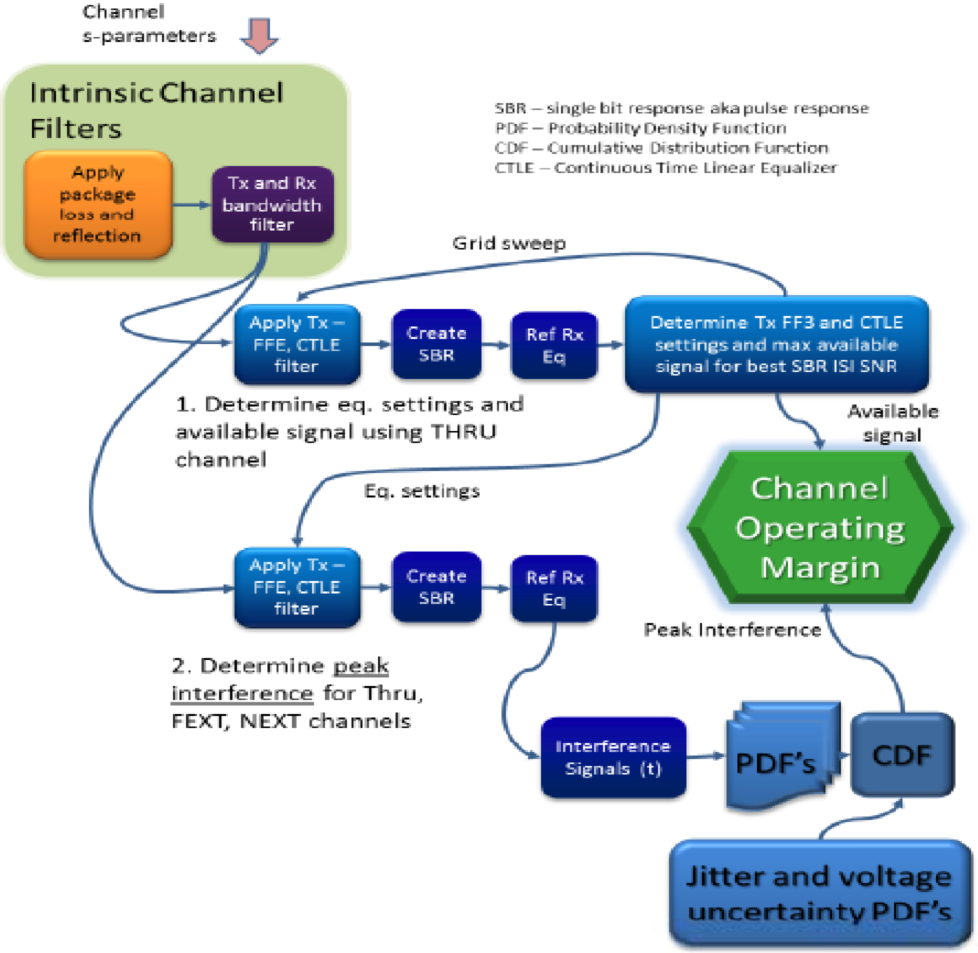
With equalized impulse, worst case signal amplitude and crosstalk noise could be easily computed.

Foundation of Channel Based Methods (4/4)

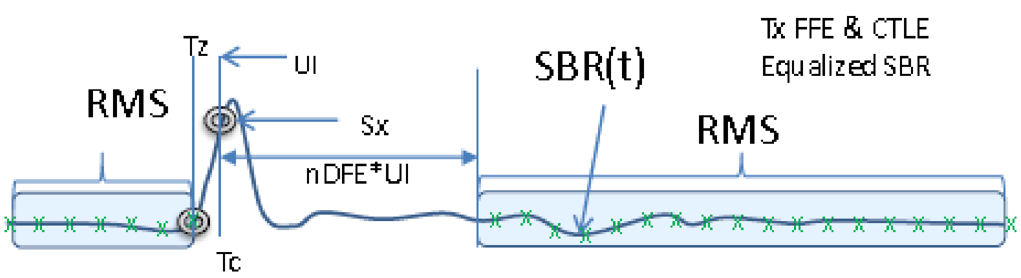
- **Illustration of different methods**

Methods adopted by COM (Channel Operation Margin)

Flow of COM



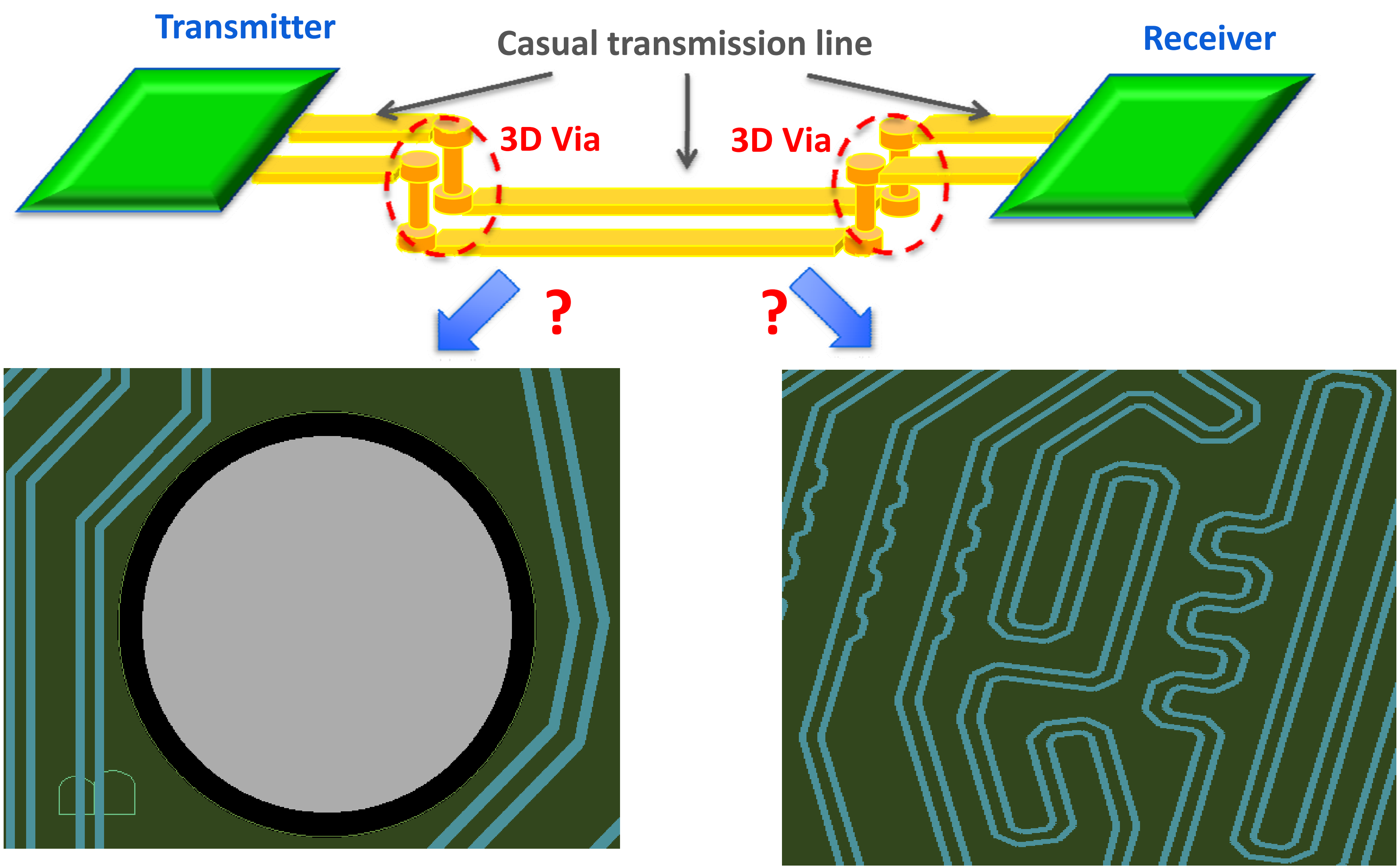
Calculation of equalized signal amplitude and noise



With equalized signal response and noise CDF, worst case operation margin could be easily computed.

Impact of Channel Extraction Method(1/2)

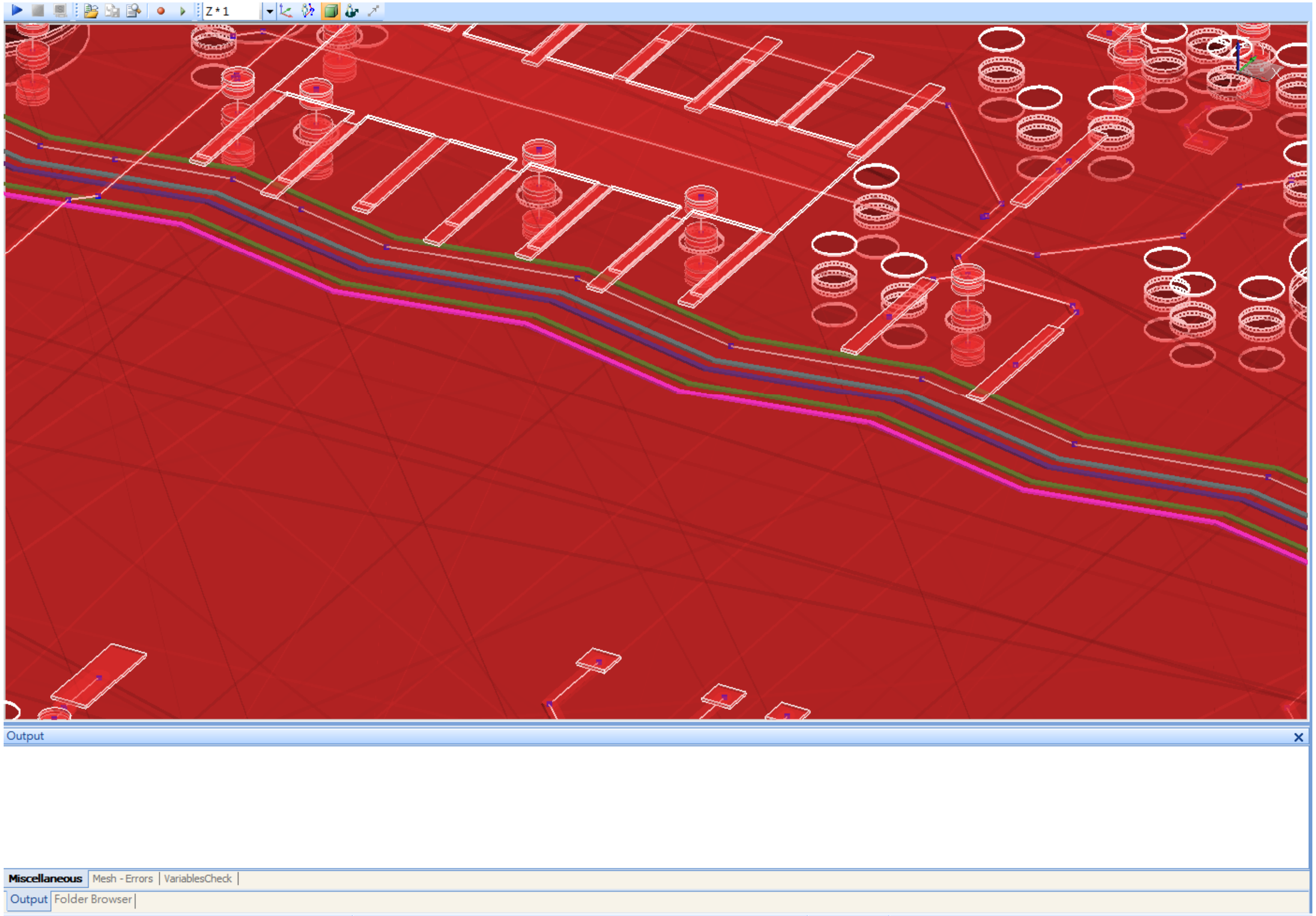
- **Common method: Casual transmission line and Via extracted by 3D field solver. While, how about following cases?**



It would consume huge computation time and resource to solve whole channel linkages by 3D field solver.

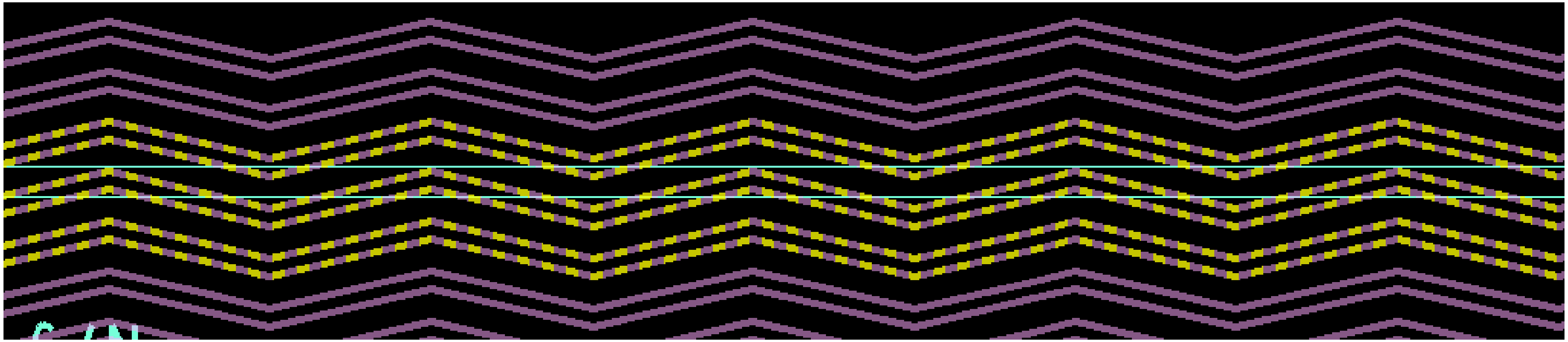
Impact of Channel Extraction Method(2/2)

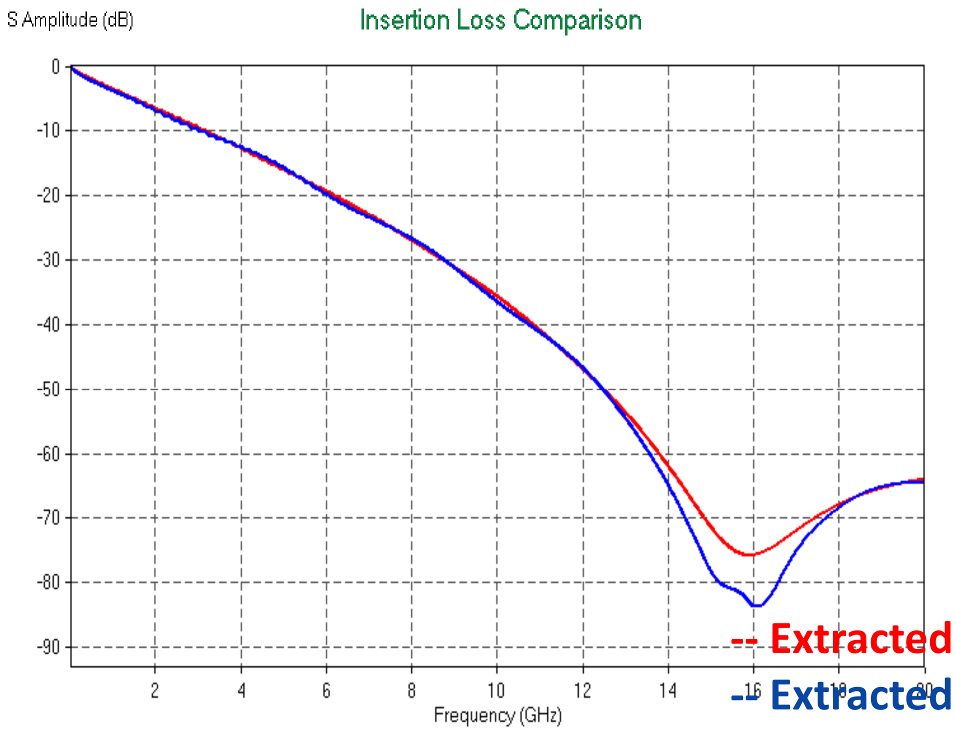
- **A quick solver with sufficient accuracy is necessary to take detail channel effect into account**

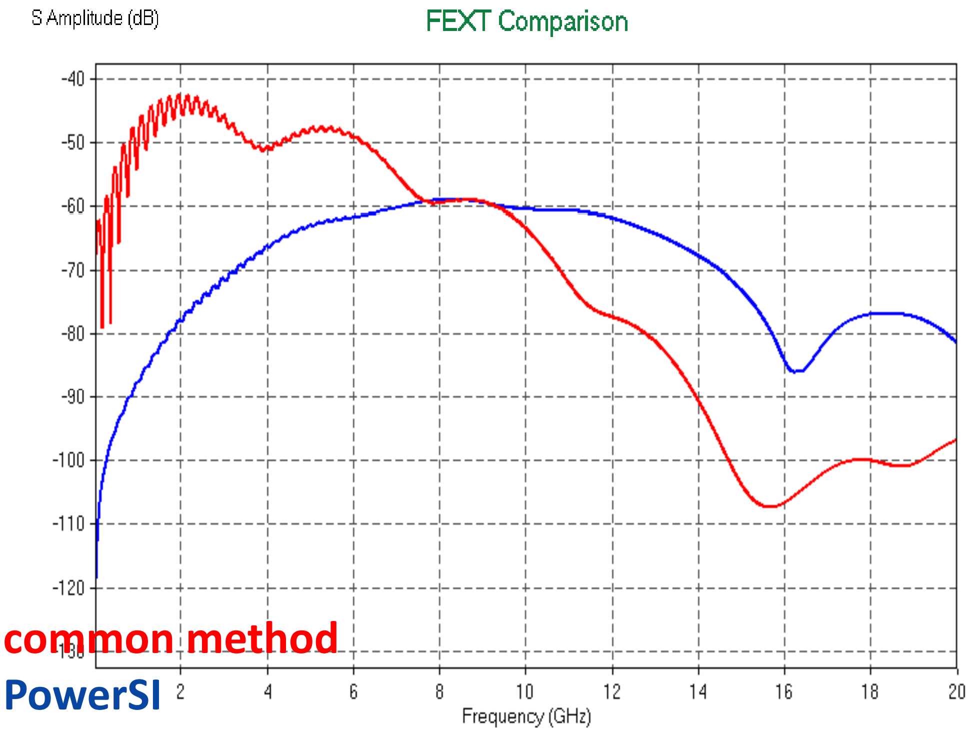


Case Study (1/9)

- **Case1: Highly parallel differential pairs**







-- Extracted by common method

-- Extracted by PowerSI

Case Study (2/9)

- **Case1: Highly parallel differential pairs**

SAS_Chan2L

Extraction Method	IL @ Nyquist	IL rms noise	Crosstalk rms noise	SNR
Common	12.7dB	18.3mV	6.7mV	27.5dB
PowerSI	12.6dB	22.8mV	0.4mV	25.1dB

SAS3_EYEOPENING

Extraction Method	Main Cursor	Relative Opening (Crosstalk included)	SNR	Relative Opening (Crosstalk excluded)
Common	120.8mVppd	83.4% => **100.7mVppd**	15.596dB	91.1%
PowerSI	112.3mVppd	86.3% => **96.9mVppd**	17.655dB	87.6%

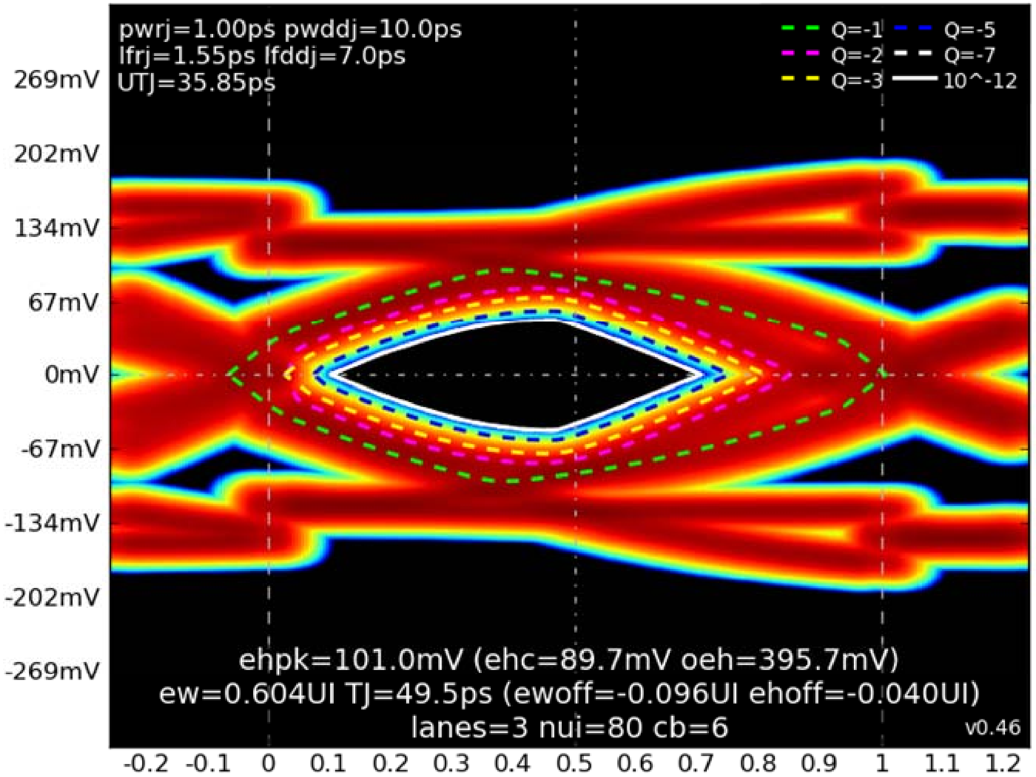
COM

Extraction Method	IL @ Nyquist	Vpeak after equalizer	Peak channel noise	SNR	Peak noise	COM	Vpeak - noise
Common	14.026dB	136.7mVppd	21.2mV	16.188dB	39.1mV	10.872dB	**97.6mVppd**
PowerSI	14.801dB	89.6mVppd	31.5mV	9.080dB	42.1mV	6.561dB	**47.5mVppd**

Case Study (3/9)

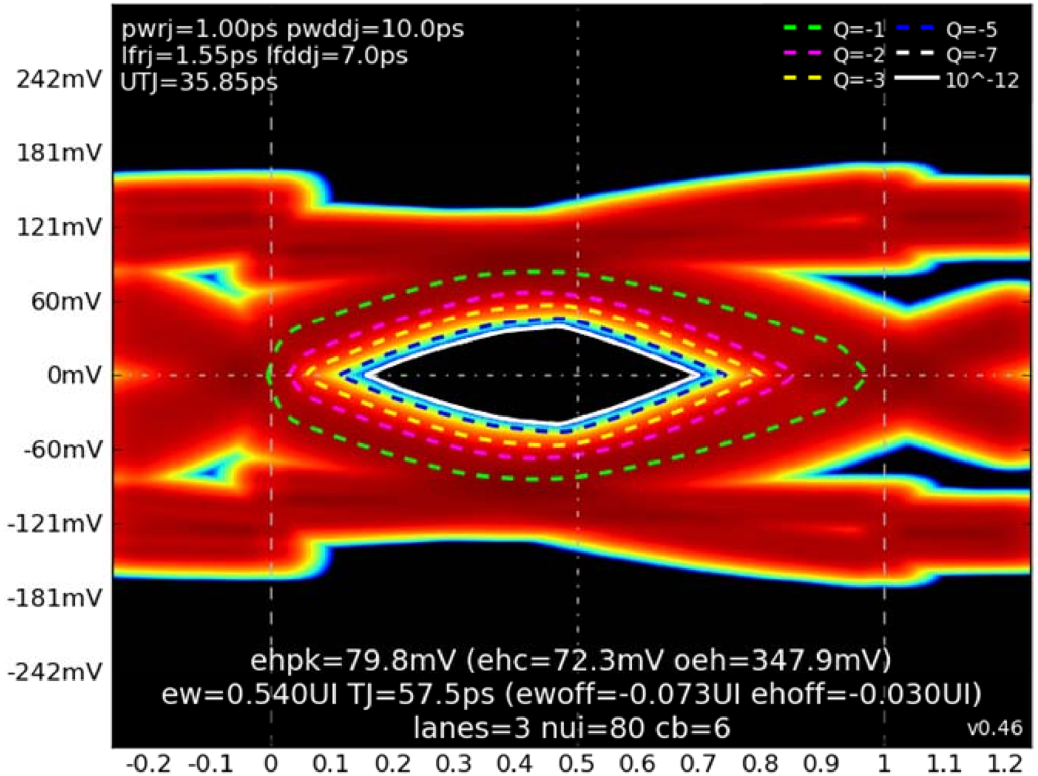
- **Examination by Seasim**

Simulation results with channel extracted by common method



Minimum eye-height is close to COM and SAS3_EYEOPENING results

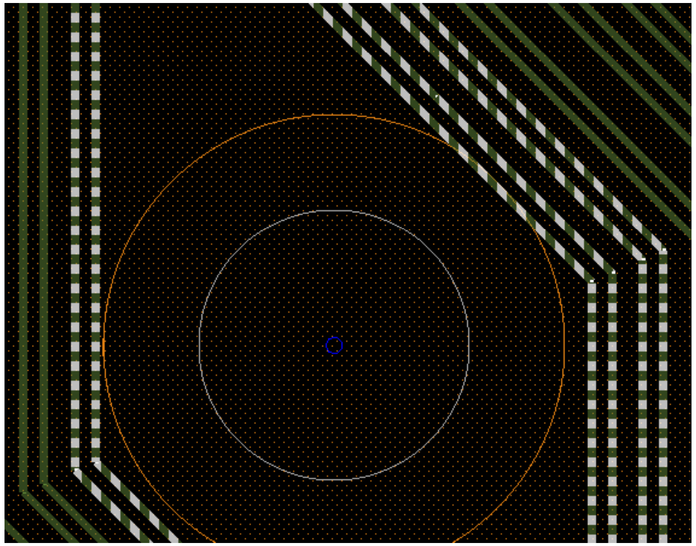
Simulation results with channel extracted by PowerSI

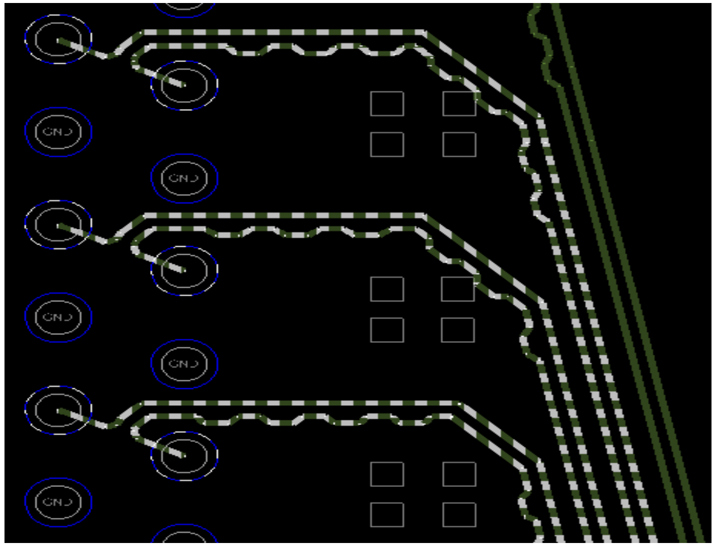


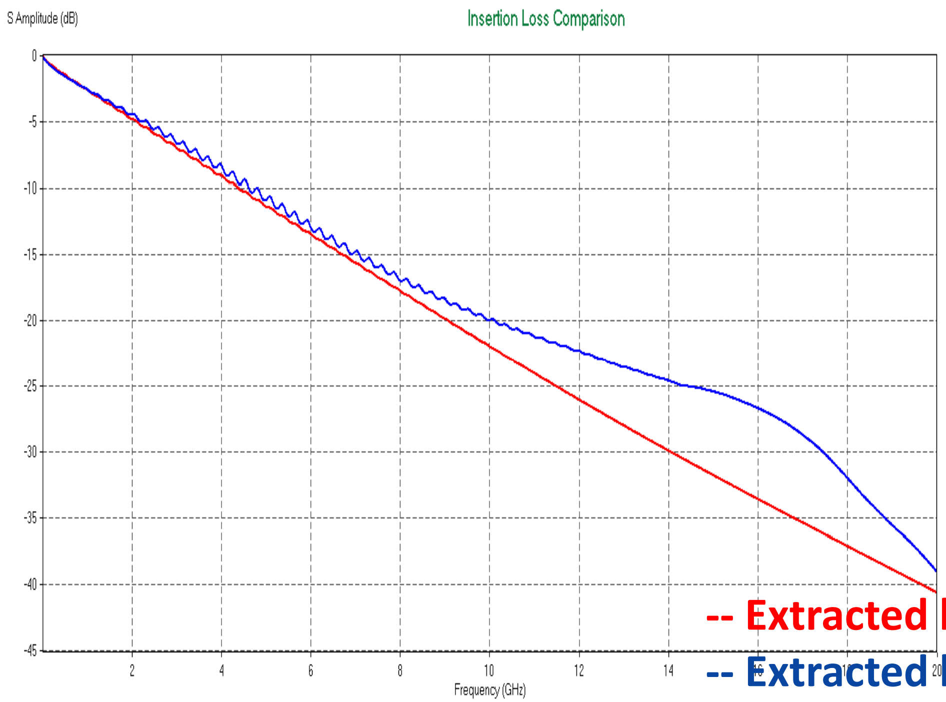
Minimum eye-height is far larger than COM results and smaller than SAS3_EYEOPENING results

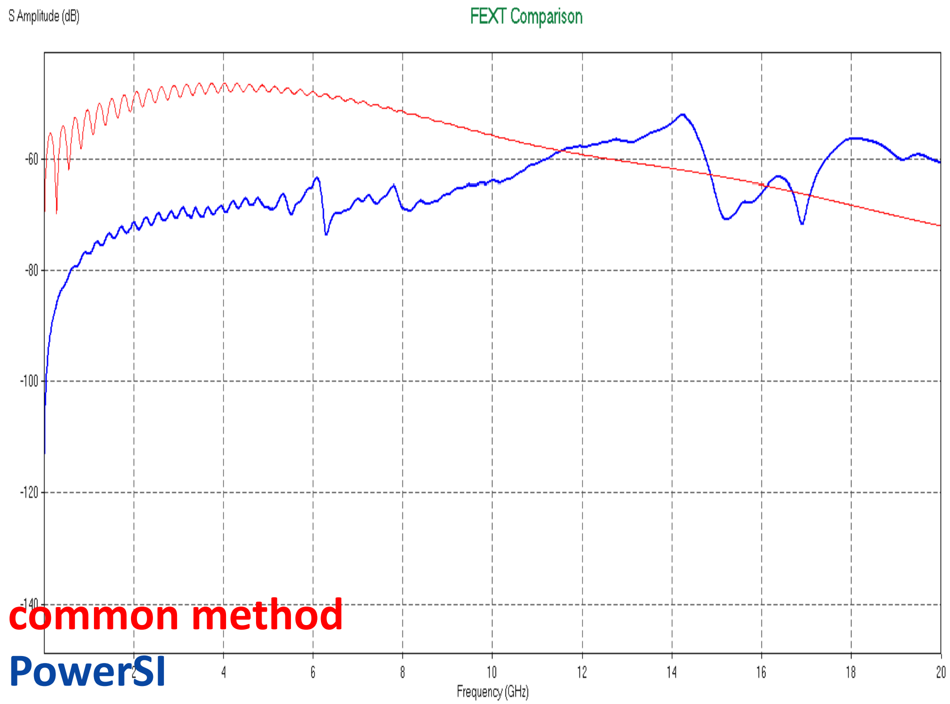
Case Study (4/9)

- **Case2: Partially non-parallel differential pairs**









-- Extracted by common method

-- Extracted by PowerSI

Case Study (5/9)

- **Case2: Partially non-parallel differential pairs**

SAS_Chan2L

Extraction Method	IL @ Nyquist	IL rms noise	Crosstalk rms noise	SNR
Common	9.2dB	17.8mV	4.9mV	30.3dB
PowerSI	8.5dB	25.3mV	1.2mV	26.8dB

SAS3_EYEOPENING

Extraction Method	Main Cursor	Relative Opening (Crosstalk included)	SNR	Relative Opening (Crosstalk excluded)
Common	188.2mVppd	93% => **175.0mVppd**	23.098dB	98%
PowerSI	186.9mVppd	94.9% => **177.4mVppd**	25.849dB	96.3%

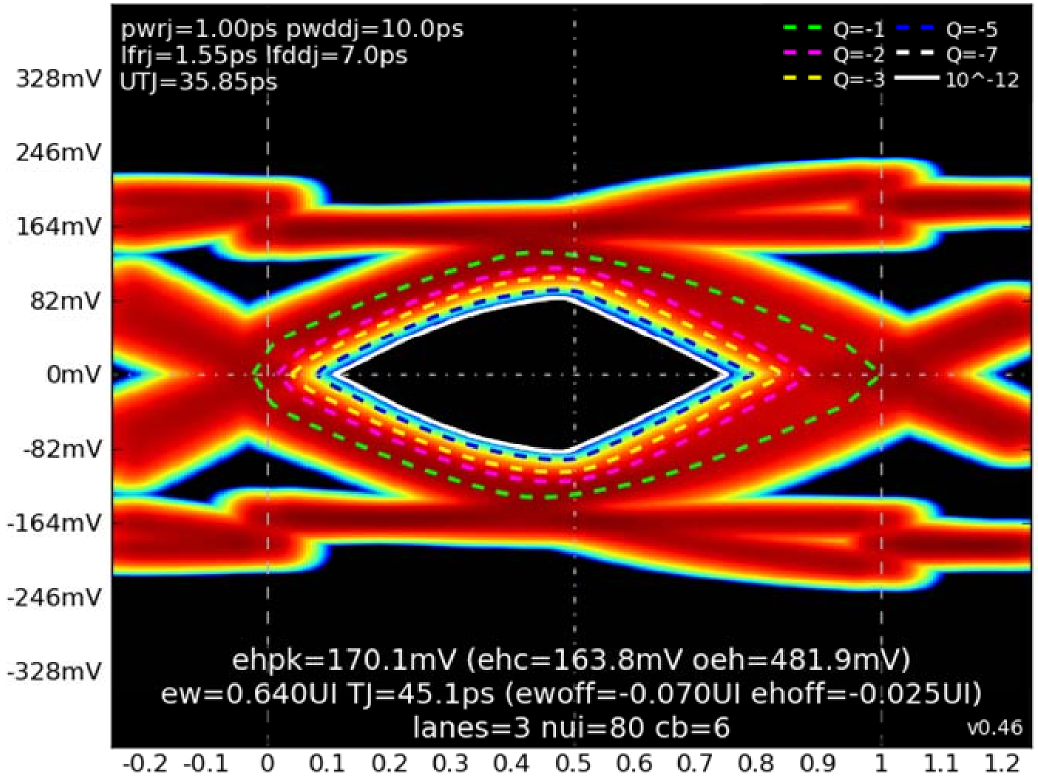
COM

Extraction Method	IL @ Nyquist	Vpeak after equalizer	Peak channel noise	SNR	Peak noise	COM	Vpeak - noise
Common	10.1073dB	219.91mVppd	29.3mV	17.402dB	58.9mV	11.443dB	**161.0mVppd**
PowerSI	10.0318dB	203.02mVppd	39mV	14.33dB	66.4mV	9.707dB	**136.6mVppd**

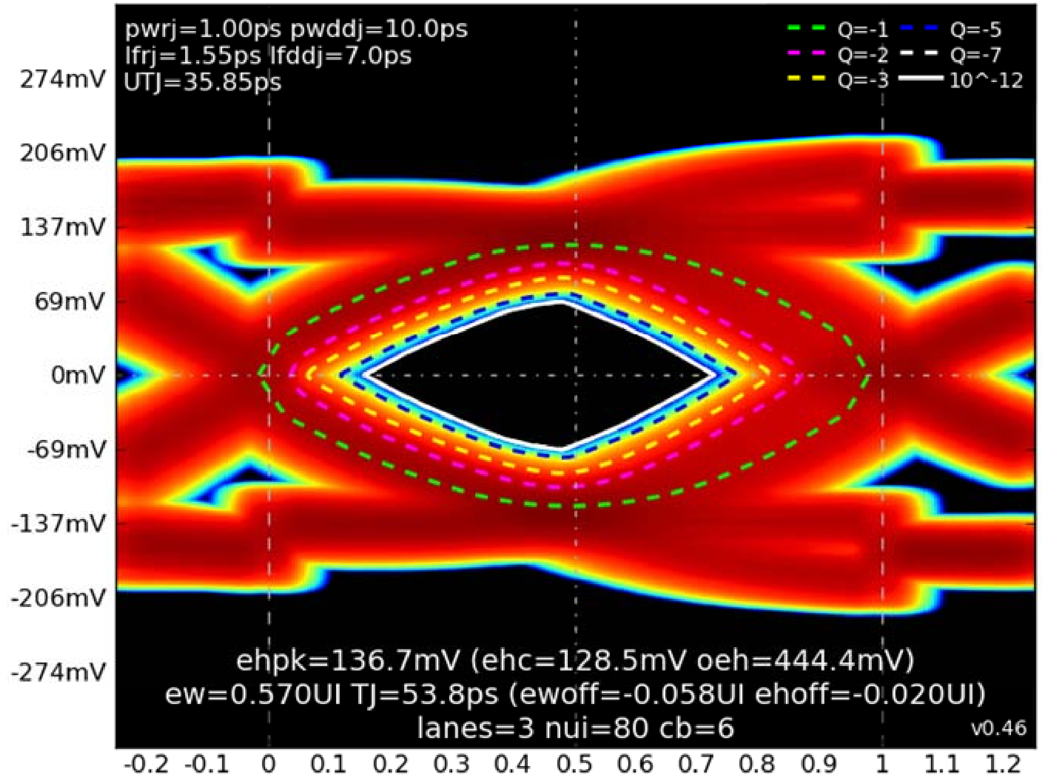
Case Study (6/9)

- **Examination by Seasim**

Simulation results with channel extracted by common method



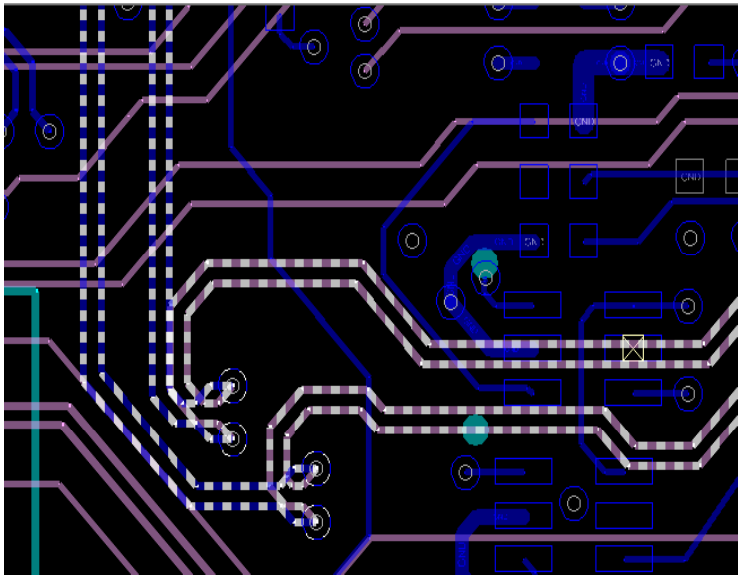
Simulation results with channel extracted by PowerSI

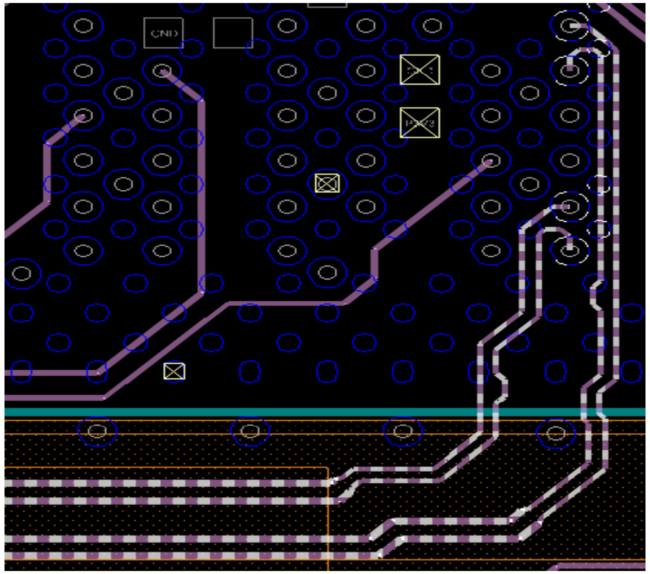


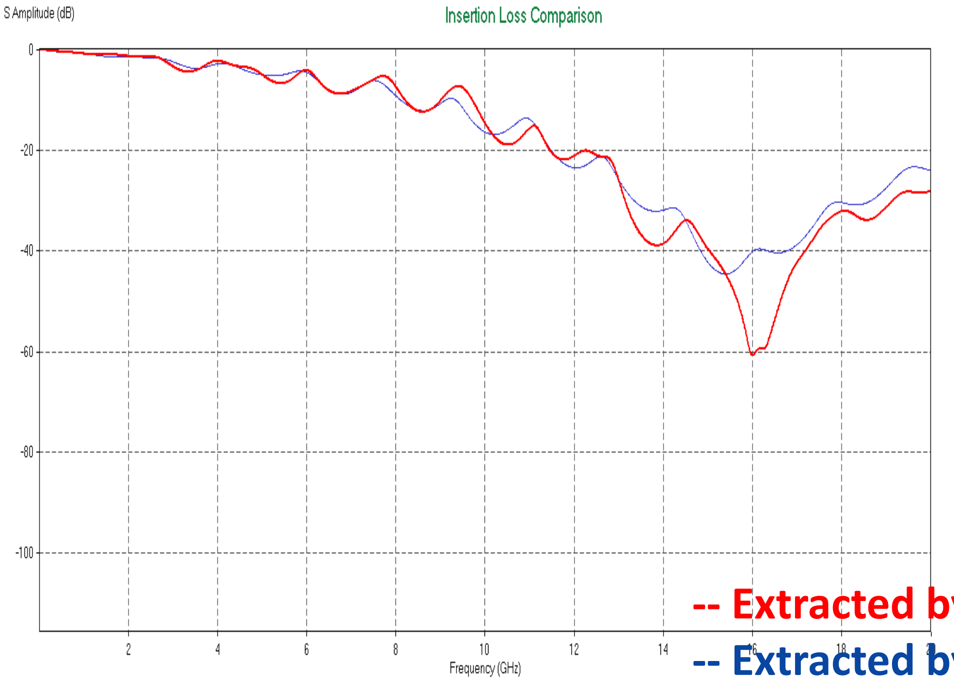
Both minimum eye-height simulation results are very close to those of COM

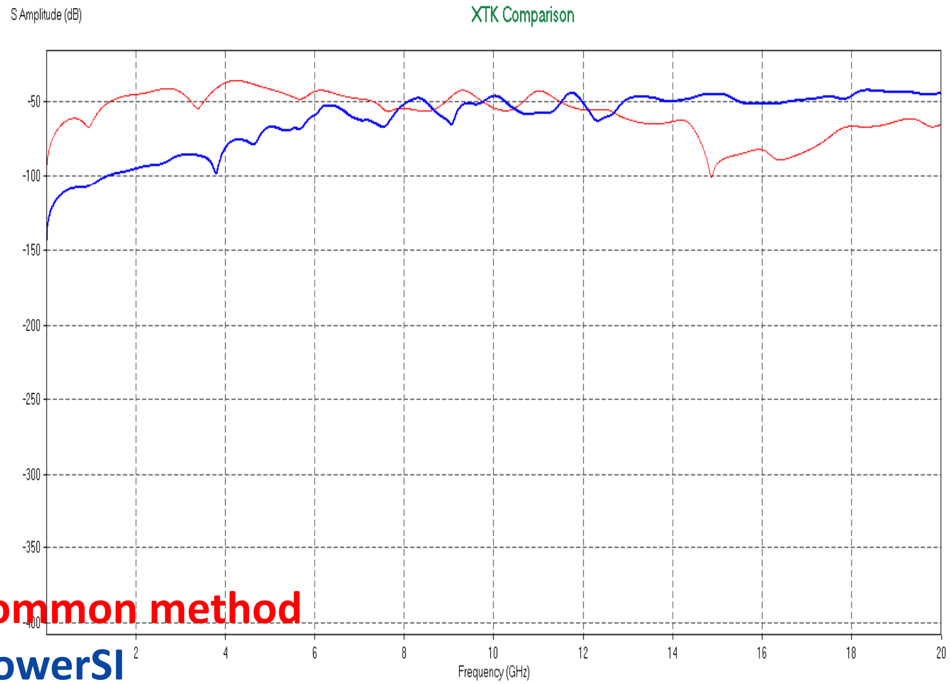
Case Study (7/9)

- **Case3: Mostly non-parallel differential pairs with layer transition**









-- Extracted by common method

-- Extracted by PowerSI

Case Study (8/9)

- **Case3: Mostly non-parallel differential pairs with layer transition**

SAS_Chan2L

Extraction Method	IL @ Nyquist	IL rms noise	Crosstalk rms noise	SNR
Common	3.4dB	67.5mV	6.3mV	22.4dB
PowerSI	3.2dB	95.6mV	0.1mV	19.1dB

SAS3_EYEOPENING

Extraction Method	Main Cursor	Relative Opening (Crosstalk included)	SNR	Relative Opening (Crosstalk excluded)
Common	554.2mVppd	78.5% => **435.0mVppd**	13.351dB	81.1%
PowerSI	539.8mVppd	80% => **431.8mVppd**	13.979dB	80.7%

COM

Extraction Method	IL @ Nyquist	Vpeak after equalizer	Peak channel noise	SNR	Peak noise	COM	Vpeak - noise
Common	3.6766dB	560.39mVppd	172.5mV	10.234dB	253.4mV	6.8937dB	**307.0mVppd**
PowerSI	4.0717dB	522.22mVppd	203.5mV	8.186dB	278.9mV	5.448dB	**243.3mVppd**

Case Study (9/9)

- **Higher data rate results**

COM of case 1 with 12Gbps

Extraction Method	IL @ Nyquist	Vpeak after equalizer	Peak channel noise	SNR	Peak noise	COM
Common	21.61dB	38.28mVppd	7.5mV	14.158dB	13.4mV	6.1164dB
PowerSI	22.97dB	-20.57mVppd	58.1mV	N/A	N/A	N/A

COM of case 1 with 25Gbps

Extraction Method	IL @ Nyquist	Vpeak after equalizer	Peak channel noise	SNR	Peak noise	COM
Common	47.26dB	6.64mVppd	0.9mV	17.359dB	2mV	10.4259dB
PowerSI	50.84dB	-6.04mVppd	21.9mV	N/A	N/A	N/A

Long Via stub channel extracted by common method can operate with 12Gbps data rate?

Conclusions

- For upcoming industrial specification of very high speed signals, channel discontinuity and crosstalk become important.
- Channel based methods are ready for signal integrity evaluation of complex signal transmission mechanism.
- A quick solver with sufficient accuracy is necessary for detail channel effect modeling of very high speed signals.
- As channel discontinuity and crosstalk dominating, accuracy of channel based methods would be critical issue.
- Though, channel based methods couldn’t take interaction between chip buffer and channel into account.

Reference

- [1] Working Draft American National Standard Information Technology – Serial Attached SCSI -3 (SAS-3)
- [2] Enhanced Equalization and Forward Correction Coding Technologies for 25+Gb/s Serial Link System
- [3] SAS3 Channel Spec Weeding Proposal
- [4] Comparison of SAS3_EYEOPENING with SAS_Chan2L
- [5] Channel Operating Margin (COM): Evolution of Channel Specifications for 25 Gbps and Beyond
- [6] Common Electrical I/O (CEI) - Electrical and Jitter Interoperability agreements for 6G+ bps, 11G+ bps and 25G+ bps I/O