Welcome to

DesignCon® 2024

WHERE THE CHIP MEETS THE BOARD

Conference

January 30 – February 1, 2024

Expo

January 31 – February 1, 2024

Santa Clara Convention Center

Comparing the different Metrics of Intra-pair Skew in Tracking Channel Performance

Track 8. Measurement & Simulation Techniques for Analyzing Jitter, Noise, BER/SER/FER

Hansel Desmond D'Silva, Achronix Semiconductor Corporation
Amit Kumar, Achronix Semiconductor Corporation
Richard Mellitz, Samtec
Adam Gregory, Samtec
Steve Krooswyk, Samtec
Beomtaek Lee, Intel Corporation
Howard Heck, Intel Corporation

SPEAKERS

Hansel Desmond Dsilva

Achronix Semiconductor Corporation
Staff Signal Integrity Engineer

hanseldsilva@achronix.com

Steve Krooswyk

Samtec
SI design and standards engineer

steve.krooswyk@samtec.com

Summary

Secondary Effects - Crosstalk:

- The impact of intra-pair skew on differential insertion loss and mode conversion noise shares a cosine and sine relation with frequency, it is always destructive.
- The impact of intra-pair skew on far-end crosstalk may be constructive or destructive based on the polarity of skew.

Skew as a specification:

- Recognize intra-pair skew as a context-sensitive metric.
  - Current limits for differential insertion loss, return loss, and crosstalk constrain permissible skew.
- Emphasizes the potential constructive or destructive impact of intra-pair skew on reflections and crosstalk.
- Blindly zeroing out the skew may lead to unintended consequences, including increased loss, mode conversion noise, and crosstalk.

Outline

1. Introduction
   - A. Background
   - B. Problem Statement
2. Impact of Intra-pair Skew
   - A. Setup
   - B. Differential Loss and FEXT
   - C. Differential insertion loss versus intra-pair skew
   - D. Differential far-end crosstalk versus intra-pair skew
   - E. Propagation Time Difference
   - F. Polarity of intra-pair skew
   - G. Transmitter- Mode conversion
3. Intra-pair Skew Metrics
   - A. List of metrics
   - B. Evaluating a PCB
   - C. Evaluating a Cable Assembly
4. Intra-pair Skew as a Specification
   - A. Intra-pair Skew as a Specification
5. Summary

1. Introduction

A. Background

- **The ever-decreasing unit interval makes intra-pair skew ever important.**
- **Observed is manufacturing variation leading to as much as **±10psec skew**.**
- **Electrical specification have started to call out mode conversion/ intra-pair skew.**
- **There exists a need to understand the impact of intra-pair skew on the channel electrical parameters.**

Table. Different IO standards for data rate, baud rate and unit interval.

IO Standard	Signaling	Data rate [Gbps]	Baud rate [GBd]	Unit Interval [psec]
PCIe Gen 3	NRZ	8	8	125.00
10G Ethernet	NRZ	10.3125	10.3125	96.97
PCIe Gen 4	NRZ	16	16	62.50
25G Ethernet	NRZ	25.78125	25.78125	38.79
50G Ethernet	PAM4	53.125	26.5625	37.65
PCIe Gen 5	NRZ	32	32	31.25
PCIe Gen 6	PAM4	64	32	31.25
100G Ethernet	PAM4	106.25	53.125	18.82

B. Problem statement

Secondary Effects - Crosstalk:

- The impact of intra-pair skew on differential loss and mode conversion noise is well documented.
- Intra-pair skew is linked to crosstalk, which can degrade the signal significantly.

Skew as a specification:

- Complexity arises from a wide range of measurement techniques, whether based in frequency or time domain.
- Lack of standardized benchmarks and clear guidance complicates the selection of appropriate methods, creating a gap between theory and practical implementation.

2. Impact of Intra-pair Skew

A. Setup

- **85 Ohm microstrip transmission line of 0.89 dB/ inch@26.56 GHz.**
- **Introduced intra-pair skew of -0.5UI:+0.05UI:+0.5UI in studying 106.25 Gbps PAM4 signaling.**
- **Simulated using Ansys HFSS 3D layout by breaking the structure into following.**
  - i. 4 inch one differential pair
  - ii. 2 inch two differential pair (coupled)
  - iii. Intra-pair skew structure

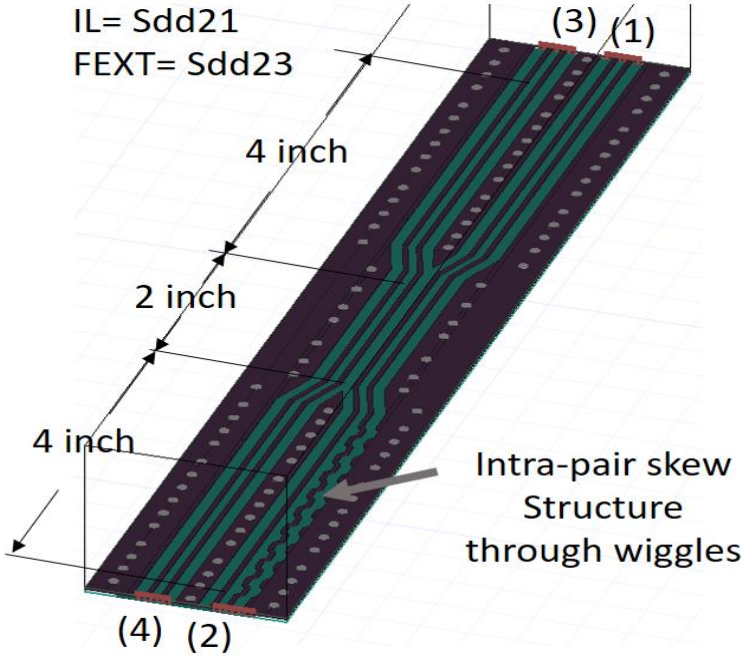


Figure. Differential microstrip test structure in introducing positive value of intra-pair skew (not to scale).

B. Differential Loss and FEXT

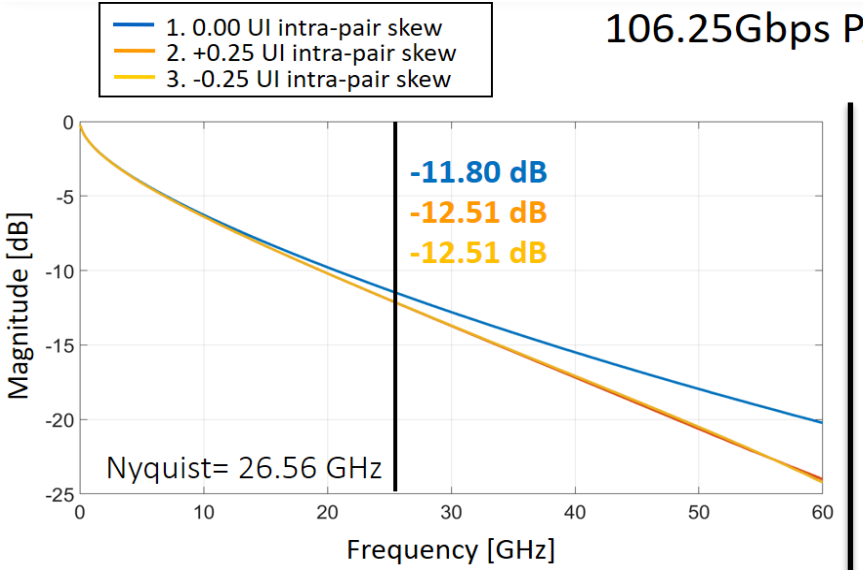


Figure. Differential insertion loss plot.

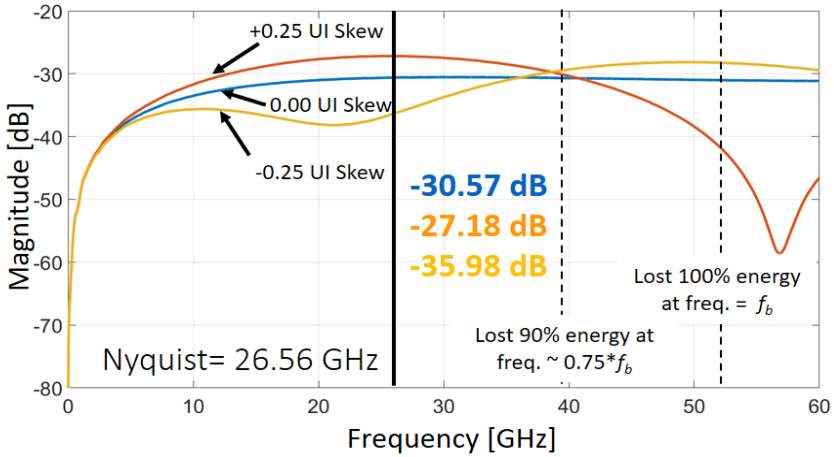


Figure. Differential far-end crosstalk plot.

- **Intra-pair skew is added through wiggles in a differential pair.**
- **Loss does not show dependency on the polarity of intra-pair skew.**
- **Crosstalk does show dependency on the polarity of intra-pair skew.**

C. Differential insertion loss versus intra-pair skew

- **Differential loss does not show dependency on the polarity of intra-pair skew.**
- **The receiver equalization would be able to compensate for energy lost to common mode.**

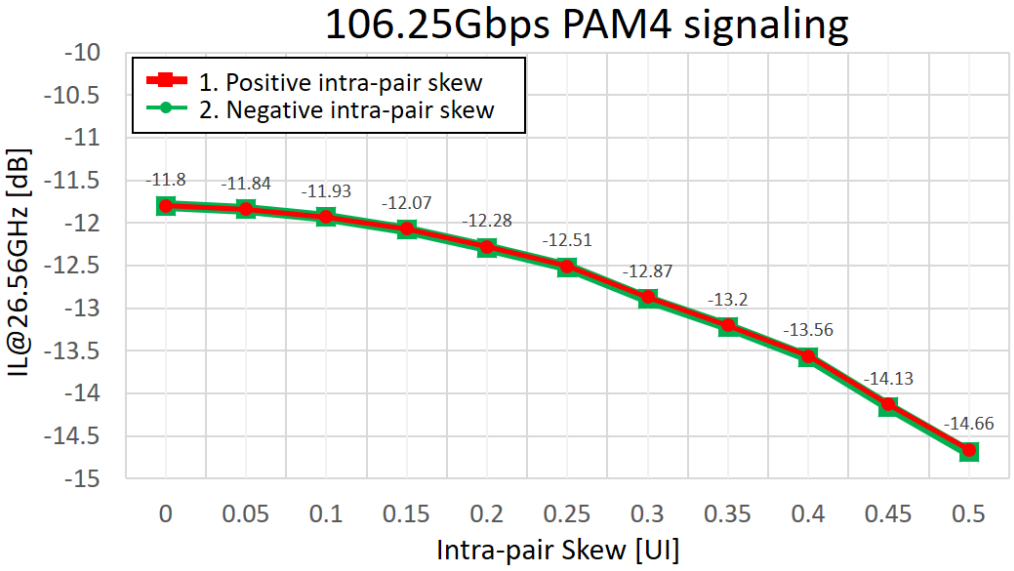


Figure. Differential insertion loss versus intra-pair skew.

$$IL_{with\ skew}[dB] = IL_{without\ skew}[dB] + 20*\log_{10}(\cos(\pi*frequency*Skew))$$

D. Differential far-end crosstalk versus intra-pair skew

- **Differential far-end crosstalk does show dependency on the polarity of intra-pair skew.**
- **Intra-pair skew impacts the propagation delay with the differential pair which in turn impacts the far-end crosstalk.**
- **The receiver would get significantly impacted by the far-end crosstalk.**

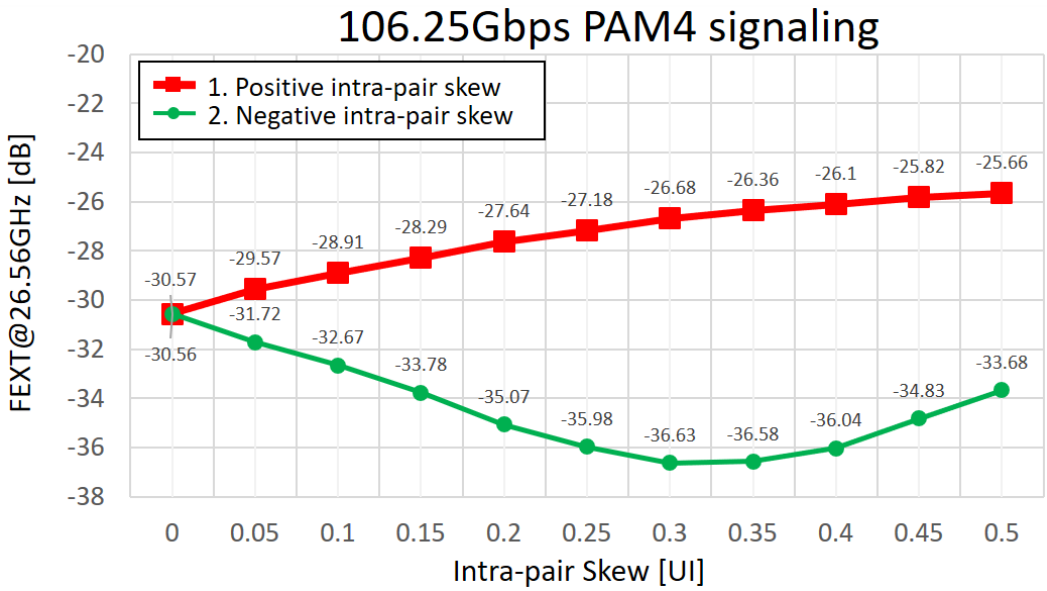
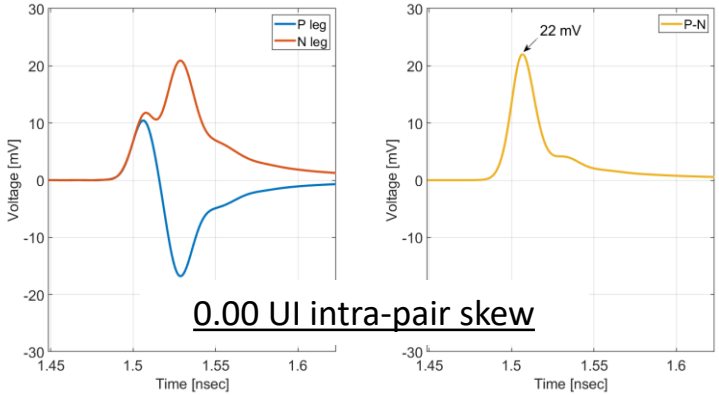
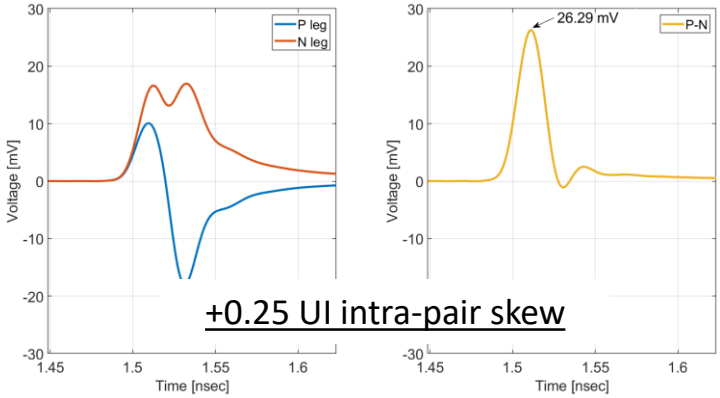


Figure. Differential far-end crosstalk versus intra-pair skew.

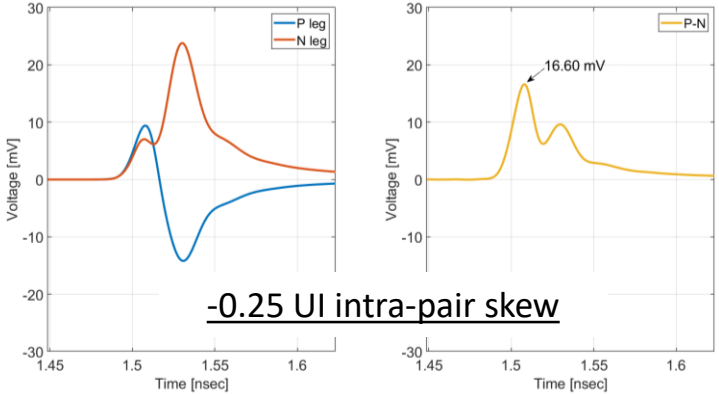
E. Propagation Time Difference



0.00 UI intra-pair skew



+0.25 UI intra-pair skew



-0.25 UI intra-pair skew

- **The difference in the propagation time of the single-ended signals within a differential pair may lead to a constructive or destructive impact on crosstalk.**

F. Polarity of intra-pair skew

- **Channel Operating Margin does show dependency on the polarity of intra-pair skew.**
- **It is worth noting that the polarity of intra-pair skew depends on the location of the victim pair relative to the aggressor pair.**

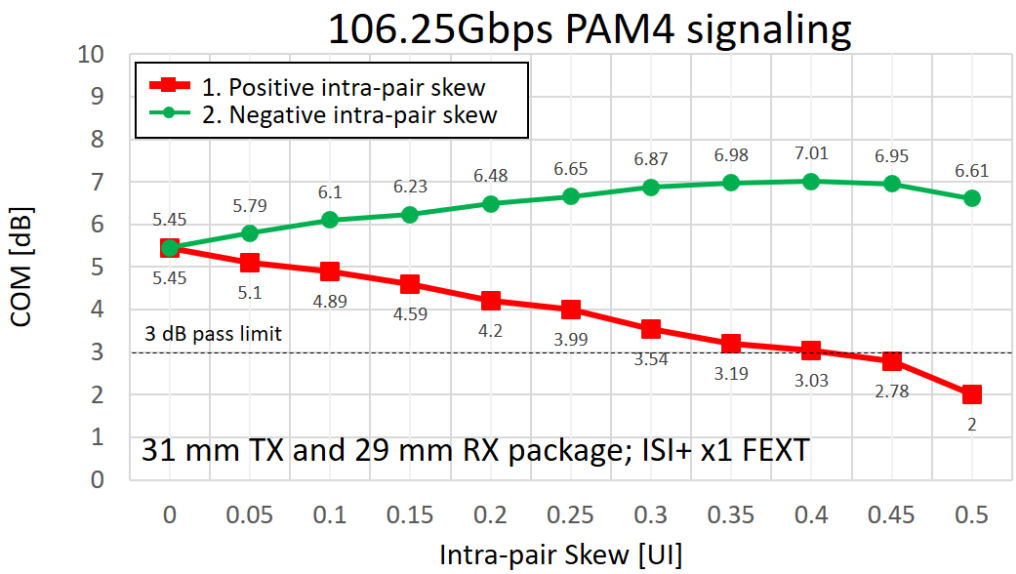
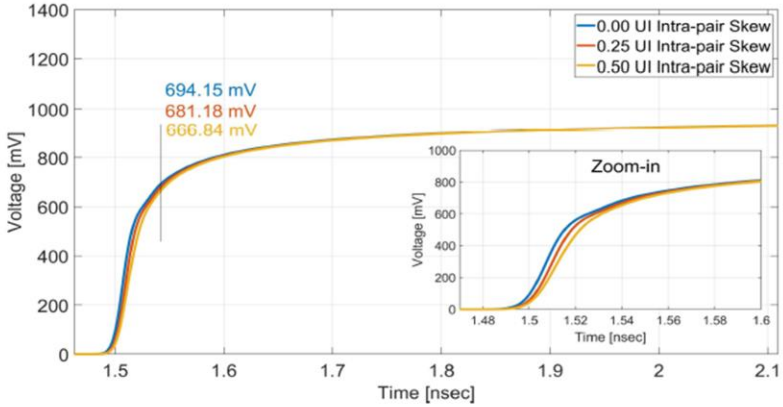


Figure. COM versus intra-pair skew.

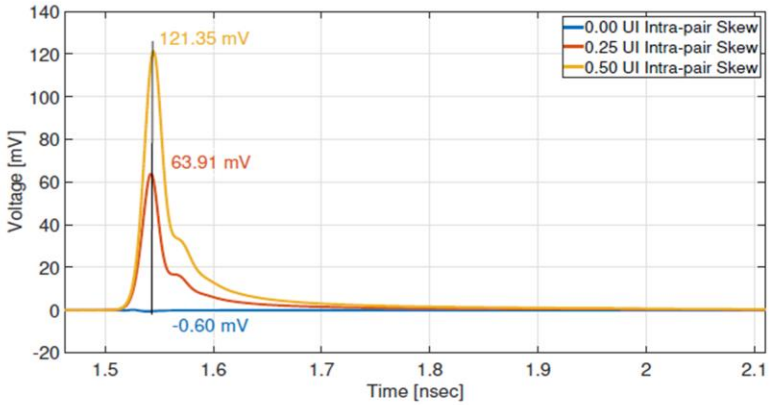
Channel Operating Margin (COM),

- **ISI and crosstalk**
- **Transmitter equalization**
- **Receiver equalization**

G. Transmitter Mode Conversion



(a) Step response of differential signal (Sdd21).



(b) Step response of mode conversion (Sdc21).

Figure. Figure. Step response of differential signal (Sdd21) and mode conversion (Sdc21) for 11 psec rise time 20-80%.

- **Intra-pair skew leads to mode conversion (SDC21) which may amplify the crosstalk for transmitter with common-mode noise.**
- **Many channel simulation tools do not take into account mode conversion.**

3. Intra-pair Skew Metrics

A. List of metrics

Below is a list of metrics for intra-pair skew.

A. **Threshold based single-ended step or pulse response skew.** (time-domain)

B. **Difference in Phase Delay versus Frequency.** (frequency-domain)

C. **Mode conversion versus Frequency.** (frequency-domain)

D. **Effective Intra-pair Skew (EIPS).** (frequency-domain)

E. **Signal to AC common-mode noise ratio (SCMR).** (time-domain)

F. **Intra-pair Skew based on the minimum SCMR.** (time-domain)

- **The time domain analysis offers insights into the precise time alignment of signals.**
- **Frequency domain analysis delves into the spectral characteristics of signals.**

B. Evaluating a PCB

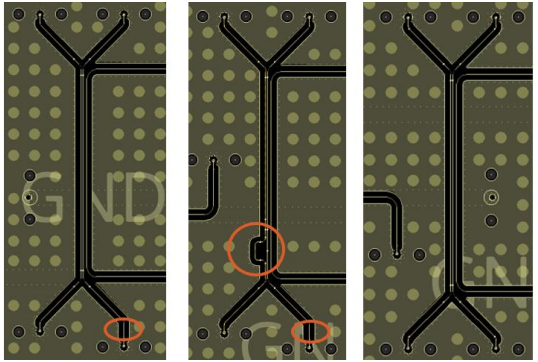


Figure. Measured PCB:
Left: intentional skew,
Center: intentional skew compensated,
Right: no skew.

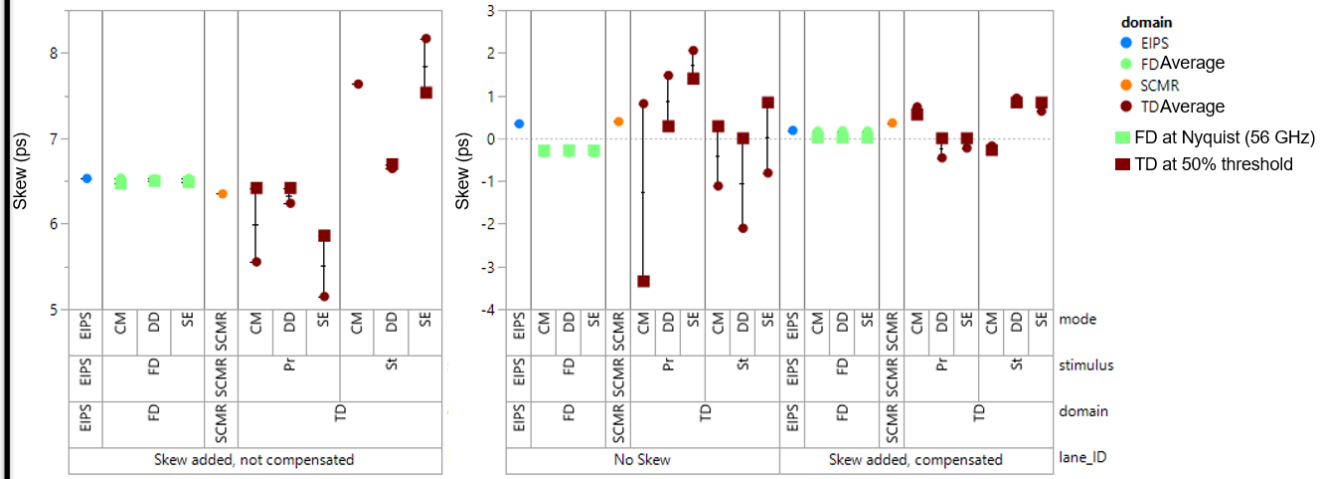


Figure. Measured skew of a PCB.

- **High consistency between the frequency domain measurements (any stimulus), EIPS and SCMR methods.**
- **Time-domain methods show a higher degree of variation.**
- **EIPS and skew based on minimum SCMR calculated skew are consistent with frequency domain calculated values, varying < 0.5ps**

C. Evaluating a Cable Assembly

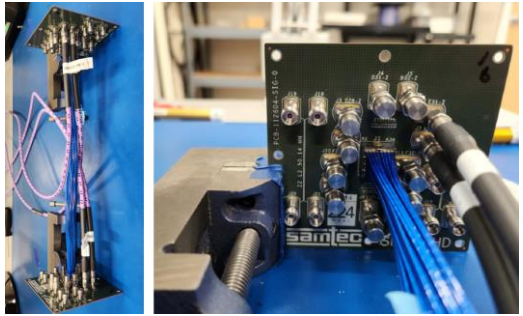


Figure. Measured 300 mmm assembly of Samtec CPC 224G-PAM4 cable (Si-Fly HD).

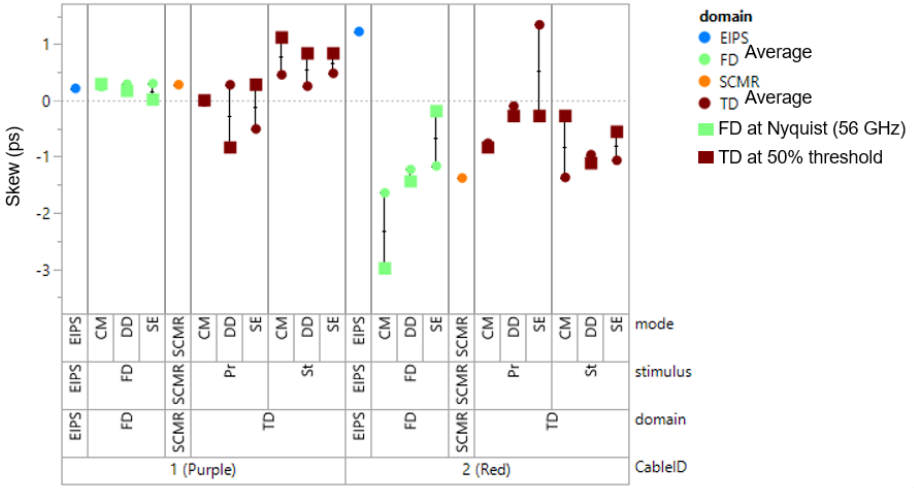


Figure. Measured skew of a 300mm cable assembly.

- **High consistency between the frequency domain measurements (any stimulus), EIPS and SCMR methods.**
- **Time-domain methods show a higher degree of variation.**
- **EIPS and skew based on minimum SCMR calculated skew are consistent with frequency domain calculated values, varying < 0.5ps**

4. Intra-pair Skew as a Specification

A. Intra-pair Skew as a Specification

100 Gbps PAM4, 1UI= 18.82 psec

Table. Variation across the various channel metrics for intra-pair skew.

Case	Skew based on min. SCMR [UI]	COM [dB]	VEC [dB]	VEO [dB]	Fitted IL at Nyquist [dB]	FOM ILD [dB]	ERL [dB]	ICN [mV]
0	0.17	6.85	5.26	13.17	14.25	0.0857	14.39	3.08
1	0.29	6.79	5.31	12.63	14.75	0.1033	14.73	3.16
2	0.4	6.49	5.57	10.74	15.56	0.138	14.27	3.2
3	0.53	5.97	6.07	9.23	16.89	0.1988	13.33	3.28
4	0.66	4.84	7.39	6.52	19.07	0.3023	11.96	3.3
5	0.75	3.94	8.75	4.6	20.76	0.3971	11.32	3.28
6	0.88	2.06	13.51	2.12	23.46	0.5649	10.43	3.35
7	1.01	0.1	39.17	0.1	26.53	0.8406	9.62	3.35

- **Above is Backplane Cabled channel operating at 100 Gbps PAM4.**
- **The current limits for differential insertion loss, return loss, and crosstalk constrain the permissible amount of skew in a channel.**

5. Summary

Summary

Secondary Effects - Crosstalk:

- The impact of intra-pair skew on differential insertion loss and mode conversion noise shares a cosine and sine relation with frequency, it is always destructive.
- The impact of intra-pair skew on far-end crosstalk may be constructive or destructive based on the polarity of skew.

Skew as a specification:

- Recognize intra-pair skew as a context-sensitive metric.
  - Current limits for differential insertion loss, return loss, and crosstalk constrain permissible skew.
- Emphasizes the potential constructive or destructive impact of intra-pair skew on reflections and crosstalk.
- Blindly zeroing out the skew may lead to unintended consequences, including increased loss, mode conversion noise, and crosstalk.

Thank you!

—

QUESTIONS?