Intra-pair skew metric (SILD): Skew-Induced Insertion Loss Deviation

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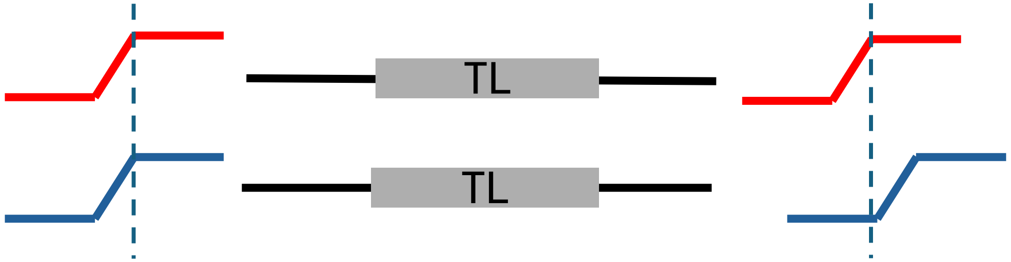
Outline

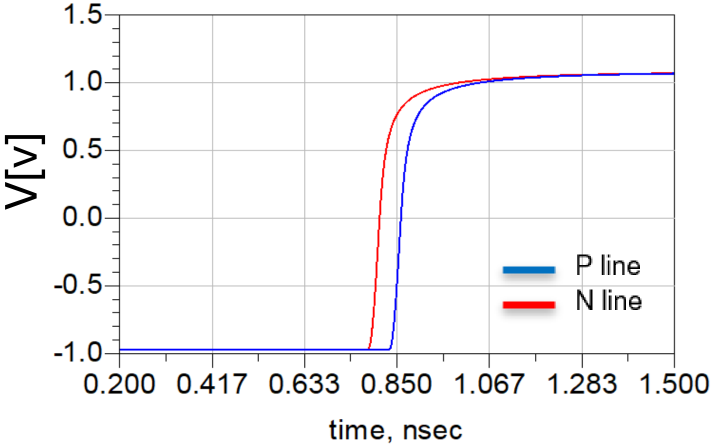
- Introduction
- De-skewing differential insertion loss
- Skew metric – Skew-Induced Insertion Loss Deviation (SILD)
- SILD correlation to measured BER with 224G SerDes IP
- SILD statistics – DAC cable measurements
- Conclusions

Effect of channel asymmetry results in different types of P/N skew



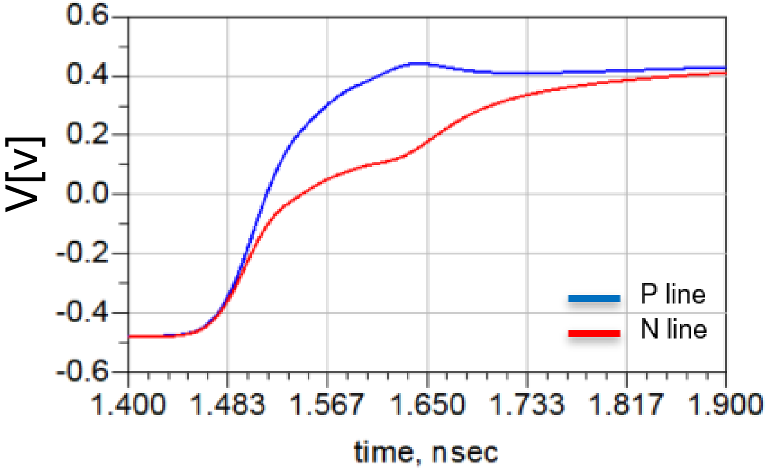
Transmission Line - TL
Stripline - SL

Time delay skew



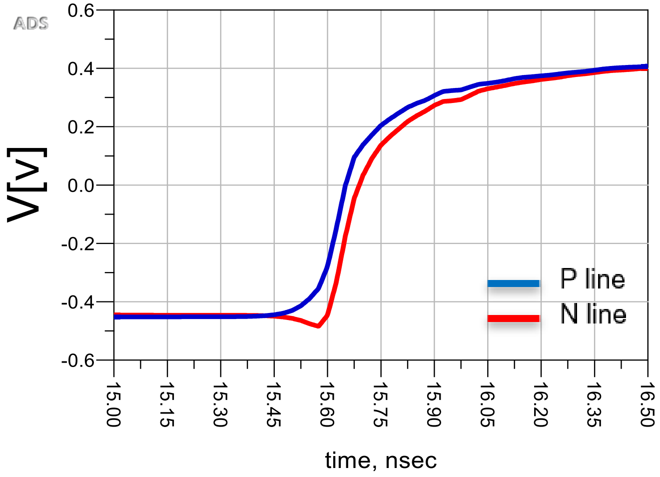
When differential and common modes speeds are same
typically, in SL PCB

Rise time skew



Differential mode travels faster than common mode
typically, in microstrip PCB

Amplitude skew



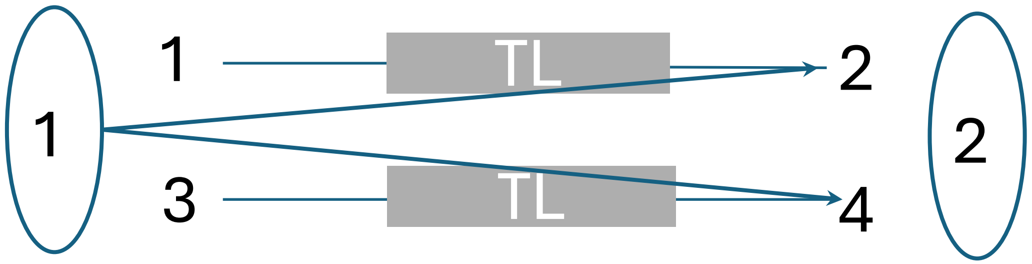
When common mode travels faster than differential mode
typically, in twinax cables

- In real channel skew can be combinations off all 3 different kind of skews
- Time-domain skew measurement is no longer reliable because the rise edge shifts vary at different voltage levels.

- D. Nozadze, et al., "Effective channel budget technique for high-speed channels due to differential P/N skew", 2017 EMC SIPI symposium
- D. Nozadze, et al., "Effect of time delay skew on differential insertion loss in weak and strong coupled PCB traces", 2017 EPEPS
- A. Koul, et al., "Fiber weave effect: Modeling, measurements, challenges and its impact on differential insertion loss for weak and strong-coupled differential transmission", DesignCon 2018

Frequency dependent skew and its asymmetry

Coupled TLs

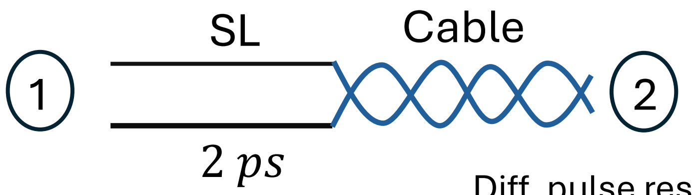


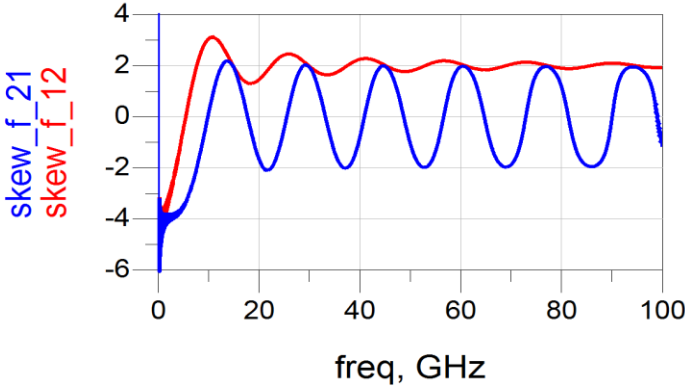
Skews: $t_{skew_{2,1}}(f) = \frac{phase(S_{sd21})}{2\pi f} - \frac{phase(S_{sd41})}{2\pi f}$

$$t_{skew_{1,2}}(f) = \frac{phase(S_{sd12})}{2\pi f} - \frac{phase(S_{sd32})}{2\pi f}$$

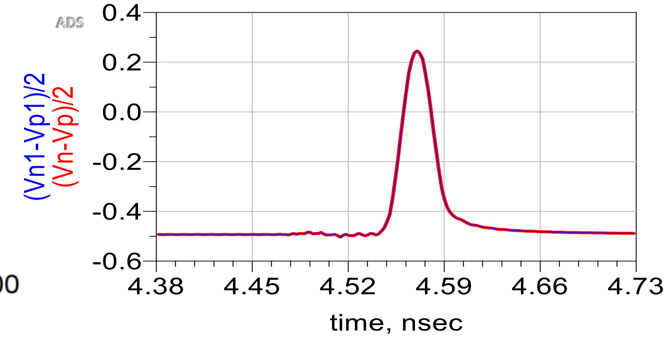
Difference in propagation time between P/N lines when differential mode signal is sent into TL.

Simulations

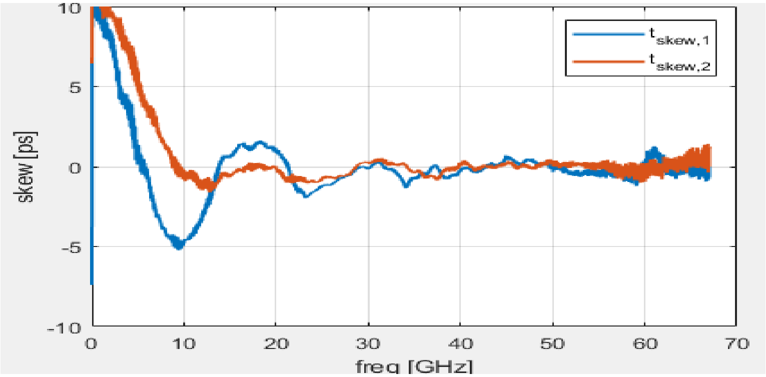




Diff. pulse response is reciprocal



Measurements- DAC cable

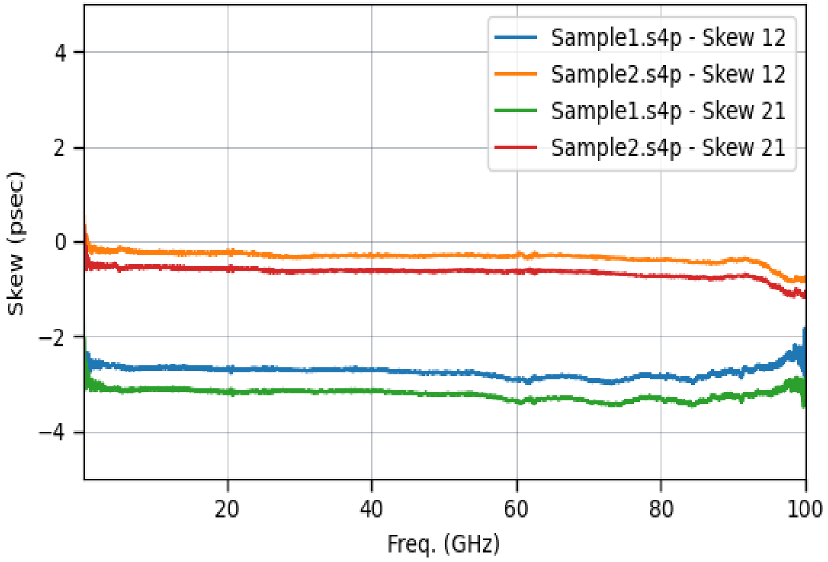


In coupled channels skew can be asymmetric, but its impact is inherently reciprocal

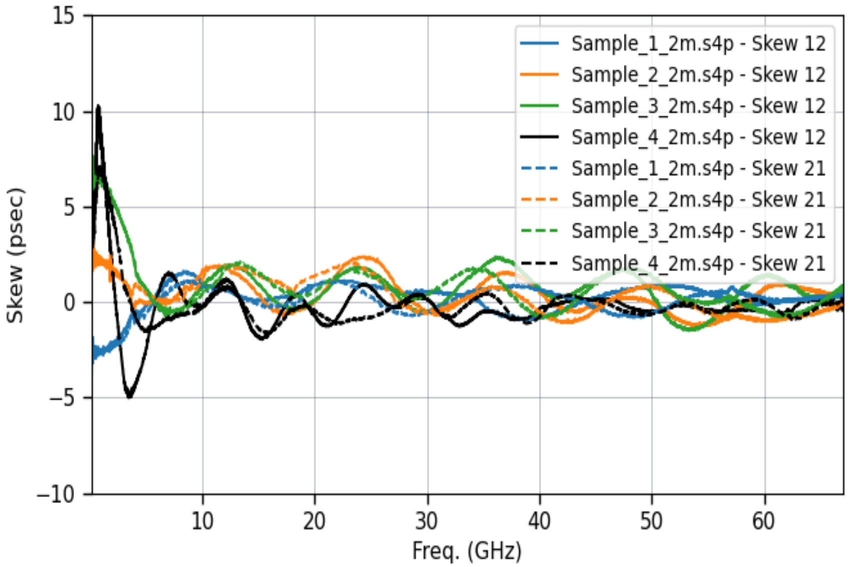
- D. Nozadze, et al., “Intra-Pair Skew Propagation Graph (ISPG): An Analytical Model for Cascaded Channels”, submitted to *IEEE Transactions on Signal and Power Integrity*
- D. Nozadze, et al., “Analytical Derivation of P/N Skews in Coupled Channels: Impact on 400G PAM6 SerDes", DesignCon 2026

Measured skews

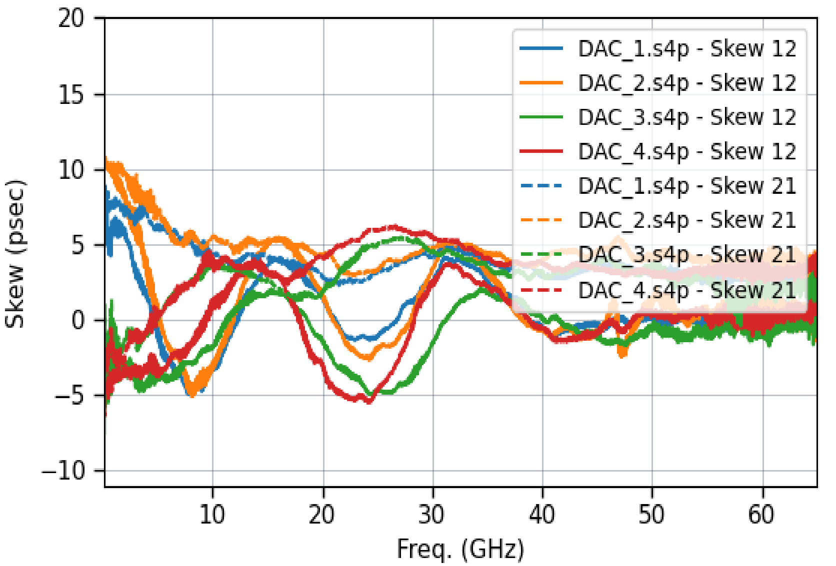
Stripline-PCB



Bulk cables



DAC cables



Skew is **constant**– no frequency dependence

Skew **attenuates very fast**– could be shifted overall vertically up/down because of skew introduced by measurements

Skew **may not attenuate** – complex mixture of Time Delay skew and cable skew- includes connectors and MCB’s

Connector-cable termination or/and paddle card introduces large skew?!

Takeaways from conventional methods

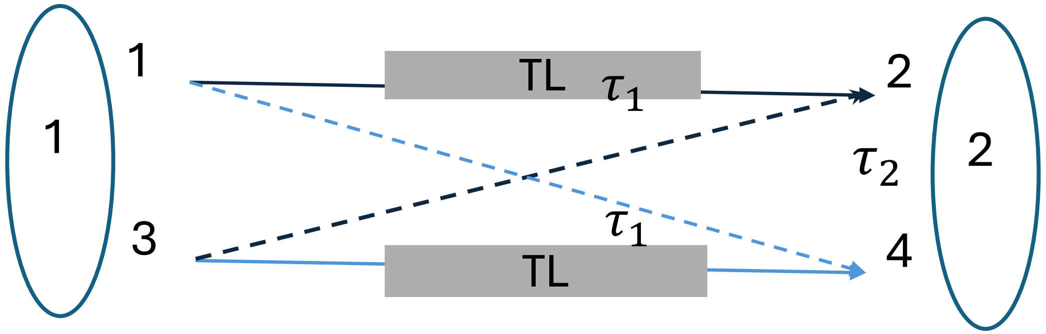
- Time-domain method are unreliable for coupled interconnects because skew differs across voltage levels

- Frequency domain conventional method have issue with reciprocity/symmetry
  - It is problematic if a channel passes the skew specification from one direction but fails from the other, since skew impact is inherently reciprocal

- It is preferable to assess skew impact using a reciprocal parameter to which the SerDes receiver is sensitive; differential insertion loss is such a parameter

De-skewing S-parameters

Coupled TLs



τ_1 - skew between through and forward coupling S−params

τ_2 - skew between differential signal traveling from diff port 1 to single ended port 2 and port 4 (assumed τ_1 skew is already de-skewed)

Numerically solve for τ_1, τ_2 subject to zero-skew conditions $t_{skew_{2,1}}(f) = t_{skew_{1,2}}(f) = 0$

$$\tau_2 + arctan\left(\frac{\frac{Im(z_1)}{Re(z_1)} - \frac{Im(z_2)}{Re(z_2)}}{1+\frac{Im(z_1)}{Re(z_1)}\frac{Im(z_2)}{Re(z_2)}}\right) = 0,$$

$$\tau_1 + arctan\left(\frac{\frac{Im(z_3)}{Re(z_3)} - \frac{Im(z_4)}{Re(z_4)}}{1+\frac{Im(z_3)}{Re(z_3)}\frac{Im(z_4)}{Re(z_4)}}\right) = 0,$$

where

$$z_1 = S_{21}e^{-i\tau_1} - S_{23}, \quad z_2 = S_{43} - S_{41}e^{-i\tau_1}$$
$$z_3 = S_{12}e^{-i\tau_2} - S_{14}, \quad z_4 = S_{34} - S_{32}e^{-i\tau_2}$$

De-skewed differential Insertion loss is

τ_2

$$\left|S^0_{dd21}\right| = 0.5\left|\overbrace{S_{21}e^{-i\tau_1 - i\tau_2} - S_{23}e^{-i\tau_2}} + \overbrace{S_{43} - S_{41}e^{-i\tau_1}}\right|$$

$S_{21}\ vs\ \ S_{23}\!:\ \tau_1$ $\qquad$ $S_{43}\ vs\ \ S_{41}\!:\ \tau_1$

- D. Nozadze, et al., "Practical Approaches to Quantifying Intra-Pair Skew Impact via Insertion Loss Deviation," *IEEE Transactions on Signal and Power Integrity*
- D. Nozadze, et al., “Intra-Pair Skew Propagation Graph (ISPG): An Analytical Model for Cascaded Channels” submitted to *IEEE Transactions on Signal and Power Integrity*

Skew Metric: Skew-Induced Insertion Loss Deviation (SILD)

Skew-induced Insertion Loss Deviation (SILD)

$$SILD = IL(skew = 0)\text{-}IL\,(skew \neq 0)$$

$$FOM_{SILD} = \left(\frac{1}{N}\sum_{i=1}^{N} W_i * SILD_i^2\right)^{1/2}$$

Option 1

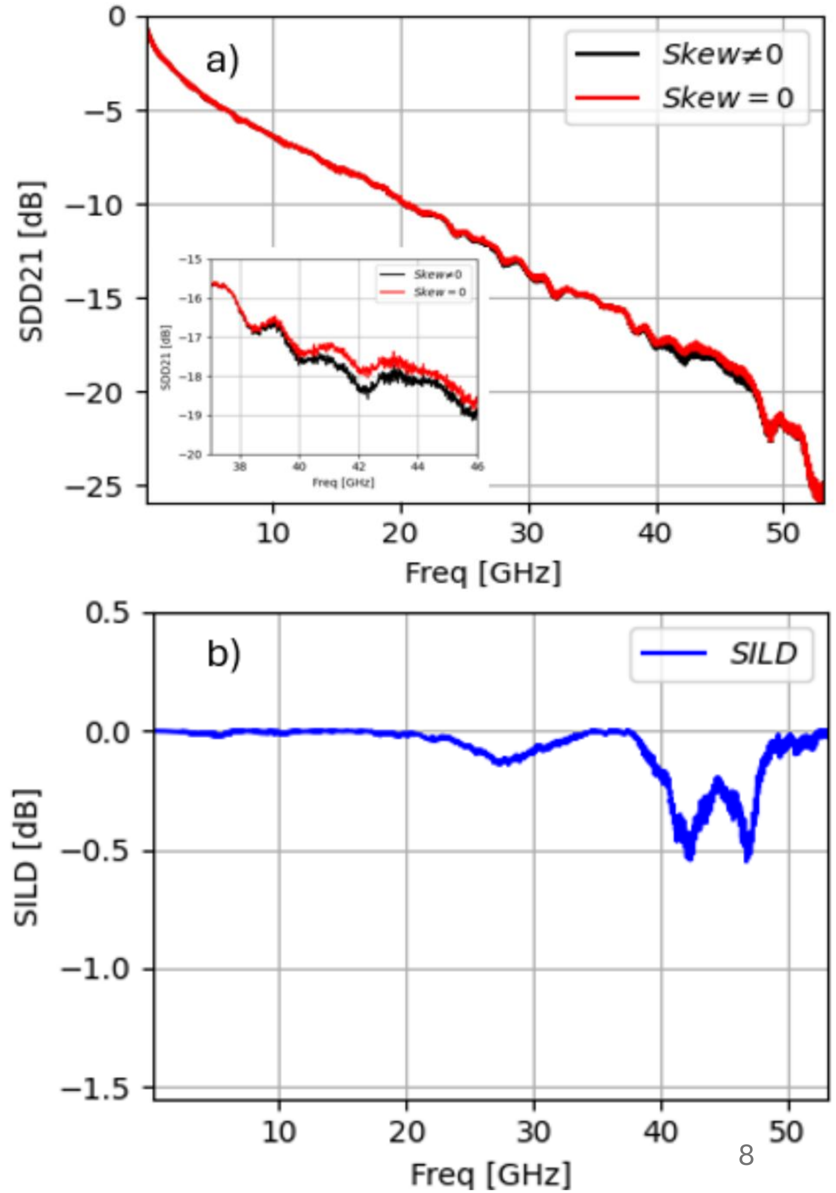
$$W_i = sinc\left(\frac{f_i}{f_b}\right)^2 \frac{1}{1+\left(\frac{f_i}{f_t}\right)^4}\frac{1}{1+\left(\frac{f_i}{f_r}\right)^8}$$

The *W* weight function (IEEE 802.3) uses f_b (signal rate), f_r (receiver 3 dB bandwidth), and f_t (transmit filter 3 dB bandwidth), with the sum up to the maximum frequency up to Nyquist.

Option 2

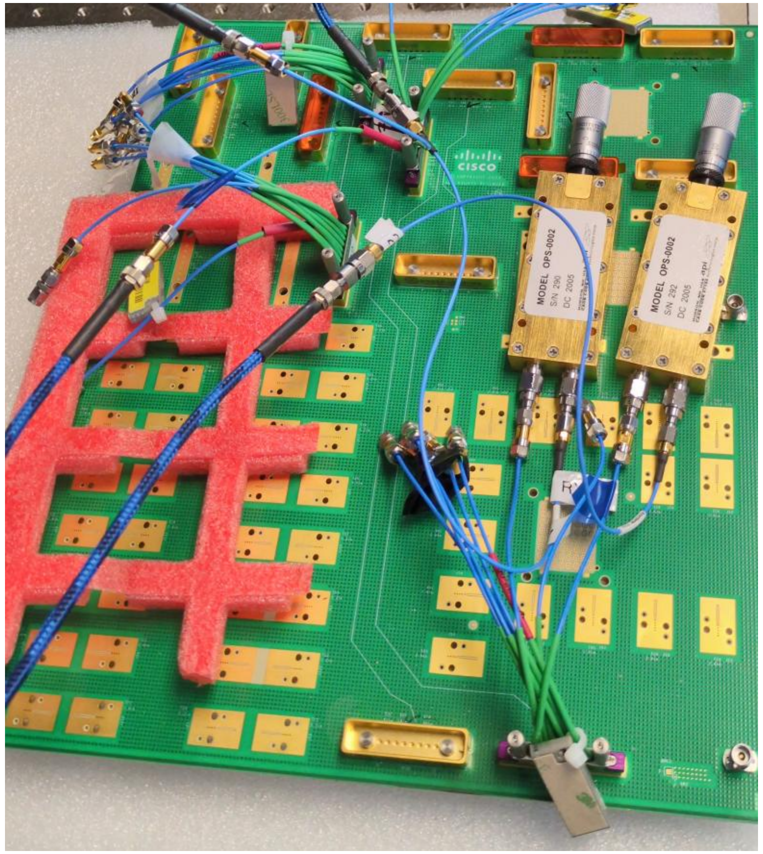
W=1 and integrate up to Nyquist frequency

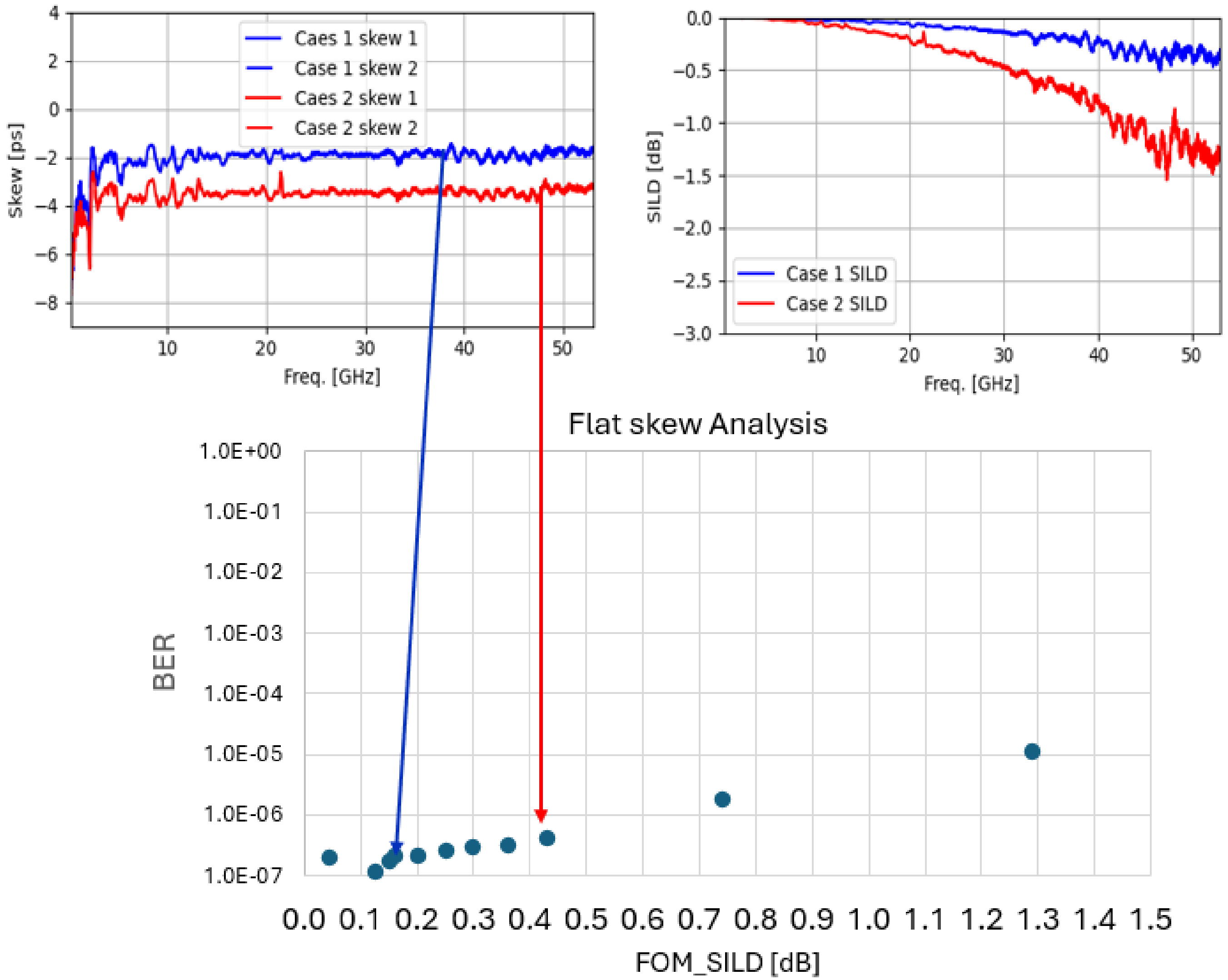
Measured DAC cable



FOM_SILD vs BER measurements using 224G Serdes – phase shifter

P/N skew varied by adjusting phase shifters

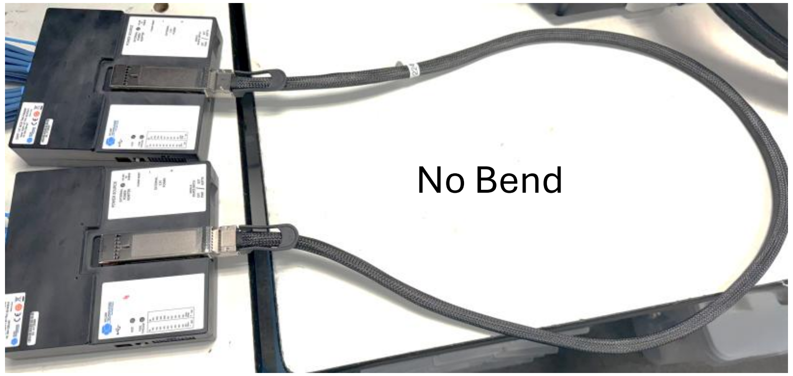


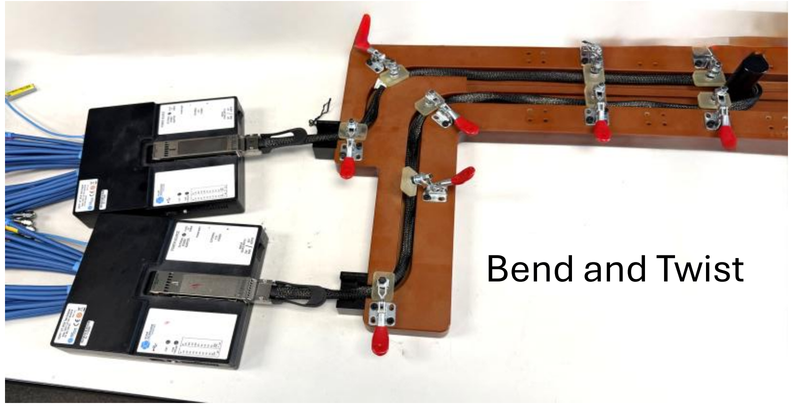


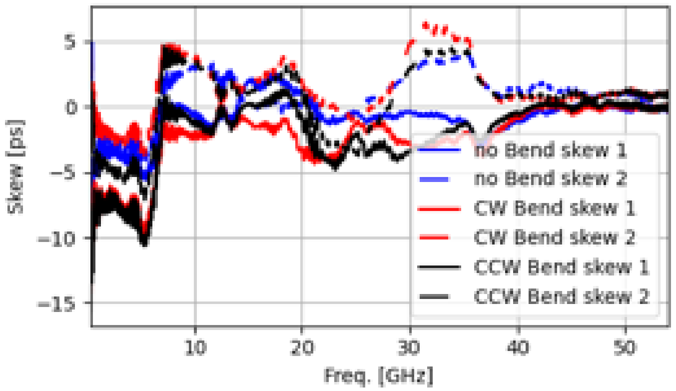
** Skew 1 and Skew 2 refer to skew measured from left to right and right to left, respectively*

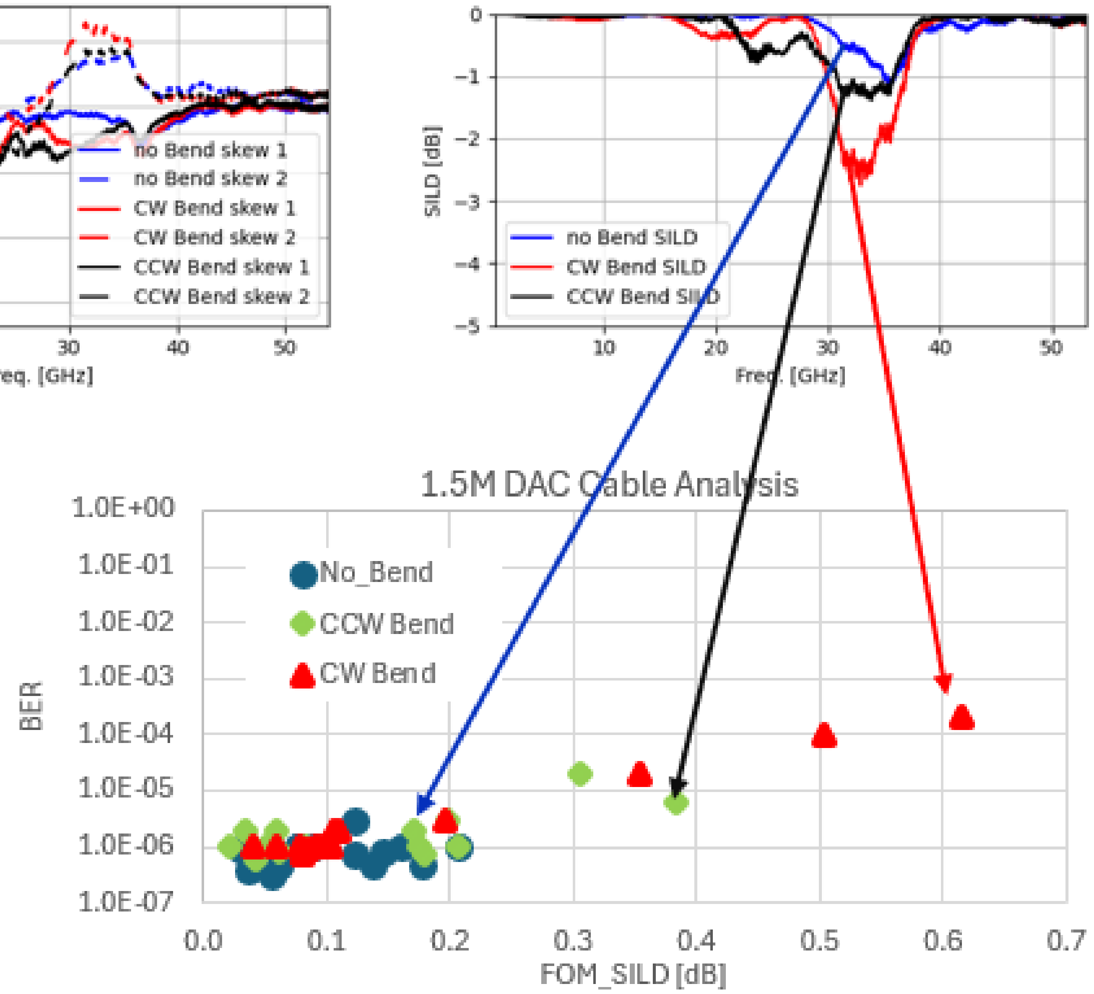
Up to a FOM_SILD of 0.3 dB, there is no significant BER degradation

FOM_SILD vs BER measurements using 224G Serdes – 1.5M DAC cable





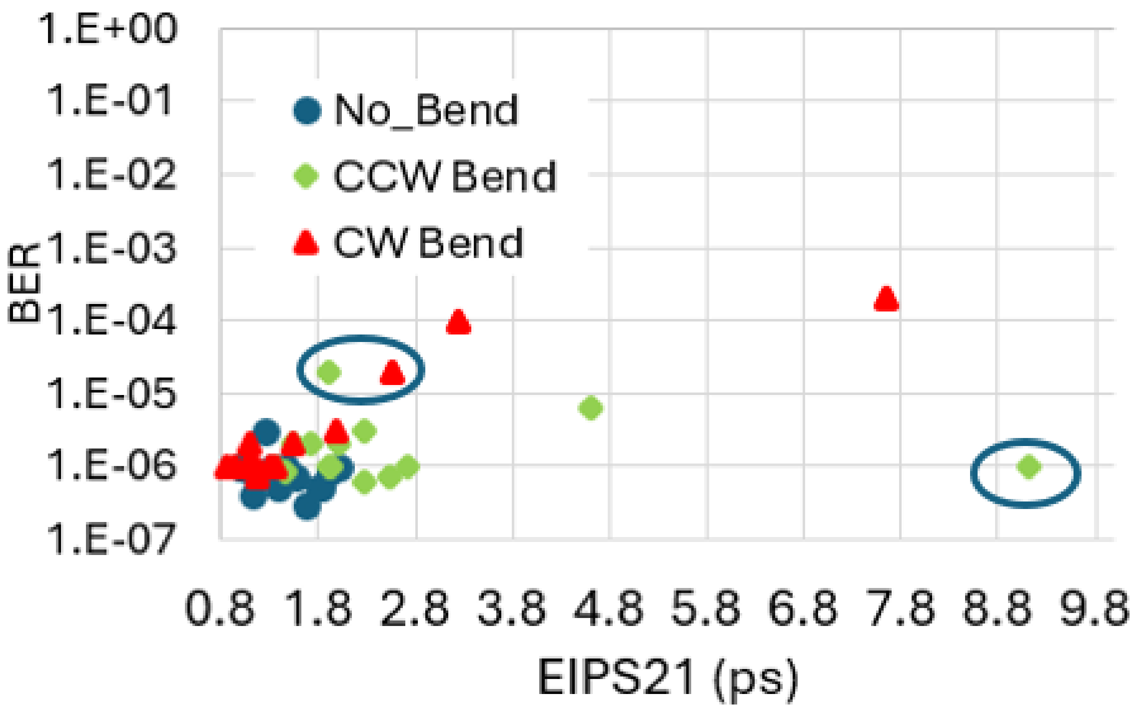


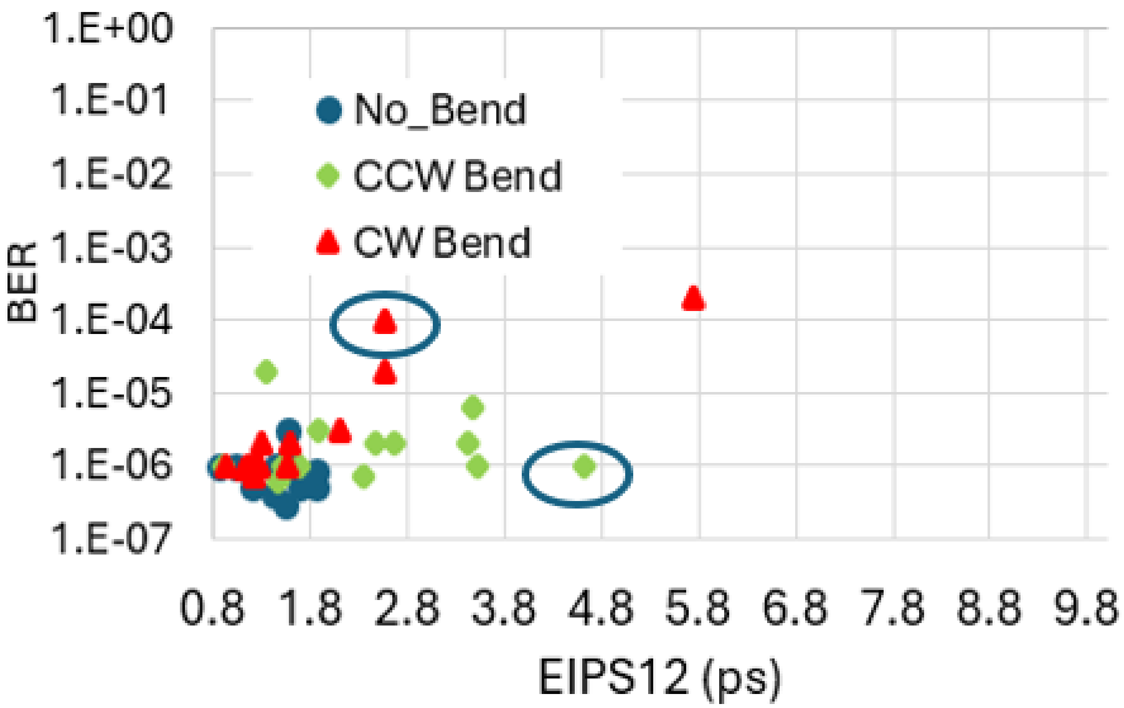


Skew 1 and Skew 2 refer to skew measured from left to right and right to left, respectively

Cable Tests:
- No Bend (regular cable routing)
- Bend and twist 360° clockwise
- Bend and twist 360° counterclockwise

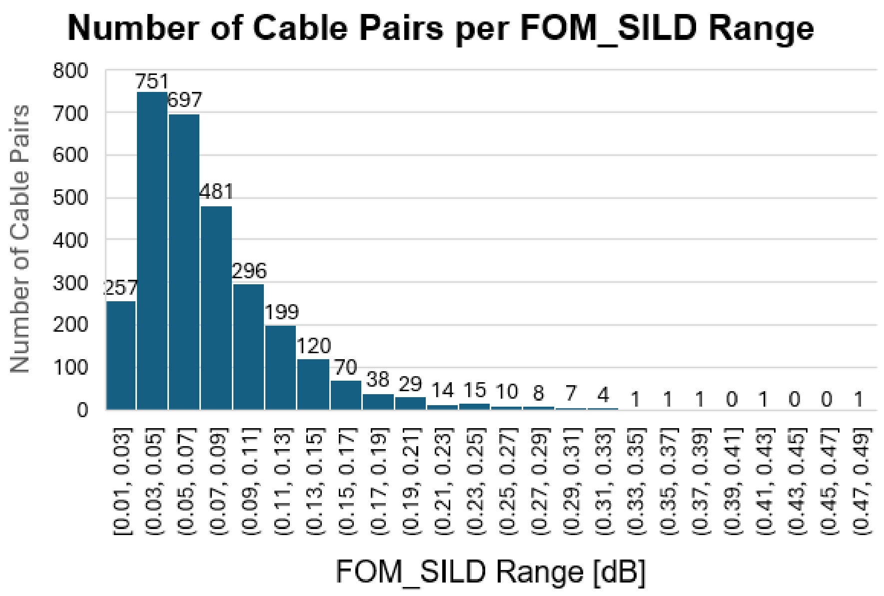
BER as a function of the left-to-right and right-to-left EIPS values

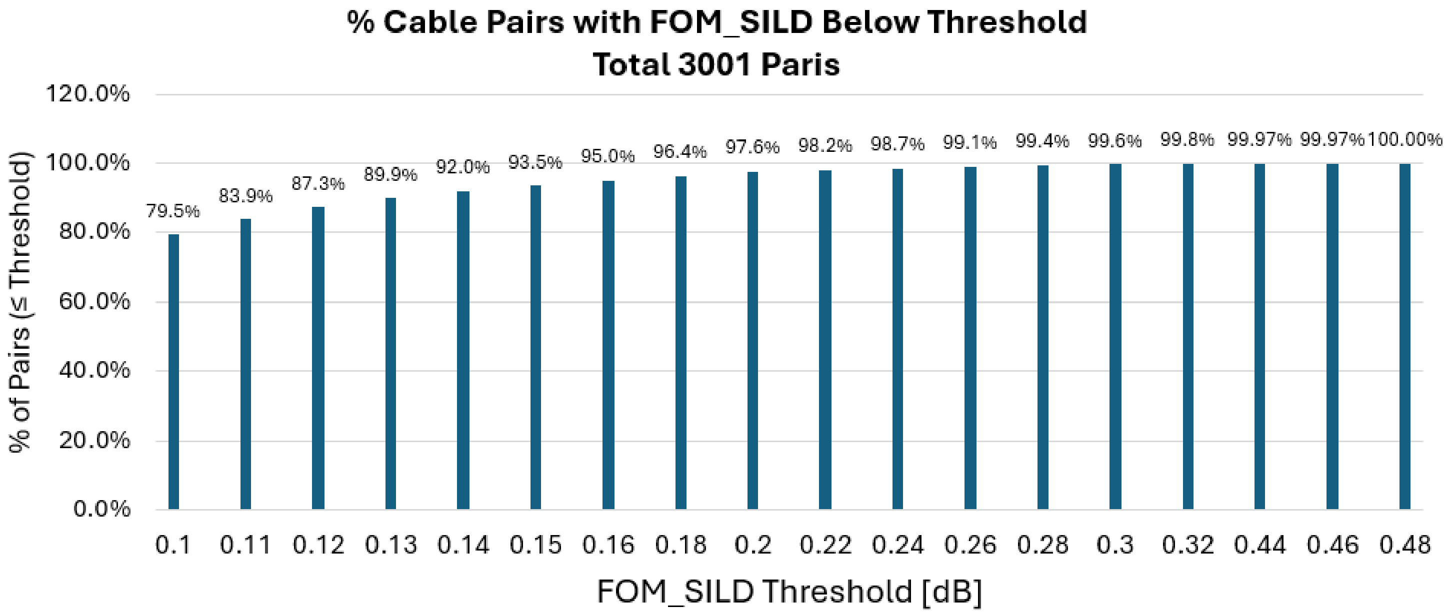




- EIPS21 and EIPS12 are for left to right and right to left signal propagation respectively
- EIPS values do not consistently reflect the BER performance trend
- Some cases, for high values of EIPS BER and SerDes performance is not impacted or vice versa

Distribution of FOM_SILDs – DAC cable measurements





Most DAC pairs exhibit FOM_SILD below 0.1 dB

Conclusions

- Introduced new SILD intra-pair skew metric is reciprocal. It is the same for left-to-right and right-to-left signal propagation
- FOM_SILD correlates well with BER trends
- Intra-pair skew with a FOM_SILD of up to 0.3 dB has little impact on BER
- Contact us for a free Python script to calculate SILD and FOM_SILD
- Once 400G channels are defined and measurement data are available, acceptable FOM_SILD limits should be established for each channel segment, i.e., including packages, PCBs, CPC cables, and DAC cables.

Thank you!