Achieving 224 Gbps PAM4: **Interconnect Challenges, Advantages, and Solutions**

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Abstract

Delivering 224 Gbps PAM4 signals will require careful analysis of signal integrity and thermal effects, as well as the development of enabling technologies and new methodologies to achieve clean signals at these data rates. Industry-leading experts are focused on this topic, developing new technologies as well as products to handle high-speed data, and engaging in interoperability demonstrations at tradeshows, demonstrations of new products for 224 Gbps PAM4 systems, and numerous ongoing panel and webinar discussions. Early designs suggest that several technologies developed for 112 Gbps can be applied to some 224 Gbps systems, but changes will also be necessary in order to address signal integrity and thermal concerns across the board.

Despite the lack of an approved 224 Gbps specification, a selection of silicon and interconnects are already available for testing and transporting this next-generation of rapidly moving signals. This paper explains how 224 Gbps PAM4 systems must differ from their 112 Gbps counterparts in terms of interconnects, what technologies and methodologies could enable new 224 Gbps PAM4 solutions, and what's available now for test and evaluation.

Integration leads to Innovation

Samtec is structured like no other company in the interconnect industry: we work in a fully integrated capacity that enables true collaboration. The result is innovative solutions and effective strategies supporting optimization of the entire signal channel.

For more information contact SIG@samtec.com

Challenges for Achieving 224 Gbps

At the heart of the 224 Gbps PAM4 interconnect design challenge are the issues of thermal dissipation, insertion loss, crosstalk, and skew.

As the data rate increases, the power consumption of the silicon increases. As a result, the size of the heat sinks must grow with each new generation. Solutions for 112 Gbps included low profile connectors (such as the Samtec Si-Fly™ LP Cable System) to fit under the heat sink (optimized for footprint, not performance).

112 Gbps PAM4 designs frequently use near chip connectors (NCCs)—connectors placed next to the ASIC and connected to twinax which links to the front panel, back panel, or mid-board. This approach reduces the overall loss of the channel [1,2]. Figure 1 shows how Samtec Flyover® systems can improve insertion loss by routing signals via ultra-low skew twinax cable versus through lossy PCB. This Flyover approach is expected to also be well suited for many, but not all, 224 Gbps PAM4 system designs.

Insertion Loss Per Inch at 56 GHz		
ModelName	Width (mil)	IL (dB)
Synth_Tline_width4p0_length1in	4	-1.72
Synth_Tline_width5p0_length1in	5	-1.54
Synth_Tline_width6p0_length1in	6	-1.4
Synth_Tline_width6p4_length1in	6.4	-1.35
Synth_Tline_width7p0_length1in	7	-1.29
Synth_Tline_width8p0_length1in	8	-1.2
Synth_Tline_width9p0_length1in	9	-1.14
Flyover TwinAx 34 AWG	34 AWG	-0.396

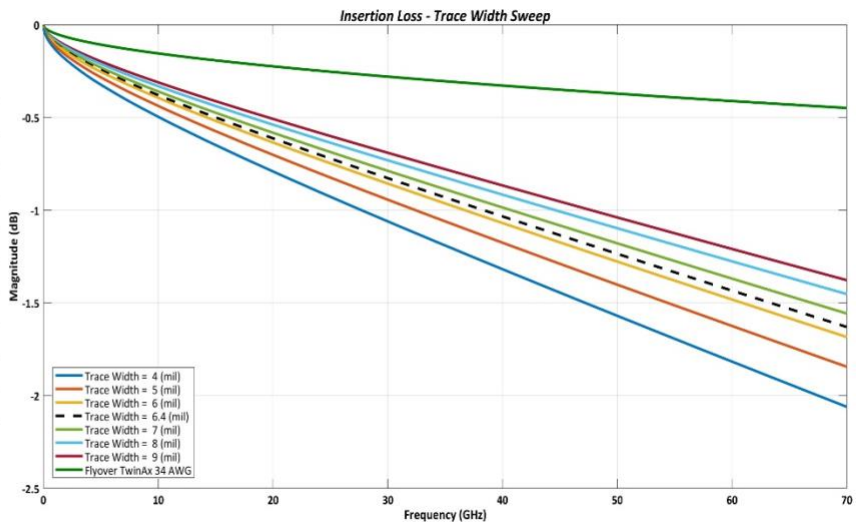


Figure 1: Cable has better insertion loss characteristics than a PCB trace, so cable is the expected solution for 224 Gbps PAM4. This graph shows insertion loss (Y axis) plotted against data rate frequency (X axis). The numerous colored lines indicate the performance of various widths of PCB traces at 1 inch of length while the green line tracks an inch of Samtec Flyover system using 34 AWG twinax cable. The graph shows better insertion loss for cables vs PCBs.

As data rate increases, the loss per inch increases significantly [1,2]. Traditional connections through the BGA ball and PCB will be treacherous to 224 Gbps PAM4 signaling. Even the loss associated with a PCB trace as short as 1.5 inches (as used in both of the 112 Gbps Flyover systems mentioned above) might still be too much for some new 224 Gbps systems. So, what can be done?

Connectors in Package

If the trace becomes an issue, can we eliminate it? Actually, this can be achieved with co-packaged connectivity (CPCs)—putting the connectors on the chip package so there is no trace on the PCB (see Figure 2). Samtec has been developing this technology for years, initially for 56 Gbps and now for 224 Gbps PAM4 [3].

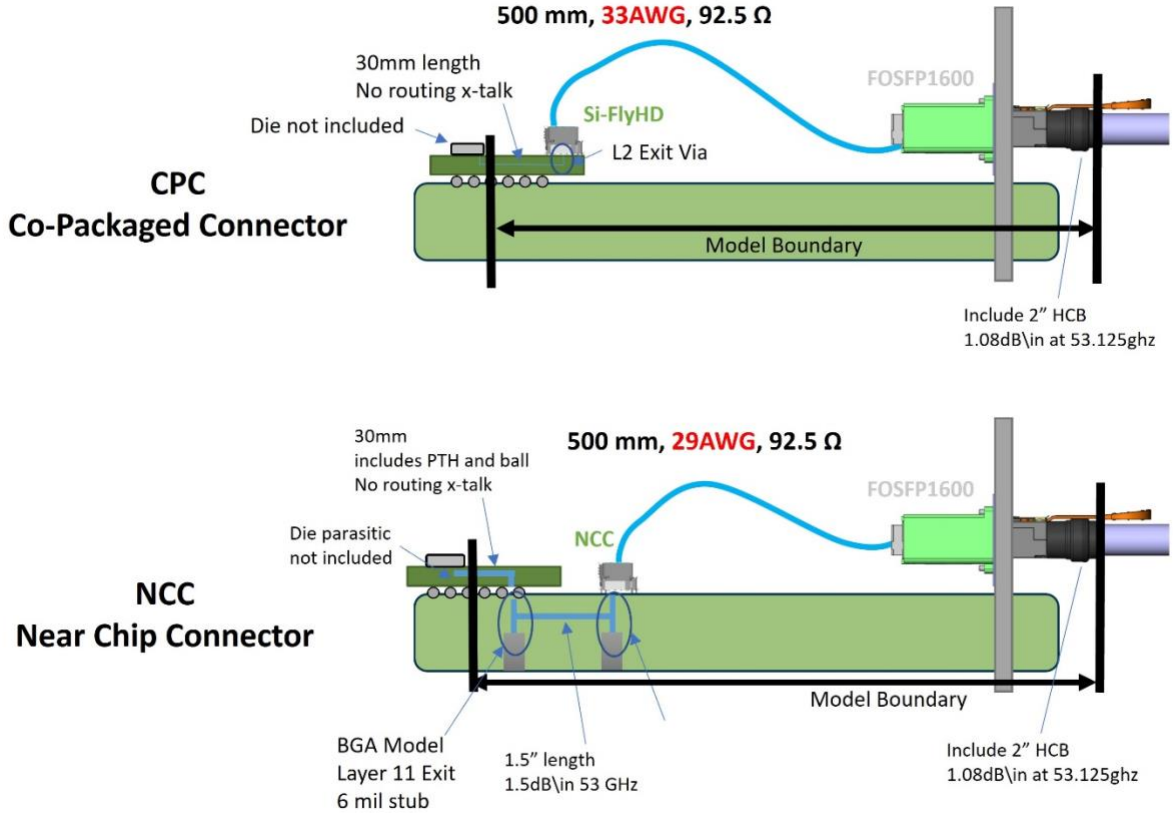


Figure 2: A co-packaged connector (CPC) design compared to a near-chip connector (NCC). Note that NCC demonstrates loss of 1.5dB/in at 53 GHz due to the 1.5" transmission line; this loss is avoided in the CPC.

New Connectors for 224 Gbps Systems

The Samtec Si-Fly HD® connector can either be placed adjacent to the ASIC or placed on the chip package itself (see Figure 3). In this CPC configuration, there is no trace through the PCB, and no subsequent "loss per inch." In the above example, this would save 1.5 dB of loss, which can make the difference for a successful 224 Gbps PAM4 system.

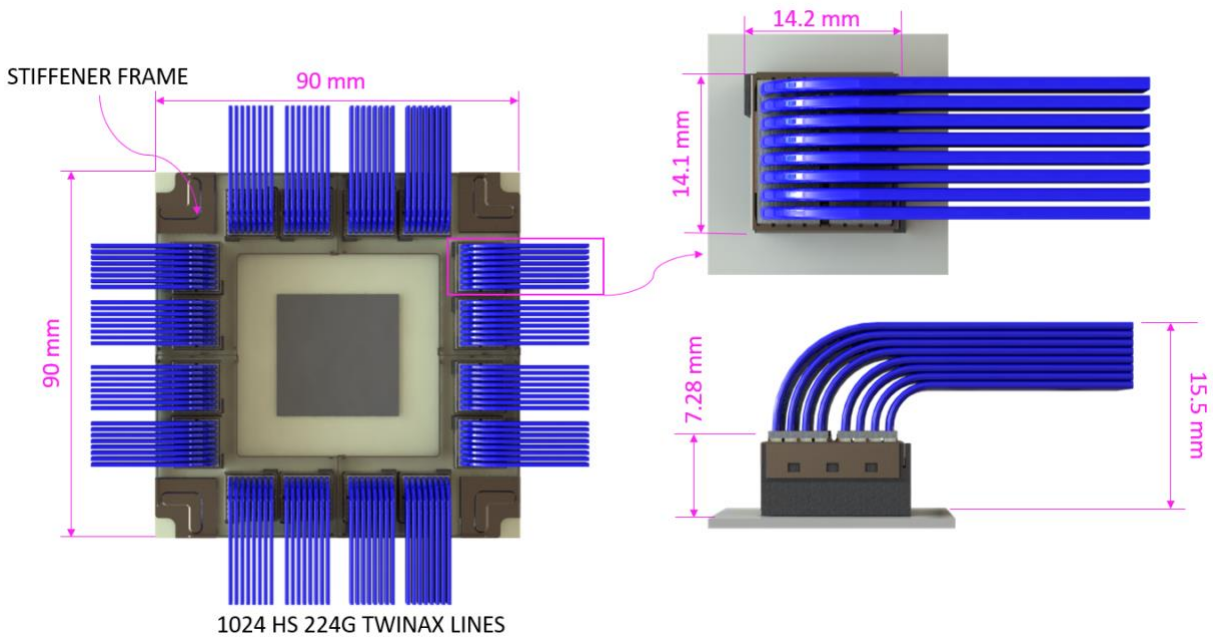


Figure 3: Samtec Si-Fly HD connector measures 14 mm² while supporting 207 differential pairs per square inch (shown with Eye Speed® Air™ cable).

Silicon die is placed on a chip substrate, which is the most expensive real estate in the system, so any connectors built into the chip package must be extremely small. The Si-Fly HD connector measures 14 mm², and it can support 64 differential pairs (64 twinax cables). The previous generation of connector, the Samtec Accelerate HP®, was the industry's highest density 112 Gbps connector system measuring 15x30 mm to support 64 DPs.

Processing is different for CPCs, as they need to be soldered onto the chip substrate. Figure 4 demonstrates the assembly process. The Si-Fly HD uses Samtec's new solder paste technology, a non-solder ball design that improves uniformity, repeatability, and coplanarity [4].

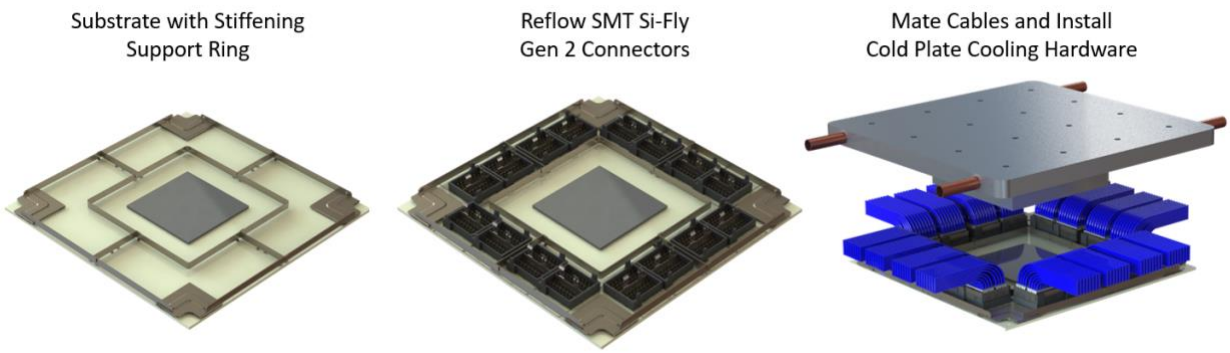


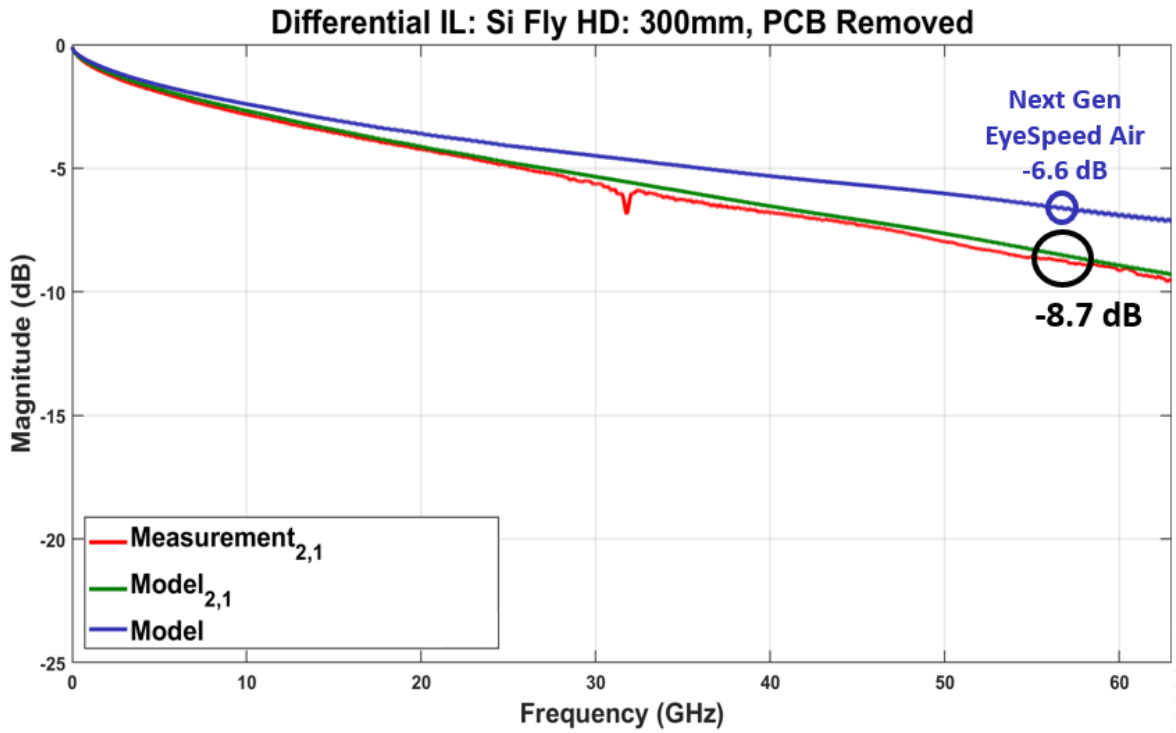
Figure 4: Si-Fly HD processing requires the non-solder ball connectors to be attached to a supported substrate. Cables are then plugged directly into the chip package. Specific solder, stiffener, and assembly process varies by application.

In addition to the processing change, on-chip vertical connectors increase the overall height of the package, which means the cooling system needs to be reimagined. Traditionally, ASIC designs use air cooled systems, with a heat sink equipped with fins. One way to improve cooling for 224 Gbps PAM4 designs is to use liquid-cooled, cool plate heat sinks instead.

Si-Fly HD Performance

While the industry standards groups continue to mature minimum SERDES capability, Samtec tests its next-generation 224 Gbps PAM4 interconnect solutions against channel models from industry standards groups such as IEEE. Initial measurements performed on the Samtec Si-Fly HD exceeded expectations, showing a significant improvement in insertion loss as compared to a NCC in a similar implementation.

In fact, connectivity from the top of the package offers a compelling reflection and insertion loss advantage. The measurements in Figure 5a of a Si-Fly HD connector show excellent measured insertion loss of -8.7dB, with expectation of -6.6dB when using EyeSpeed Air cable. Additionally, return loss is measured at -27dB. (Figure 5b).



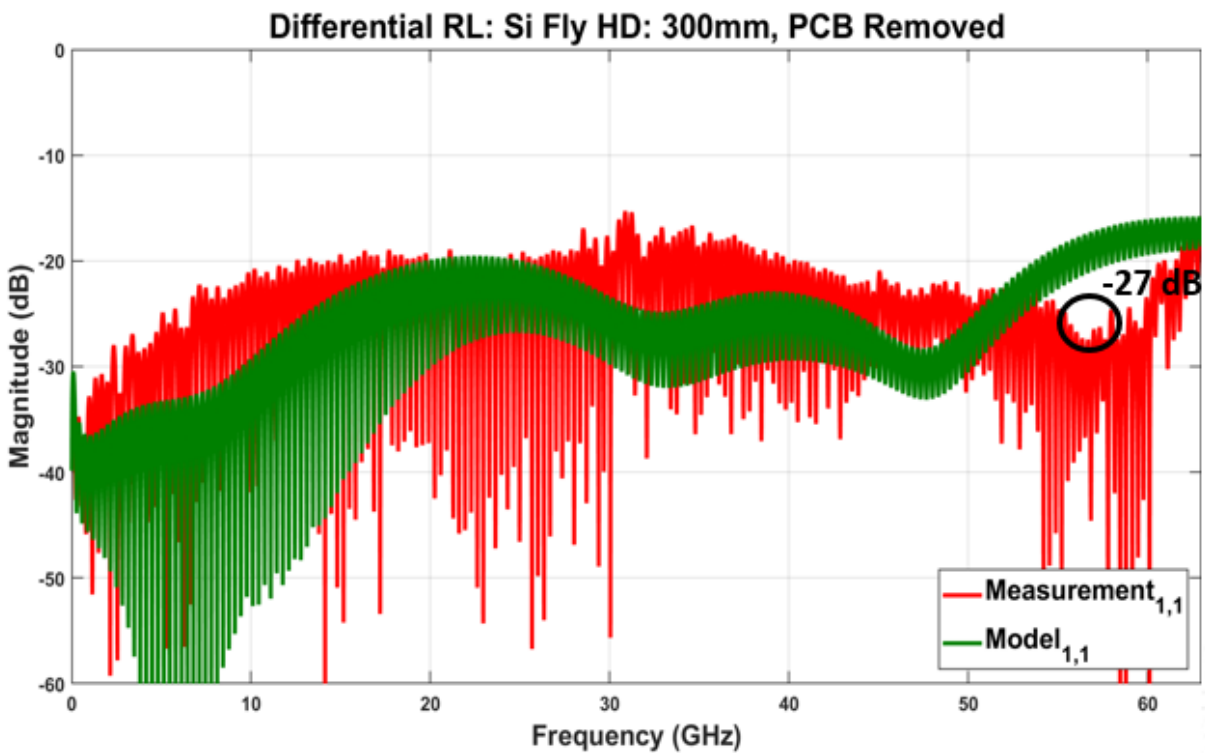
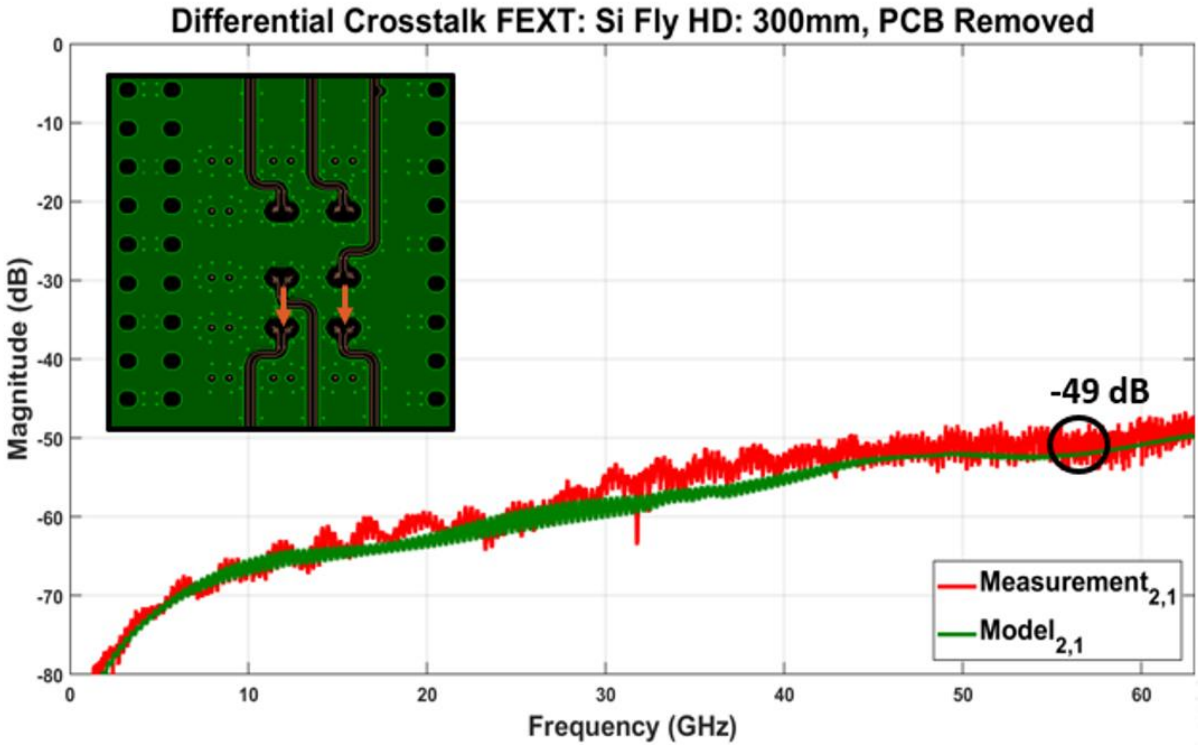


Figure 5a (top): Differential insertion loss for the Si-Fly HD CPC (with the PCB removed) at 224 Gbps PAM4. 5b (bottom): Differential return loss for the Si-Fly HD, measured versus model.

At 112 Gbps and 224 Gbps, insertion loss is a critical consideration. But one of the most difficult electrical performance criteria is crosstalk. When driven to ultra-high density (64 DPs in 14x14 mm), crosstalk usually increases due to the proximity between pins. Fortunately, measurements performed on the new Si-Fly HD show impressive crosstalk performance. Figure 6 shows measurements on the Si-Fly HD for differential FEXT (top) of -49 dB and NEXT of -53 dB up to 55 GHz (bottom).



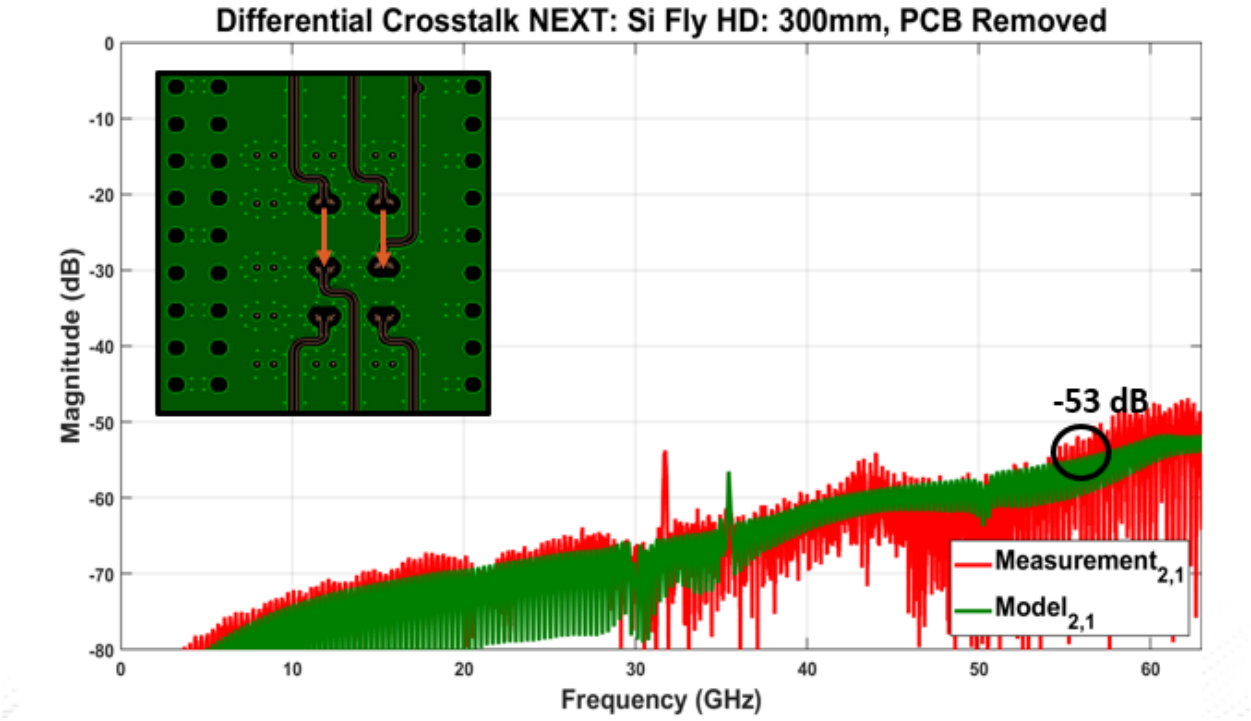


Figure 6: Si-Fly HD demonstrates extremely low crosstalk, and correlates well with model expectations.

Skew: Issues and Avoidance

Skew is another design concern for 224 Gbps PAM4, and its impact is expected to be significant. Skew can manifest as delay differences within a differential pair (due to physical and electrical construction in the channel). Asymmetry in the compliment trace (e.g. n or p) during the construction of a differential pair, or differences in the driving signals, will also contribute to skew like distortion. The design of the coupling and the amount of reflection determines the significance of the impact [5],[6].

Samtec has engaged in significant R&D as regards the impact of skew, comparing the effect in both Flyover twinax and PCB traces [5],[7]. Fortunately, tightly coupled, co-extruded twinax cable has superior skew (as well as impedance and insertion loss stability) even under realistic bending conditions that allows skew to be completely under the implementer's control. This is in stark contrast to other constructions of twinax cable. Long PCB routes are also further challenged and have step trade-off and limitations on how well skew can be considered.

For 224 Gbps PAM4 systems, controlling skew will be a key to predictable performance, particularly because one unit interval (the width of a single bit) is approximately 9 ps at 224 Gbps PAM4. CPC and NCC Flyover can be used by system designers to reduce interconnect skew to manageable levels [7].

Achieving 224 Gbps with Samtec

As the needs for 224 Gbps PAM4 evolve, Samtec continues to develop both 112 Gbps and 224 Gbps products in alignment with evolving models from IEEE and other standards bodies. Enabling technologies, such as the advanced solder paste technology mentioned above [4], will be critical to achieve the next level of signal speeds. At Samtec, other recently released enabling technologies for 224 Gbps PAM4 include the next-generation Samtec Bulls Eye® test and measurement connector (BE90) based on the successful BE70 technology, which is designed to test chips and systems with 224 Gbps data rates (Figure 7, left). The 224 Gbps family of products, such as the OSFP Flyover assembly and Si-Fly HD mentioned above, also deploy the new Samtec high-speed cable (Eye Speed® Air™ 224 Gbps), which features foamed dielectric twinax and the industry's best signal integrity performance with a 33 AWG (Figure 7, right).

The good news for system designers is there is time to get 224 Gbps PAM4 design right. Some early products that support 224 Gbps PAM4 are available for design evaluation, customization, and optimization. In addition to the Si-Fly HD, Samtec offers the OSFP 224 Gbps PAM4 Flyover® assembly (Figure 7, center) which supports up to 1.6 Tbps PAM4 aggregate data rate using Samtec Flyover cable technology and features direct-attach contacts for optimized signal integrity.

Figure 7: In addition to the Si-Fly HD, Samtec's products for 224 Gbps PAM4 designs include the Bulls Eye® test point system, Flyover® OSFP 224 Gbps PAM4, and Eye Speed® Air™ 224 Gbps.

Additional 224 Gbps PAM4 products include the Si-Fly BP extreme performance backplane system supporting 146 differential pairs per square inch and offering cable to cable connectivity. In addition, the Si-Fly MZ high-density board to board or on-package mezzanine design supports 64 pairs in a 14mm^2 low-profile design.
Contact Samtec today to find interconnect solutions that are ready for your next-generation design needs [8,9].

Resources

[1] Gore, Brandon. Next-Generation PCB Loss Analysis | Signal Integrity Journal, June 2023.
[2] Josephson, Andrew, et. al**.** Selecting a Backplane: PCB vs. Cable for High-Speed Designs | Signal Integrity Journal. May 2023.
[3] Samtec - Direct Connect to IC Package on Vimeo
[4] Huffman, Robbie & David Decker. Improved Solder Joint Connectivity for High-Density Interconnect Applications. May 2023.
[5] D'Silva, Hansel, Richard Mellitz, Steve Krooswyk, Adam Gregory, Beomtaek Lee, Amit Kumar, & Howard Heck, "Comparing the Different Metrics of Intra-Pair Skew in Tracking Channel Performance." DesignCon 2024.
[6] OIF-FD-CEI-224G-01.0.pdf (oiforum.com), p. 18.
[7] Gore, B., McMorrow, S. (2017, Sept). Vehicle for Insitu Glass Fabric Characterization, [Invited Talk]. EDI CON USA 2017, Boston, Ma
[8] Samtec 224 Gbps Products
[9] Twinax Cables, Samtec Flyover® Cable Systems | System Optimization | Samtec