Achieve 2ps/inch skew in a differential pair for 112Gbps PAM4 Design

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TestConX中国 China

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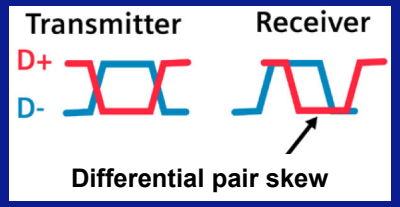
Challenge: Skew could kill 112Gbps PAM4

- Differential pair skew to insertion loss



$$S_{dd12} = \frac{|IL|}{2}\left(e^{j\theta_{13}} + e^{j\theta_{24}}\right) - \frac{|X|}{2}\left(e^{j\theta_{14}} + e^{j\theta_{23}}\right)$$

$|X| \ll |IL|$

$$S_{dd12} = \frac{|IL|}{2}\left(e^{j\theta_{13}} + e^{j\theta_{24}}\right)$$

$\theta_{13} = \theta + \frac{\Delta\theta}{2}$

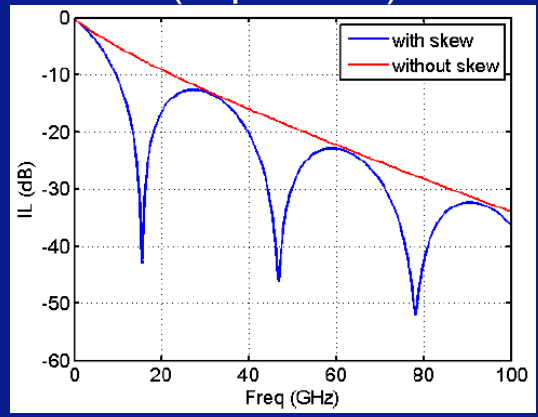
$\theta_{24} = \theta - \frac{\Delta\theta}{2}$

Using Euler's equation & trigonometric identities

$$S_{dd12} = |IL|\cos\left(\frac{\Delta\theta}{2}\right)e^{j\theta}$$

$\Delta\theta$ *represent skew in angle*

Insertion Loss (30ps skew)



Data Source: Reference 1.

Achieve 2ps/inch skew in a differential pair for 112Gbps PAM4 Design

Challenge: Skew could kill 112Gbps PAM4

- ATE load-board design key request
  - 112Gbps PAM4 loopback (DUT tx → DUT rx), UI = 17.86ps
  - 2.5inch trace length to get around -10dB insertion loss
  - Diff pair skew < 10ps (experience value) ★ ★ ★

- Sources of skew
  - Asymmetries in differential signal routing (length match)
  - Fiber weave effect ★ ★ ★
  - PCB manufacturing limitations (like via stub asymmetry)

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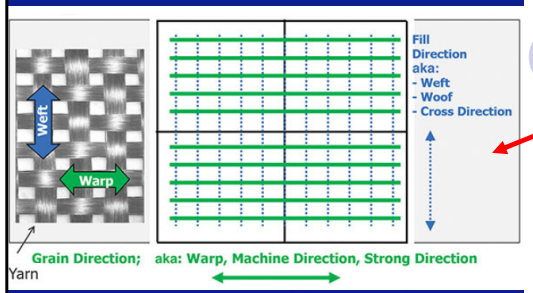
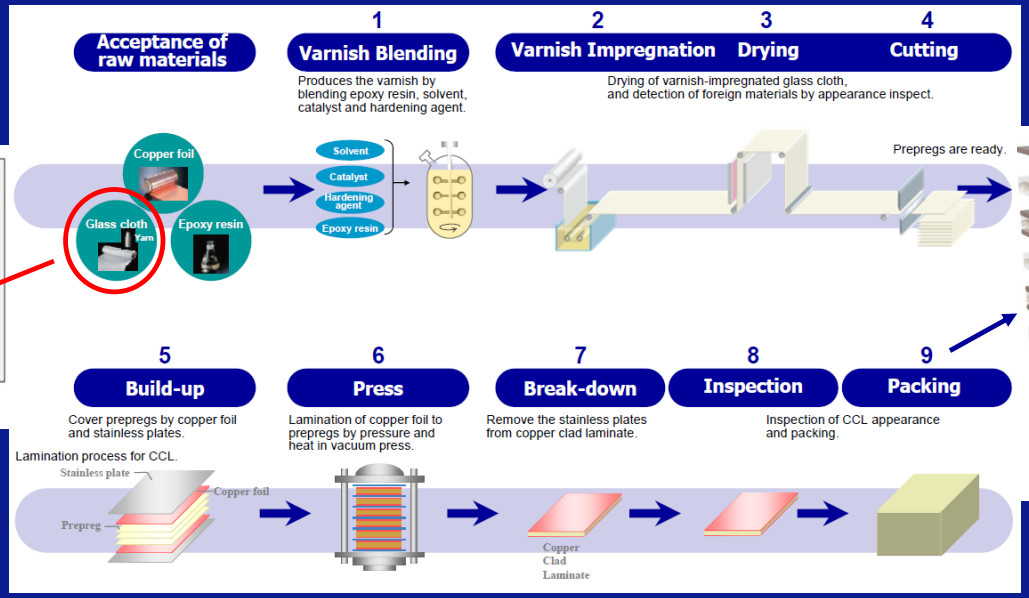
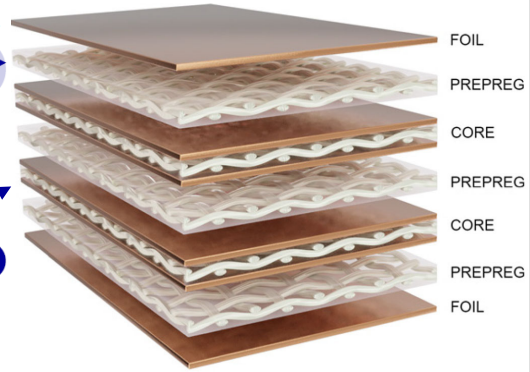
Root cause: fiber weave skew

- Fiber weave in PCB material







Data Source: Reference 4.

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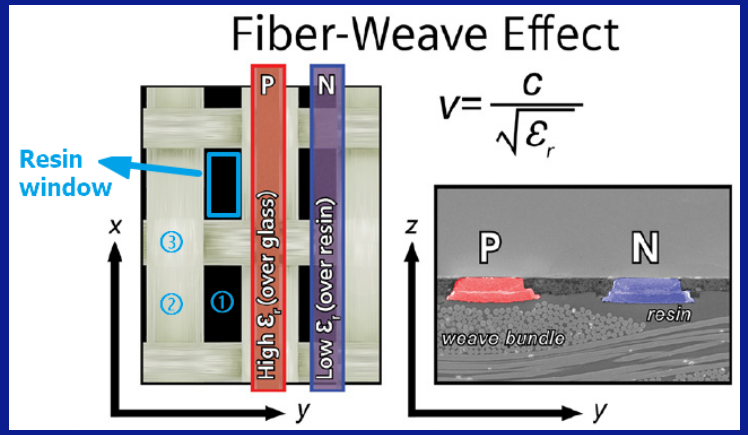
Root cause: fiber weave skew

- Fiber weave effect



Data Source: Reference 4.

  - dk(ε_r) of glass ~6
  - dk(ε_r) of resin ~4
  - Propagation delay could be different between P&N
  - Typical diff pair skew: 10ps ~ 100ps

- Resin window example

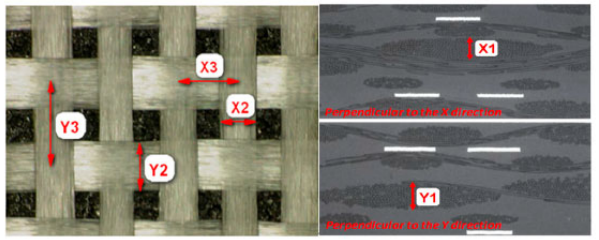


Figure 3. Photos to illustrate fiber weave bundle parameters.

Table 1. Measurement results of fiber weave bundle parameters.

Style	Measurement Results (mil)					
	X1	X2	X3	Y1	Y2	Y3
1035	0.82	8.8	14.2	0.78	12.4	13.7
1080	1.6	8.2	17.0	1.1	12.1	22.4
1078	1.4	14.2	16.2	1.0	17.6	17.8
3313	1.9	13.1	16.2	1.5	11.0	16.3
2116	2.2	14.1	17.2	2.0	15.5	17.3

Data Source: Reference 2.

  - Resin window size varies among difference glass style
  - In most cases, Resin window size X3-X2 ≠ Y3-Y2

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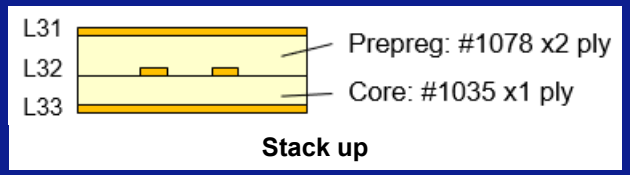
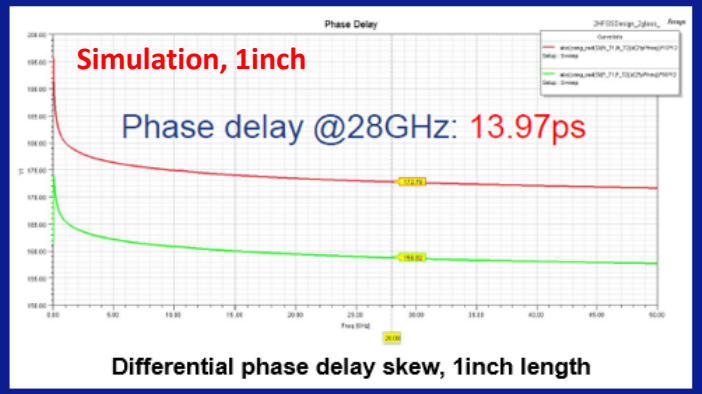
Root cause: fiber weave skew

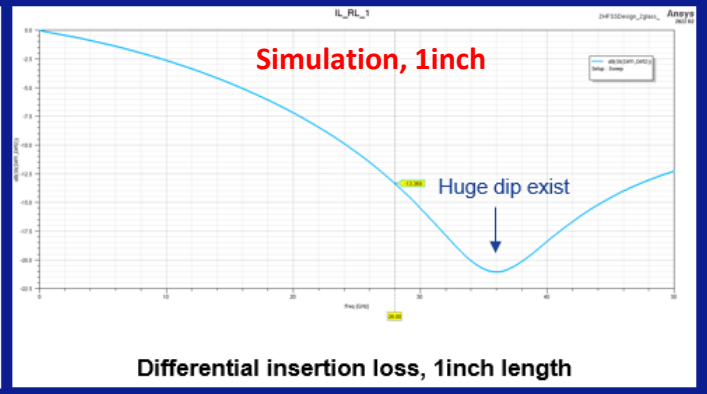
- If fiber weave effect is not considered
  - Length matching between P&N < 1mil
  - Same via stub length
  - Traces are routed in either X direction or Y direction
  - Test will fail !!!



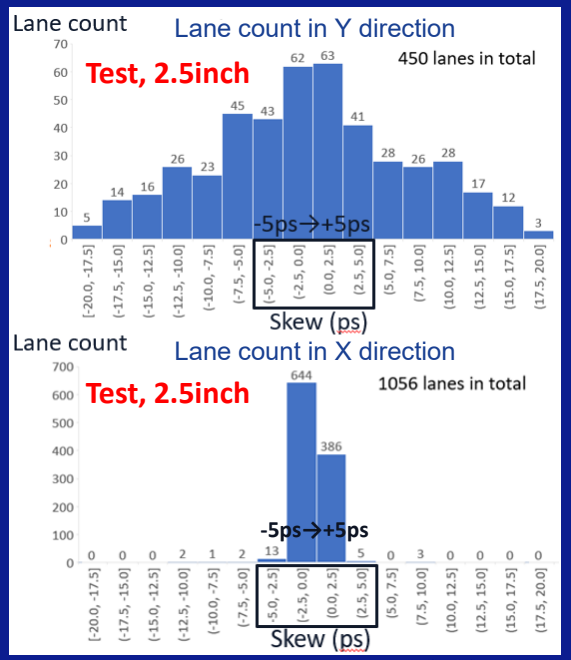
Stack up



Differential phase delay skew, 1inch length



Differential insertion loss, 1inch length



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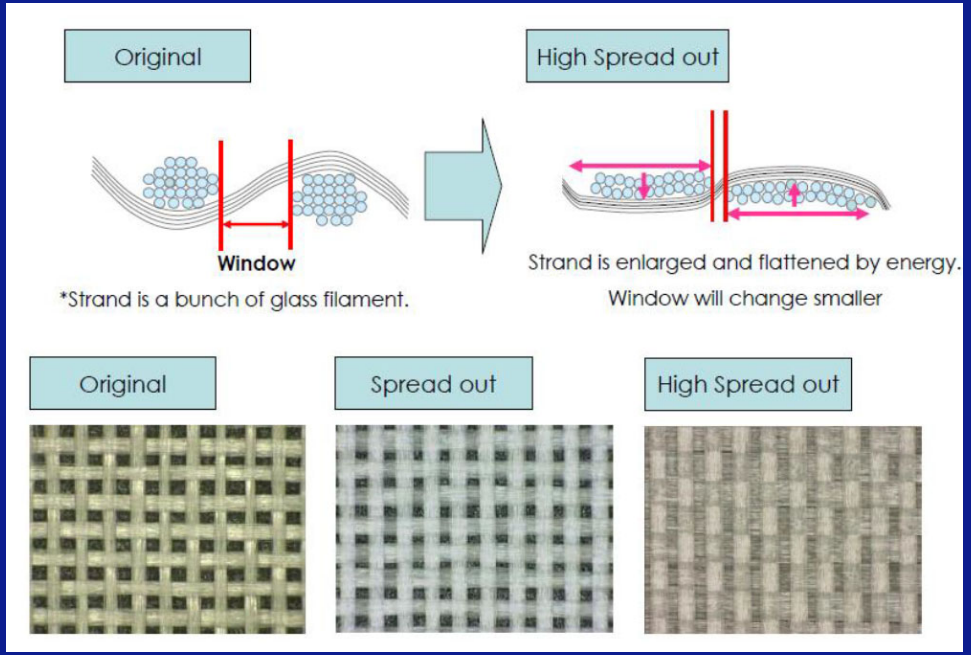
Mitigation methods for fiber weave skew

- Minimize Resin Windows by using **High Spread-out** glass fabric
  - Minimize dk difference inside dielectric material



Data Source: Reference 3.

We use #1035 & #1078 in the Test, already High Spread-Out type
However, still have 8ps/inch skew

MEGTRON6K E-glass

Style	Standard	Spread Out	High Spread Out
1027	No	No	Yes
1035	No	No	Yes
1078	No	No	Yes
1080	No	Yes	No
3313	No	Yes	No
2116	No	Yes	No

Data Source: Reference 3.

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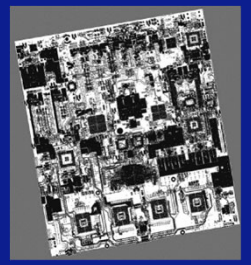
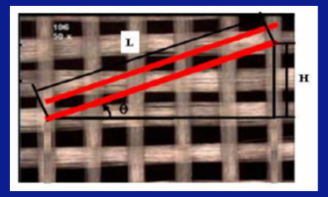
Mitigation methods for fiber weave skew

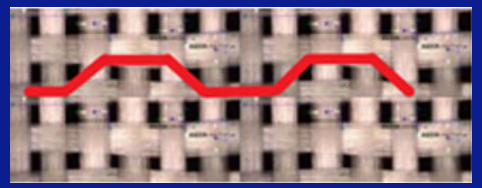
- Rotation (Gerber / CAM data / Trace)
  - Balance dk variation between P&N in a diff pair
  - a) Gerber / CAM rotation

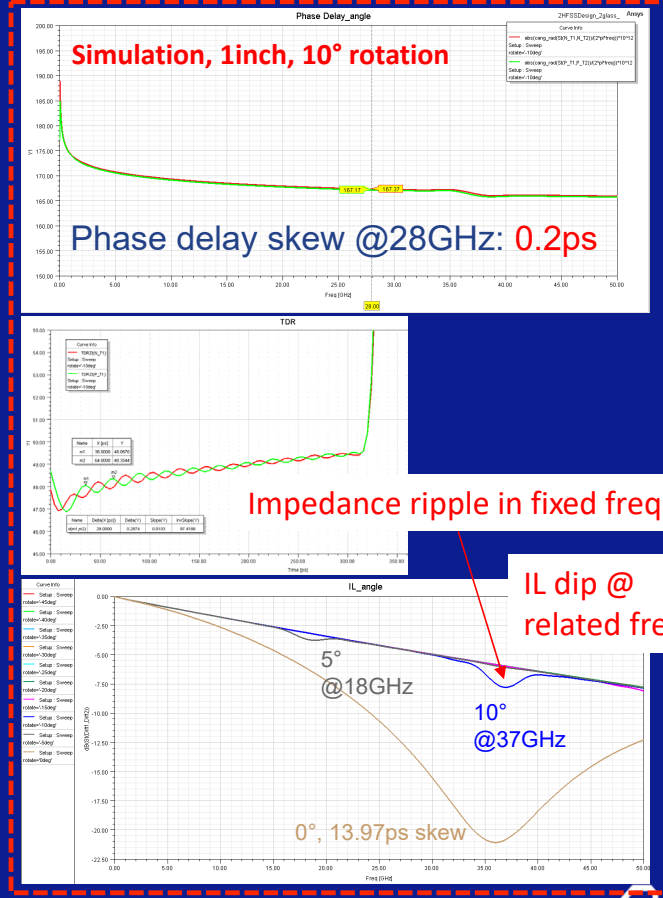


  - b) Trace rotation



  - c) Zig-Zag routing





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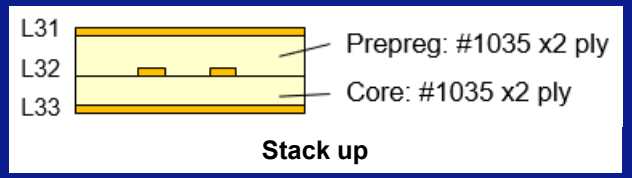
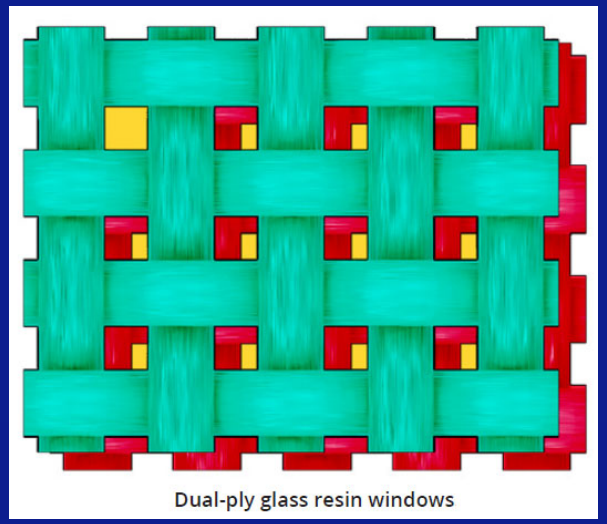
Mitigation methods for fiber weave skew

- 2 ply core + 2 ply PP stack-up
  - Minimize dk difference inside dielectric material

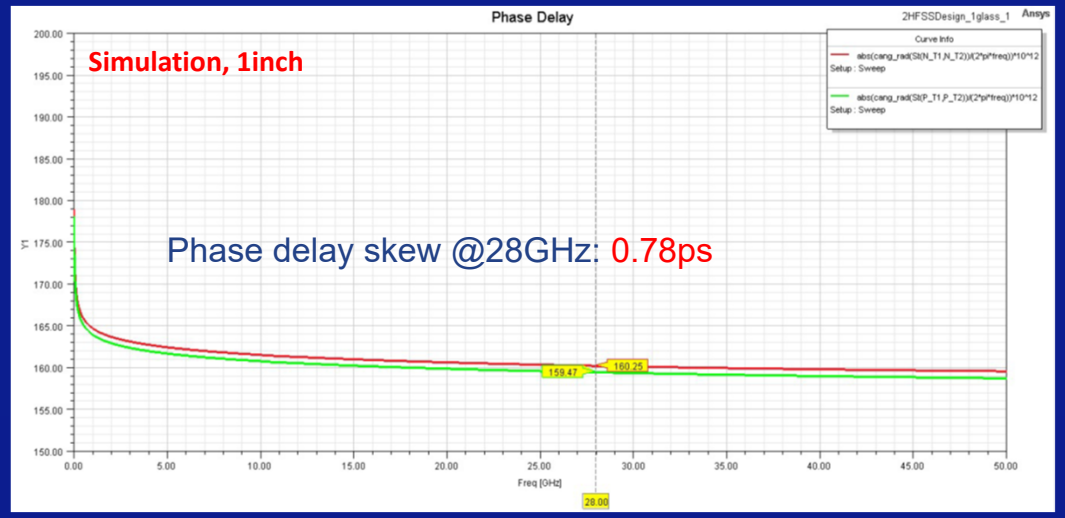


Stack up



Dual-ply glass resin windows

Data Source: Reference 4.



1. 2 plies of glass have little likelihood of aligning identically under one another.
2. The second ply serves to reduce the single-ply resin window size and hence glass-weave skew

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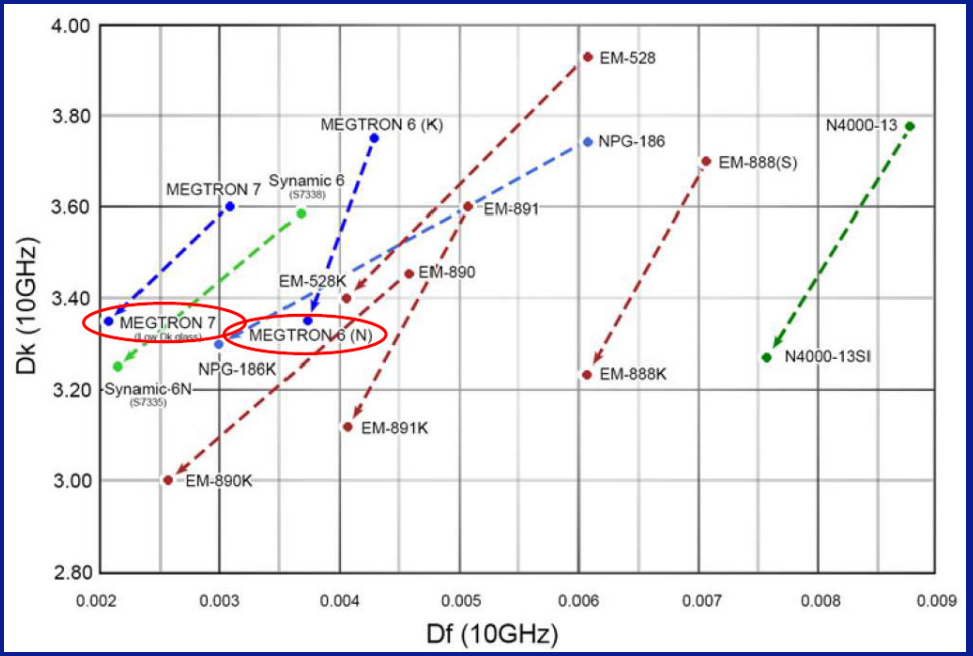
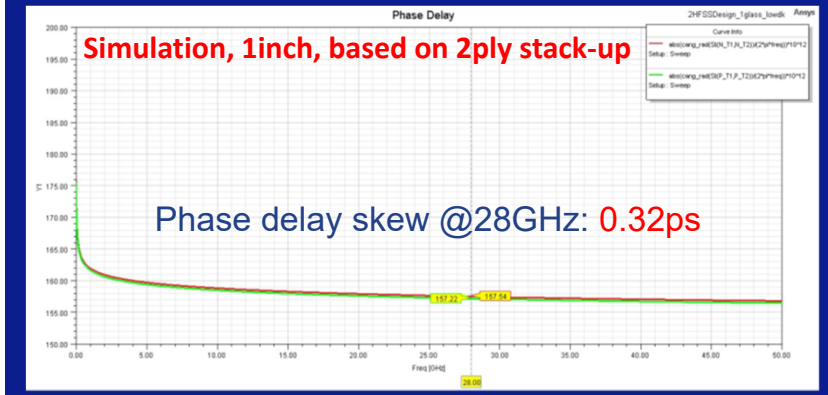
Mitigation methods for fiber weave skew

- Low-dk glass fabric
  - Minimize dk difference inside dielectric material





Data Source: Reference 4.

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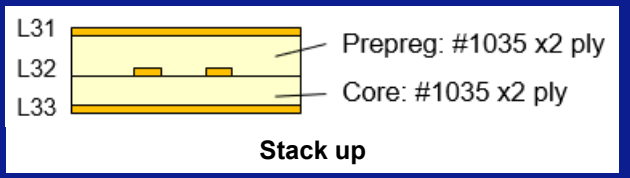
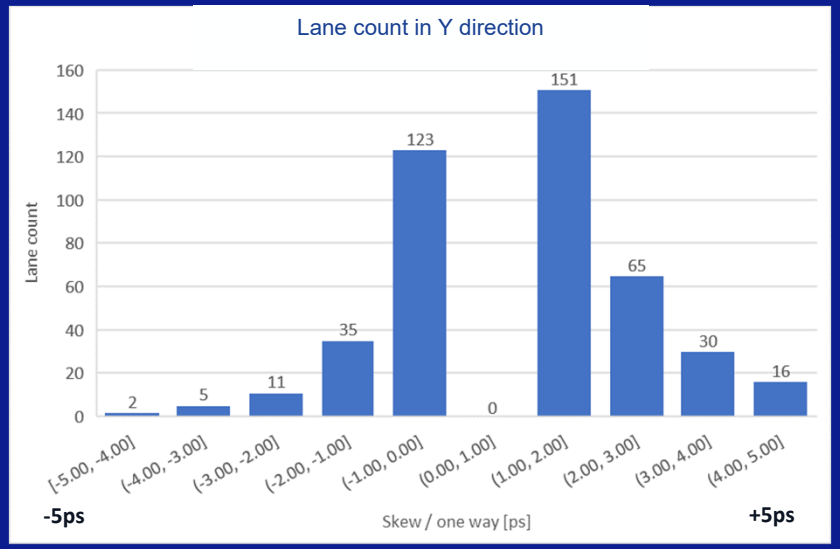
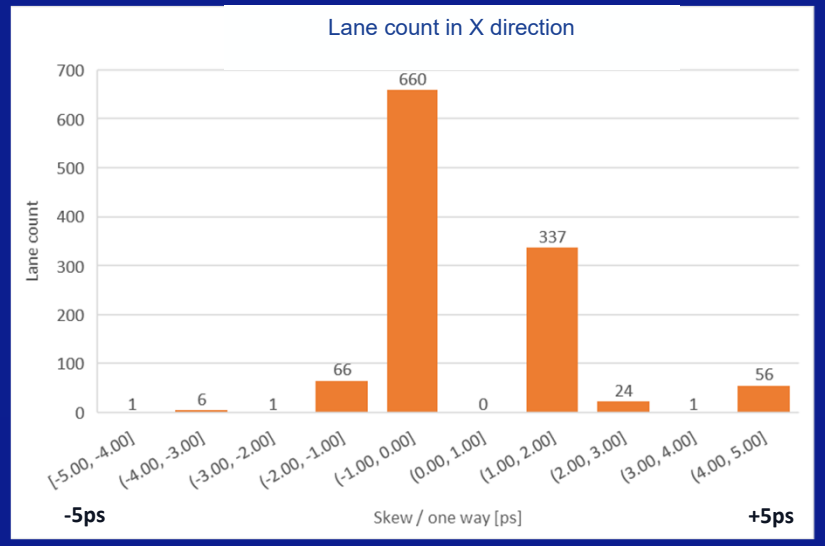
Test result with 2 ply stack-up

- Test result for reference (2.5inch length, 2 ply stack-up)







1. Achieved 2ps/inch
2. 5ps maximum < 10ps requirement
3. No issue found in loopback test !!!

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Summary and Key takeaways

- Fiber weave skew occur *randomly*, prevention is much more realistic than prediction
- 4 feasible mitigation methods, *must* discuss with your fab vendor in early design stage

	Name	Phase delay skew @28GHz
1	High spread-out glass fabric	**13.97ps/inch**
2	Rotation	From 13.97ps/inch To **0.2ps/inch** (10 degree)
3	Use 2 ply stack-up	From 13.97ps/inch To **0.78ps/inch**
4	Use low-Dk glass fabric	From 13.97ps/inch To **0.32ps/inch** (w/ 2 ply)

- We can combine some of those 4 methods above together to get better skew

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Reference

- *1. Shirin Farrahi, Vijay Kunda, Ying Li, Xun Zhang, Gustavo Blando, Istvan Novak, Oracle Corp. Does skew really degrade SERDES performance? DesignCon 2015*
- *2. Bei Chen, Ruohe Yao, HongfeiWang, Kuiwei Geng, Juan Li. Fastprint. Effect of Fiber Weave Structure in Printed Circuit Boards on Signal Transmission Characteristics. 2019*
- *3. Mika Sillgren, Panasonic. Circuit Board Laminates as a part of High Frequency PCB. Aspocomp – Piirilevytekniikkaa 2015*
- *4. Bill Hargin, Z-zero. Stackups – the design within the design. 2022*
- *5. Understanding Glass Fabric. Isola*

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