Welcome to

DESIGNCON® 2023

WHERE THE CHIP MEETS THE BOARD

Conference

January 31 – February 2, 2023

Santa Clara Convention Center

Expo

February 1 – 2, 2023

Impact Evaluation of Fiber-Weave Effect Induced Delay Uncertainty in DDR Data Links on DDR5 & Towards DDR6

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Yuriy Shlepnev, Simberian Inc.
Shimon Mordooch, Major Communication Company

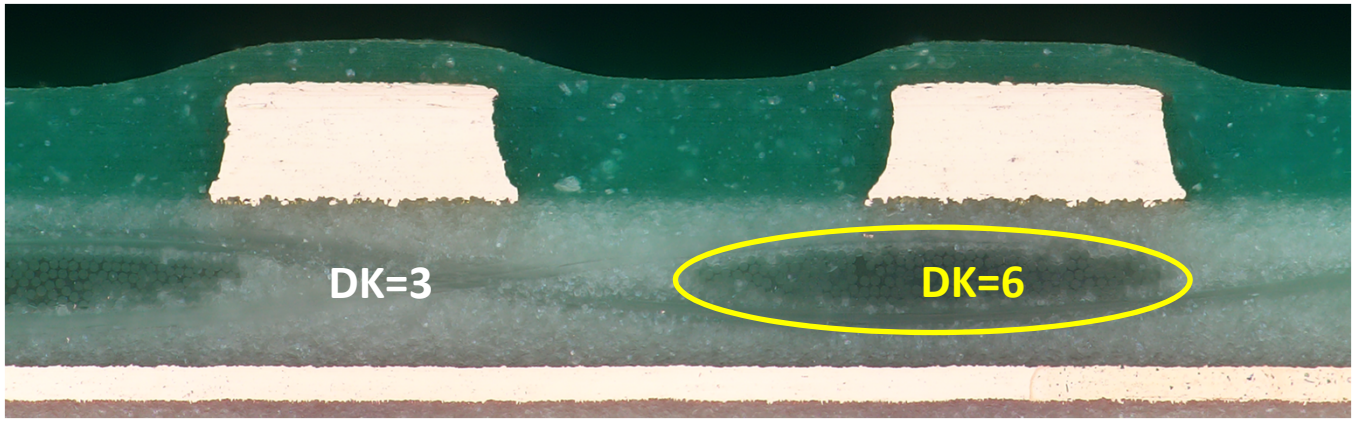
Thursday, February 2 • 8:00 AM - 8:45 AM
Pacific Time, Ballroom F

OUTLINE

- Introduction
- Numerical Model for FWE
- Delay and Impedance Variations and Uncertainty
- Differential Skew Uncertainty
- Analytical Model for Delay and Skew Uncertainty
- Conclusion

Fiber Weave Effect In A Nutshell

- Both fabric fiber and resin are composite materials with different dielectric constant (DK)
- For each trace effective Dk is deferent (relative position to glass bundles)

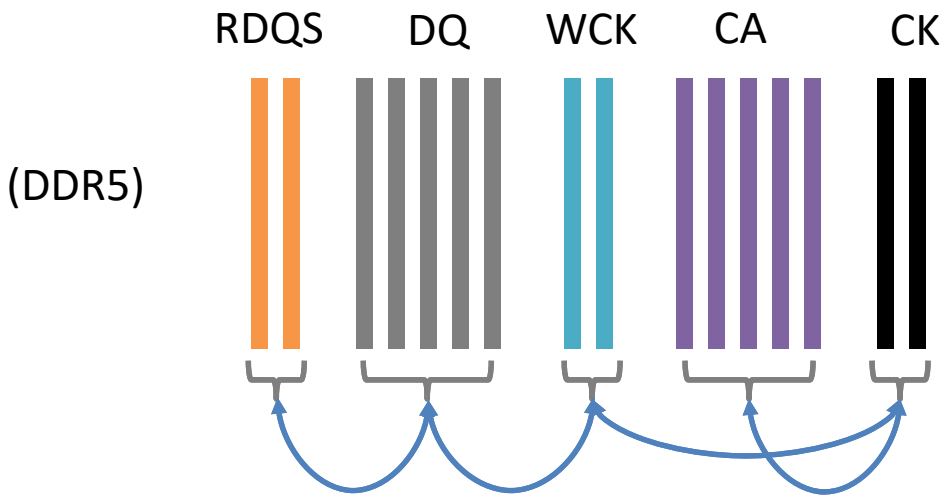


Typical Dielectric Material Property	DK
Glass Weave	4.4 - 6.1
Resin	3-3.5

Trace #1 Delay ≠ **Trace #2 Delay**

DDR Buss Signal Groups

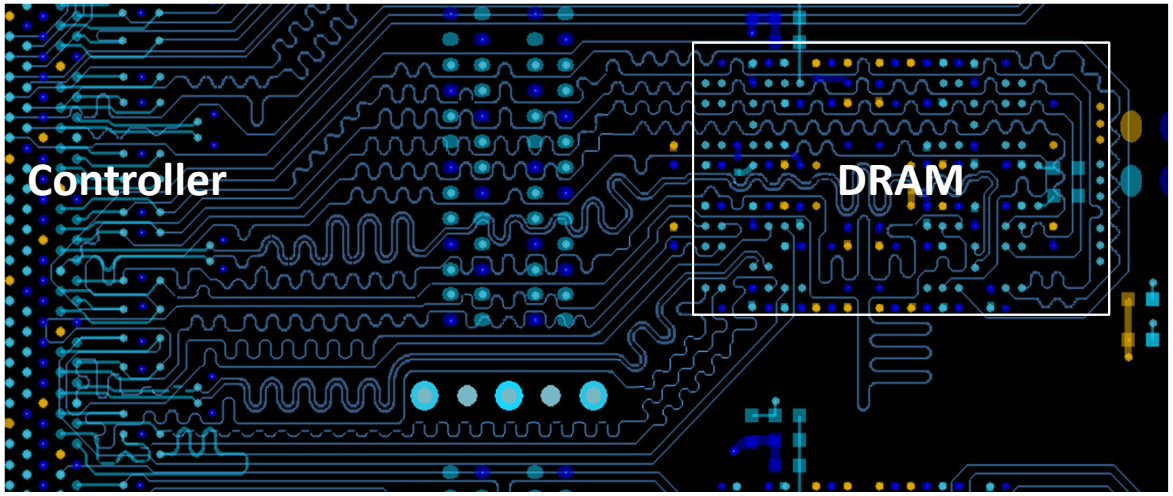
- **DDR bus has bounds on flight time across all data lanes within a signal group**
  - Typical: 20-50 ps for DDR5 operating in 6400 MT/s
  - Expected :10-25 ps for DDR6 with maximum data rate peaks above 12800 MT/s



DDR Routing Length Matching Challenges

1

Physical Length ≠ Electrical Length



2

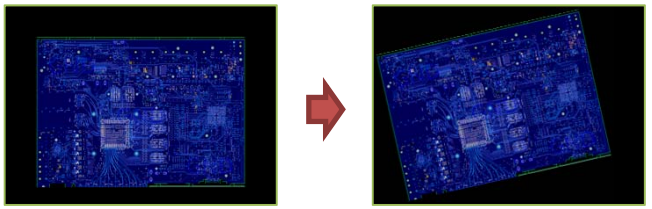
⇧ Length Matching

⇧	Routing Density	=	⇧ Xtalk
⇩	Trace width	=	⇧ Impedance
			⇧ RL and Reflections
⇧	Channel Length	=	⇧ Channel Loss

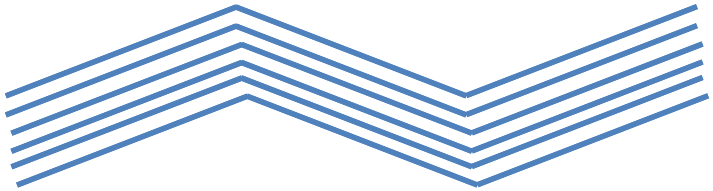
⇩ Buss Performance

Mitigation Options

1. Homogenous Dielectrics-$$
2. Spread Glass -$
3. Panel Rotation –Panel Utilization Impact



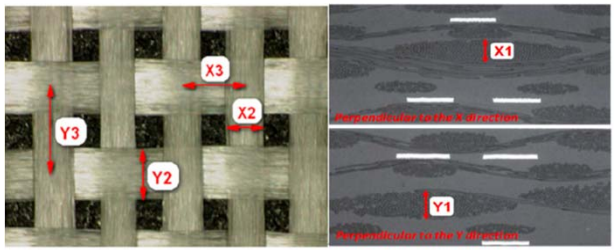
4. Angled Routing- Channel Length, Area



Is this required in my design?

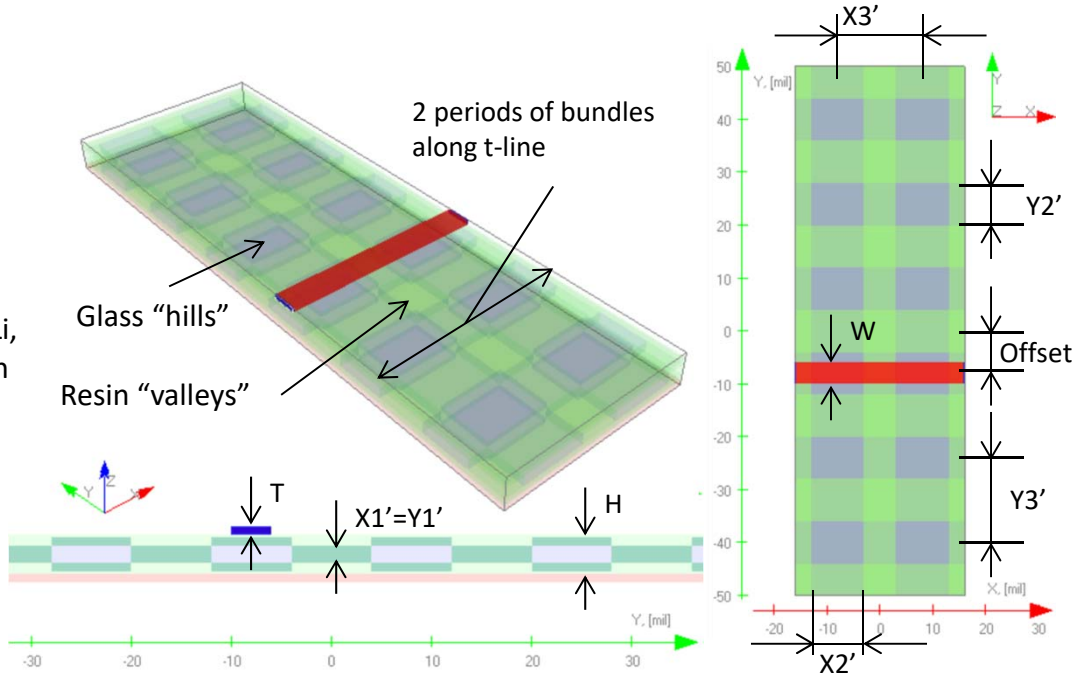
How match of an issue is this ?

3D EM Model For Single Ended Microstrip



Laminate data from: B. Chen, R. Yao, H. Wang, K. Geng, J. Li, Effect of Fiber Weave Structure in Printed Circuit Boards on Signal Transmission Characteristics. *Appl. Sci.* 2019, *9*, 353

Style	X1/X1'	X2/X2'	X3/X3'	Y1/Y1'	Y2/Y2'	Y3/Y3'
1035	0.82/0.8	8.8/7	14.2/14	0.78/0.8	12.4/9	13.7/14
1080	1.6/1.35	8.2/6	17/17	1.1/1.35	12.1/9	22.4/22
1078	1.4/1.2	14.2/10	16.2/16	1.0/1.2	17.6/13	17.8/18
3313	1.9/1.7	13.1/10	16.2/16	1.5/1.7	11/8	16.3/16

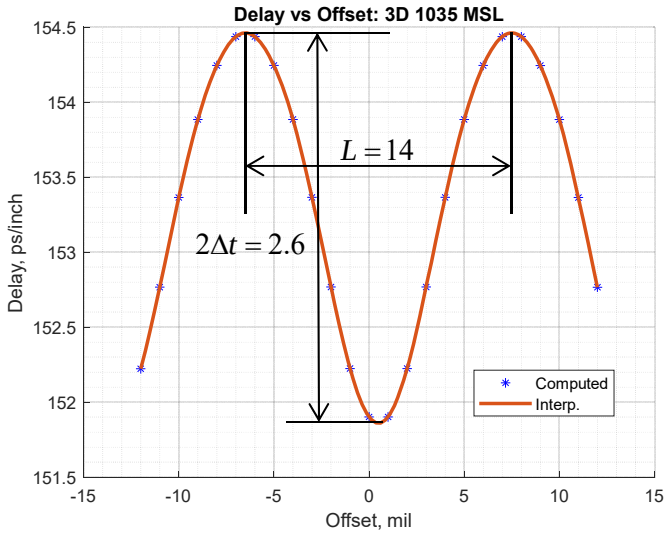


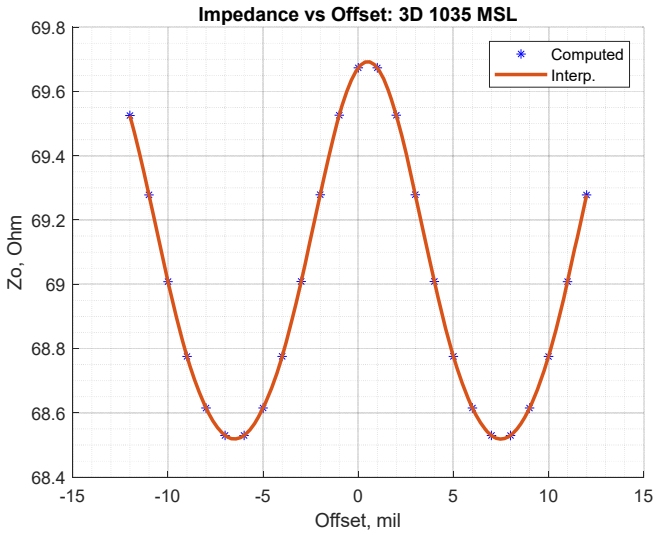
X1'-X3', Y1'-Y3' are values adjusted in the model

Trefftz Finite Element solver Simbeor 3DTF and HFSS are used for analysis

Results for 1035: Delay and Impedance vs Offset

Delay is computed with zero reflections option – variation of impedance do not change the phase delay, 4 mil trace on 4 mil laminate, DKresin = 3.5, DKglass = 6



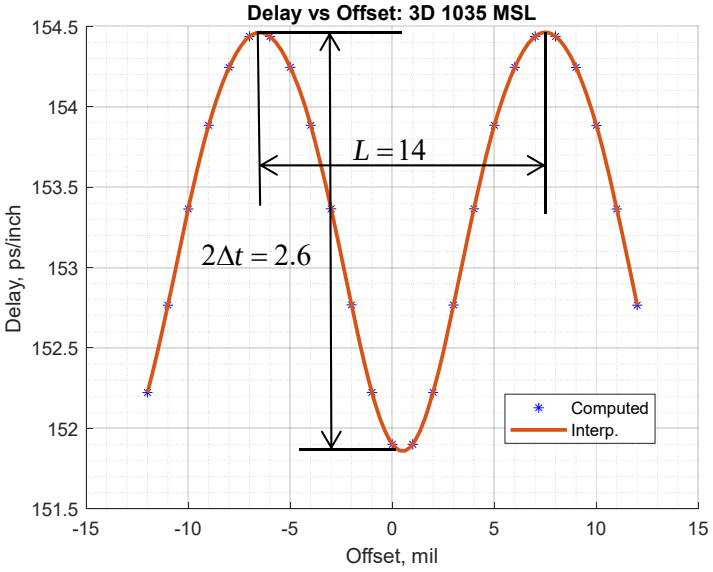


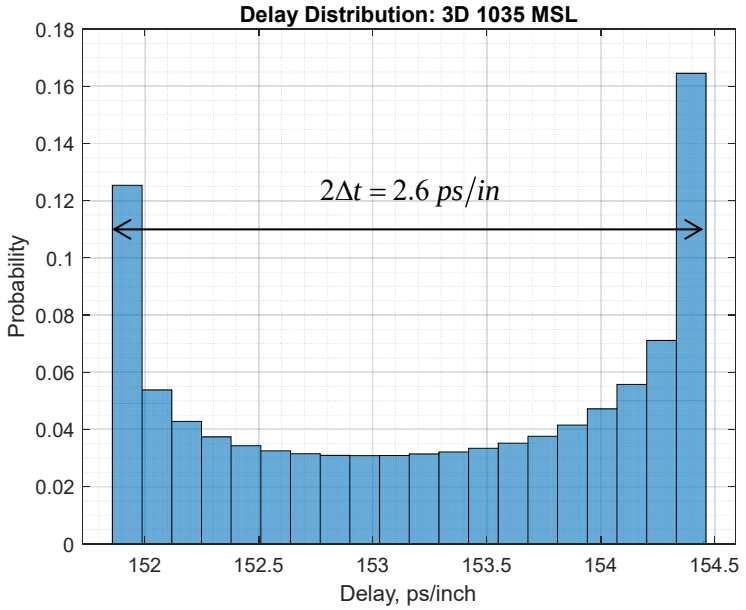
Almost sinusoidal dependency…

Simulated with Simbeor SDK + Matlab

Results for 1035: Delay vs Offset and Probability

Probability density is computed with 100000 samples and 20 bins

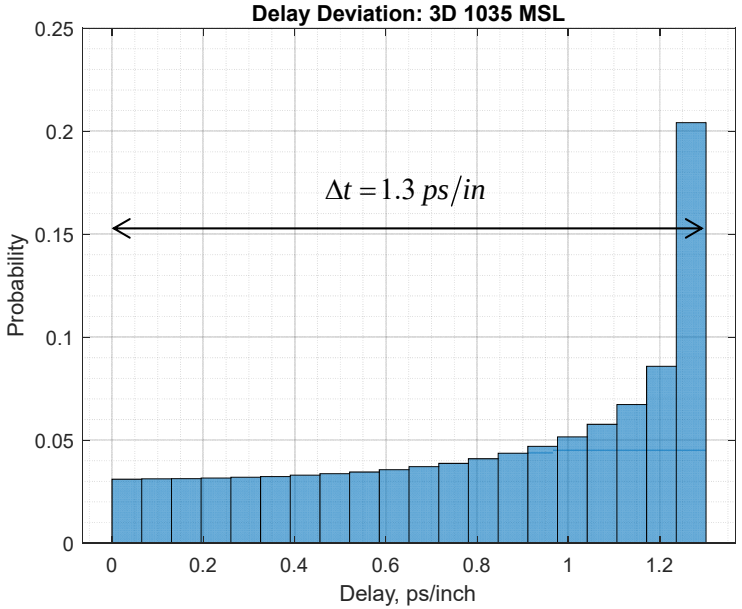




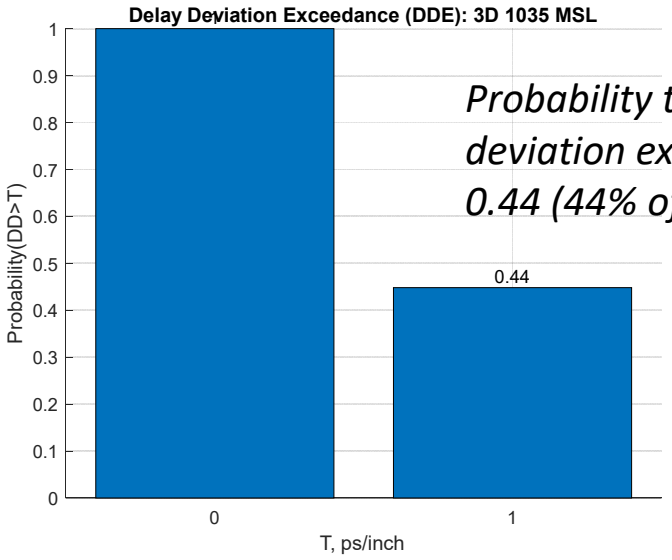
The probability to have the minimal and maximal delay values is the highest!

Results for 1035: Probability and Exeedance

Probability of Delay Deviation from 0.5*(Dmin+Dmax)



Complimentary Cumulative Distribution Function (CCDF) -> Delay Deviation Exceedance (DDE)

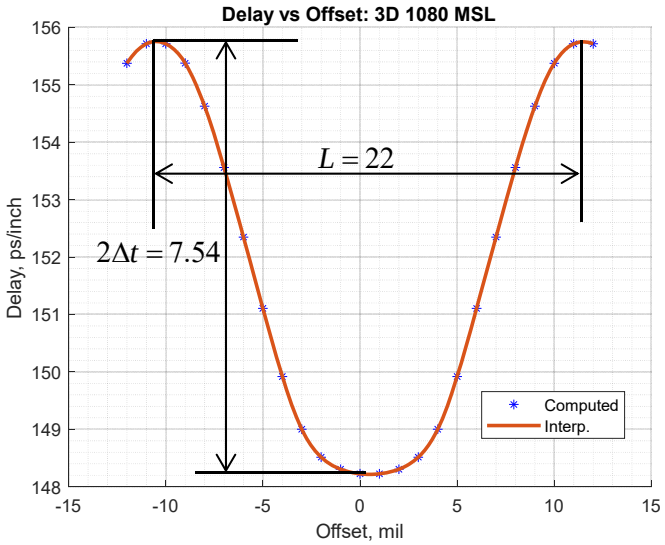


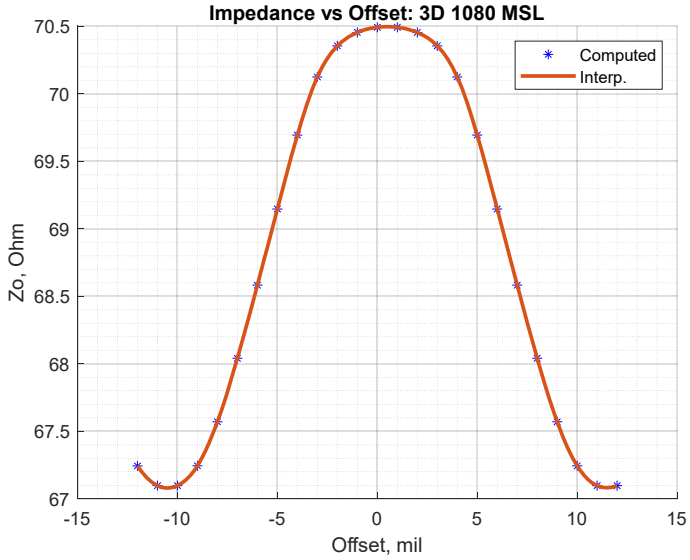
Probability to have delay deviation exceeding 1 ps/in is 0.44 (44% of all cases)

No cases with DD>2ps

Results for 1080: Delay and Impedance vs Offset

Delay is computed with zero reflections option – variation of impedance do not change the phase delay, 4 mil trace on 4 mil laminate, DKresin = 3.5, DKglass = 6



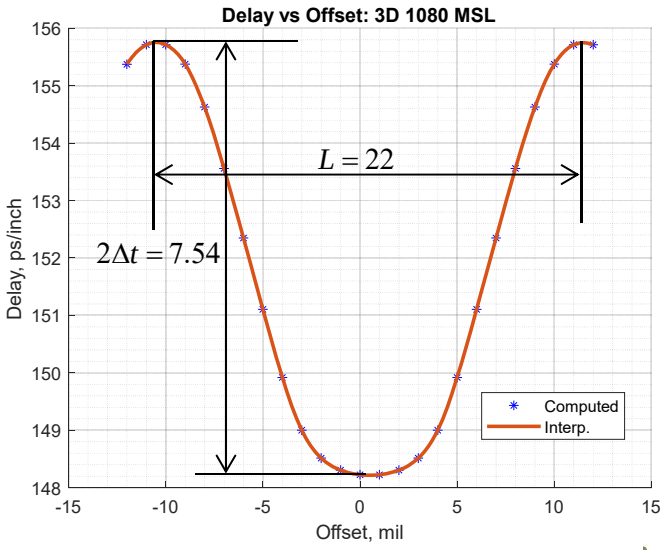


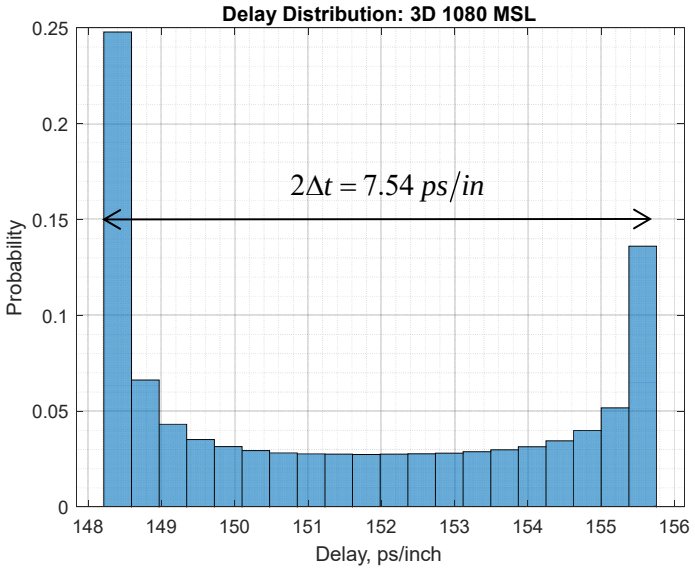
Sharper glass peaks, wider resin valleys…

Simulated with Simbeor SDK + Matlab

Results for 1080: Delay vs Offset and Probability

Probability density is computed with 100000 samples and 20 bins

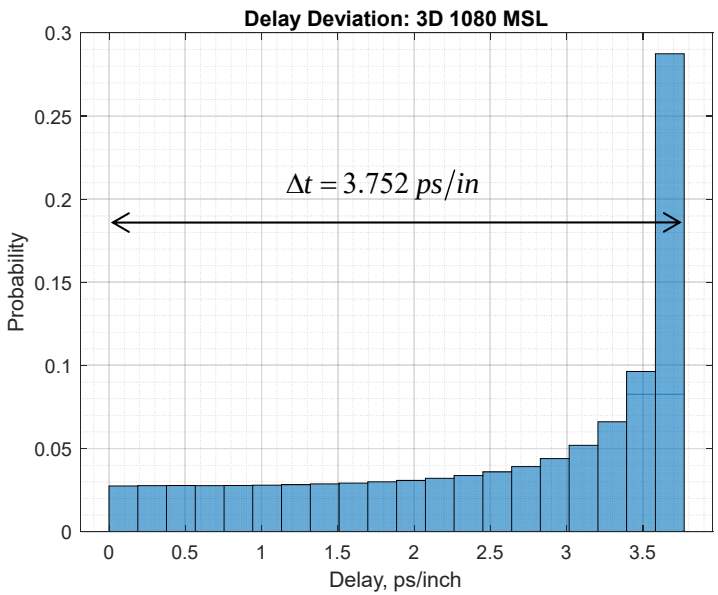




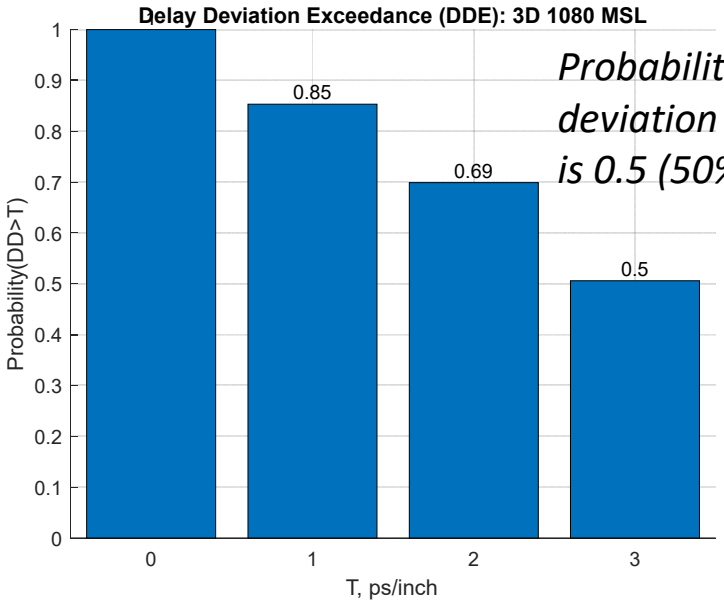
The probability to have the minimal and maximal delay values is the highest!

Results for 1080: Probability and Exeedance

Probability of Delay Deviation from 0.5*(Dmin+Dmax)



Complimentary Cumulative Distribution Function (CCDF) -> Delay Deviation Exceedance (DDE)

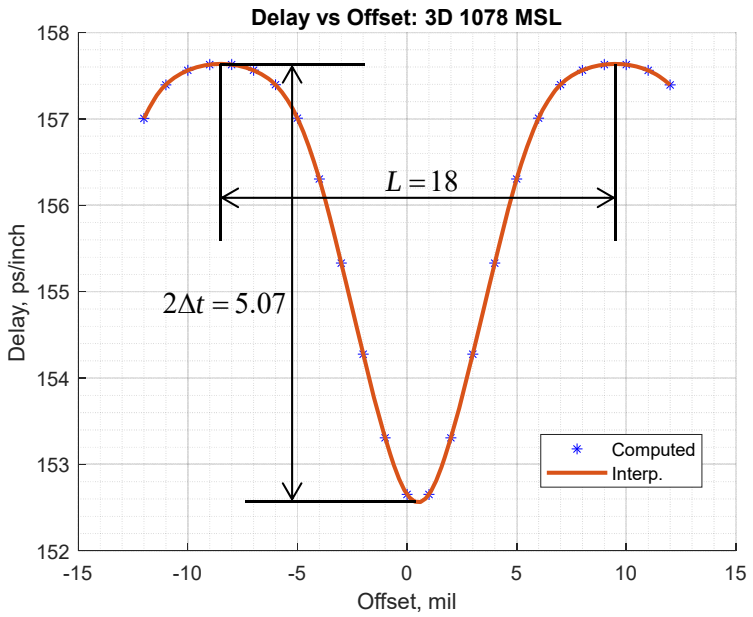


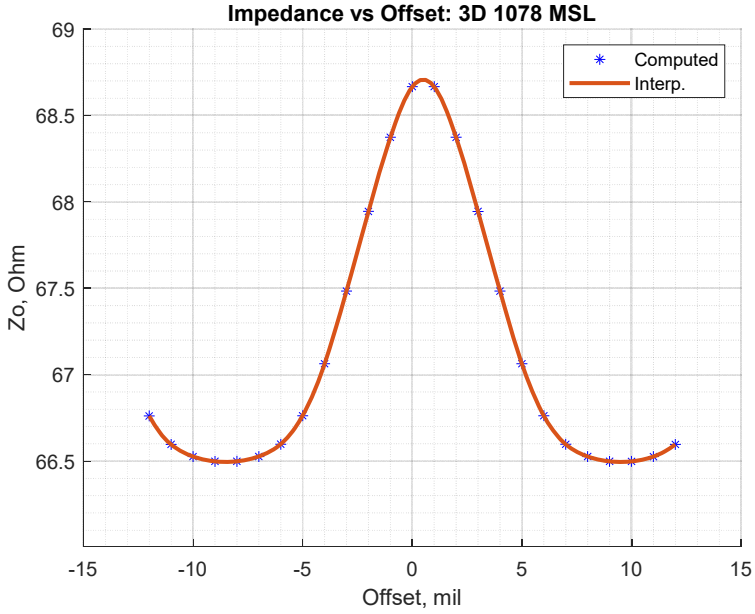
Probability to have delay deviation exceeding 3 ps/in is 0.5 (50% of all cases)

No cases with DD>4ps

Results for 1078: Delay and Impedance vs Offset

Delay is computed with zero reflections option – variation of impedance do not change the phase delay, 4 mil trace on 4 mil laminate, DKresin = 3.5, DKglass = 6



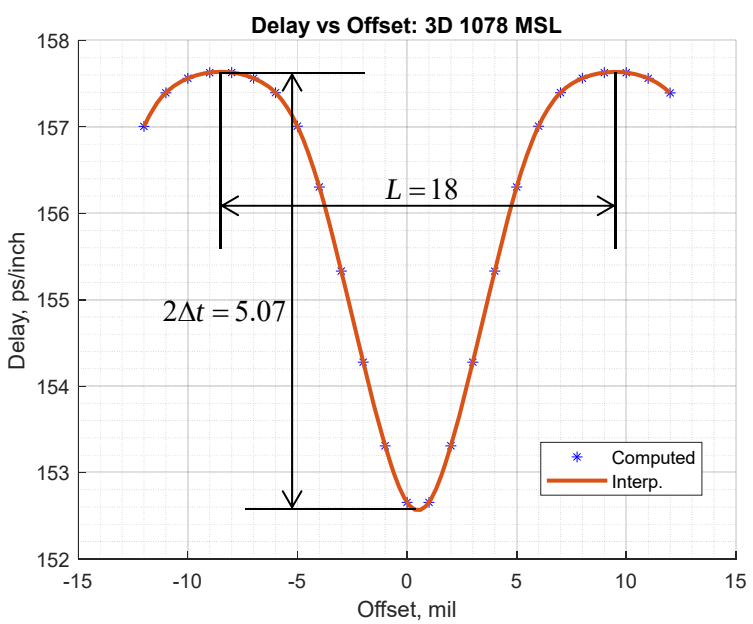


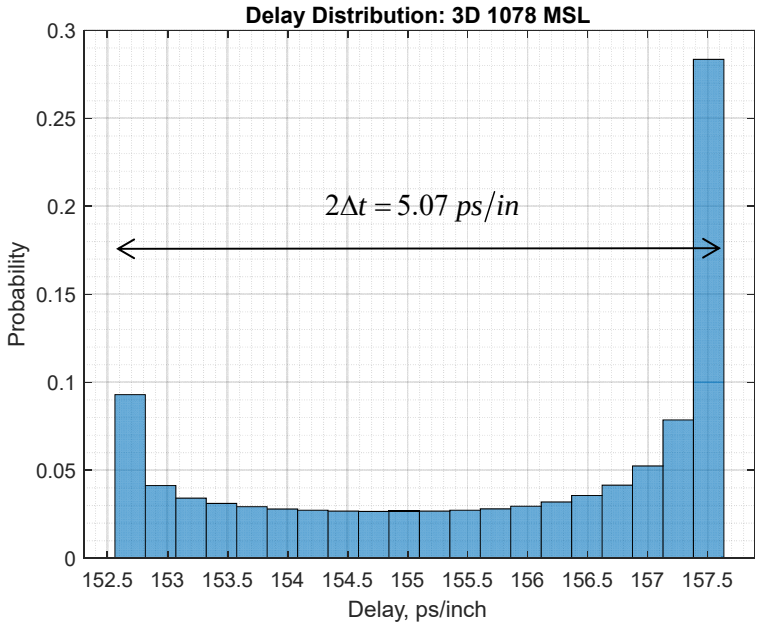
Wider glass peaks, narrower resin valleys…

Simulated with Simbeor SDK + Matlab

Results for 1078: Delay vs Offset and Probability

Probability density is computed with 100000 samples and 20 bins

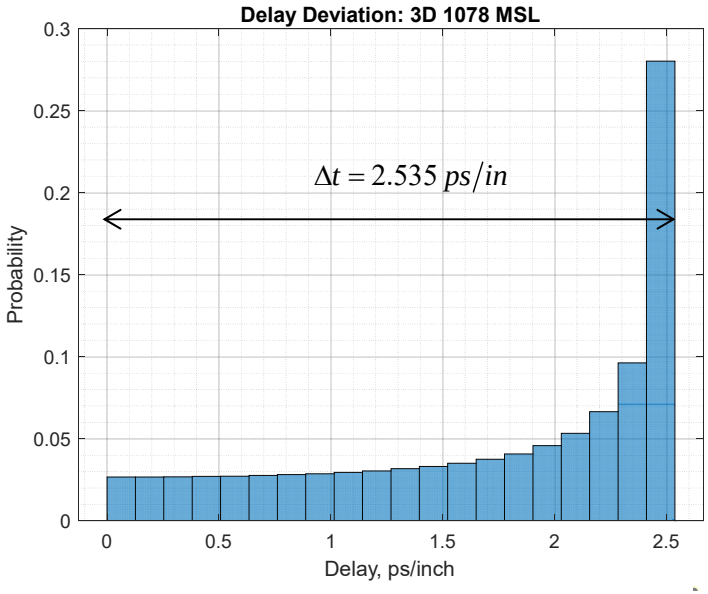




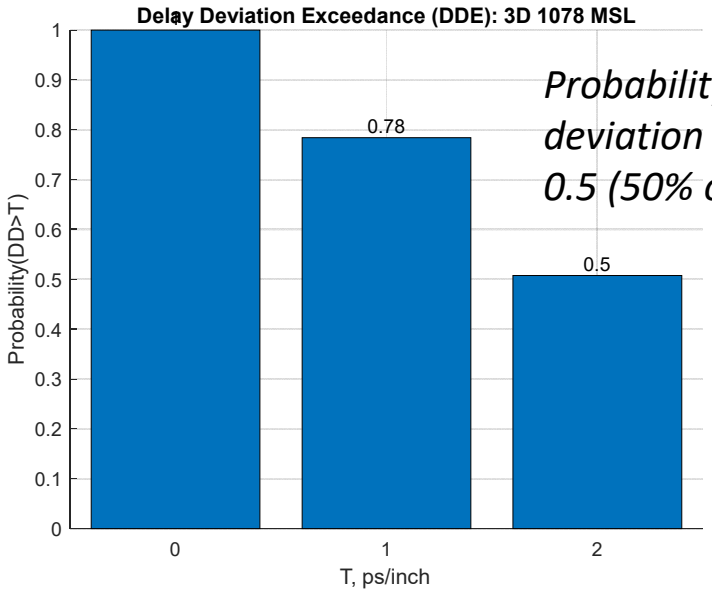
The probability to have the minimal and maximal delay values is the highest!

Results for 1078: Probability and Exeedance

Probability of Delay Deviation from 0.5*(Dmin+Dmax)



Complimentary Cumulative Distribution Function (CCDF) -> Delay Deviation Exceedance (DDE)

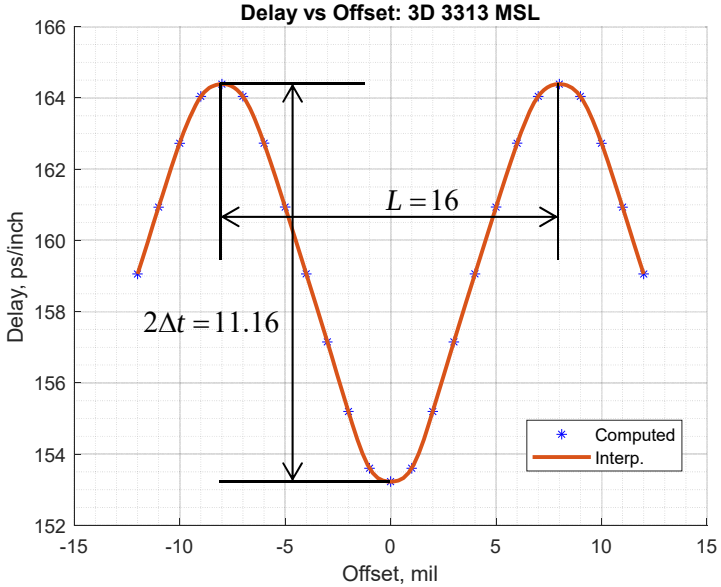


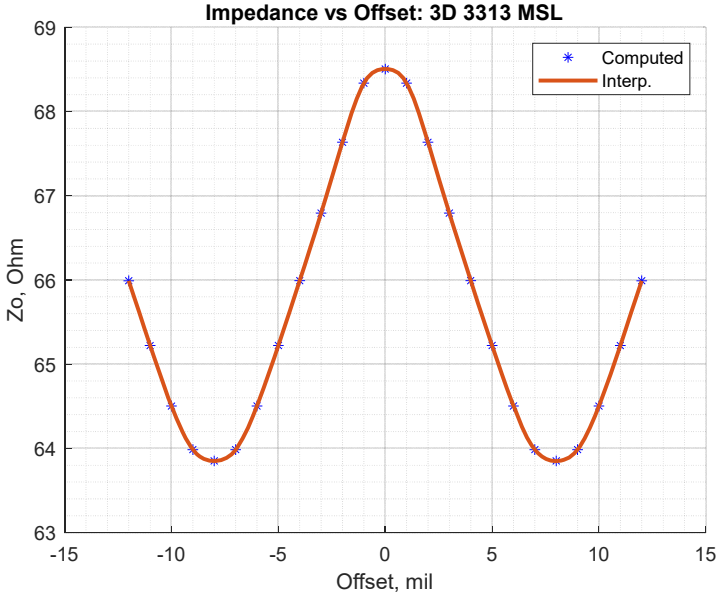
Probability to have delay deviation exceeding 2 ps is 0.5 (50% of all cases)

No cases with DD>3ps

Results for 3313: Delay and Impedance vs Offset

Delay is computed with zero reflections option – variation of impedance do not change the phase delay, 4 mil trace on 4 mil laminate, DKresin = 3.5, DKglass = 6



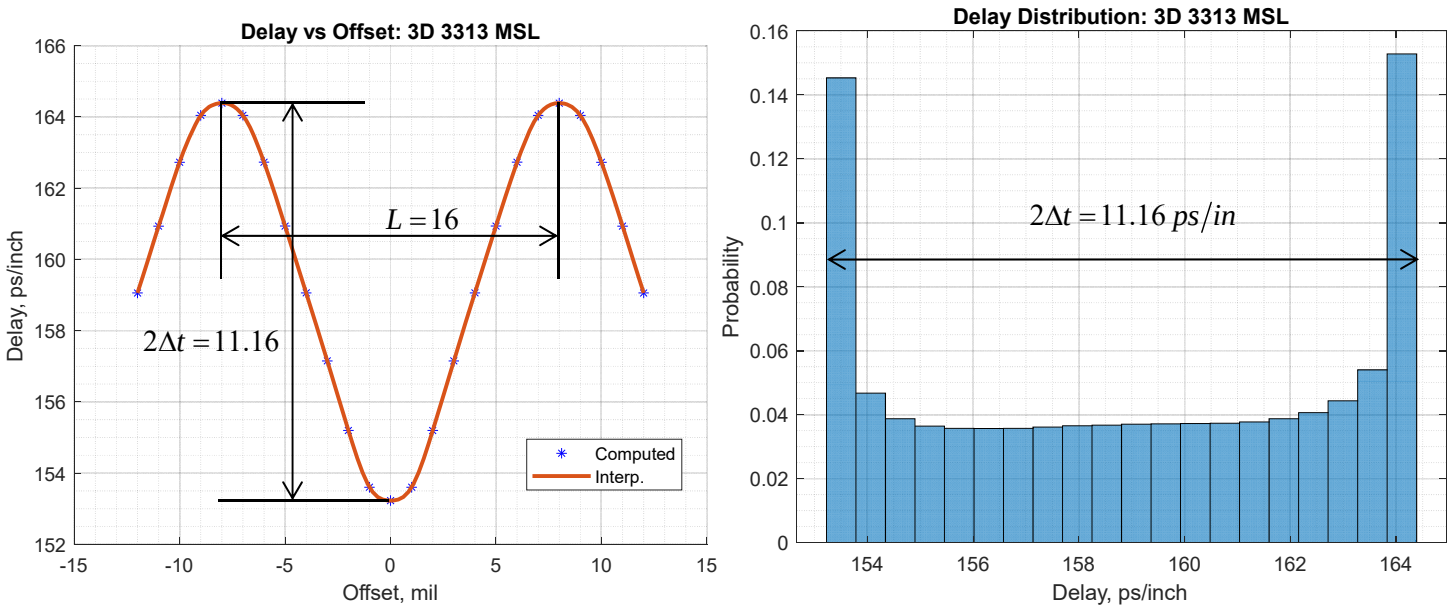


Almost sinusoidal again…

Simulated with Simbeor SDK + Matlab

Results for 3313: Delay vs Offset and Probability

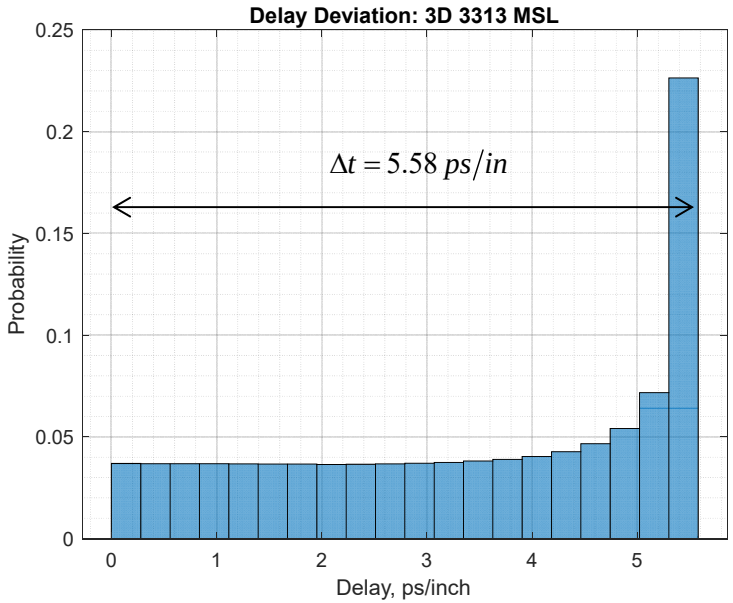
Probability density is computed with 100000 samples and 20 bins



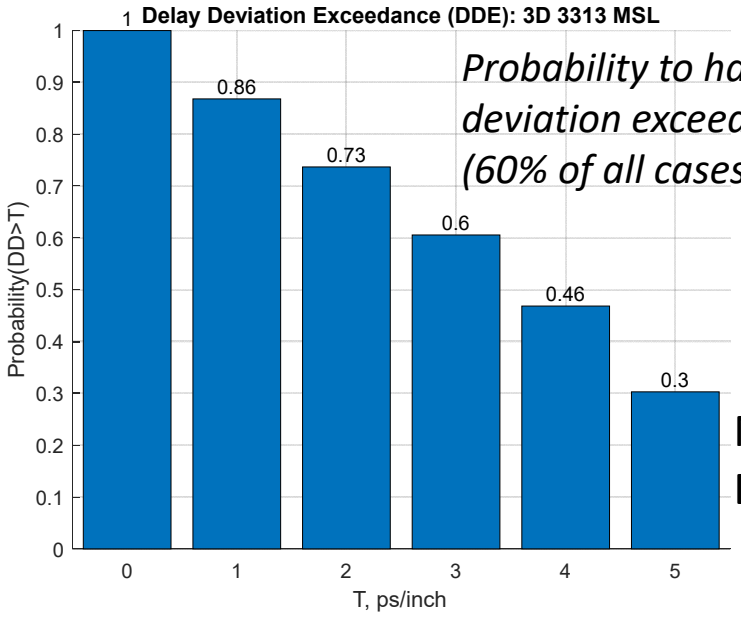
The probability to have the minimal and maximal delay values is the highest!

Results for 3313: Probability and Exeedance

Probability of Delay Deviation from 0.5*(Dmin+Dmax)



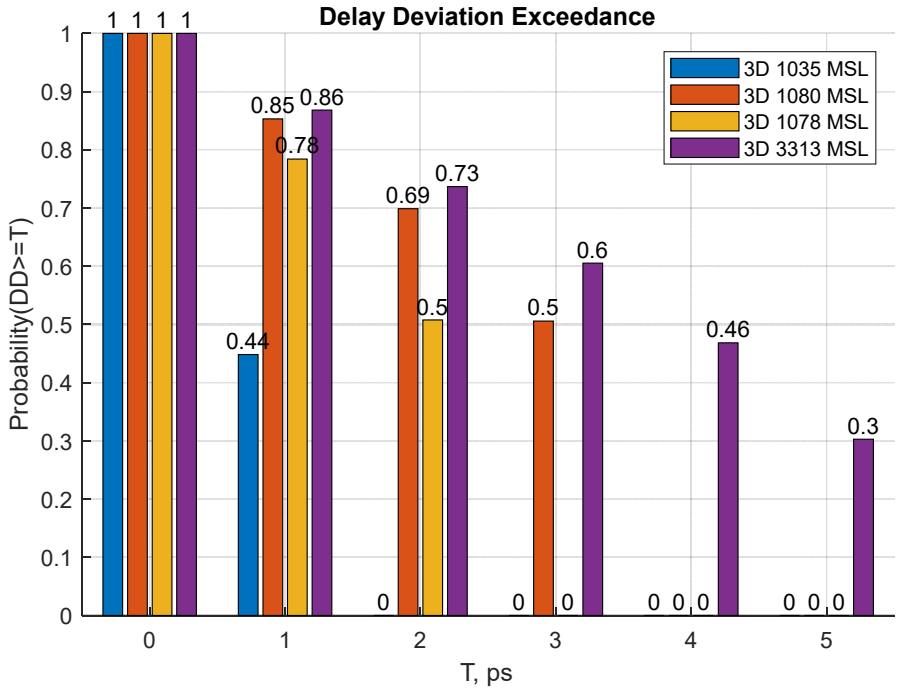
Complimentary Cumulative Distribution Function (CCDF) -> Delay Deviation Exceedance (DDE)



Probability to have delay deviation exceeding 3 ps is 0.6 (60% of all cases)

No cases with DD>6ps

Example of Laminates DDE Comparison



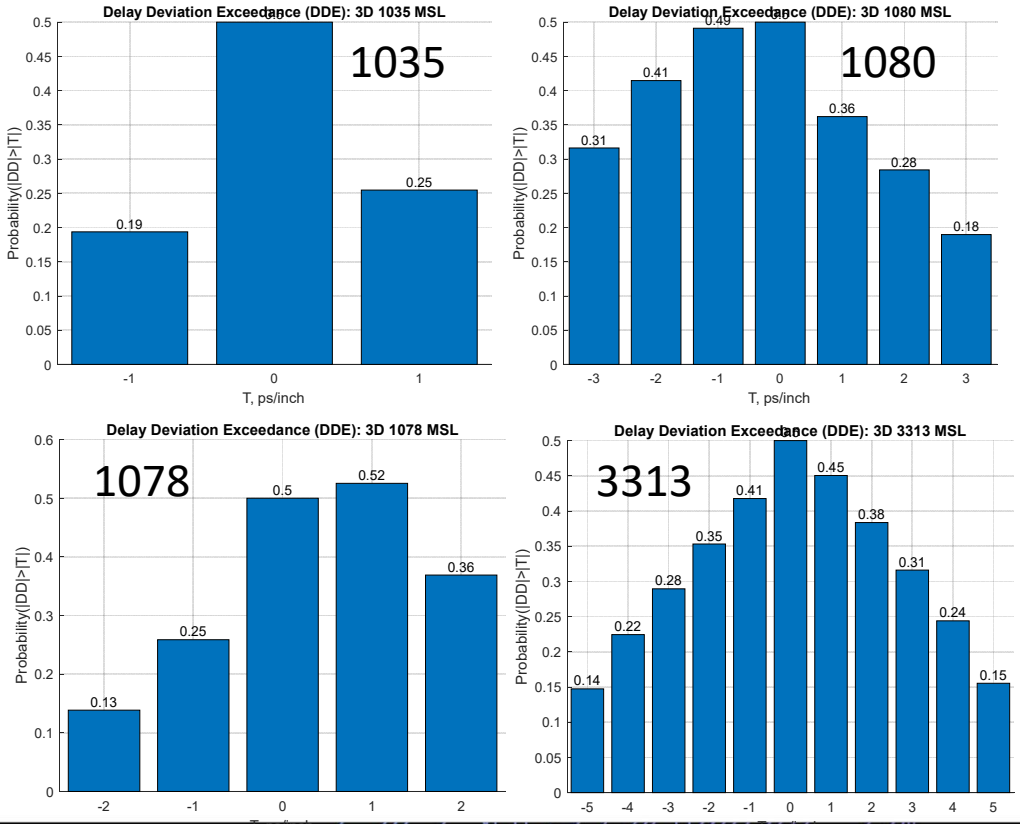
Disclaimer: DDE numbers provided here are purely for illustrative purpose and should not be considered as the actual characteristics of corresponding fabrics

Simulated with Simbeor SDK + Matlab

Symmetrical DDE for Single Ended Traces

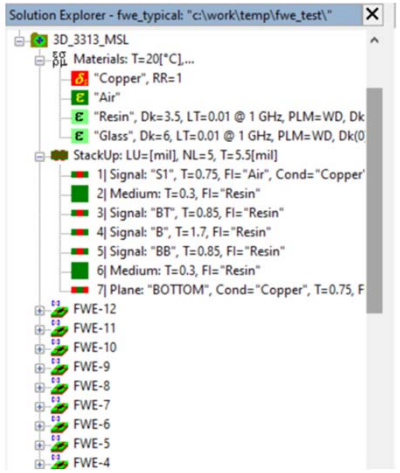
Probability to have delay deviation up or down from the average between min and max values

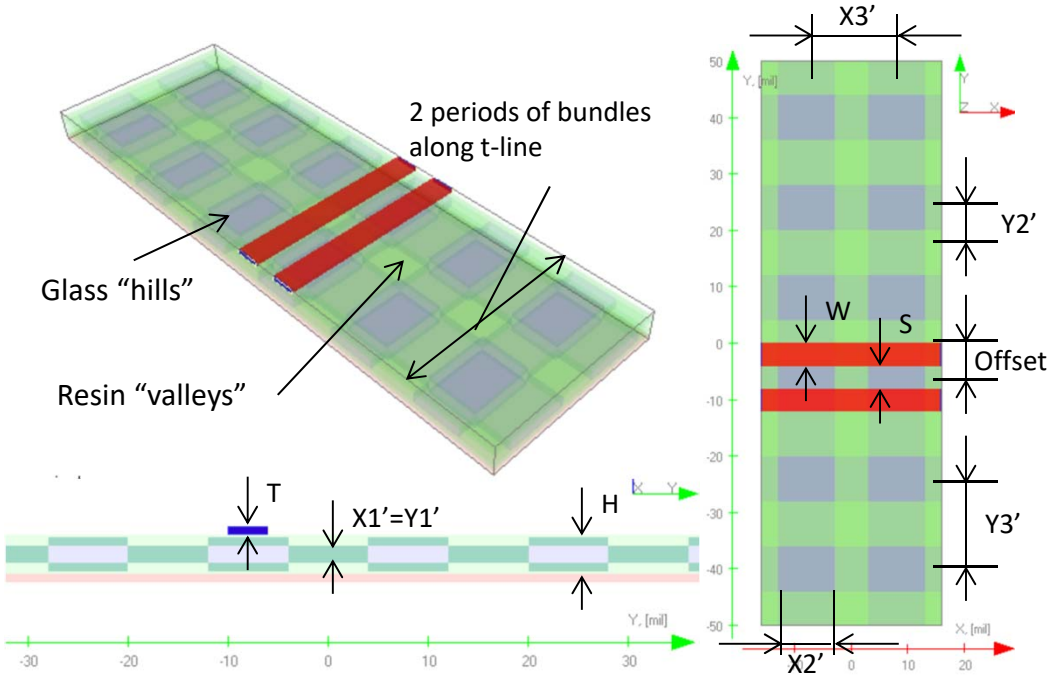
Un-symmetry of this DDE reflects deviations of delay dependency from sinusoidal



3D EM Model for Differential Microstrip

- **All other parameters are exactly the same as in the single-ended case**

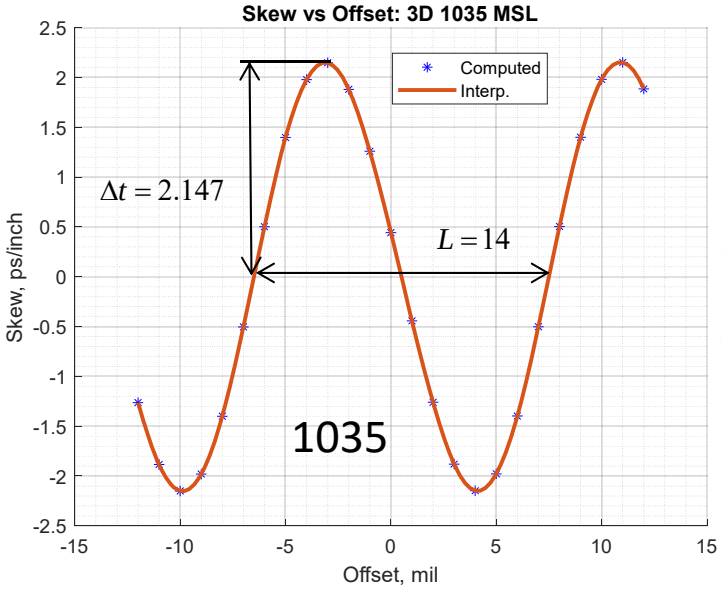


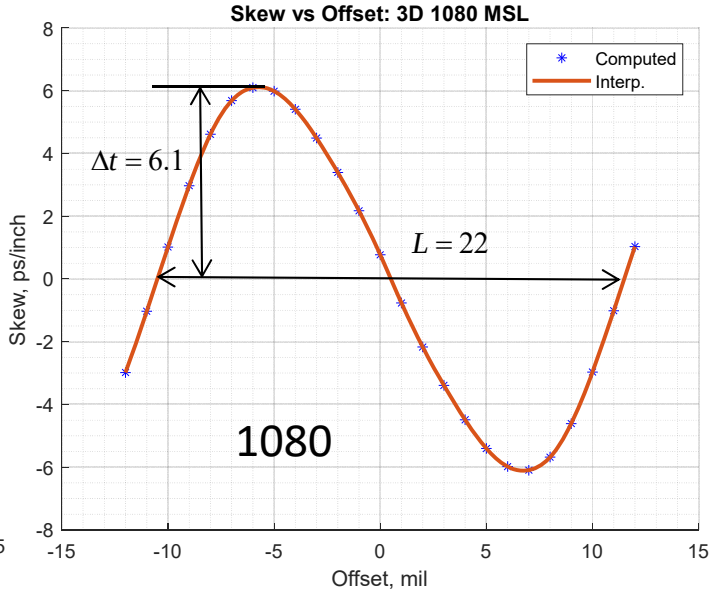


Automated in Simbeor SDK, FWE_Kit

Differential Skew vs Offset for 1035 and 1080

Delay is computed with zero reflections option – variation of impedance do not change the skew, 4 mil traces, 4 mil separation on 4 mil laminate, DKresin = 3.5, DKglass = 6

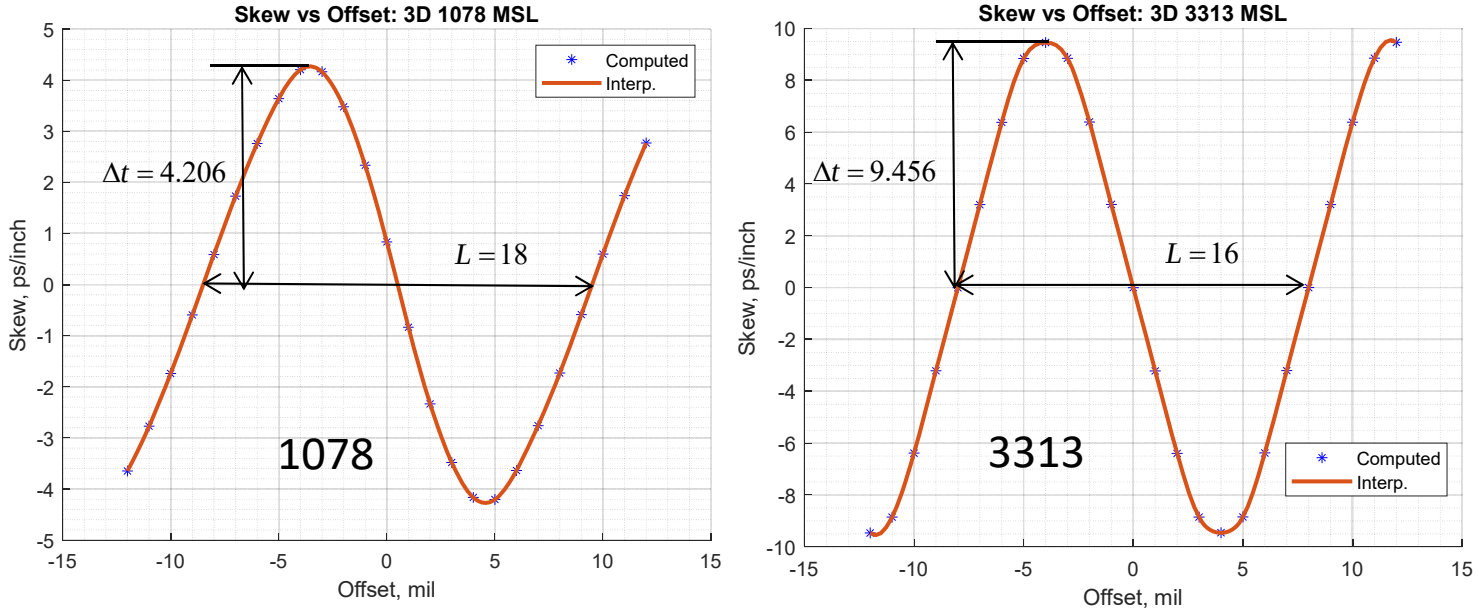




Computed as phase difference with zero reflection condition

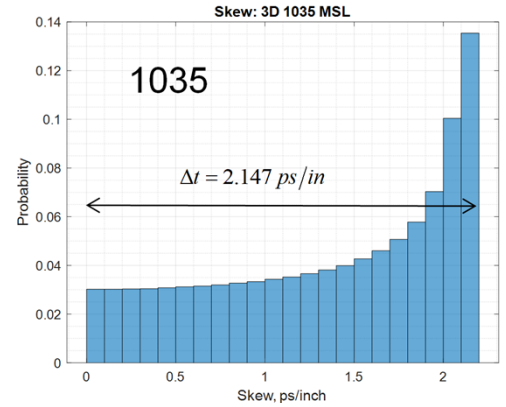
Differential Skew vs Offset for 1078 and 3313

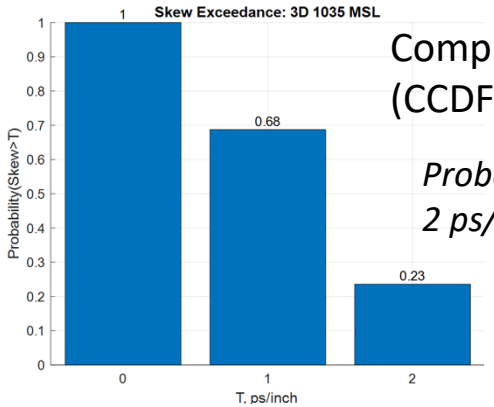
Delay is computed with zero reflections option – variation of impedance do not change the skew, 4 mil traces, 4 mil separation on 4 mil laminate, DKresin = 3.5, DKglass = 6



Computed as phase difference with zero reflection condition

Skew Probability and Exceedance for 1035 & 1080

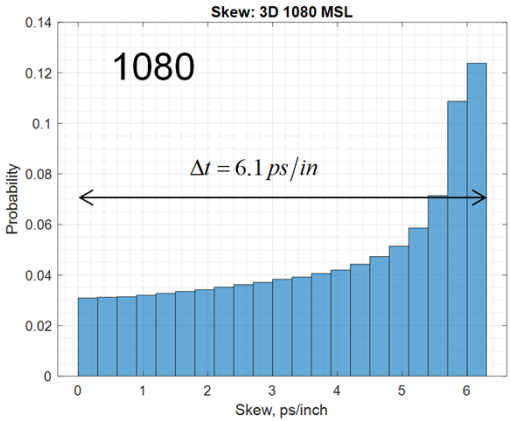


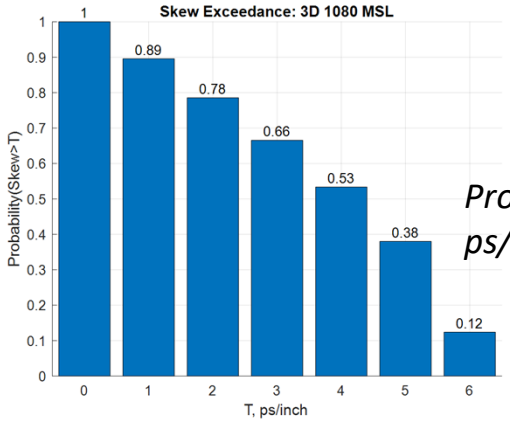


Complimentary Cumulative Distribution Function (CCDF) -> Differential Skew Exceedance (DSE)

Probability to have skew exceeding 2 ps/in is 0.23 (23% of all cases)

No cases with Skew>3ps

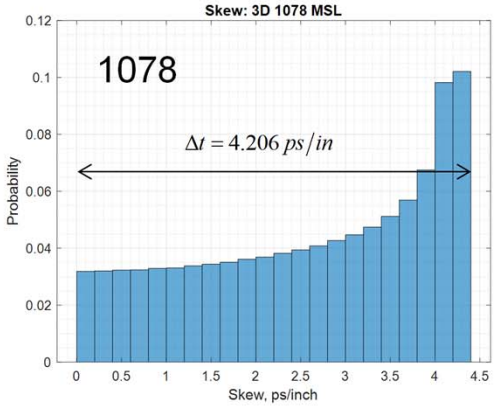


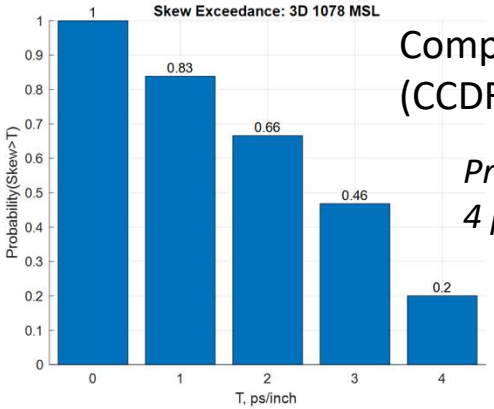


Probability to have skew exceeding 6 ps/in is 0.12 (12% of all cases)

No cases with Skew>7ps

Skew Probability and Exceedance for 1078 & 3313

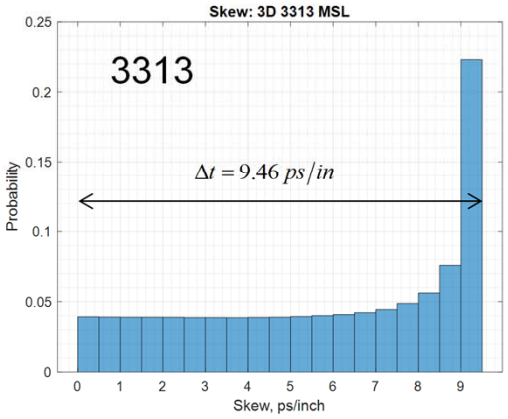


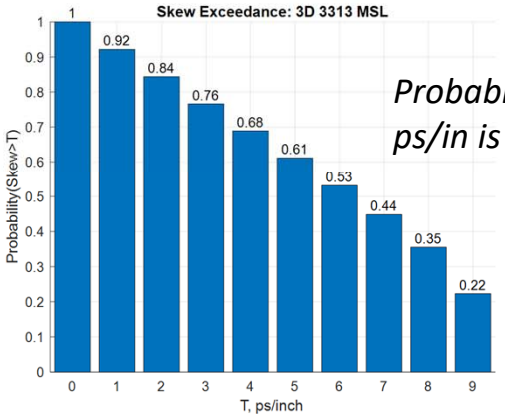


Complimentary Cumulative Distribution Function (CCDF) -> Differential Skew Exceedance (DSE)

Probability to have skew exceeding 4 ps/in is 0.2(20% of all cases)

No cases with Skew>5ps

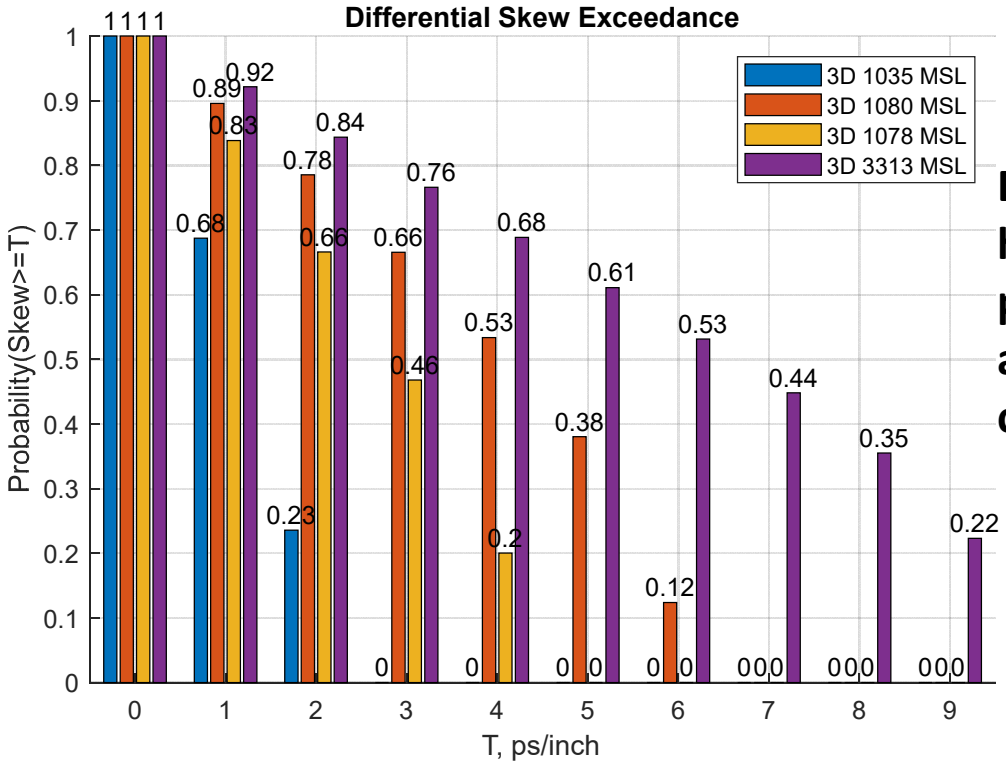




Probability to have skew exceeding 9 ps/in is 0.22 (22% of all cases)

No cases with Skew>10ps

Example of Laminates DSE Comparison



Disclaimer: DSE numbers provided here are purely for illustrative purpose and should not be considered as the actual characteristics of corresponding fabrics

Simulated with Simbeor SDK + Matlab

Approximate Arcsine Model

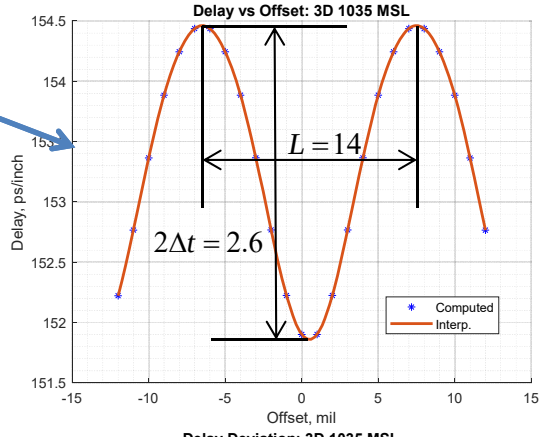
Delay Deviation: $DD(x) = \Delta t \left| \sin\left(\frac{2\pi x}{L} + \alpha \right) \right|, \; x \in [-L/4, +L/4]$

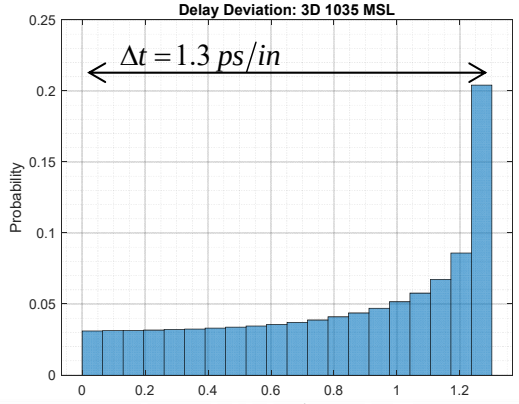
Probability Density Function (PDF): $P(t) = \frac{2}{\pi \cdot \Delta t \sqrt{1 - \left(\frac{t}{\Delta t} \right)^2}}, \; t \in [0, +\Delta t]$

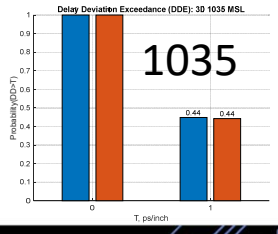
Cumulative Distribution Function (CDF): $F(t) = P(T \le t) = \frac{2}{\pi} \arcsin\left(\frac{t}{\Delta t} \right), \; t \in [0, +\Delta t]$

Complimentary CDF (Delay Deviation Exceedance): $S(t) = P(T \ge t) = 1 - \frac{2}{\pi} \arcsin\left(\frac{t}{\Delta t} \right), \; t \in [0, +\Delta t]$

Require just one parameter – maximal delay deviation!



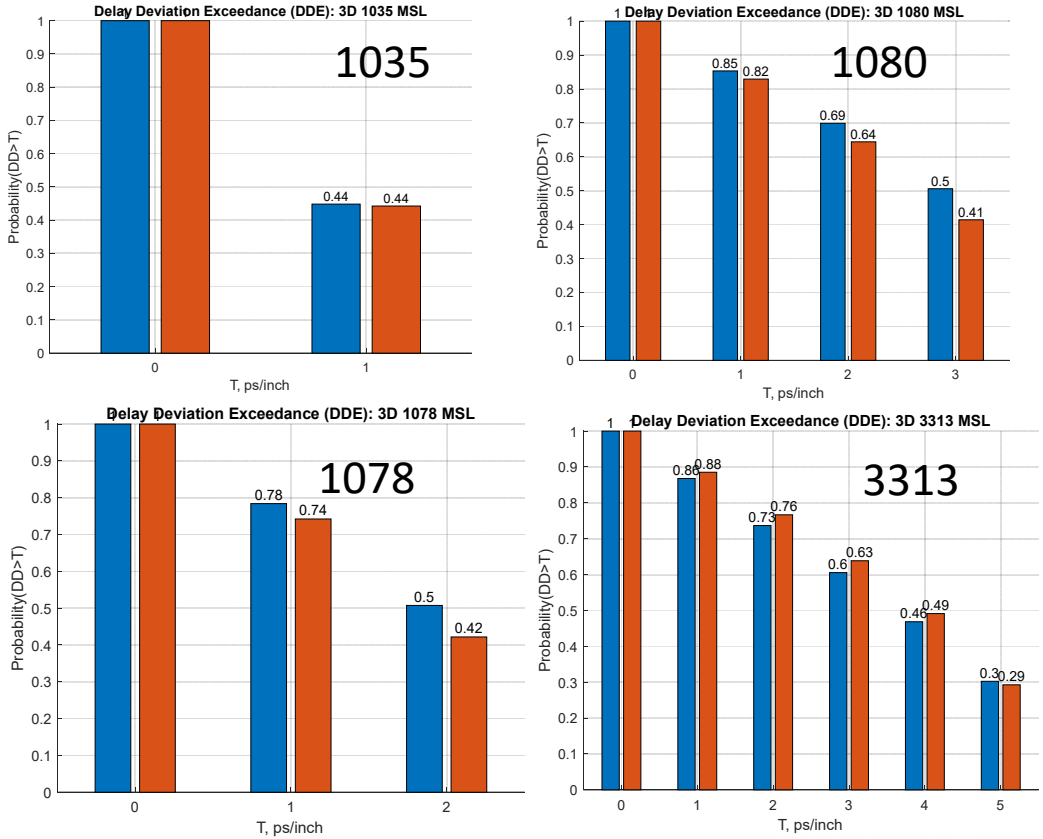




Arcsine Model for DDE (Single-Ended)

Blue bars: directly from numerical experiment
Brown bars: delay deviation from numerical experiment and Arcsine distribution for CCDF

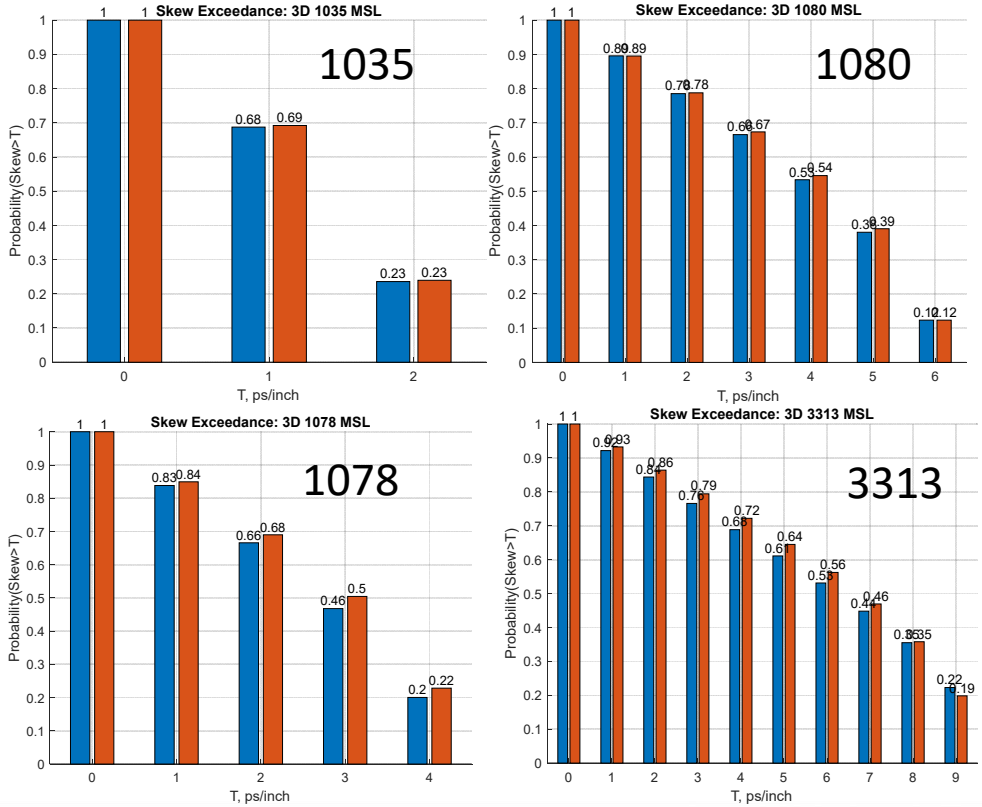
Instead of Arcsine Distribution, Kumaraswamy or Beta Distribution can be used for better accuracy



Arcsine Model for DSE (Differential)

Blue bars: directly from numerical experiment
Brown bars: delay deviation from numerical experiment and Arcsine distribution for CCDF

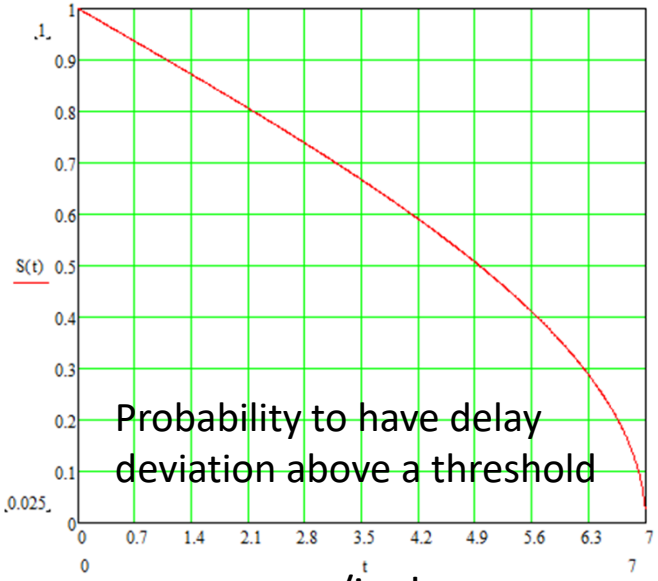
Instead of Arcsine Distribution, Kumaraswamy or Beta Distribution can be used for better accuracy



Practical DDE Evaluation Example 1

Delay Deviation Exceedance for 3313

$$S(t) = P(T \geq t) = 1 - \frac{2}{\pi}\arcsin\left(\frac{t}{\Delta t}\right),\ t \in [0, +\Delta t]$$



Probability to have delay deviation above a threshold

ps/inch

B. Chen, R. Yao, H. Wang, K. Geng, J. Li, Effect of Fiber Weave Structure in Printed Circuit Boards on Signal Transmission Characteristics. *Appl. Sci.* 2019, *9*, 353.

$$dt := \frac{L\cdot\left(\sqrt{\varepsilon max} - \sqrt{\varepsilon min}\right)}{2c0}\cdot 10^{12}$$

L=1 inch

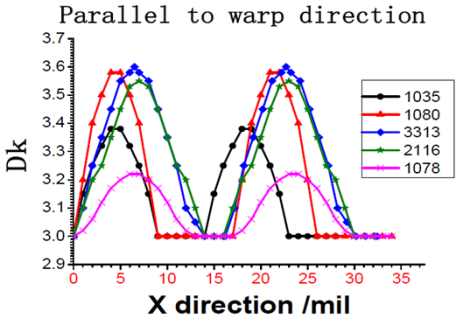
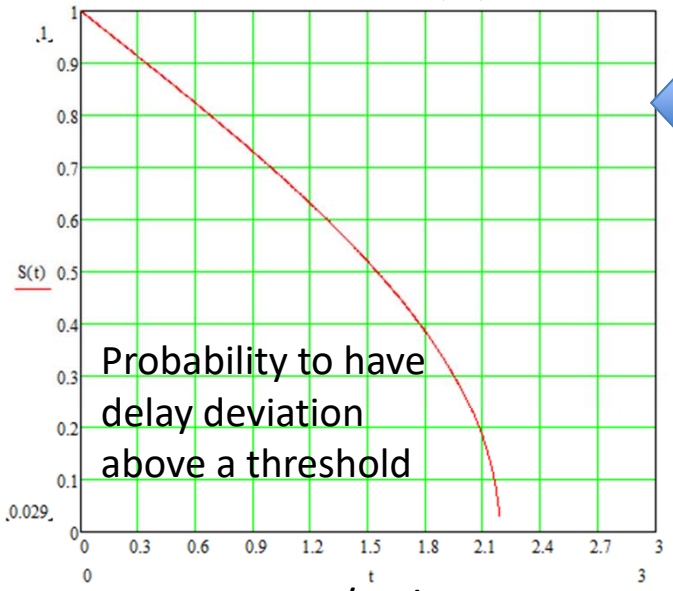


Figure 4. The Dk fluctuation amplitude parallel to warp direction.

Practical DDE Evaluation Example 2

Delay Deviation Exceedance for 2116

$$S(t) = P(T \geq t) = 1 - \frac{2}{\pi}\arcsin\left(\frac{t}{\Delta t}\right),\ t \in [0, +\Delta t]$$

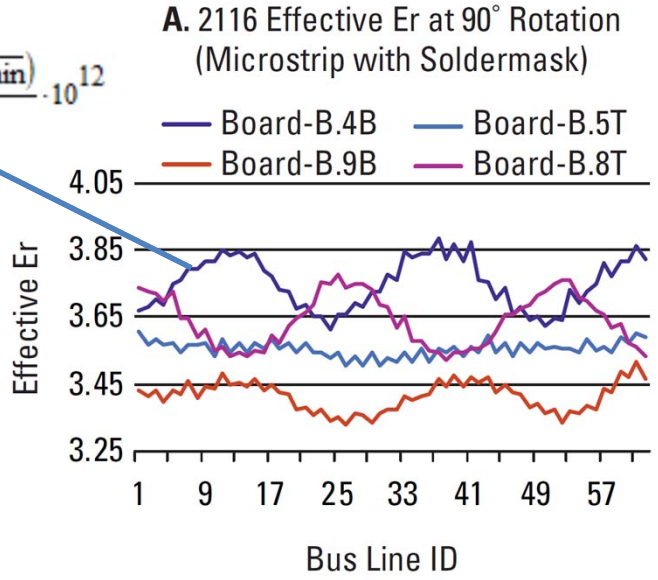


ps/inch

$$dt := \frac{L\cdot\left(\sqrt{\varepsilon max} - \sqrt{\varepsilon min}\right)}{2c0}\cdot 10^{12}$$

L=1 inch

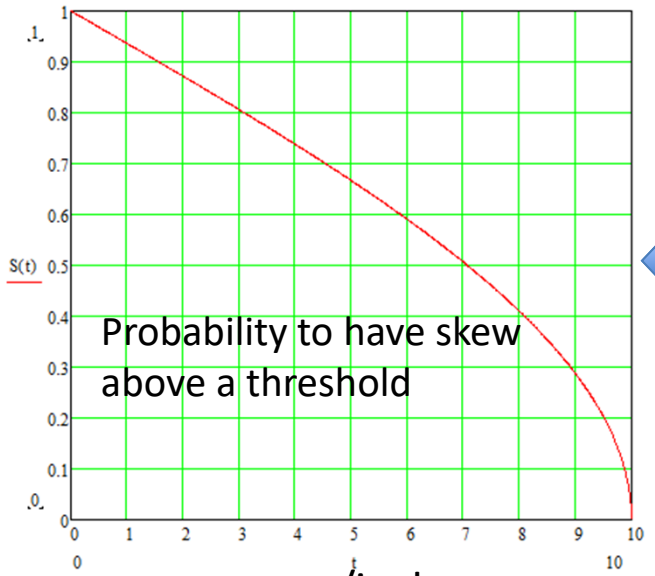
G. Brist, B. Horine and G. Long, "Woven glass reinforcement patterns", Printed Circuit Design & Manufacture, pp. 28-33, Nov. 2004.



Practical DSE Evaluation Example

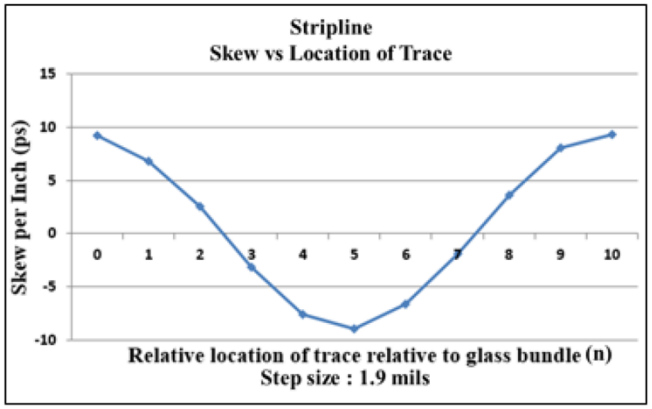
Differential Skew Exceedance

$$S(t) = P(T \geq t) = 1 - \frac{2}{\pi}\arcsin\left(\frac{t}{\Delta t}\right),\ t \in [0, +\Delta t]$$



ps/inch

A. Koul, K. Nalla, D. Nozadze, M. Sapozhnikov, Y. Yang, Fiber weave effect: Modeling, measurements, challenges and its impact on differential insertion loss for weak and strong-coupled differential transmission lines, DesignCon 2018



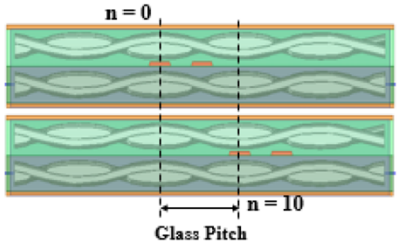


Figure 18 – Sweeping location of trace w.r.t glass bundle to find worst case skew

CONCLUSION

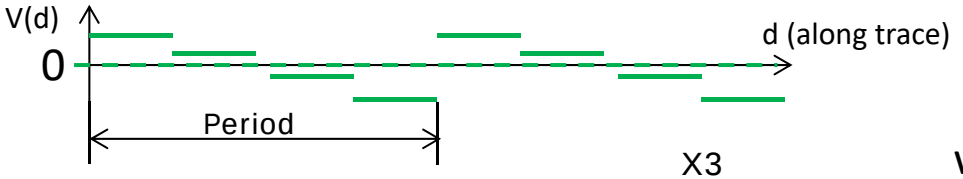
- **To quantify uncertainties introduced by fiber weave effect, two new metrics are introduced**
  - o Delay Deviation Exceedance (DDE) for delay uncertainty in single-ended links
  - o Differential Skew Exceedance (DSE) for skew uncertainty in differential links
- **Examples of fabric evaluation with 3D EM analysis and on the base of experimental data are provided**
- **Arcsine distribution can be used for approximate evaluation of delay uncertainty in DDR buses and skew uncertainty in serdes**
- **Plan for further investigation (see backup slides)**
  - o Effect of small variations of trace direction
  - o Extension to strip line cases

Thank you!

QUESTIONS?

Effect of Small Variations in Trace Direction

Modulation Factor
= 1+V(d)

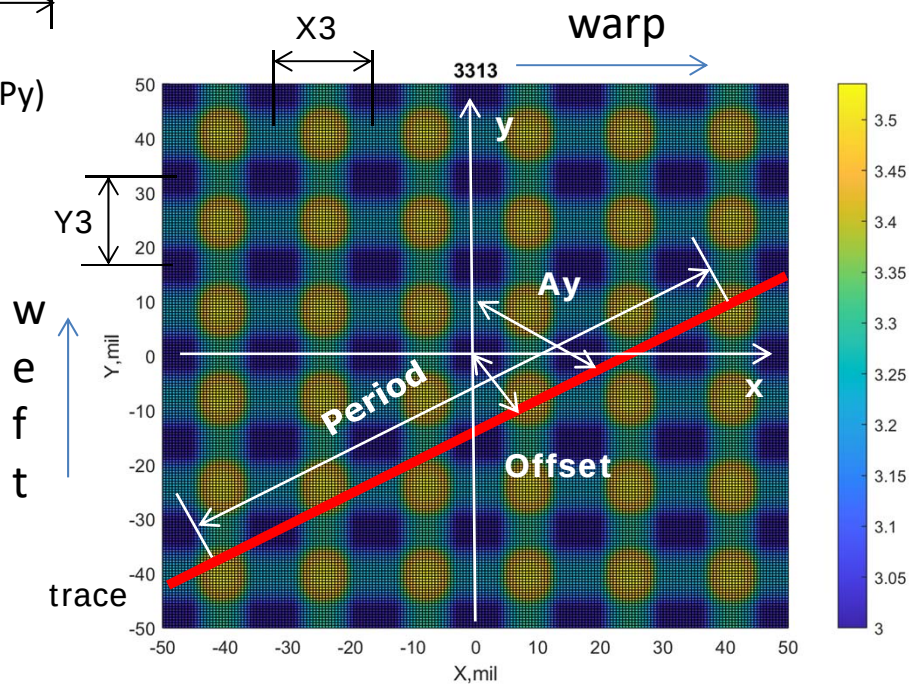


Simbeor NUTL model over 2D bump model of FWE is used to evaluate uncertainty related to angle

Periods from Weft(Py) and Warp(Px)

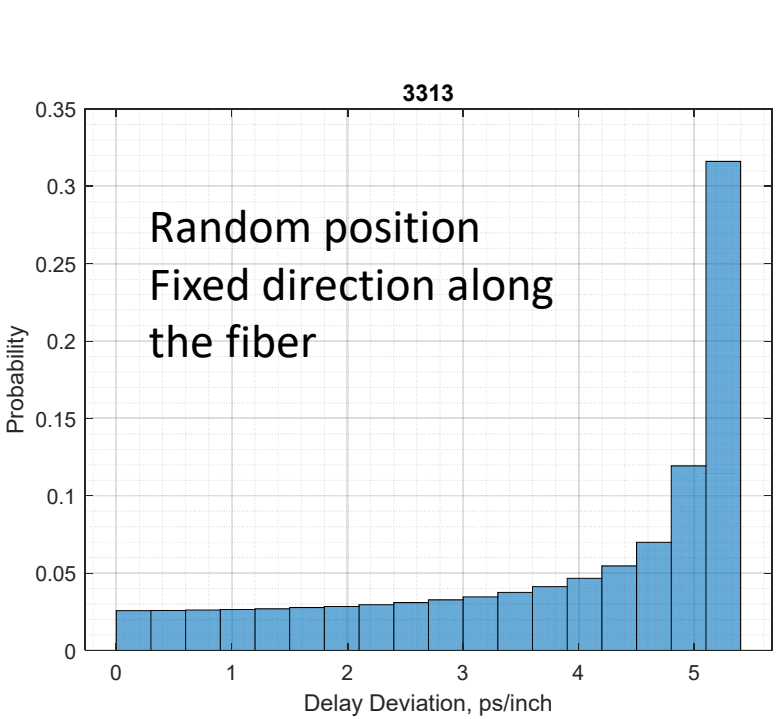
$$Py = \frac{X3}{\sin(Ay)}$$

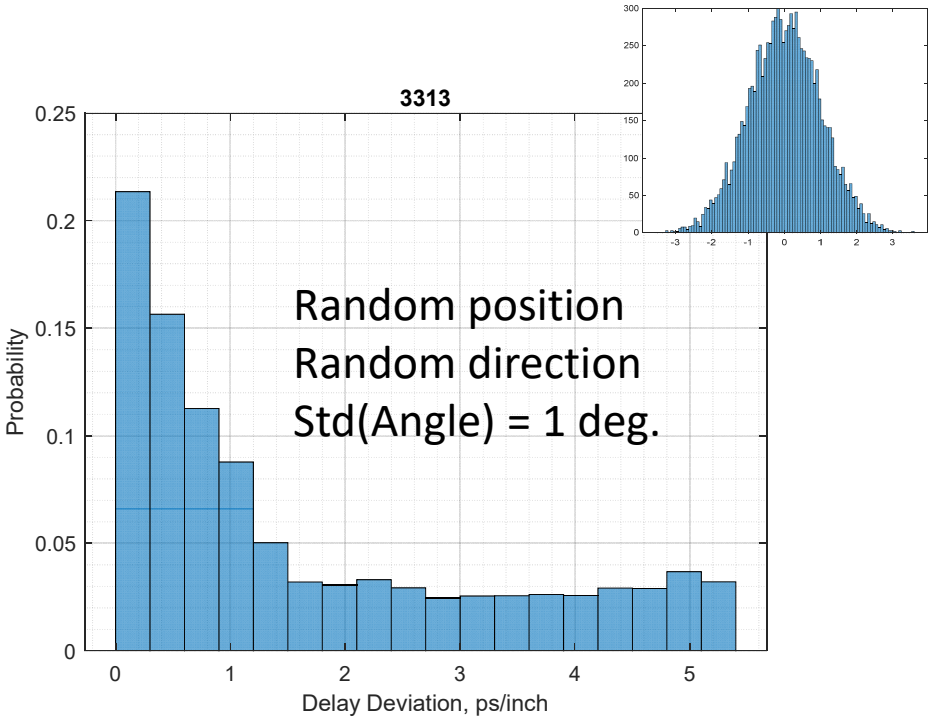
$$Px = \frac{Y3}{\cos(Ay)}$$



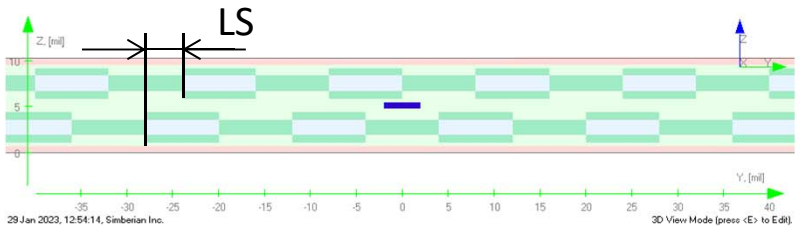
Y. Shlepnev and C. Nwachukwu, "Modelling jitter induced by fibre weave effect in PCB dielectrics," 2014 IEEE International Symposium on Electromagnetic Compatibility (EMC), 2014, pp. 803-808, doi: 10.1109/ISEMC.2014.6899078

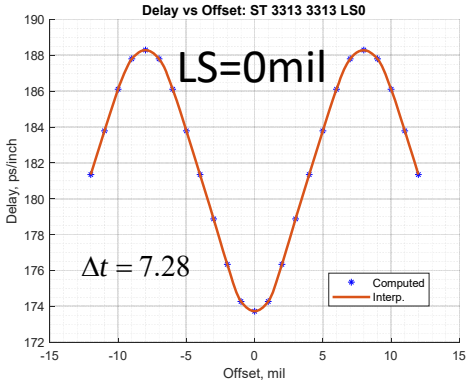
Effect of Small Variations in Trace Direction



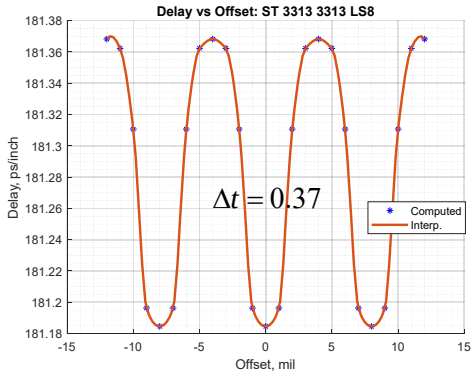


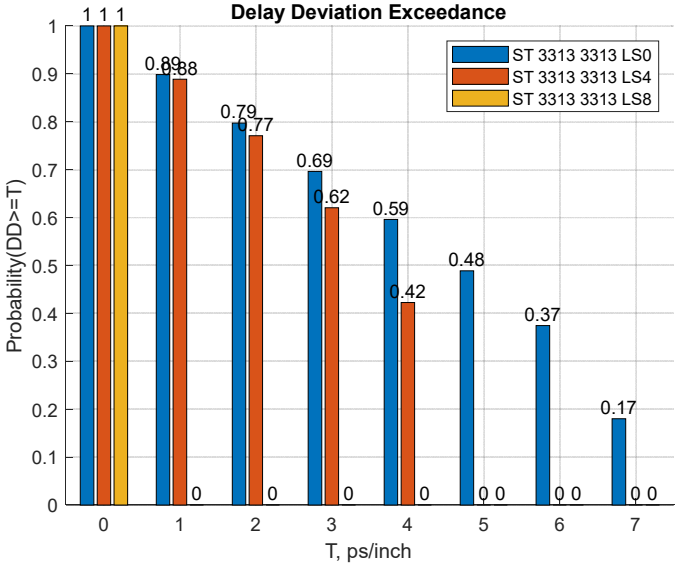
Stripline: 3313 on 3313

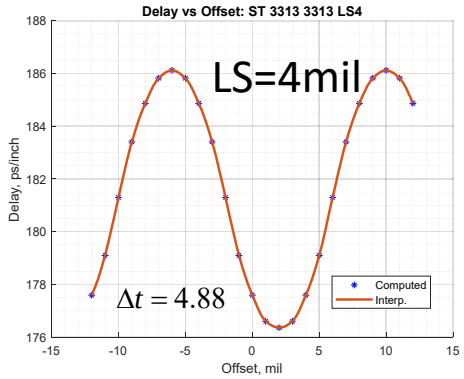




LS=8mil







Possible way to mitigate FWE…