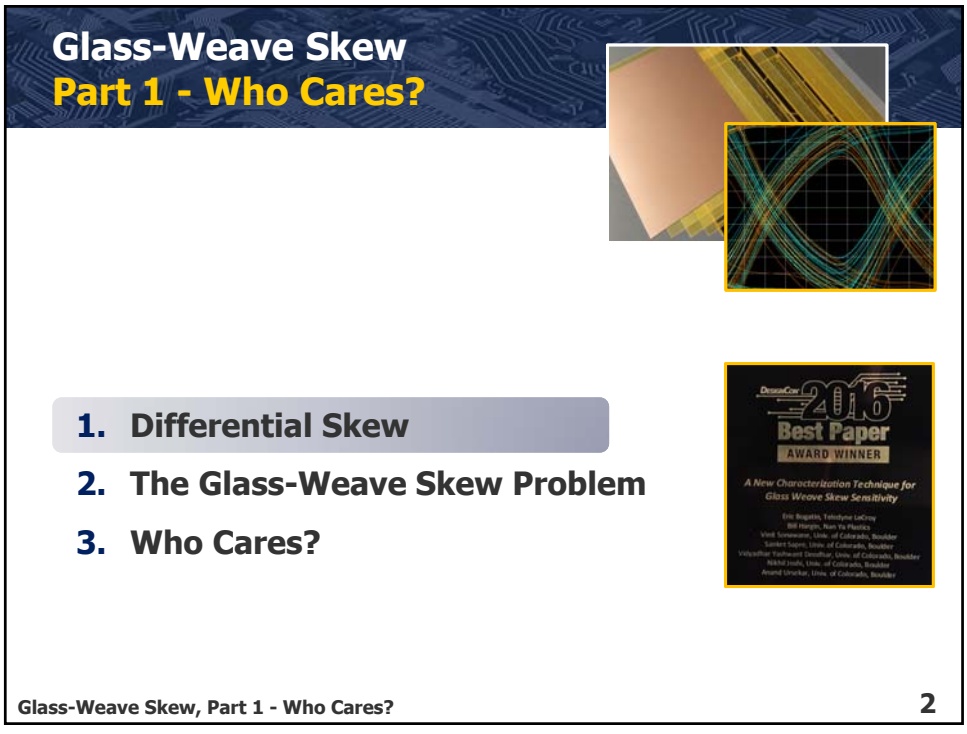
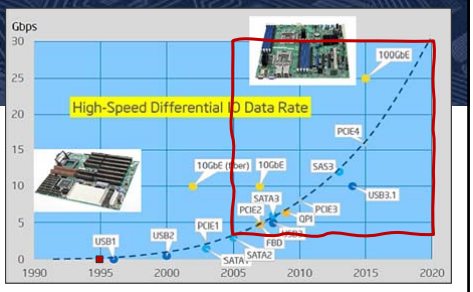
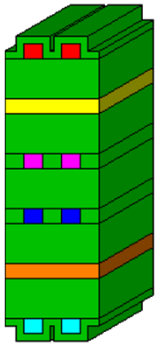



## Some time ago …

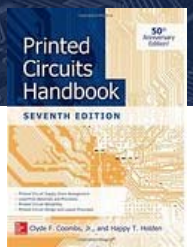



- Speeds were slow
- Layer counts were low
- Dks were high
- Loss Tangents were high
- Design margins were wide
- Copper roughness didn't matter
- Glass weave styles didn't matter
- I weighed less
- We called dielectrics "FR-4"
  - — And their properties didn't matter much



3

## Why do we care?
## Two Worlds at War

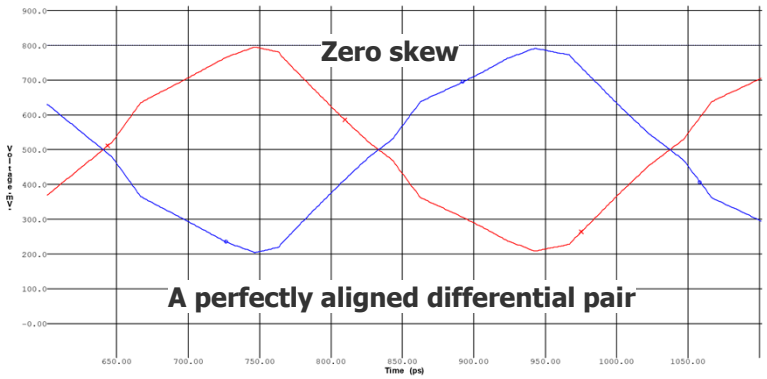



***"Everything … in the process of building a printed circuit board (PCB) … works against signal quality. This is why we spend so much time with 'signal integrity' —the electrical world and the physical world are fighting against each other."***

**Glass-Weave Skew, Part 1 - Who Cares?** Source: Bill Hargin, Printed Circuits Handbook, 7th Ed. 4

## Defining Differential Skew
## Zero Skew

- Differential skew, or simply "skew," is typically measured in picoseconds (ps)

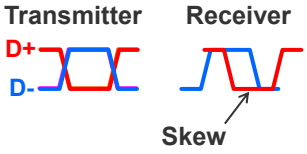



Simulated with HyperLynx LineSim from Mentor. (Lee Ritchey, Speeding Edge, "Minimizing Skew in High Speed Differential Links," 2015.)



## Defining Differential Skew
## 3 Primary Sources

- Skew or misalignment of the two edges in a diff pair can come from three places:
  1. Signal misalignment coming out of the transmitter due to length mismatches in the IC packages
     - Today's ICs are able to maintain alignment at the package level to as little as 1 picosecond (ps)
  2. Different PCB routing lengths
     - Modern PCB layout tools can match lengths to as close as 1 ps
  3. Differences in flight time on the two paths due to GWS
     - From 10-100 ps
     - "Glass-Weave Skew"
- Misalignment results in ISI



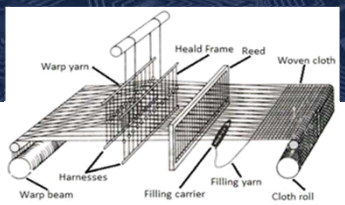
## Defining Differential Skew
## 40 ps of Skew

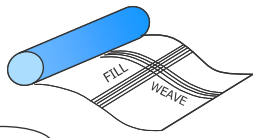
- If one signal arrives before the other, the resulting skew distorts the eye and often results in data errors

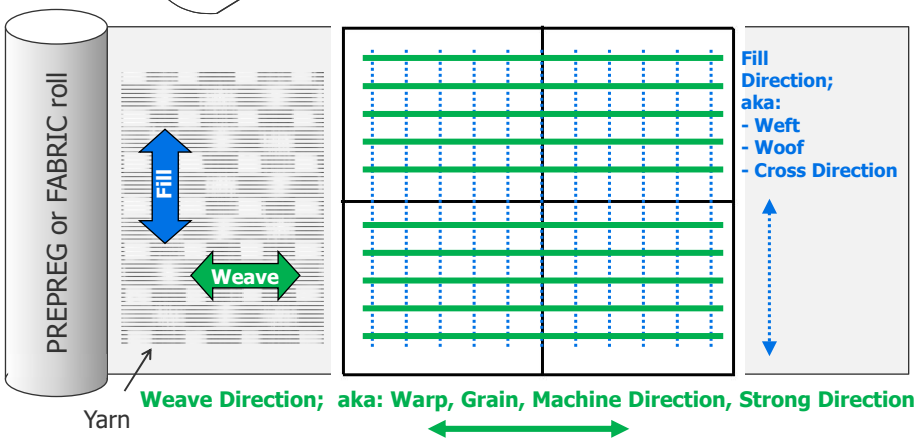

Simulated with HyperLynx LineSim from Mentor. (Lee Ritchey, Speeding Edge, "Minimizing Skew in High Speed Differential Links," 2015.)

Glass-Weave Skew, Part 1 - Who Cares? 7

## Glass-Fabric Terminology
## Weave or "Grain" Direction

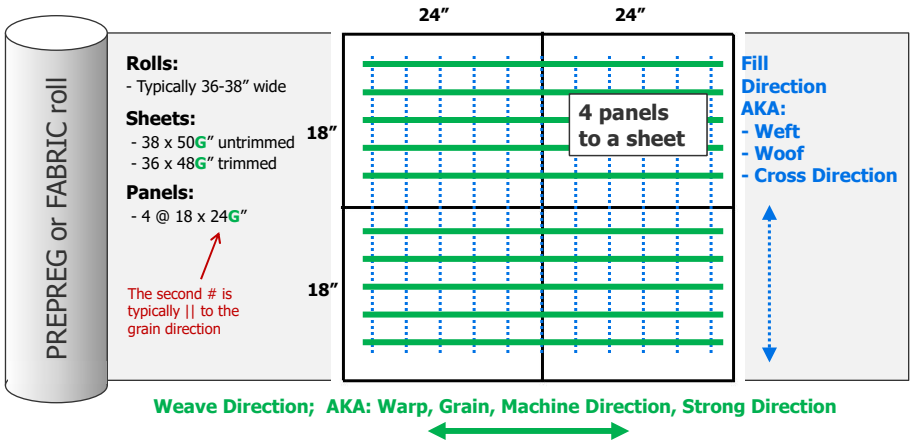



Glass-Weave Skew, Part 1 - Who Cares? 8

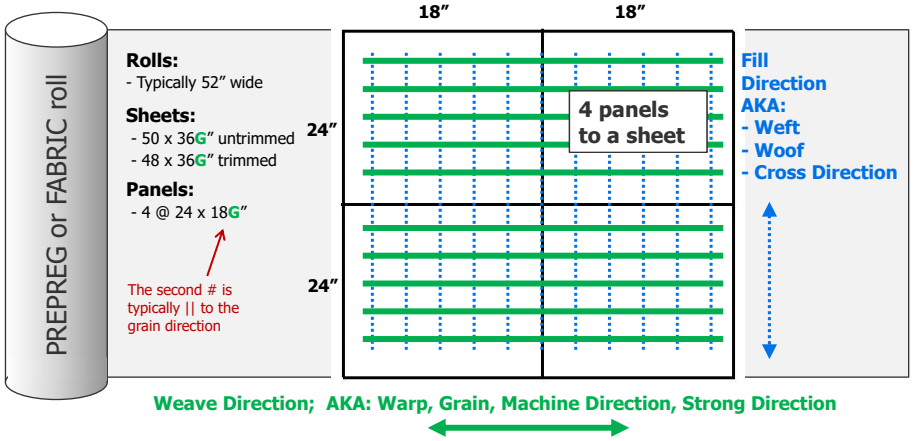
## Sheets, Panels, and Grain Direction
## Longer Dimension || to Weave




- **North America** has run this orientation for many years
- Some large N.A. fabs have shifted to the long dimension || to the fill, to match their high-volume counterparts in Asia

Glass-Weave Skew, Part 1 - Who Cares? 9

## Sheets, Panels, and Grain Direction
## Short Dimension || to Weave

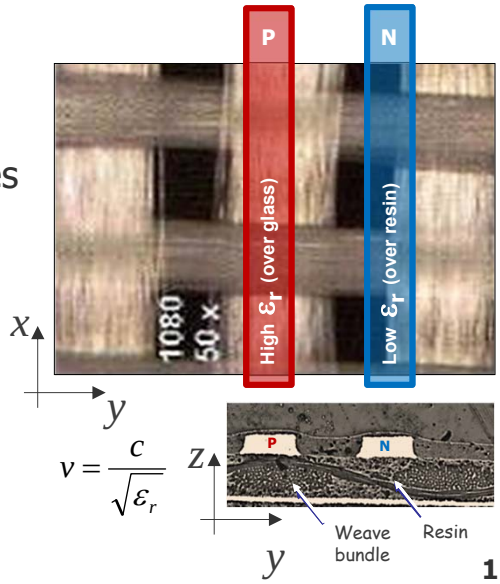



- In **Asia,** the short dimension || to the weave is standard
- At some larger North American fabs, as well (e.g., TTM)

Glass-Weave Skew, Part 1 - Who Cares? 10

## The Glass-Weave Skew Problem
## Signals see Different Er's (Dk)

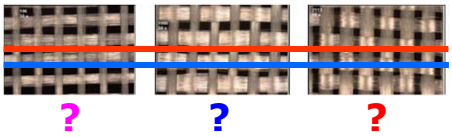
- Different dielectric constants mean different signal-propagation velocities
  - E-glass $\varepsilon_r$~7
  - vs. ~3 for resin
- Signals travel faster when $\varepsilon_r$ is lower
  - A line routed over a glass bundle travels more slowly due to the higher $\varepsilon_r$

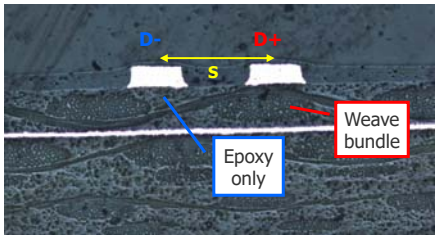



Glass-Weave Skew, Part 1 - Who Cares? 11

## The Glass-Weave Skew Problem
## Difficult to Track

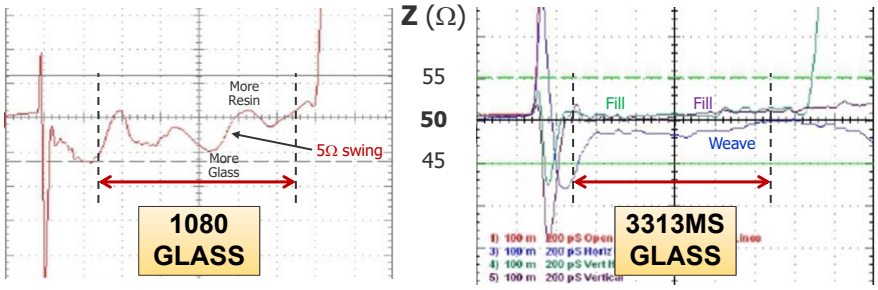
- A *real* problem, but hard to characterize because it's statistical in nature
- What is the chance that one line in a pair will see a different dielectric constant than the other?
  - It depends on glass pitch, differential trace pitch, glass weave, line length, fabric and resin Dk, and the chance alignment of the glass bundles under the two lines




Glass-Weave Skew, Part 1 - Who Cares? Adapted from Jeff Loyer, et al, "Fiber Weave Effect: Practical Impact Analysis and Mitigating Strategies," DesignCon 2007 12

## Fiber-Weave Effect
## Glass Style's Impact on Impedance Variation




- Impedance variation is due to Dk variation
- This also causes velocity to vary, resulting in differential skew in differential pairs

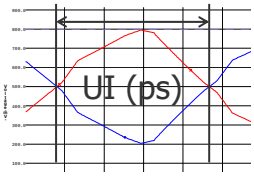
$$V_p = c\sqrt{\frac{1}{D_k}}$$


Bill Hargin, Z-zero
Measurements from Lee Ritchey, Speeding Edge


## Glass-Weave Skew (GWS)—Who Cares?
## AKA: Fiber-Weave Effect (FWE)

- Skew tolerance
  - The generally-accepted skew that a differential channel can tolerate is one-quarter UI before signal quality degrades and data is lost (ISI) Lee Ritchey, DesignCon
- More conservative
  - Most high-speed serial links specify that a line-to-line skew in a channel should be less than 20% the unit interval (UI)

Eric Bogatin, Signal and Power Integrity - Simplified




Fastest Signaling Speeds

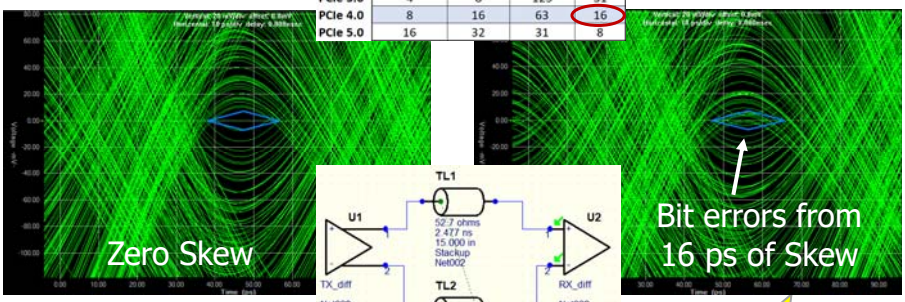
$$20\%\ UI\ (pSec) = \frac{(0.20)\ x\ 1000}{Data\ Rate\ (Gbps)}$$

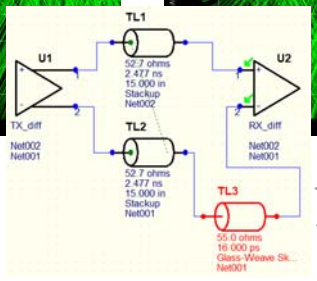
| Data Rates (Gb/s) | Unit Interval (pSec) | Quarter UI (pSec) | 20% UI (pSec) |
|---|---|---|---|
| 1 | 1000 | 250 | 200 |
| 2.4 | 417 | 104 | 83 |
| 3.125 | 320 | 80 | 64 |
| 5 | 200 | 50 | 40 |
| 6.125 | 163 | 41 | 33 |
| 10 | 100 | 25 | 20 |
| 13.5 | 74 | 19 | 15 |
| 27 | 37 | 9.3 | 7 |
| 40 | 25 | 6.25 | 5 |
| 100 | 10 | 2.5 | 2 |

## Glass-Weave Skew (GWS)—Who Cares?
## PCIe 4.0 Example – 16 Gbps

The cause and effect are clear …

| | Frequency (GHz) | Data Rates (Gb/s) | Unit Interval (pSec) | Quarter UI (pSec) |
|---|---|---|---|---|
| PCIe 3.0 | 4 | 8 | 125 | 31 |
| PCIe 4.0 | 8 | 16 | 63 | 16 |
| PCIe 5.0 | 16 | 32 | 31 | 8 |




The problem is that this failure won't necessarily show up in prototypes.

The only symptom is field failure.

Glass-Weave Skew, Part 1 - Who Cares? Simulated with HyperLynx 15

## Q&A
## Resources

**THANK YOU!**

- 3 questions during recorded session
- Additional questions offline
- E-mail: billh@z-zero.com


**PLANNER Enterprise**

- GWS software tutorial
- z-zero.com/z-planner-enterprise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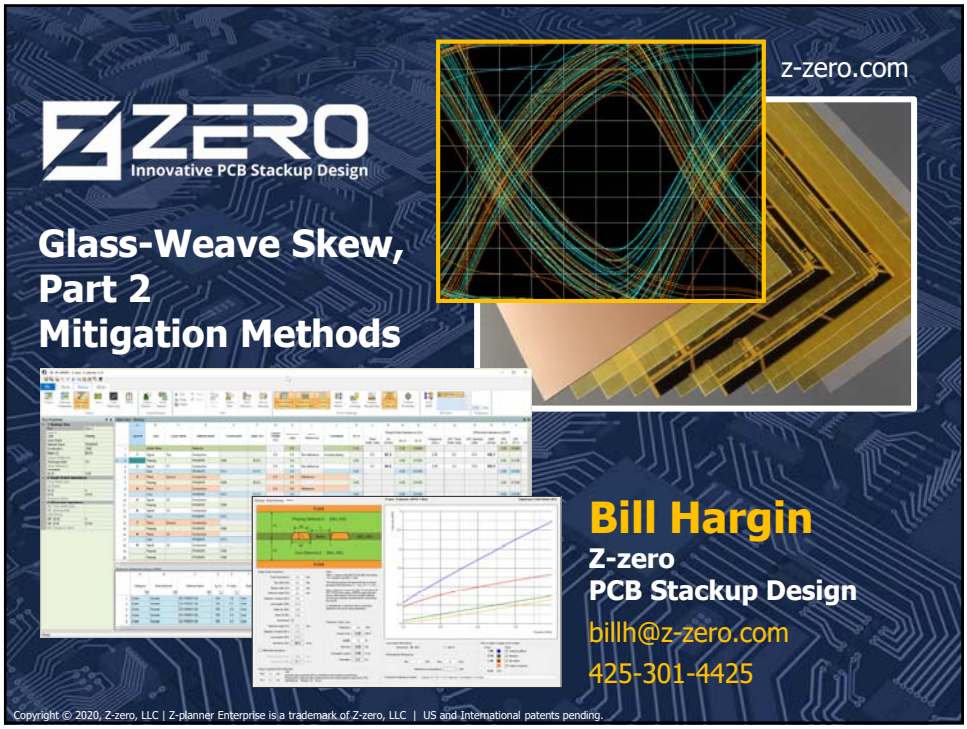
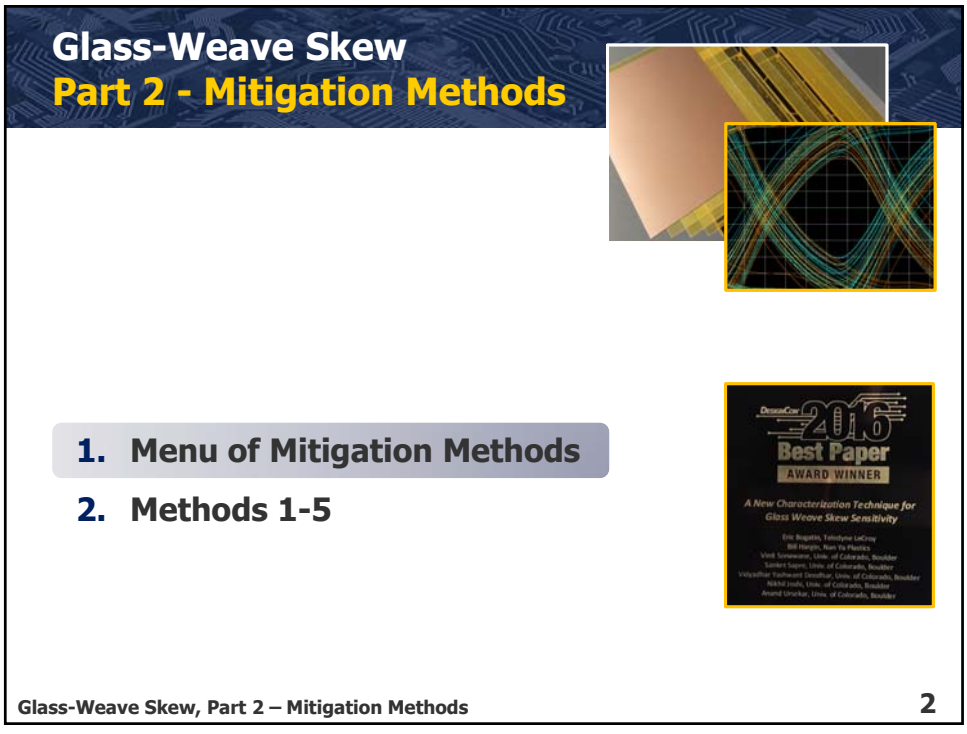
- Next webinar
- Glass-Weave Skew, Part 2
- 4/29/20

Glass-Weave Skew, Part 1 - Who Cares? 16



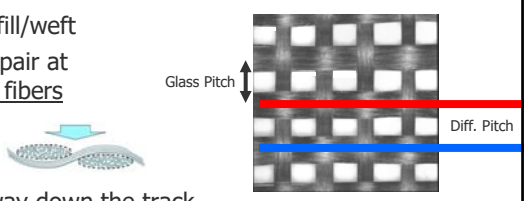
## Proposed Methods for Controlling Weave Induced Skew

Several methods have been proposed …

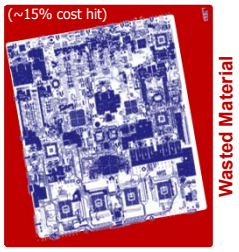
$
1. Choose a glass style that minimizes resin windows
2. Align trace direction to the fill/weft
3. Route each member of the pair at the same pitch as the glass fibers
4. Mechanically spread glass
5. Dual-ply glass

$$
6. Half weave pitch jog—halfway down the track
7. Zigzag routing of differential pairs at a 10º angle to the weave
8. Build each PCB with the artwork rotated at a 10º angle to the panel and weave
9. Use glass with a lower dielectric constant (closer to the resin Dk)

$$$
10. Use PTFE (Teflon) laminate





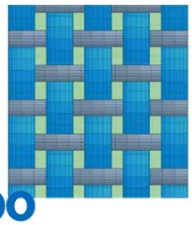

Various industry sources



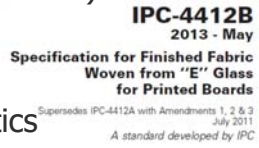
## Glass/Epoxy Laminate Landscape

- There are 3 big weavers
  - — Asahi
  - — Nanya
  - — Nittobo
  - — And several smaller weavers

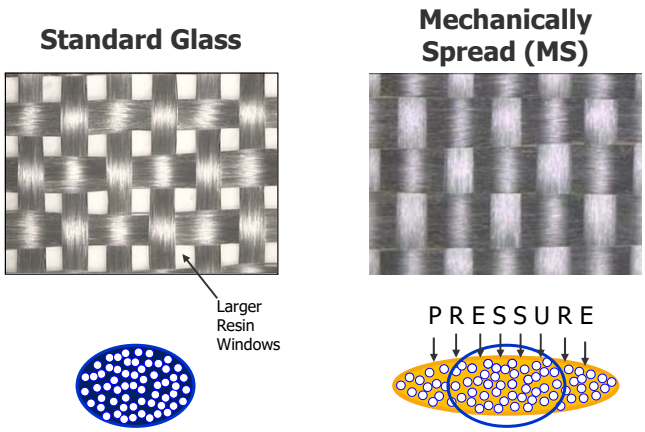
AGC NAN YA Nittobo



- And 10 or so laminate vendors
  - — Who often get their glass from multiple sources
  - — Exceptions: Nanya and Isola, who make their own glass (possibly AGC-Nelco … I need to check)
- A cat-herding exercise
  - — Unless you know the glass source, you don't know its characteristics



## Terminology: Mechanically-Spread Glass

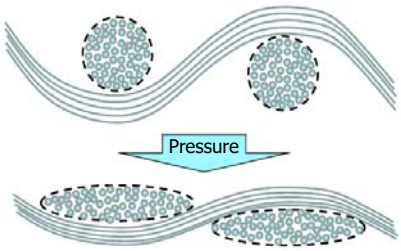



Adapted from Lee Ritchey, Speeding Edge

Glass-Weave Skew, Part 2 – Mitigation Methods 5

## Loose Definitions: Flat vs. Spread Glass

- Various names for 3 glass types tied to GWS
  - Standard glass
  - Spread glass ("expanded filaments")
  - Super-spread glass ("flat"/"flattened")
- Spread glass
  - Standard glass is spread through watter jetting
- Super-spread glass
  - Watter jetting followed by an additional process where the glass is pressed between heavy calendaring rollers




Glass-Weave Skew, Part 2 – Mitigation Methods 6

## Two Primary Methods of Characterizing Spread Glass

1. Airflow resistance/permeability (AP) method
2. Window size (microscope) measurement method

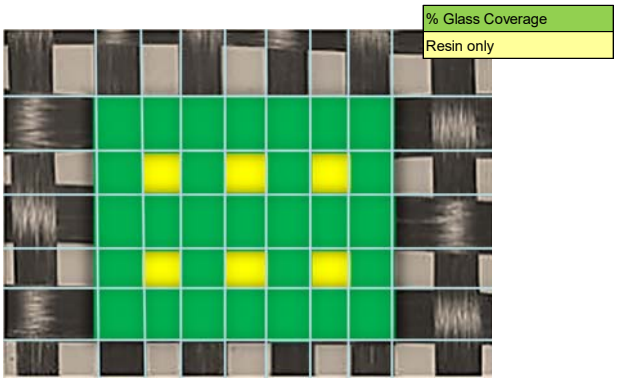
- Glass manufacturers are roughly split 50/50 on the two methods


ASTM 737-96 Airflow resistance/permeability test setup



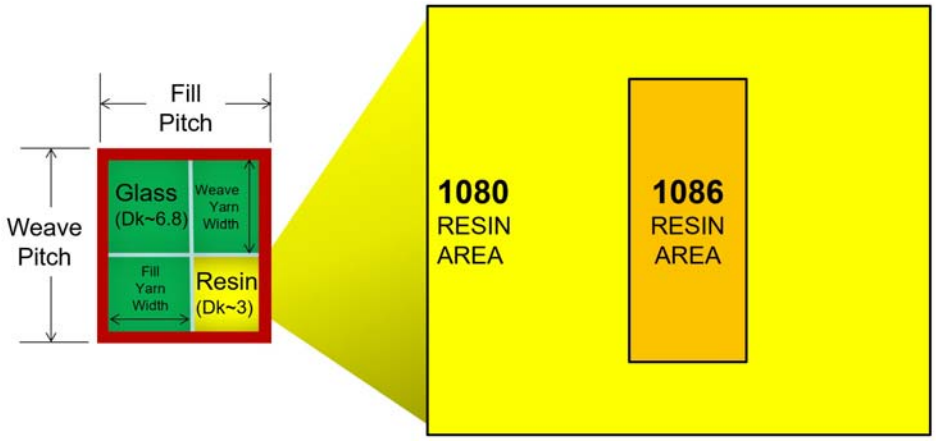
## Window Size: % Coverage of Glass Fabrics

- % Coverage = Area share of glass fabric
- Theoretical Max is 100%, though actual % Coverage is going to be less than that, of course
- The rest is resin




Bill Hargin, "How to Avoid Getting Totally Skewed, Part 3," Printed Circuit Design & Fab, Aug. 2019

## Example:
## Comparing 1080 and 1086 Resin Windows

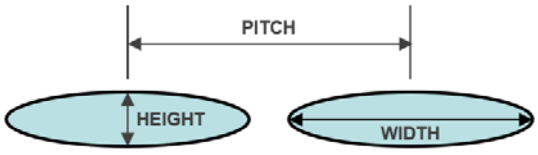



Glass-Weave Skew, Part 2 – Mitigation Methods

Bill Hargin, "Why You Should Quit Using 1080 Glass," Printed Circuit Design & Fab, Oct. 2019

9

## Example:
## Woven Glass Fiber Dimensions




| | | WARP | | | FILL | | |
|---|---|---|---|---|---|---|---|
| | | HEIGHT | WIDTH | PITCH | HEIGHT | WIDTH | PITCH |
| Nanya CCL | 106 | 0.82 | 8.50 | 17.89 | 0.73 | 15.55 | 18.21 |
| Isola | 106 | 1.00 | 4.80 | 18.50 | 0.60 | 10.20 | 20.60 |
| Nanya CCL | 1067 | 0.73 | 9.21 | 14.16 | 0.57 | 12.72 | 14.45 |
| Isola | 1067 | 0.82 | 8.85 | 14.30 | 0.78 | 12.40 | 13.70 |

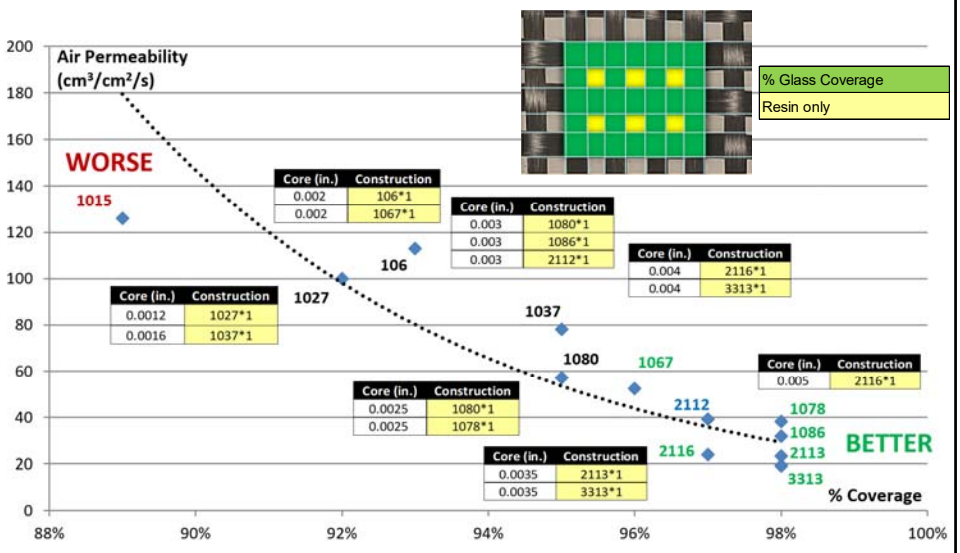
isola 南亞塑膠 NAN YA PLASTICS

Glass-Weave Skew, Part 2 – Mitigation Methods

Bill Hargin, "What's the Difference between 106 and 1067 Glass?" Printed Circuit Design & Fab, May 2019

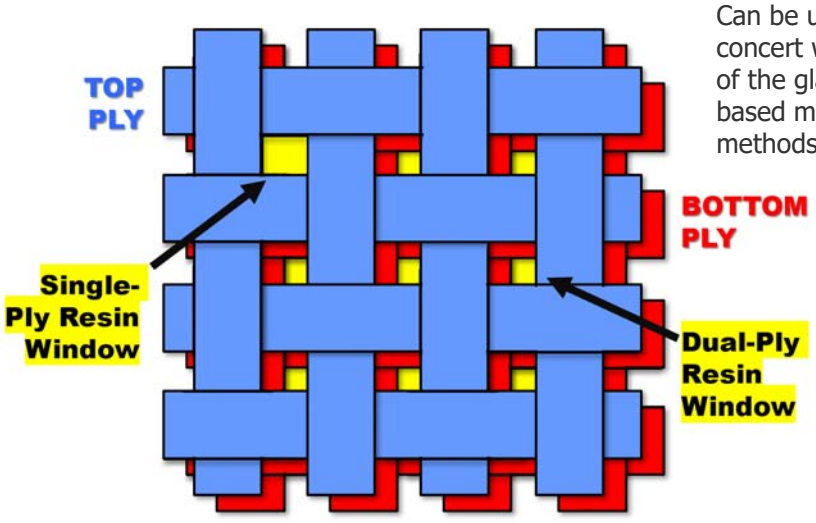
10

## Air Permeability Correlates to Total Glass Coverage




 Source: Nanya Plastics 

## Method #5: Dual-Ply Glass




Can be used in concert with any of the glass-based mitigation methods

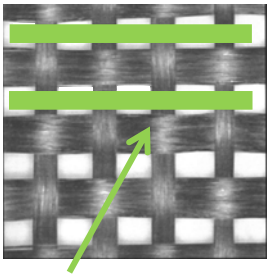
 Bill Hargin, "How to Avoid Getting Totally Skewed, Part 4," Printed Circuit Design & Fab, Sept. 2019 

## Method #3:
## Match Differential Pitch to Glass Pitch

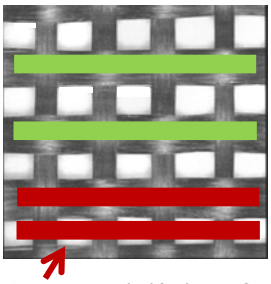
$$Glass\ Pitch = \frac{1000}{Yarn\ Count/inch}$$

**Differential signal pitch matches glass pitch**

OK



Cross-sectional Dk's change from resin to glass to resin, but each t-line experiences the same overall delay



OK

Not OK

Cross-sectional Dk's change from resin to glass to resin on just one line; each t-line experiences a different overall delay

| Construction | Weave Pitch (mils) | Fill Pitch (mils) |
|---|---|---|
| 1027 | 13.3 | 13.3 |
| 1037 | 14.3 | 13.7 |
| 106 | 17.9 | 17.9 |
| 1035 | 15.2 | 14.7 |
| 1067 | 14.3 | 14.3 |
| 1078 | 18.5 | 18.5 |
| 1080 | 16.7 | 21.3 |
| 1086 | 16.7 | 17.2 |
| 2113 | 16.7 | 17.9 |
| 2313 | 16.7 | 15.6 |
| 3313 | 16.7 | 16.1 |
| 2116 | 16.7 | 17.2 |
| 7628 | 22.7 | 32.3 |

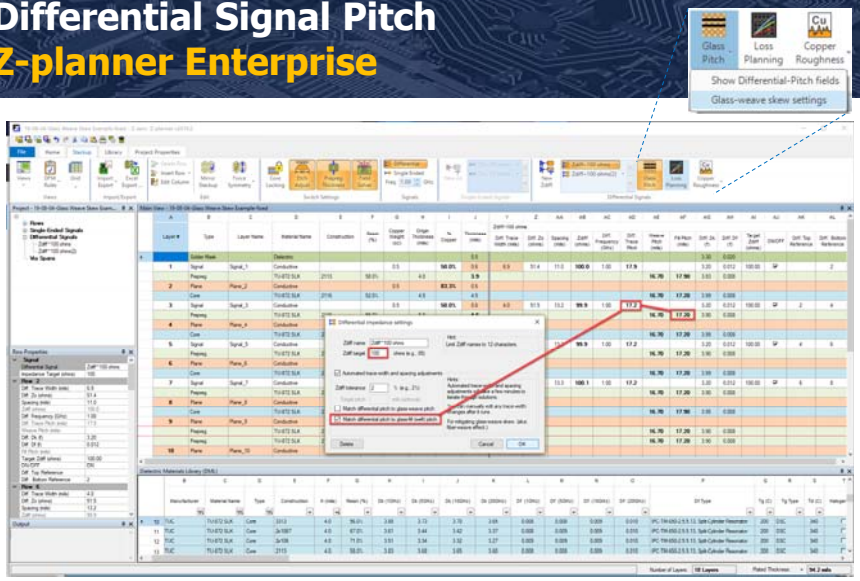
Nominal IPC-4412B glass pitches (+/- two strands) for common glass constructions

**Differential signal pitch DOES NOT match glass pitch**

Adapted from Jeff Loyer, et al, "Fiber Weave Effect: Practical Impact Analysis and Mitigating Strategies," DesignCon 2007



## Differential Signal Pitch
## Z-planner Enterprise



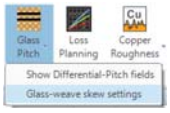

Differential-impedance targets achieved while matching differential pitch to the adjacent glass-fill pitch

* Shown with Z-zero Z-planner

## Q&A
## Resources

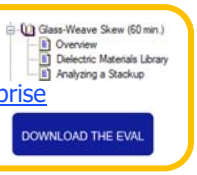
**THANK YOU!**

- 3 questions during recorded session
- Additional questions offline
- E-mail: billh@z-zero.com




**PLANNER** Enterprise

- GWS software tutorial
- z-zero.com/z-planner-enterprise

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- Embedded Capacitance for PDN Design
- 5/13/20 z-zero.com/events/

Glass-Weave Skew, Part 2 – Mitigation Methods 15

## Glass-Weave Skew
## References


1. Bill Hargin, "Who should be Concerned about the Fiber-Weave Effect?," Printed Circuit Design & Fab, May 2020
2. Bill Hargin, "How to Avoid Getting Totally Skewed, Parts 1-4," Printed Circuit Design & Fab, June-Sept. 2019
3. Panel, Amendra Kohl, Bill Hargin, Dave Hoover, Lee Ritchey, Stephen Scearce, "How to Avoid Getting Totally Skewed," DesignCon 2018
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