Additional Trace Losses due to Glass-Weave Periodic Loading

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Introduction

- PCB laminates are composed of resin and a glass fabric
- Two materials have different electrical properties
- Previous publications have looked at the impact of this on differential skew
- In this paper we look at the impact of this on signal loss
- The effect on signal loss is due to periodic loading of the interconnect which alters Dk and Df along the trace
Introduction

- Periodic loading of transmission lines is well understood.
- Prior studies looked at the impact of periodic loading due to plane cutouts on both loss and crosstalk
- Results in a fundamental resonance where the distance is one half of a wavelength
- Creates peak in reflection profile and dip in insertion loss at that frequency
- Magnitude of dip depends on number of discontinuities and size of the discontinuity

Half wave resonance is $\frac{1}{2} \times 500\text{mils} \times 150\text{ps/in} = 6.6\text{GHz}$
Introduction

- Glass weave periodic loading has been ignored presumably due to the relative high half-wave resonance it will establish.
- A number of factors which we will cover make this important now:
  - Data rates are increasing
  - Steepening of loss curve below fundamental
  - Lower frequency resonances can be established

\[
\frac{1}{2} \times 60 \text{mils} \times 150 \text{ps/in} = 55 \text{ GHz}
\]
Agenda

• Examine physical dependencies such as impact of glass thickness, proximity and glass pitch
• Investigate how trace route angle can set up secondary resonance patterns
• Impact of meandering trace routes
• Test structure measurements
• Conclusions
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Examining the Dependencies

- Examined three Cases (a)-(d); Case (e) will be looked at later (as well as meander routes)
- Created a simplified structure representing a unit cell
- Selected a range of values based on glass types
Examining the Dependencies

(a) 0 deg, abutting
(b) 0 deg, overlaid
(c) 0 deg, centered
(d) 90 deg, overlaid
(e) 45 deg

![Graph showing S12 dB vs Frequency for different cases.]

- **Case (a)**
- **Case (b)**
- **Case (c)**

Frequency [Hz] × 10¹⁰
Examining the Dependencies

![Graph](image)
Examining the Dependencies

60 mils

4 mils

S12 [dB]

0 2 4 6

x 10^10

0 -20 -40 -60 -80

Frequency [Hz]

S12 [dB]

0 -50 -100

Frequency [Hz] x 10^10

S12 [dB]

0 -50 -100

Frequency [Hz] x 10^10

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Section Summary

- The glass weave resonance frequency corresponds to the half wave resonance distance between bundles (pitch).
- Although the resonance frequency can be relatively high (dependent on the bundle pitch) there is additional low frequency loss due to this resonance.
- Wider bundles, increased weave thickness and closer proximity to the trace increases the magnitude of the periodic resonance.
- Going forward, when this resonance is generated by a simple repeating unit cell we call this a single-cell periodicity (SCP).
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Impact of Trace Route to Glass Weave Angle

- Looked at traces crossing the weave at 0 or 90 – Cases (a)-(d) – now look at Case (e) and arbitrary angles ($0 < \theta < 45$)
- Due to symmetry, also covers $45 < \theta < 90$
- Glass weaves are typically oriented parallel to the board edges
- Note that even if a trace is also routed parallel to the board edges (0 or 90), there will likely be some small angle that arises
- For now we look at straight traces only (meandering will be covered later)
Impact of Trace Route to Glass Weave Angle

- Example of trace routed in 10 degree steps using Matlab
- 0, 45, 90 only result in a single periodicity (i.e. SCP)
- 45 deg routes will have lowest frequency SCP
- Other angles will have periodicities which span multiple cells – we call these multi-cell periodicities (MCP) – now we look at these in detail

![Graph showing periodicity at various angles]
Impact of Trace Route to Glass Weave Angle

SCP freq decreases as move towards 45 degree

Repeating long range pattern (i.e. MCP)

Separation increases as approach 0 degrees
Impact of Trace Route to Glass Weave Angle

Plot of horizontal crossings for different trace route angles for a 2500 mil trace

Decreasing MCP resonance frequency
Impact of Trace Route to Glass Weave Angle

MCP Resonance 2500 mil trace
Impact of Trace Route to Glass Weave Angle

- Surface plots were generated using Matlab, assuming infinitely thin grid and that the long range periodicities could in fact be established.
- To validate MCPs (beyond Matlab) we used CST MWS.
- CST allowed us to simulate the whole route, without resorting to concatenating unit cells in HFSS.
Impact of Trace Route to Glass Weave Angle

MCP Resonance, 2500 mil trace

(θ=75, pitch=60, Zres=12.4G)

(θ=88, pitch=60, Zres=SCP)

(θ=60, pitch=50, Zres=28G)
Section Summary

- The lowest possible SCP is with a 45 degree route for a square grid.
- When the angle between the glass and trace is other than 0, 45 and 90 degrees it is possible to observe a much lower frequency periodic loading. This type of periodic loading is called Multi-Cell Periodicity (MCP).
- Glass-weave pitch and route angle determine the MCP resonance frequency (as well as the dielectric constant).
- The lowest MCP resonance frequency occurs with widely pitched glass-weaves and trace route angles close to 0 (or 90) degrees.
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Impact of meandering trace routes

- MCP resonances are created when the trace is slanted with respect to the glass bundles, creating periodicity over several or many glass-weave cells.
- MCP can be introduced even if the trace is not slanted due to the trace routing itself. Consider a trace routing through a BGA pin field with plated through hole (PTH) vias.
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Test Structure Measurements

- Test board was designed with 14-inch differential pairs routed parallel to the board edge on different layers and different pitches
- Striplines pairs were measured using VNA to 20 GHz
Test Structure Measurements

Two ‘identical’ boards showed resonances at 11.1 GHz (board #1) and 8.9 GHz (board #2)
Test Structure Measurements

- Test board #1 was milled down from opposite sides
- Can then measure where parallel bundles cross each side of the differential pair
Test Structure Measurements

Distance between parallel bundle crossings (either side of the diff pair)

![Graph showing distance between parallel bundle crossings in mils]

![Graph showing distance between single trace crossings in mils]

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Test Structure Measurements

Nominally 90 but varies up to 4 deg!
Also not constant angle!
Test Structure Measurements

Board #1

Distance between Trace Crossings

- Count
- Distance in [mils]
- BOTTOM
- TOP

Board #2

Distance between Trace Crossings

- Count
- Distance in [mils]
- BOTTOM
- TOP
Test Structure Measurements

Board #1

Board #2
SEM data confirmed two suspicions:

> Upper level dielectric are fairly well aligned (consisting of two independent weaves)

> Vertical separation of glass from trace is very small (~0.1mils) (which we know increases the glass weave resonance)
Section Summary

- Trace to glass-weave routing angle can vary by layer and can be different above and below the trace.
- Trace to glass-weave routing angle can vary along the trace length.
- A wide distribution of resonances can be introduced due to the variation in glass-weave angle along the trace's length.
- Measurement results showed an insertion loss dip at two different frequencies on two otherwise identical boards, which showed correlation to the distribution of MCP trace crossings.
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Conclusions

• Identified a new trace loss mechanism due to glass-weave periodicity

• Glass-weave periodic loading was demonstrated using physical measurements and s-parameter measurements of test boards, field solvers (CST and HFSS) and Matlab simulations

• Two terms identified: SCP and MCP

• SCP have a high resonance frequency but there is additional loss below fundamental

• MCP come about when longer range unit cells are established introducing much lower resonances
Conclusions

• 45 degree routes are preferred to minimize differential skew but results in lowest SCP

• 0 and 90 degree routes, on the other hand, have their own issues due to MCPs

• Glass-weave routing angle was found to vary layer by layer and along the entire length of the trace

• Due to the random nature of the weave simulating this effect a priori is not feasible
Conclusions

Possible mitigation strategies:

- Tightening the weave by spreading out the glass fabric
- Increase resin Dk
- Decrease glass Dk
- Randomized routing angle
- Randomized jogging patterns
THANK YOU!