Outline

• Introduction
• Background theory and simulation methodology
• Test board definition and measurements
• Measurement to simulation correlation
• Periodic discontinuities characteristics
• Parameterization studies
• Summary and conclusions
• Q & A
Introduction

• Periodic discontinuities, what are they?
  • Refers to the loading of some element, for example, a transmission line, at periodic intervals
  • Many kinds can be found in practice, ranging from the periodic loading in multi-drop busses, to the periodic loading of plate capacitors

• Which ones are we going to study and why?
  • Traces routed over perforated planes.

→ We will present parametric studies on realistic cases and will show its effects
Background theory and simulation methodology

- Periodically loaded transmission lines can be analyzed by identifying a unit cell, which is repeated along the structure, and calculating the loaded propagation delay.
- Unit cell length -> half wave resonance
- Number of unit cells -> size of the resonance
- Discontinuity size/kind -> size of the resonance dip
- From a practical standpoint, we could, for example, get the unit cell from a field-solver
- Or, do different type of analysis, for example

\[
\cosh(\gamma_p d) = \cosh(\gamma d) + \left(\frac{Z_d}{2Z_0}\right) \sinh(\gamma d)
\]

Length of one unit cell

\[
A = D = \cosh(\gamma d) + \left(\frac{Z_d}{2Z_0}\right) \sinh(\gamma d)
\]

\[
B = Z_0[\sinh(\gamma d) + \left(\frac{Z_d}{2Z_0}\right) \{\cosh(\gamma d) + 1\}]
\]

\[
C = \left[\sinh(\gamma d) + \left(\frac{Z_d}{2Z_0}\right) \{\cosh(\gamma d) - 1\}\right] / Z_0
\]
Simulation plan

Gain modeling confidence level

Design guidelines

Create a test board:
- Easily modifiable
- Simple to measure
- With “N” unit cells

HFSS:
- Solve a single unit cell

Many variations

Same?

yes

no

Concatenate “N” unit cells

Periodical-disc effects study

Transmission Line generation

Simulation of:
- Saturation
- Frequency dependency

Results and conclusions

Real case simulations, definitions and parameterization
Test board

2.5 mm wide, 6in long microstrip on top of a 800 mil wide, 63 mil thick FR4 dielectric

Fixed 125 mils from the edge of the trace to center of the hole

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

500mils pitch

Edge launch SMA

Hole diameter increased from: 125, 164, 194, 250mils

TDR response (rho)
Test board measurements

S21 magnitude [dB]

Baseline

Solid plane 125-mil

164-mil 194-mil 250-mil

Half wave resonance

Dip

Frequency [Hz]

Full wave resonance
Simulation setup

- Ansoft HFSS, v10
- Unit cell approach used
- Material: FR4
  - $D_k = 4.5$
  - $\tan \delta = 0.03$
- The hole diameters were progressively increased to match the test board
- MATLAB was used to perform the concatenation of 12 unit cells
Measurement correlation (1)

Good correlation

Used a frequency independent dK

- Good correlation

- Simulated

- Measured

- 250mils hole diameter

- 194mils hole diameter

- Frequency [GHz]

- dB
Measurement correlation (2)

164 mil hole diameter

125 mil hole diameter
Periodically loaded line characteristics

- Doing some mathematical post-processing, several periodic discontinuity effects can be studied.
  - Study 1: Examine how the location of the resonance dip changes as a function of unit cell length
  - Study 2: Examine the first resonance amplitude as a function of the number of cascaded cells for a 500-mil long unit cell
Frequency vs. pitch dependency

12 unit cells

\( \frac{1}{2 \times \text{tpd}} \)
Saturation effect

Increasing number of cells

(Baseline – Dip) / (numbers of Cells)

Number of Cells

frequency [GHz]

dB

0 25 50 75 100

5.9 6.1 6.3 6.5 6.7

0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18

0 50 75 100

Baseline – Dip / (numbers of Cells)
Parameterization

• Examine the impact of additional losses introduced by the periodic discontinuities in real-world designs
• Large number of variables including:
  • Number of periodic discontinuities
  • Distance between the discontinuities
  • Separation between the discontinuity and the trace
  • Size of the discontinuity
**Parameterization cases**

- **Case 1:** Trace routed through a pin field, such as a connector, where the trace would periodically encounter a hole located on either side of a trace.

- **Case 2:** Trace routed near to a single cutout but due to misregistration and manufacturing tolerances, the trace gets routed over a portion of the plane cutout.

<table>
<thead>
<tr>
<th>Example: 4 mil line width, BGA (1mm, 39.37 mil), 30 mil antipad</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
</tr>
<tr>
<td>Different core misregistration</td>
</tr>
<tr>
<td>Same core misregistration</td>
</tr>
</tbody>
</table>
Parameter ranges

- 50-ohm microstrip was simulated using a 4-mil wide trace and a 4-mil thick dielectric (2%, $\varepsilon_r=4.5$)
- Number of periodic discontinuities: 10
- Distance between the discontinuities: 500 mils ($\lambda/2=6.6$ GHz)
- Trace to hole separation: -4 (-100%) mils to 6 mils (+150%)
- Size of the discontinuity (antipad diameter): 50 mils to 150 mils
Case 1, third resonance
Parameterization

(20.23 GHz)
Case 1, second resonance Parameterization

(13.44 GHz)
Case 1, first resonance
Parameterization

(6.89 GHz)
Case 1, etch to antipad separation
Parameterization

![Graph showing parameterization results with edge-to-edge [mils] on the x-axis and extra-loss [dB (%baseline)] on the y-axis. The graph includes three lines: f1, f2, and f3, each representing different conditions or frequencies. The y-axis shows extra-loss in dB (%baseline) ranging from 0% to 3% at various points. The x-axis shows edge-to-edge [mils] ranging from 0 to 150%. A 100 mil antipad diameter is indicated.]
Case 1, antipad diameter change
Parameterization

![Graph showing the relationship between extra-loss [dB] and hole diameter [mils].](image)

- **0 mil separation**:
  - f1: 0.2 dB (0%)
  - f2: 0.5 dB (6%)
  - f3: 1.0 dB (11%)

- **50 mil separation**:
  - f1: 0.5 dB (6%)
  - f2: 1.0 dB (11%)
  - f3: 1.5 dB (16%)

- **100 mil separation**:
  - f1: 1.0 dB (11%)
  - f2: 1.5 dB (16%)
  - f3: 2.0 dB (22%)

- **150 mil separation**:
  - f1: 1.5 dB (16%)
  - f2: 2.0 dB (22%)
  - f3: 2.5 dB (27%)

- **200 mil separation**:
  - f1: 2.0 dB (22%)
  - f2: 2.5 dB (27%)
  - f3: 3.0 dB (32%)
Case 2, third resonance
Parameterization

(extra-loss [dB (%baseline)]

10 (106%)
8 (85%)
6 (64%)
4 (43%)
2 (22%)
0 (0%)
120

hole-diam [mils]

edge-to-edge [mils (% baseline)]

(20.23 GHz)
Case 2, second resonance Parameterization

(13.44 GHz)
Case 2, first resonance Parameterization

(extra-loss [dB (%baseline)]

hole-diam [mils]  edge-to-edge [mils(%line wid)]

(6.89 GHz)
Case 2, etch to antipad separation Parameterization

- edge-to-edge [%line-width]
- extra-loss [dB]
- hole-diam [mils]
- edge-to-edge [mils (%line-width)]

58 mil antipad diameter
Case 2, antipad diameter change
Parameterization
Conclusions (1)

- Due to periodic discontinuity the slope of transfer function increases and sharp dips appear in the loss profile
- Extra attenuation varies almost linearly with frequency

Simplified discontinuity model

\[ Z = j\omega L(\omega) \]

- Increases linearly with frequency
- Decreases weakly with frequency

- Due to this effect, at lower frequencies (less than ~3 GHz), for the type of discontinuities studied here, the additional loss is not too pronounced
- The extra attenuation starts to sharply increase as the separation between antipad and trace approaches zero
Conclusions (2)

• Due to misregistration the loss can increase dramatically
• Loss has a close to linear relationship to antipad diameter
• Loss scales with the number of discontinuities until it saturates
• Distance between the discontinuities determines the lowest resonance frequency
Next steps

• Understand different types of discontinuities
  > Including a complete via structure (some studies have already been done)
  > Understand the crosstalk effect between same layers and adjacent layers due to perforated planes
  > Understand the same effect on stripline structures, (all the measurements and simulations have been done on microstrips)
  > Create behavioral models to account for these effects
THANKS!!!!

ATTENUATION IN PCB TRACES DUE TO PERIODIC DISCONTINUITIES

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Eye mask degradation due to periodic discontinuities (1)

- Four cases have been created:
  - Six inch trace without perforation: **F-6in**, (Baseline)
  - Six inch trace formed by twelve, 500mils perforated unit cells: **D-6in** (Dip)
  - Eighteen inch trace with no perforation: **F-18in**
  - Twenty seven inch trace without perforations: **F-27in**

- Different bit times have been used

- Internal differential eye contour, area and UI have been computed for every simulated bit time
Eye mask degradation due to periodic discontinuities (1)

- Simulations have been run using a 10ps rise-time.
- The discontinuity has been generated fitting the half wave resonance of the 250mils hole diameter using a RLC T-network
Frequency domain channel characteristics

- Notice the cases have been created to study the difference between:
  - Baseline
  - Discontinuity
  - Longer uniform line, presenting the same attenuation than the periodic discontinuity case at the resonance frequency
  - Medium line length, falling in between the baseline and the long case
Back-Up-Slides

11.1111GB/s

10GB/s

9.0909GB/s

8.3333GB/s

7.1429GB/s

5GB/s

4GB/s

3.125GB/s

2.5GB/s

F-6in
D-6in
F-27in
F-18in
Horizontal eye opening

- Note how the periodical discontinuity case is closely following the 18” case. Maybe a shorter line, 12” would be closer.
- The 27” has by far the biggest horizontal eye closure as seen on the eyes in the previous page
Eye area

- The area computation follows the same trend as the horizontal eye opening computation.
- Clearly in all these cases, the line with periodic discontinuities is the one that has more fluctuations.