ATTENUATION IN PCB TRACES DUE TO PERIODIC DISCONTINUITES

Gustavo Blando, Jason R. Miller, Istvan Novak, Cheryl Preston

Sun Microsystems

Jim DeLap

Ansoft Corporation

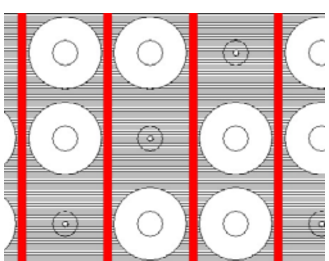
Outline

- 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

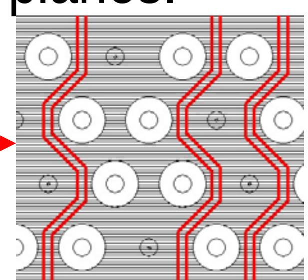
Introduction

- 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.

BGA pin-field



Conn pin-field

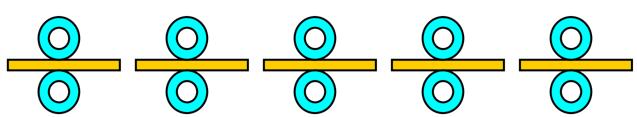


In most cases, a great percentage of the PCB trace length has to be routed over perforated areas

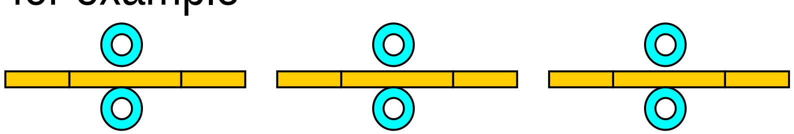
→ We will present parametric studies on realistic cases and will show its effects

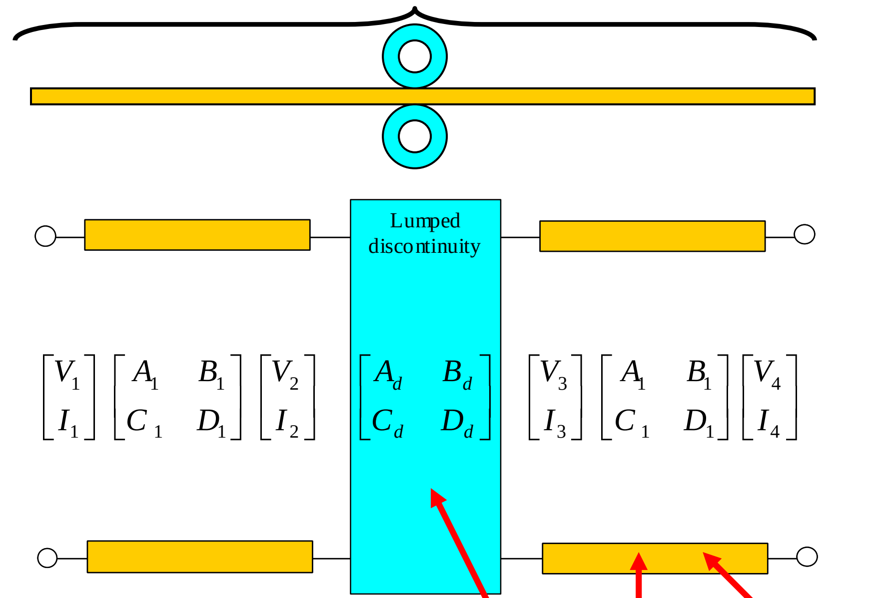
Background theory and simulation methodology

- 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 stand point, we could, for example, get the unit cell from a field-solver



- Or, do different type of analysis, for example





$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \begin{bmatrix} A_d & B_d \\ C_d & D_d \end{bmatrix} \quad \begin{bmatrix} V_3 \\ I_3 \end{bmatrix} \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} V_4 \\ I_4 \end{bmatrix}$$

$$\cosh(\gamma_p.d) = \cosh(\gamma.d) + (Z_d / 2.Z_0)\sinh(\gamma.d)$$

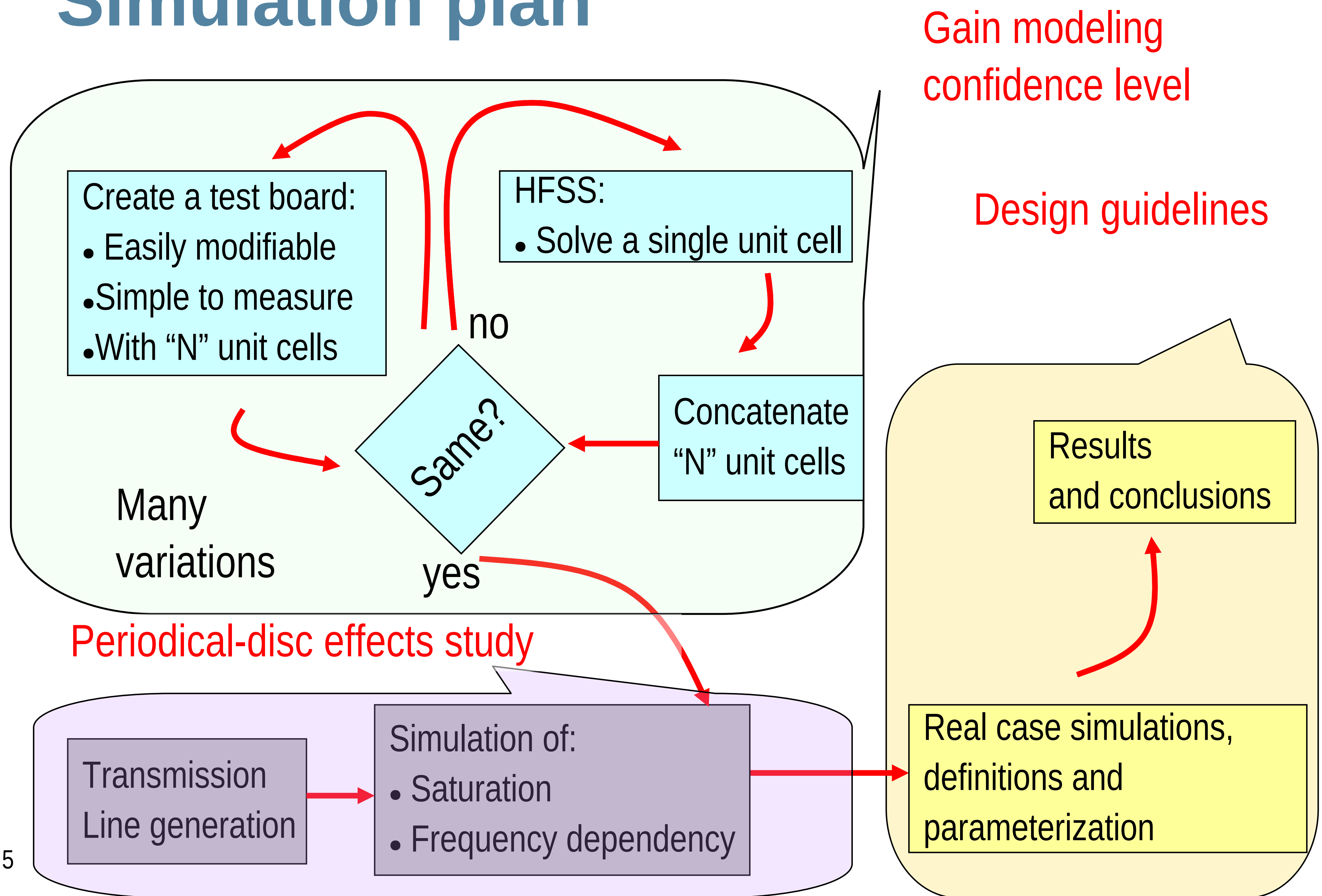
Length of one unit cell

$$A = D = \cosh(\gamma d) + (Z_d / 2Z_0)\sinh(\gamma d)$$

$$B = Z_0[\sinh(\gamma d) + (Z_d / 2Z_0)\{\cosh(\gamma d) + 1\}]$$

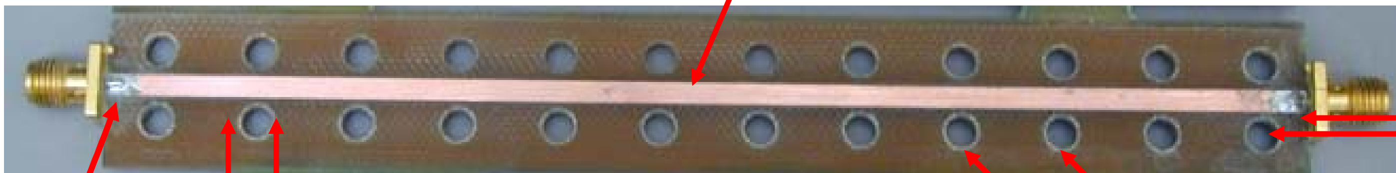
$$C = [\sinh(\gamma d) + (Z_d / 2Z_0)\{\cosh(\gamma d) - 1\}] / Z_0$$

Simulation plan



Test board

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



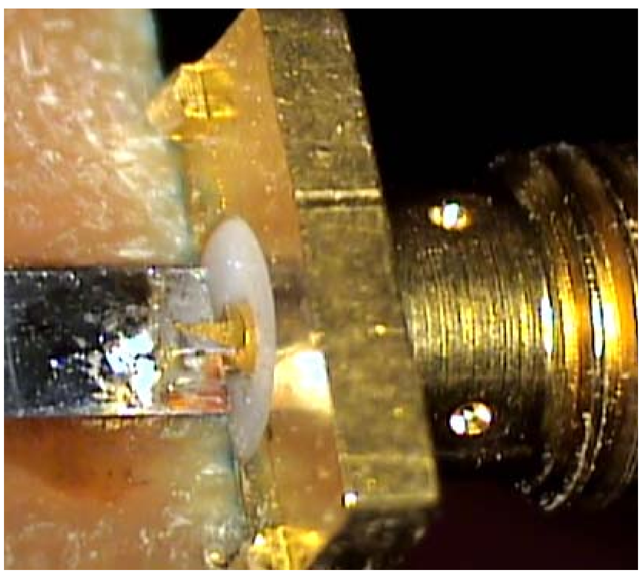
Fixed 125 mils from the edge of the trace to center of the hole

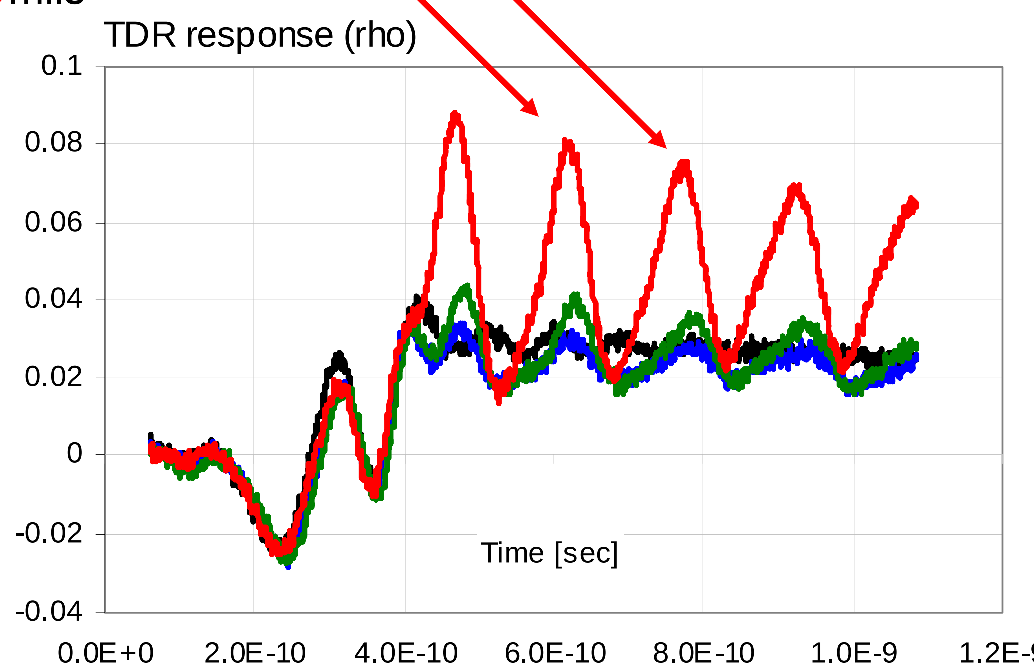
500mils pitch

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

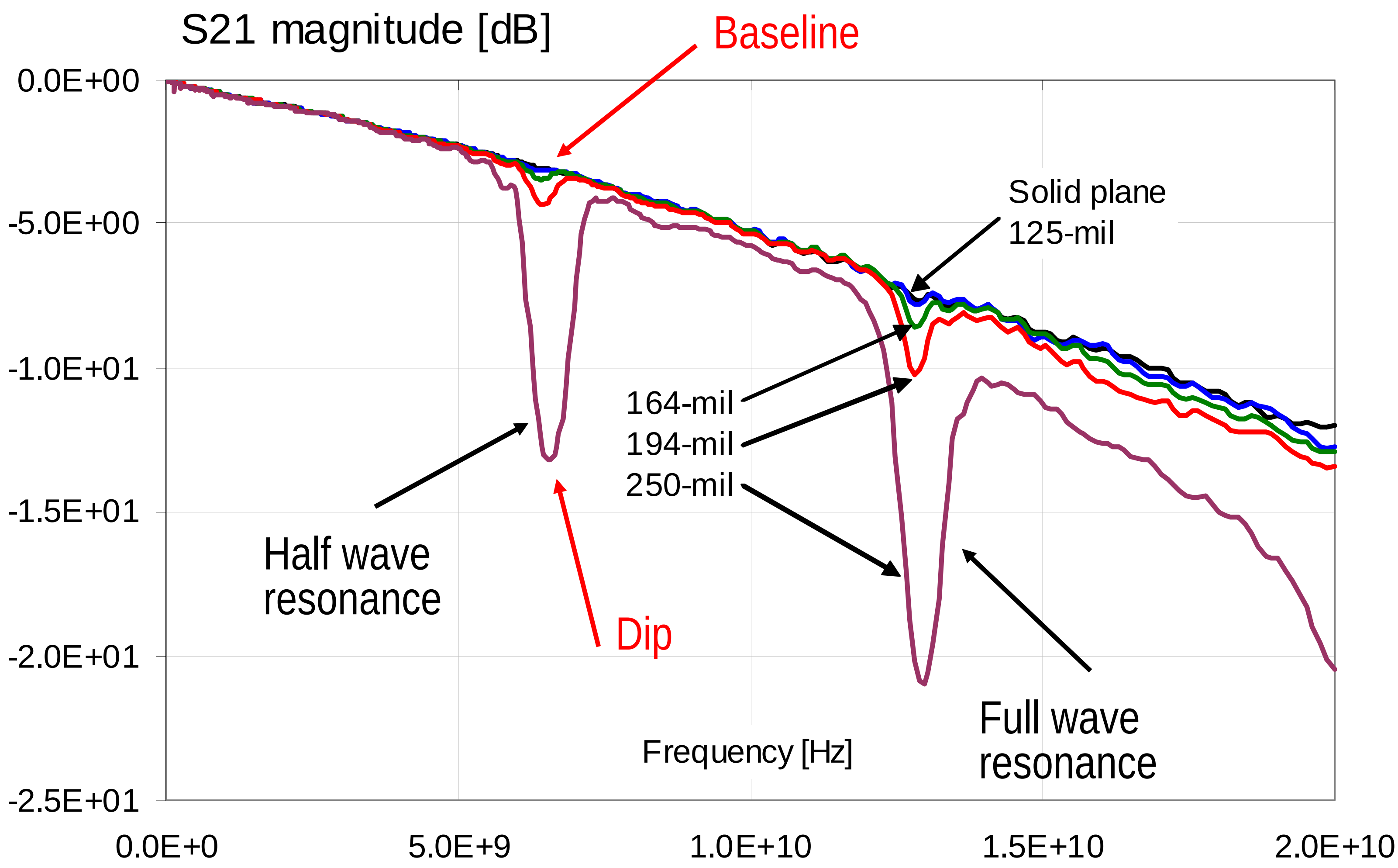
Half wave resonance
1/ 2*500mils*150ps/in=6.6GHz

Edge launch SMA



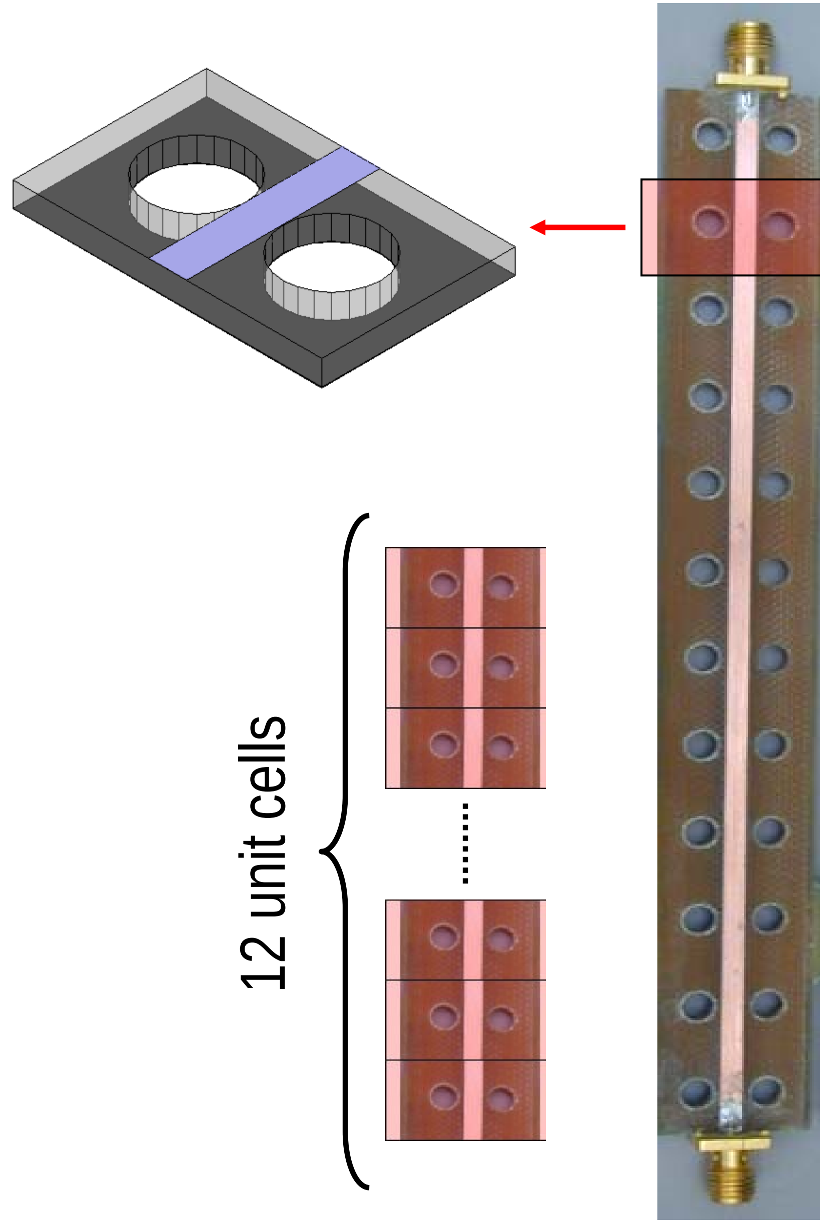


Test board measurements

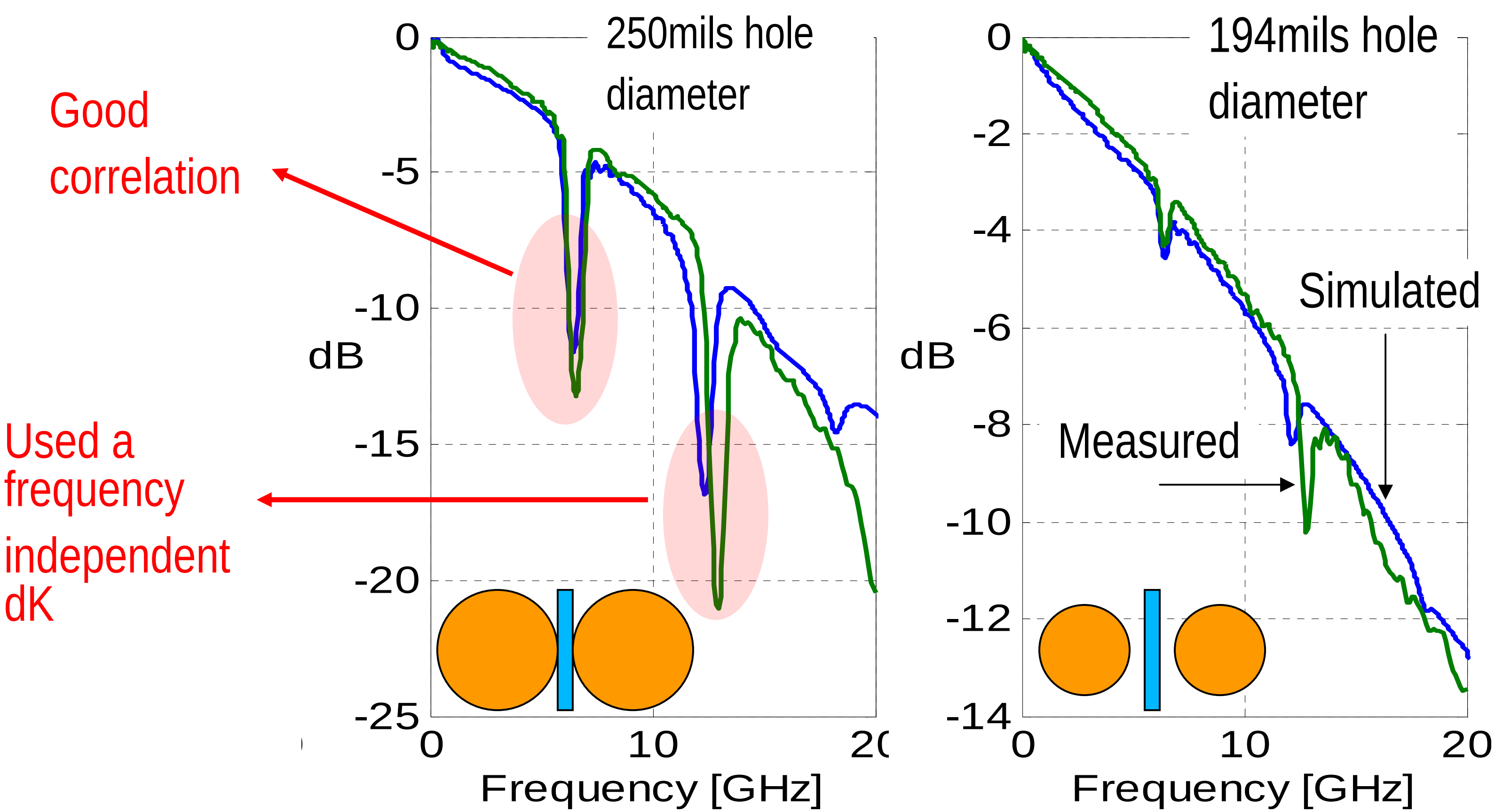


Simulation setup

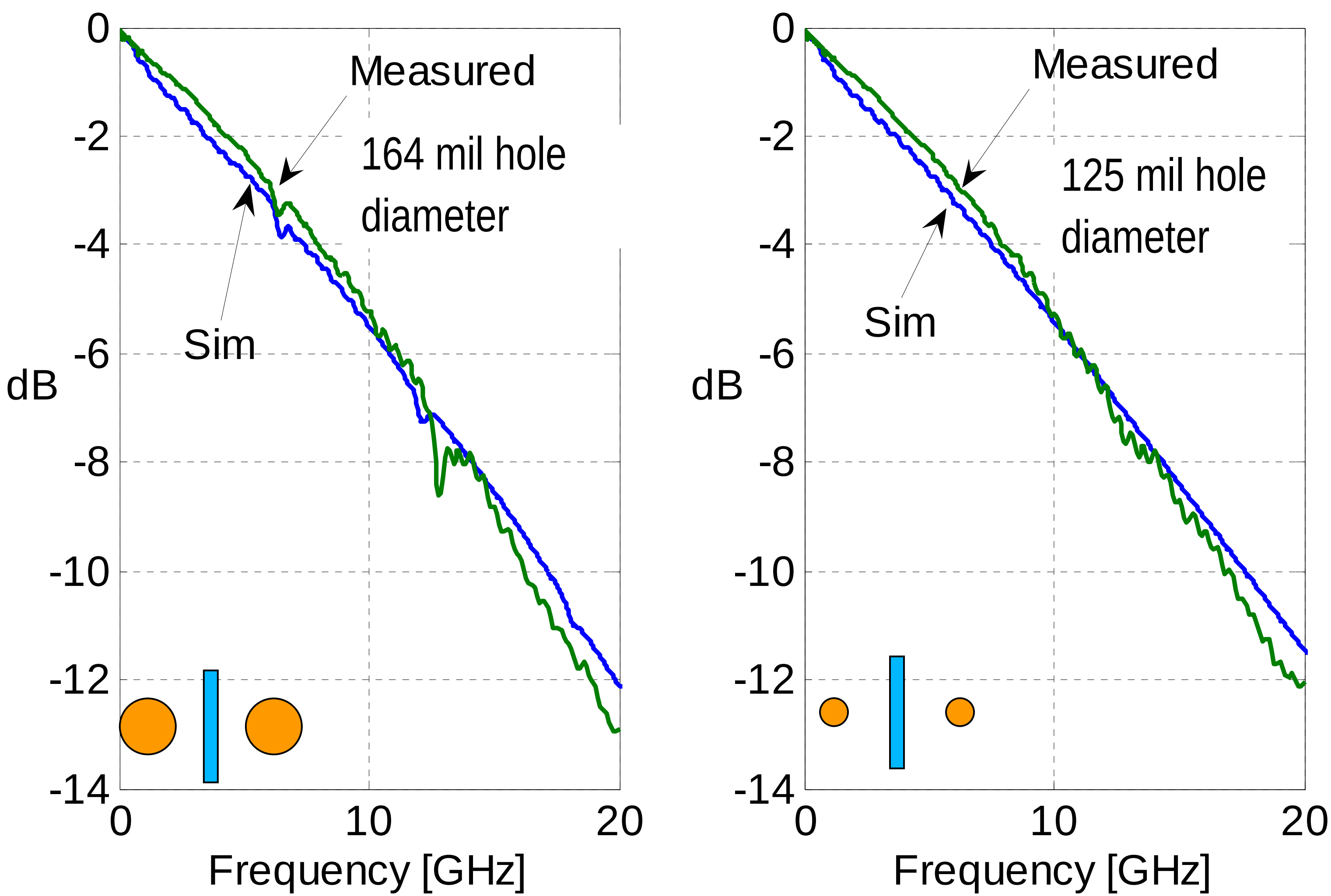
- Ansoft HFSS, v10
- Unit cell approach used
- Material: FR4
  - Dk = 4.5
  - Tand = 0.03
- The hole diameters were progressively increased to match the test board
- MATLAB was used to perform the concatenation



Measurement correlation (1)



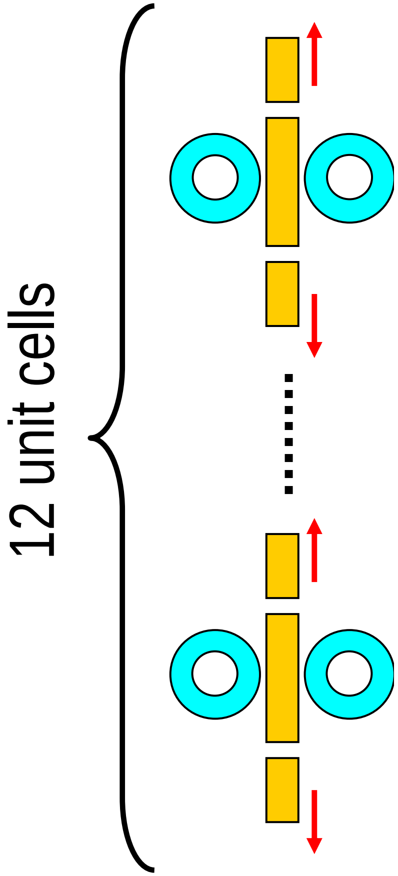
Measurement correlation (2)

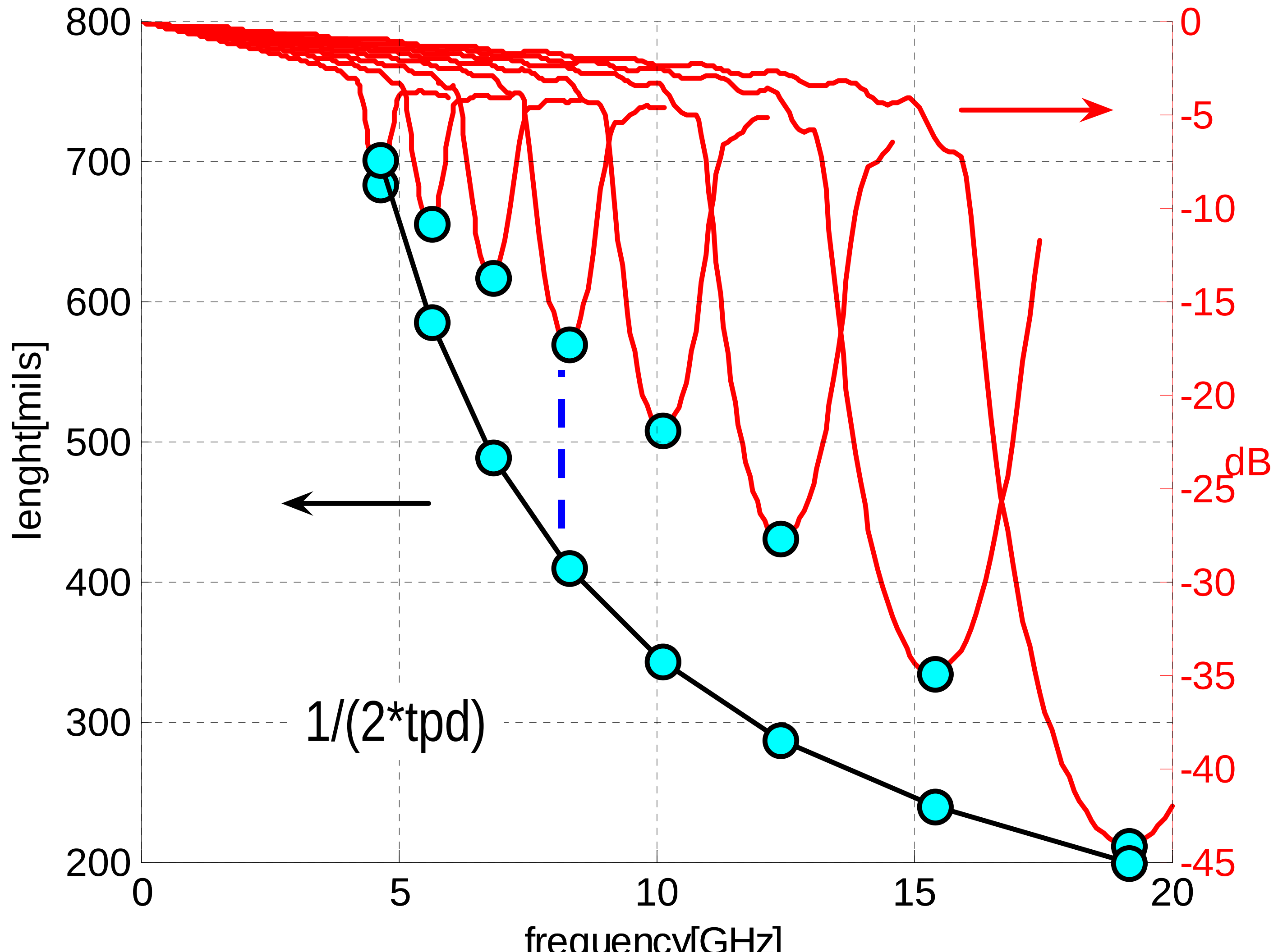


Periodically loaded line characteristics

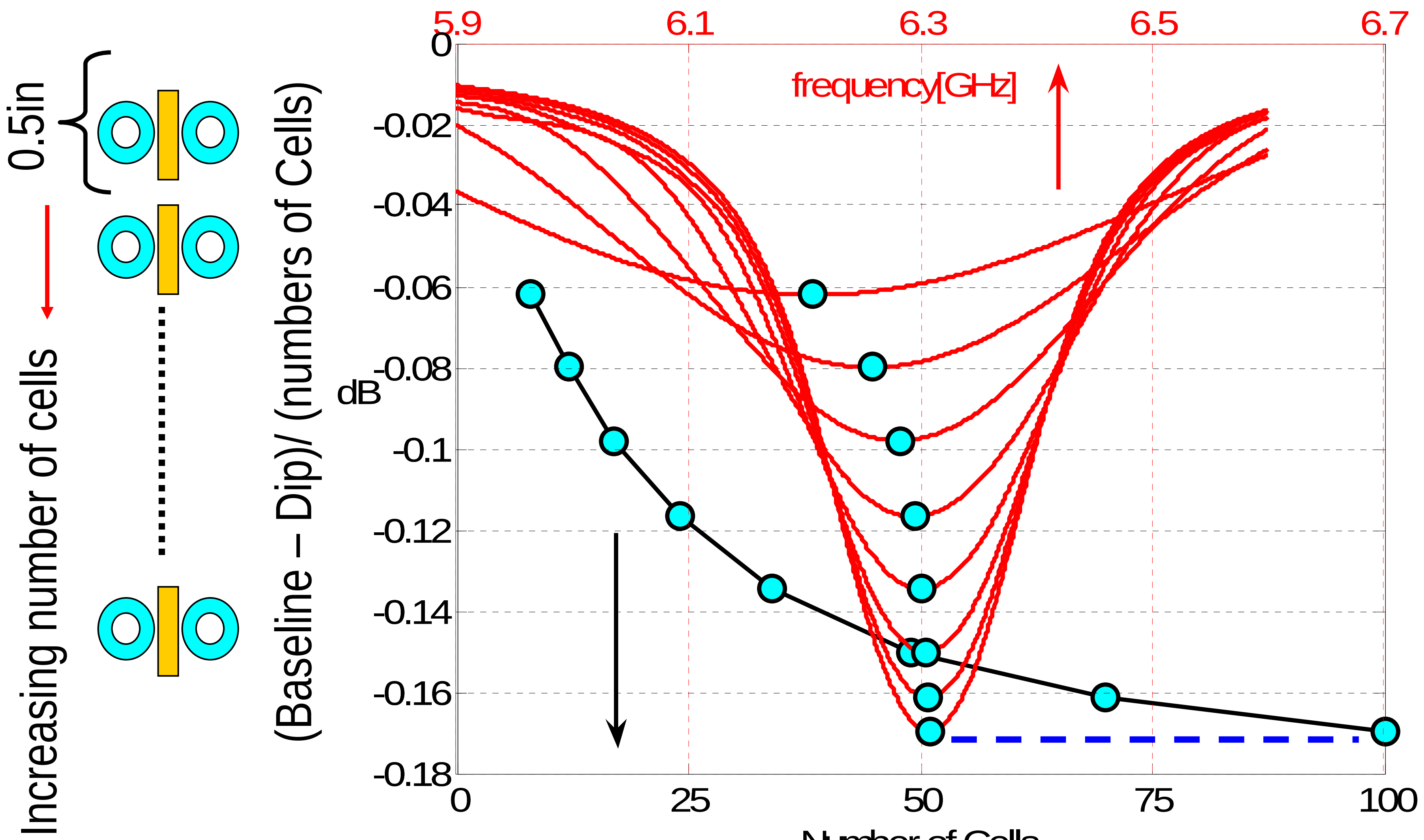
- Doing some mathematical post-processing, several periodic discontinuity effects can be studied.
  - Study 1: Examine how the location of the resonance dip changes as a function of unit cell length
  - Study 2: Examine the first resonance amplitude as a function of the number of cascaded cells for a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

Frequency vs. pitch dependency





Saturation effect

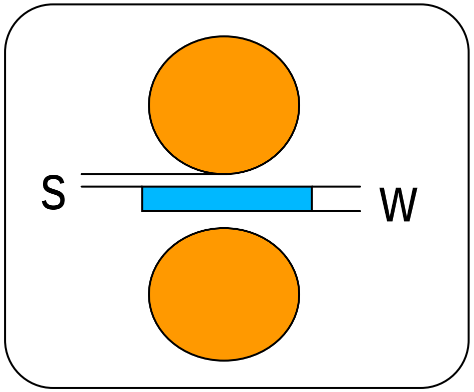


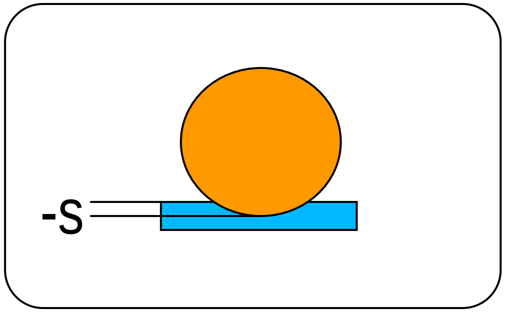
Parameterization

- 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



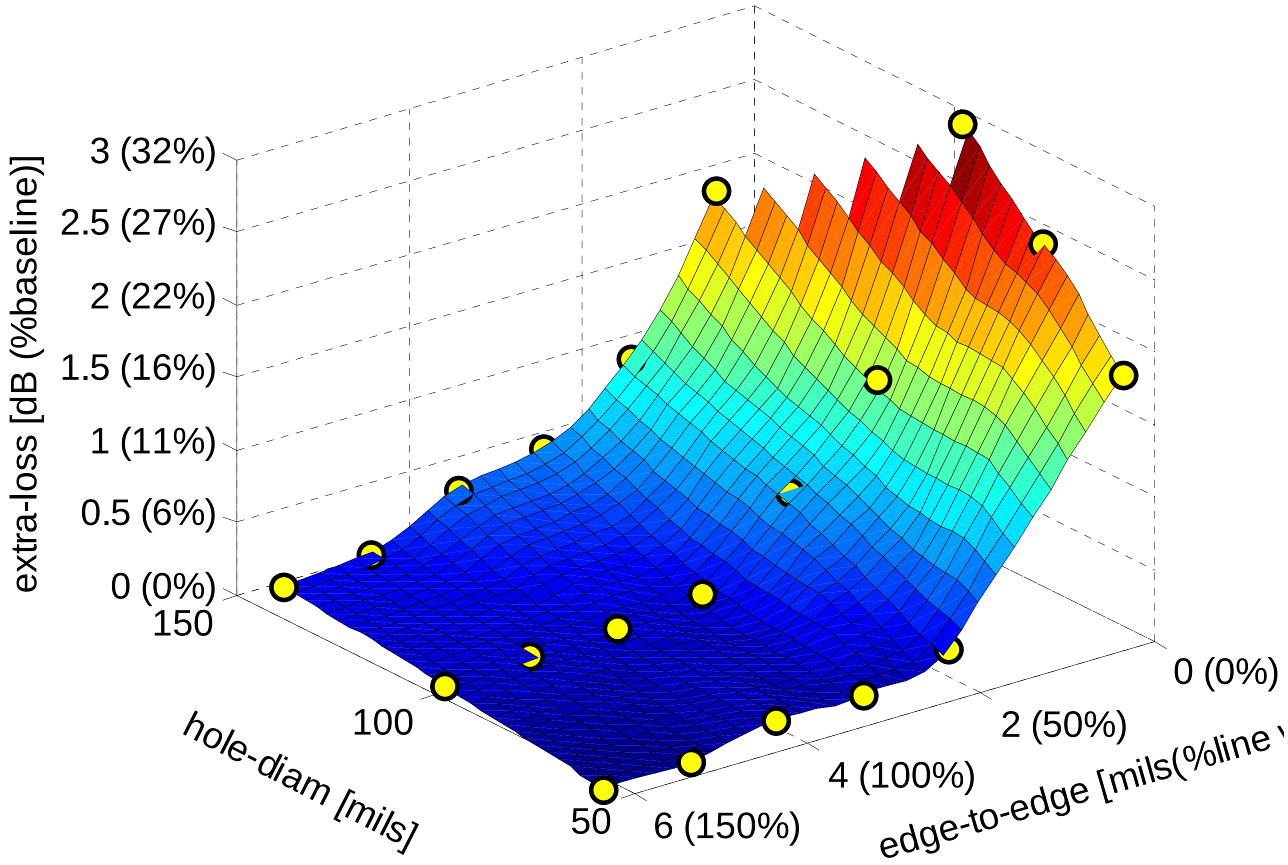


Example: 4 mil line width, BGA (1mm, 39.37 mil), 30 mil antipad		
	Range	Antipad edge to trace edge separation
Different core misregistration	+/-5 mils	-3.315 mils (-82%)
Same core misregistration	+/-3 mils	-1.315 mils (-33%)

Parameter ranges

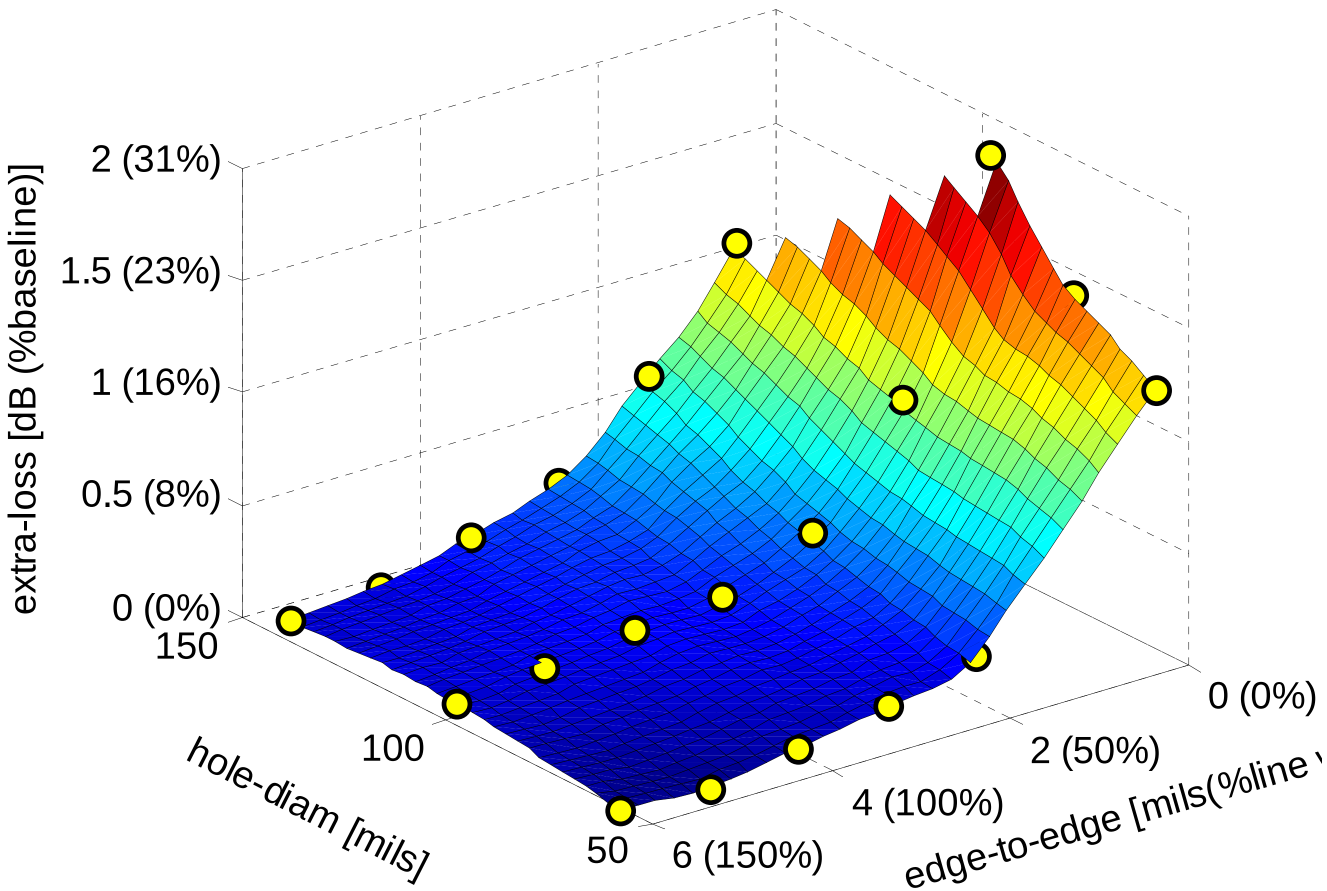
- 50-ohm microstrip was simulated using a 4-mil wide trace and a 4-mil thick dielectric (2%, ε_r=4.5)
- Number of periodic discontinuities : 10
- Distance between the discontinuities: 500 mils (λ/2=6.6 GHz)
- Trace to hole separation: -4 (-100%) mils to 6 mils (+150%)
- Size of the discontinuity (antipad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

Case 1, third resonance
Parameterization



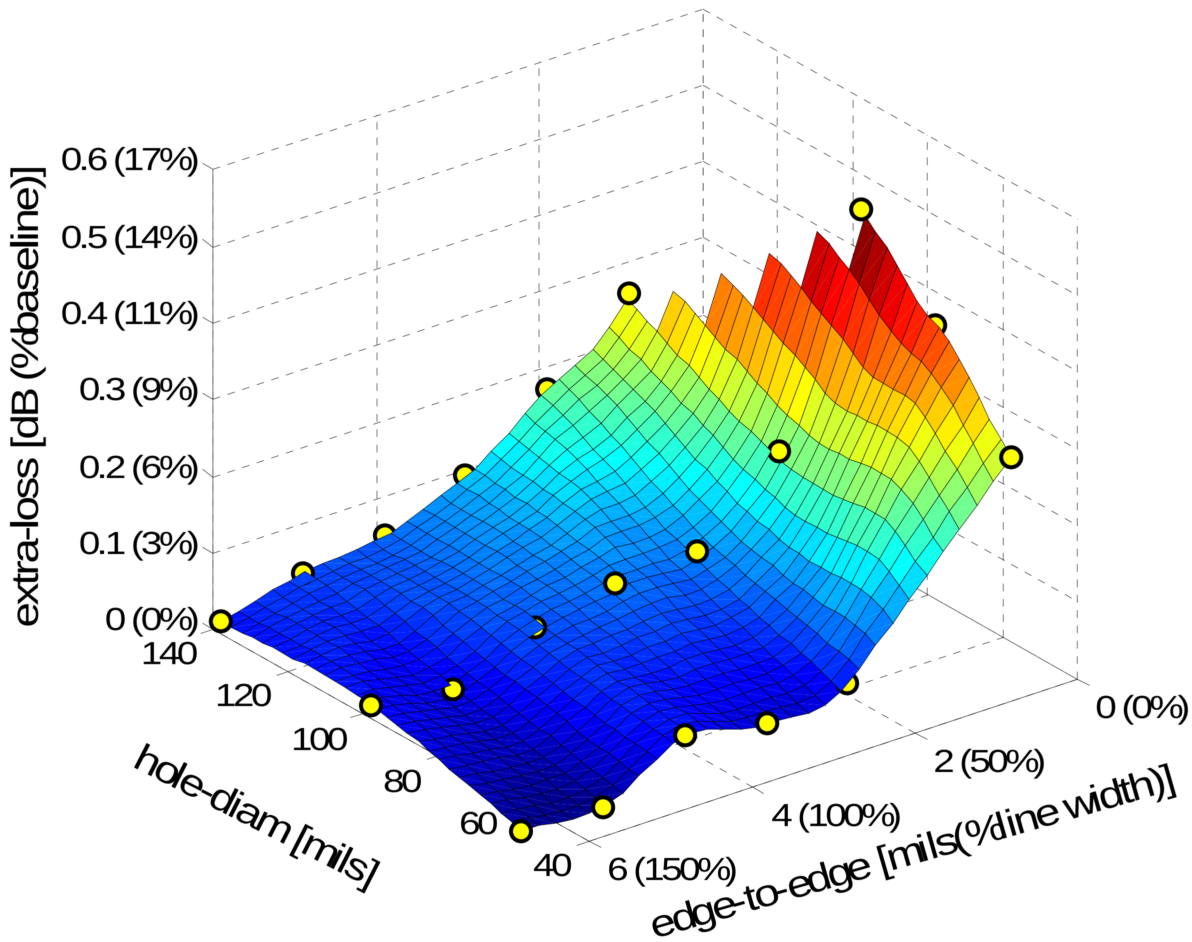
(20.23 GHz)

Case 1, second resonance
Parameterization



(13.44 GHz)

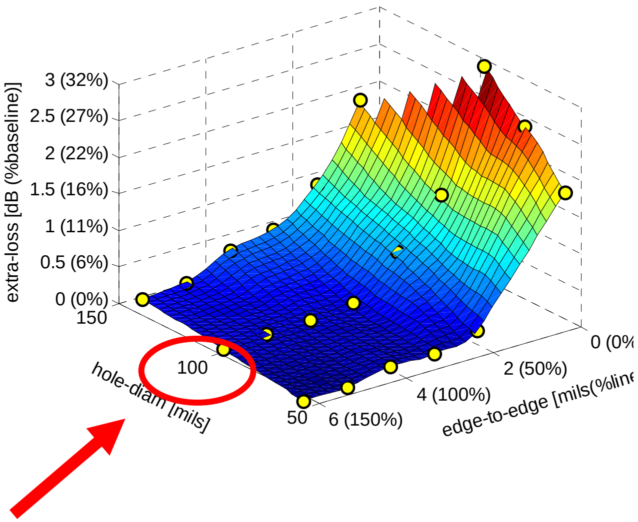
Case 1, first resonance
Parameterization

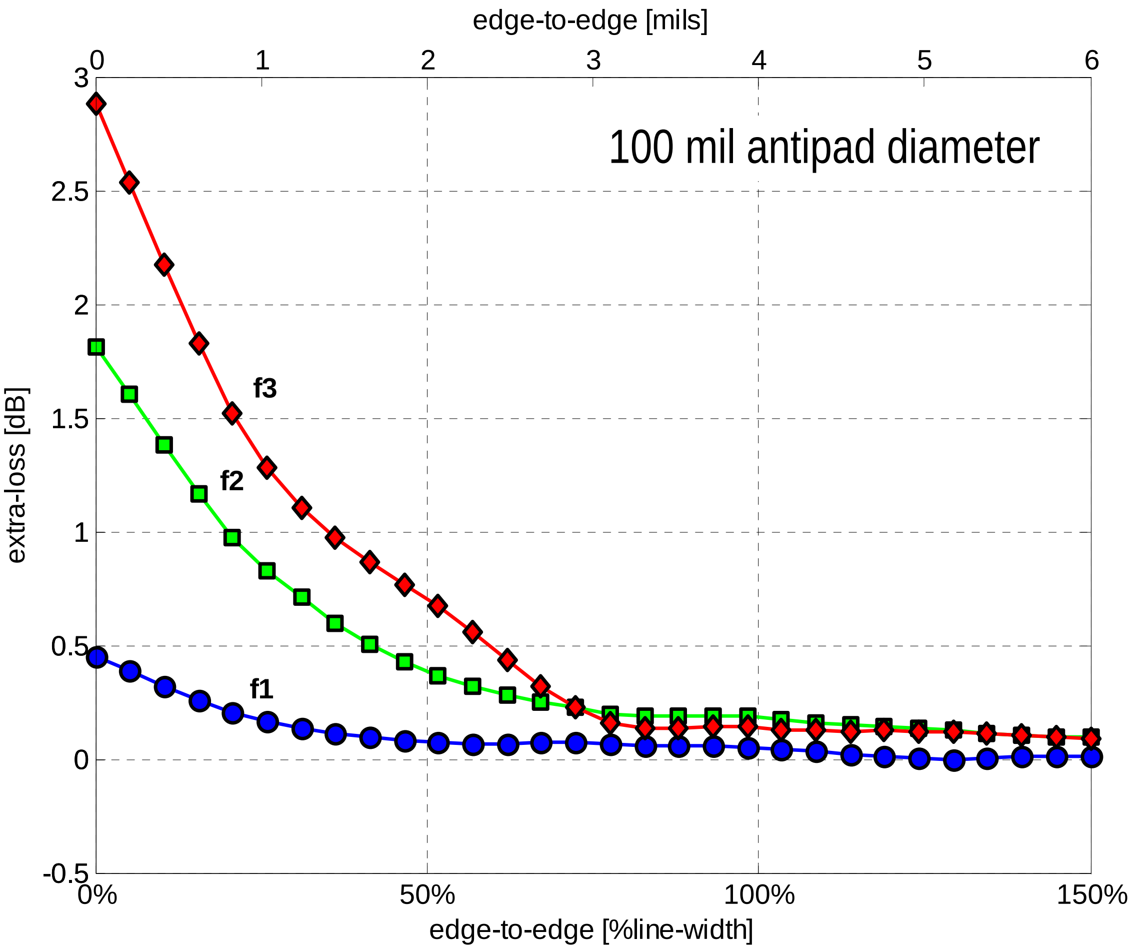


(6.89 GHz)

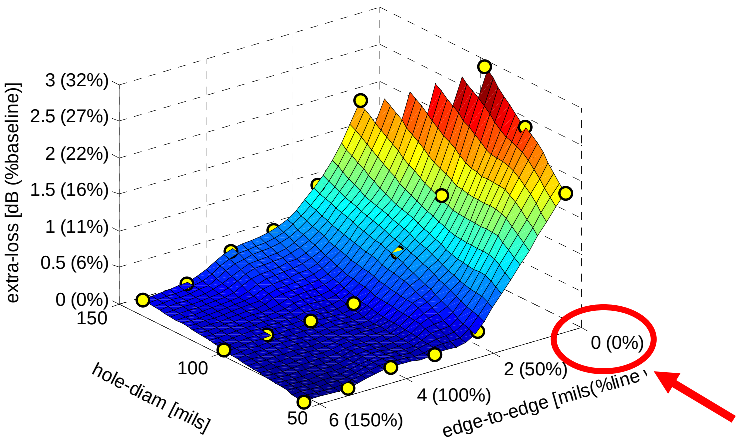
Case 1, etch to antipad separation

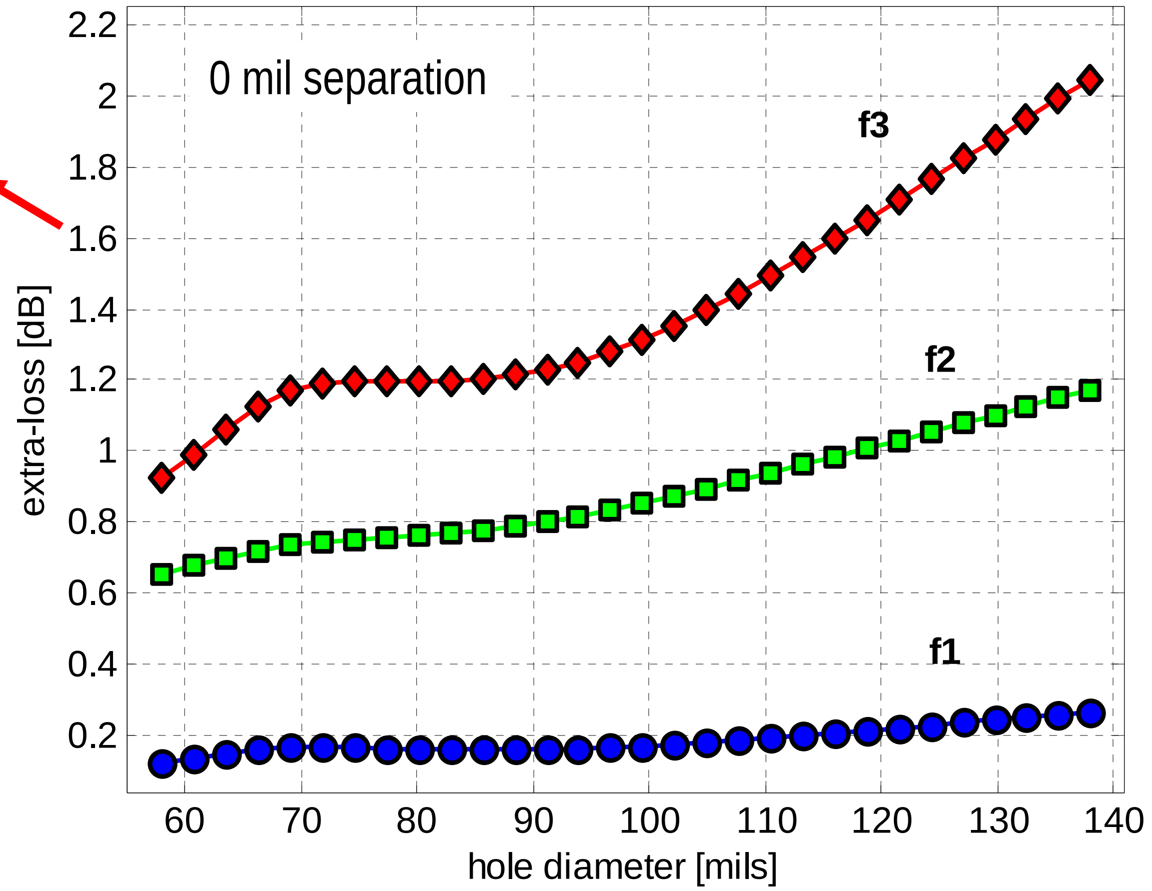
Parameterization



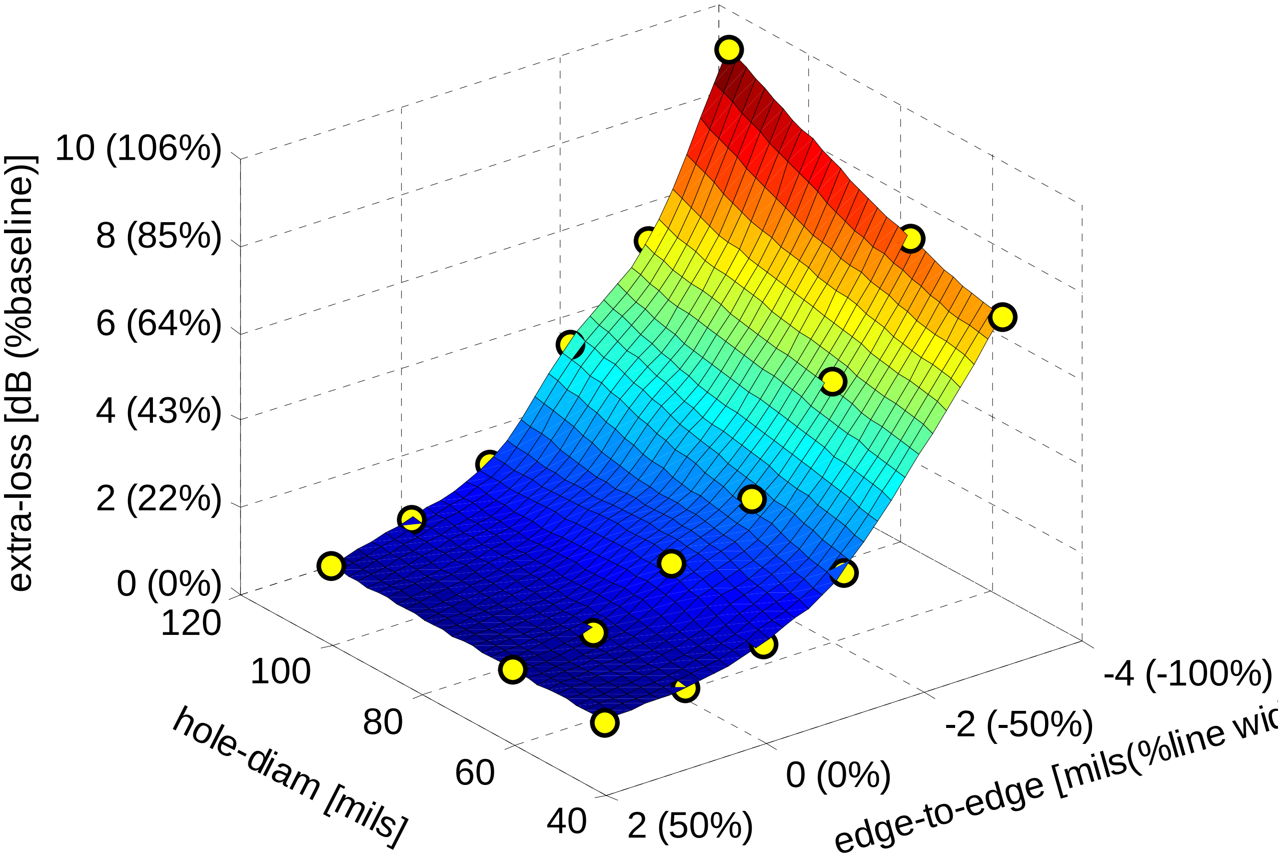


Case 1, antipad diameter change
Parameterization



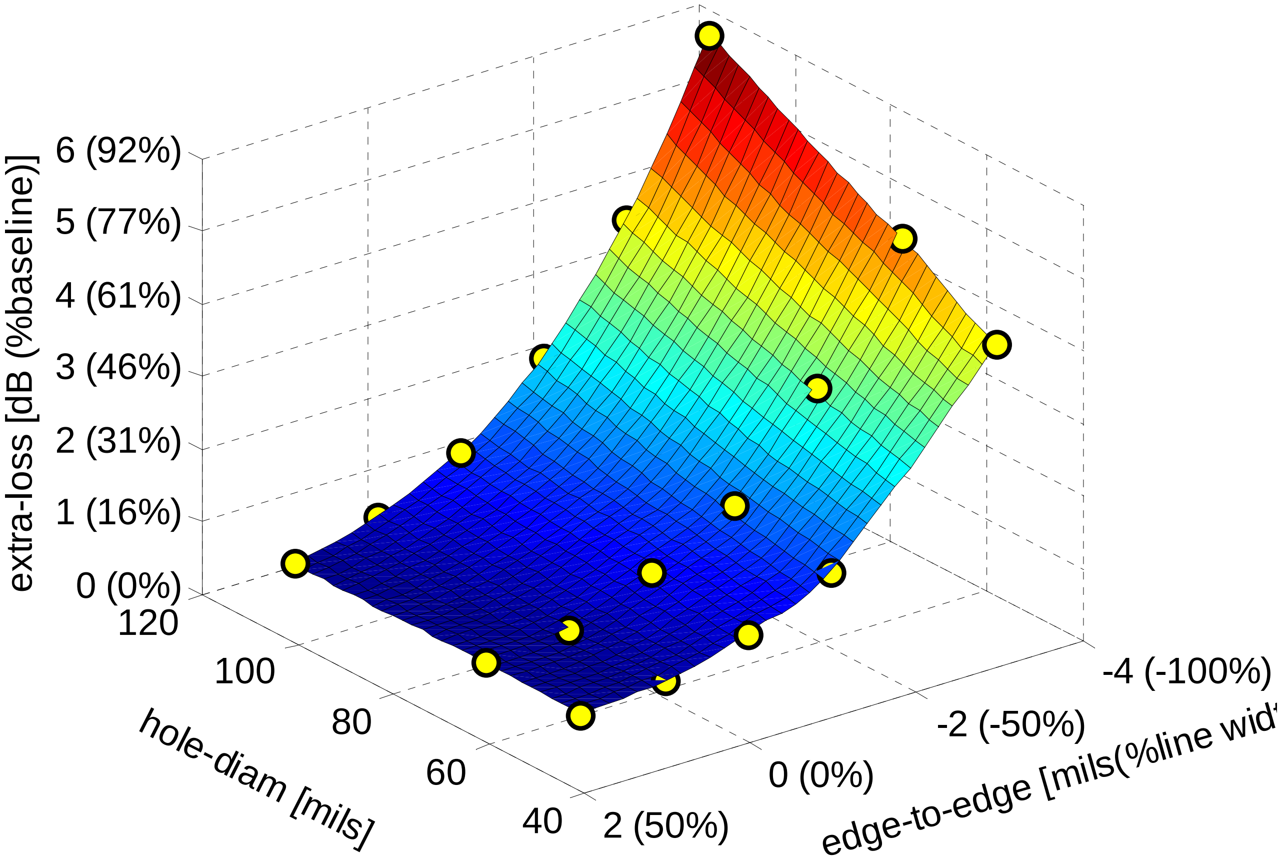


Case 2, third resonance
Parameterization



(20.23 GHz)

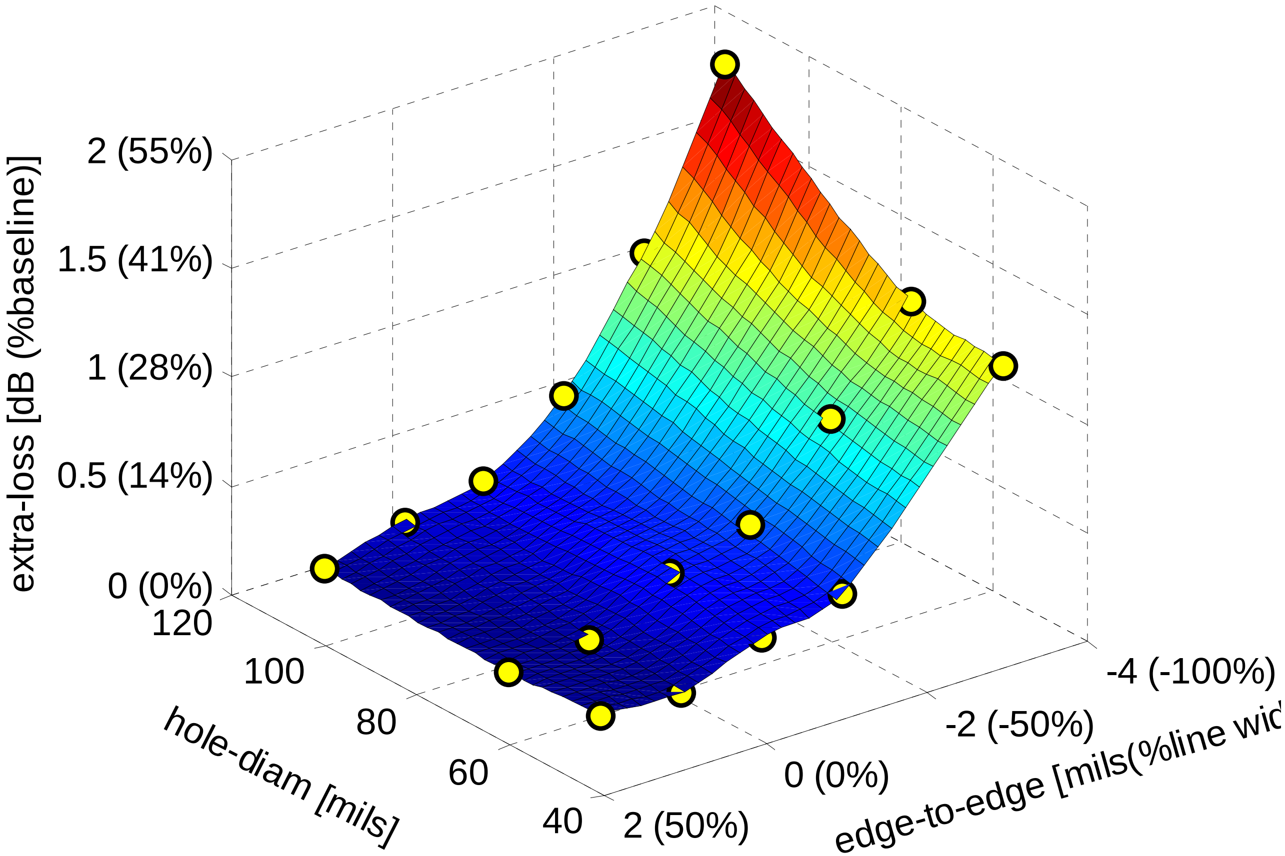
Case 2, second resonance
Parameterization



(13.44 GHz)

Case 2, first resonance

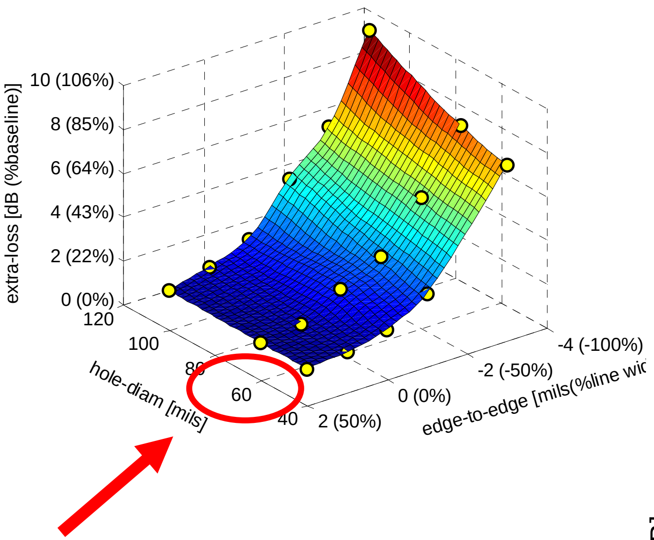
Parameterization

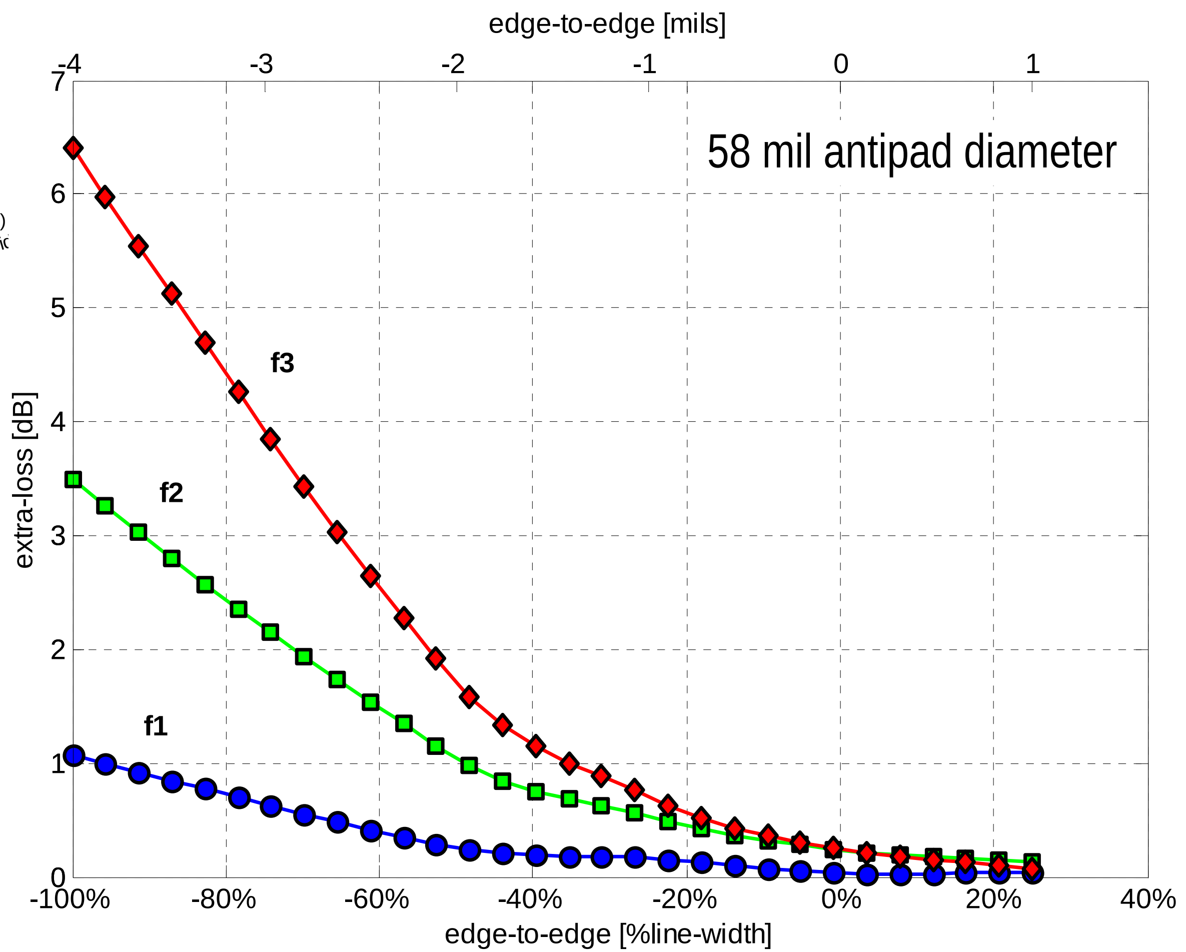


(6.89 GHz)

Case 2, etch to antipad separation

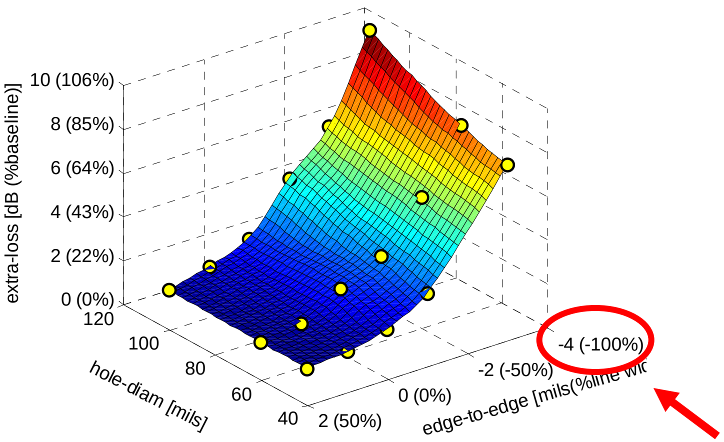
Parameterization

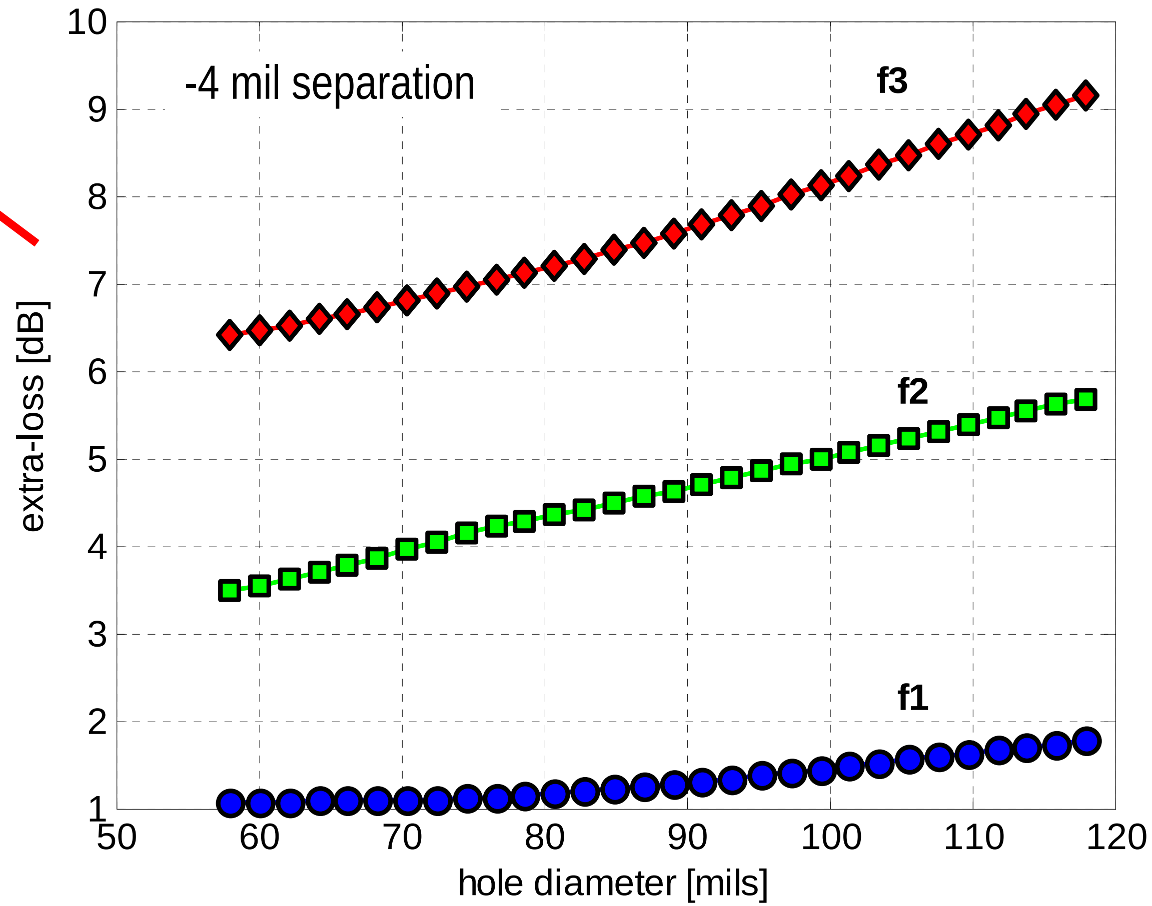




Case 2, antipad diameter change

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

$$Z = j\omega L(\omega)$$

$j\omega$ → Increases linearly with frequency

$L(\omega)$ → 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 DISCONTINUITES

Gustavo Blando

Gustavo.blando@sun.com

Eye mask degradation due to periodic discontinuities (1)

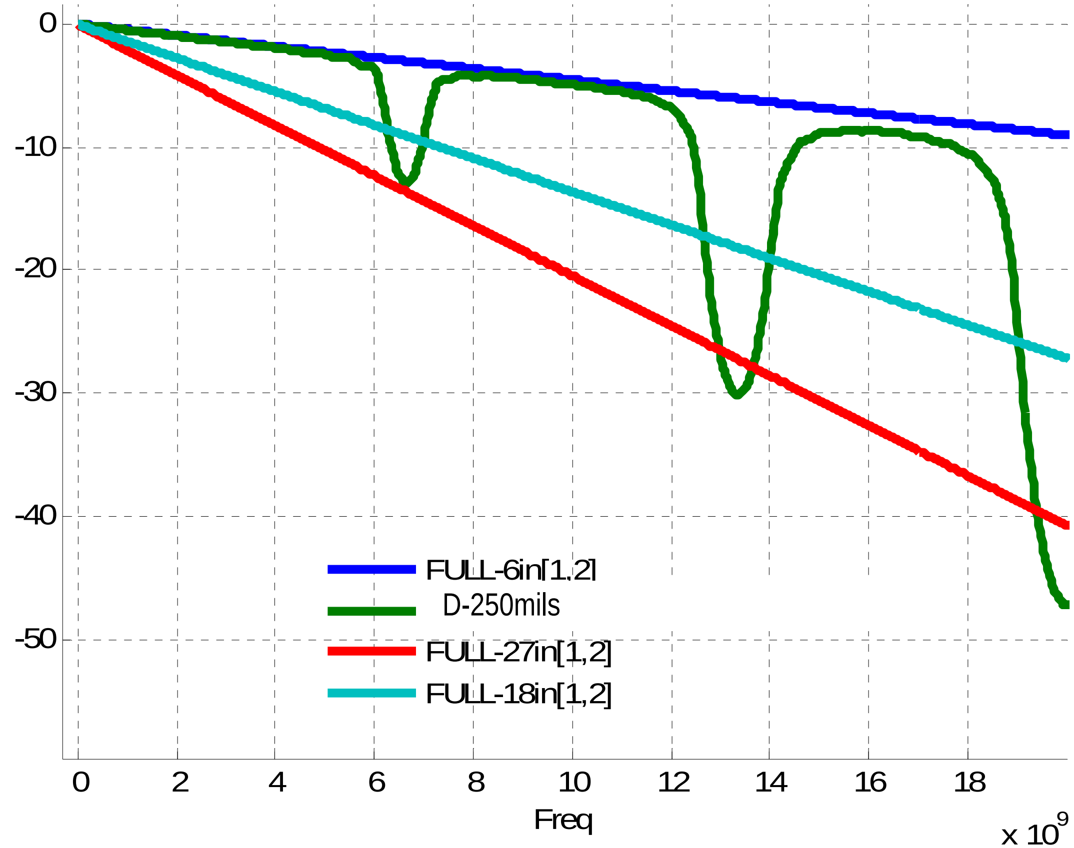
- Four cases have been created:
  - Six inch trace without perforation: F-6in, (Baseline)
  - Six inch trace formed by twelve, 500mils perforated unit cells: D-6in (Dip)
  - Eighteen inch trace with no perforation: F-18in
  - Twenty seven inch trace without perforations: F-27in
- Different bit times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

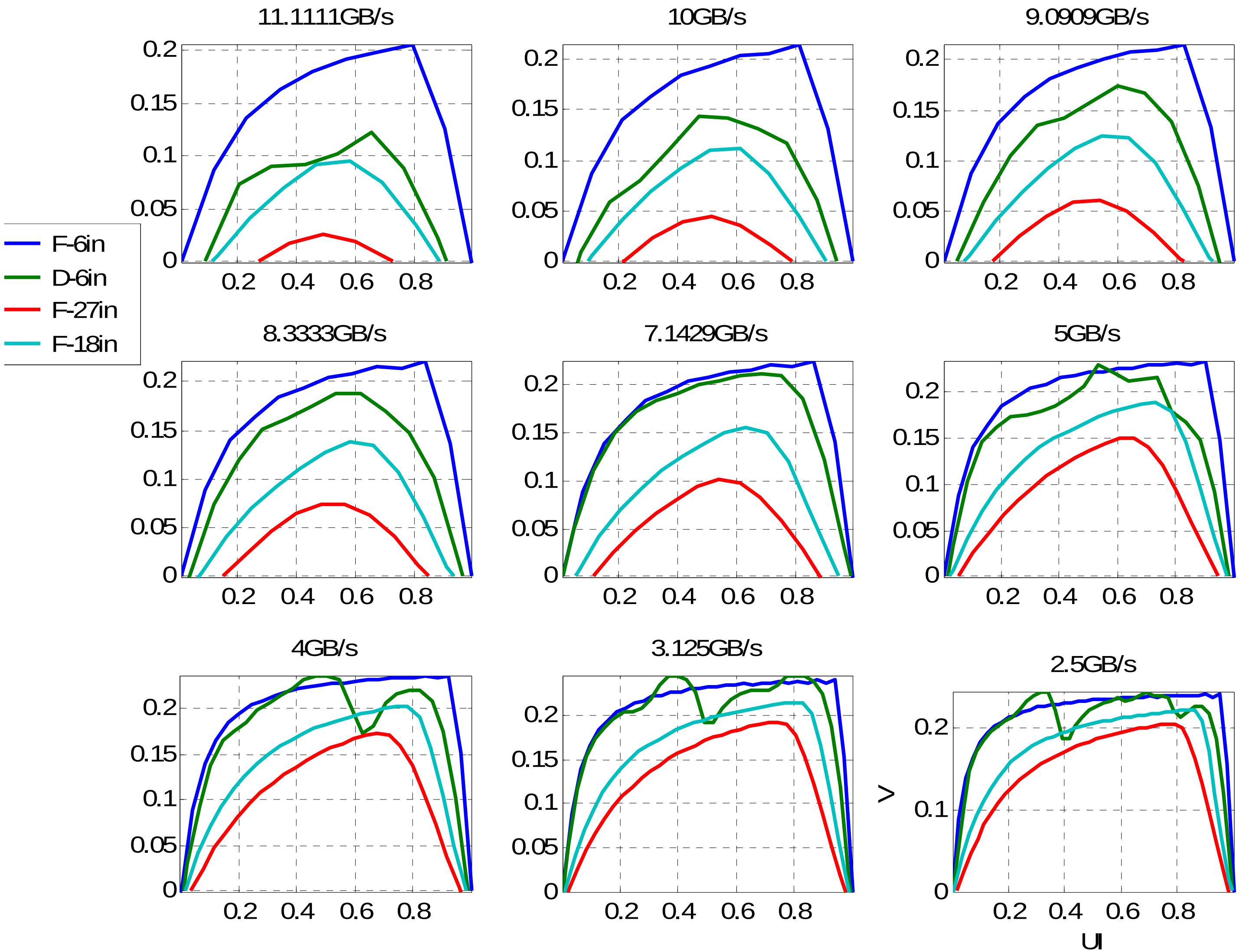
- Simulations have been run using a 10ps rise-time.
- The discontinuity has been generated fitting the half wave resonance of the 250mils hole diameter using a RLC T-network

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

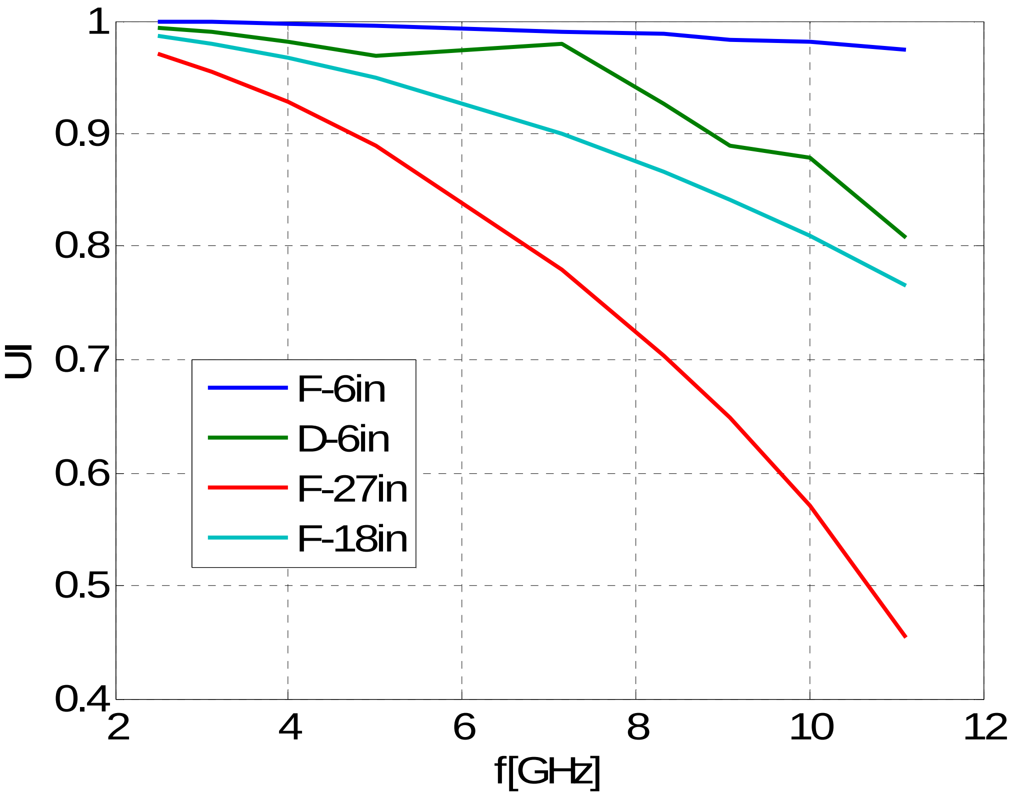


Back-Up-Slides



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 have more fluctuations