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SANTA CLARA CONVENTION CENTER

Fast, efficient and accurate: via models that correlate to 20 GHz

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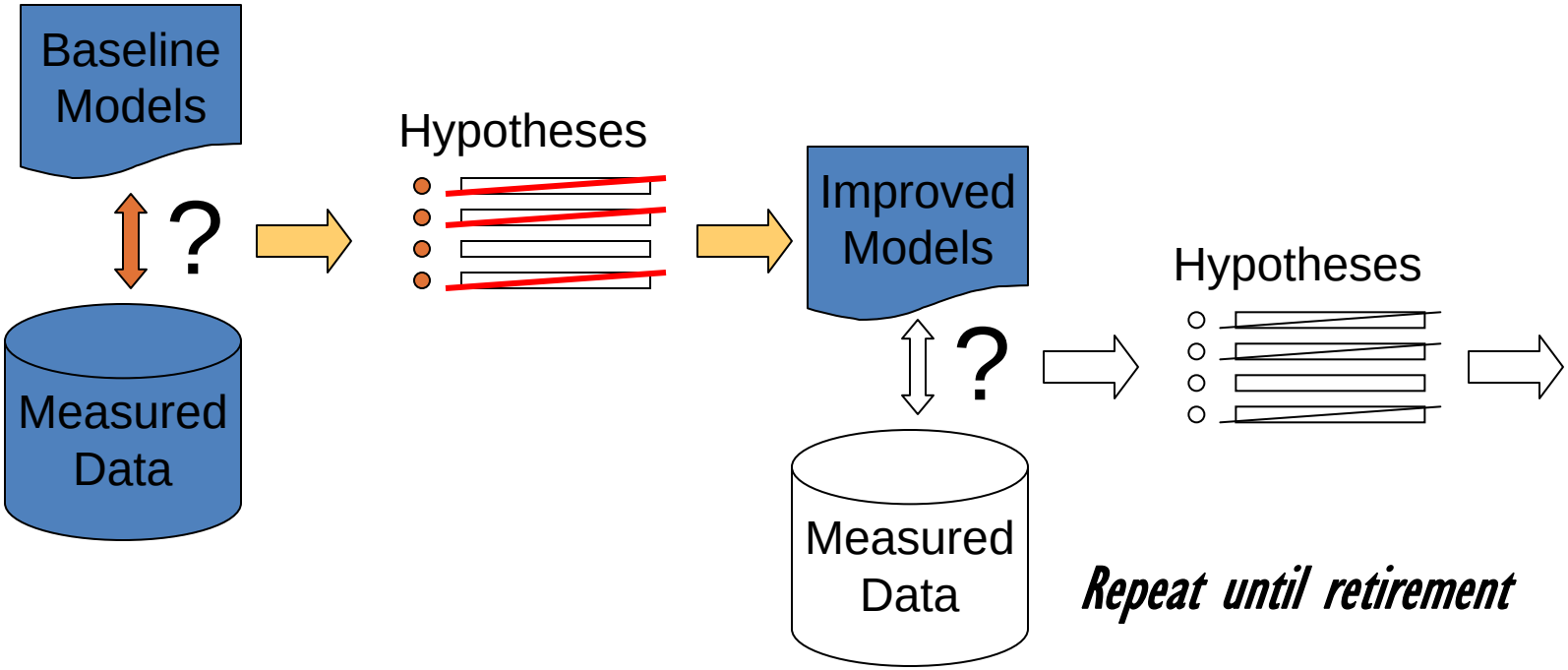
SiSoft We Are Signal Integrity

SI GUYS

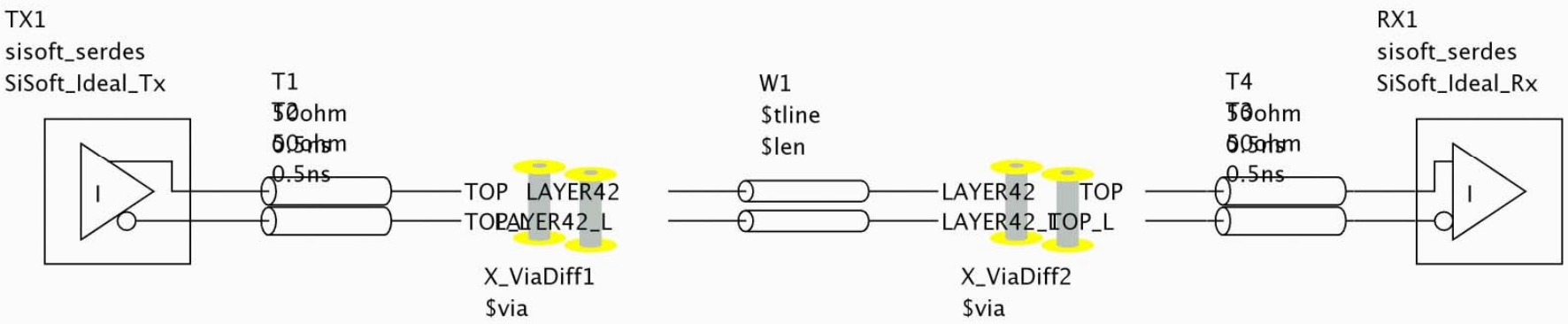
UBM Tech

Via Presentation Outline



Understand the Physics.

Baseline Circuit Model



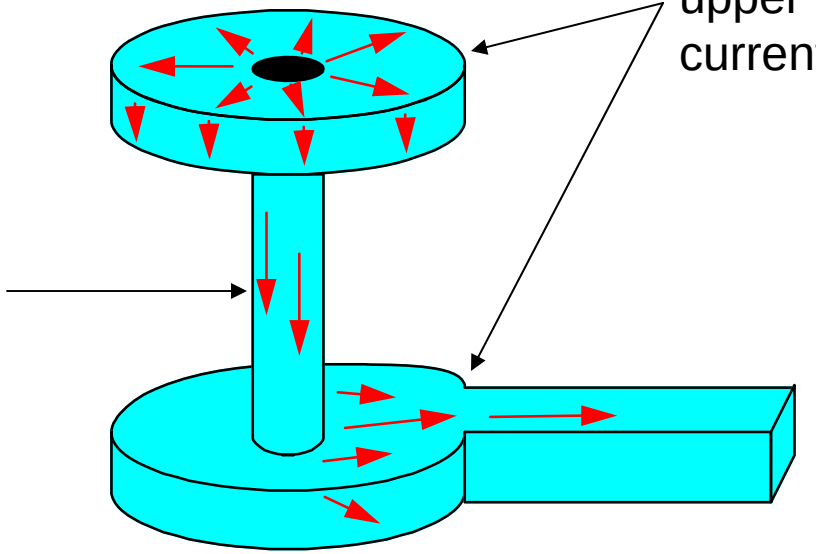
Baseline Transmission Line Model

W line RLGC Model

- Causal dielectric with constant loss tangent (Djordjevic et. al.)
- Conductor roughness (Brist et. al.)
- Conductor internal impedance (Ramo, Whinnery and Van Duzer)

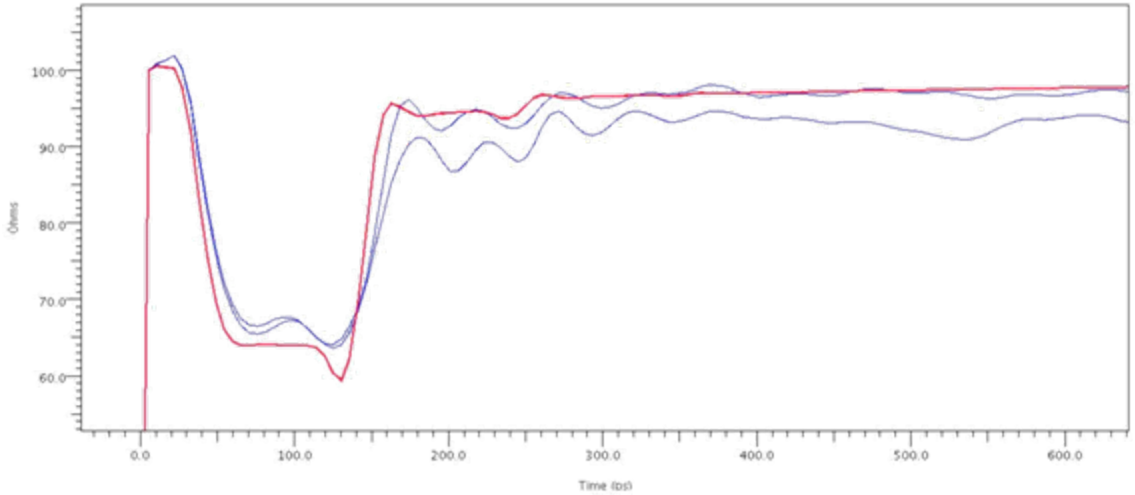
Parameter	**Stripline routing layers**	**Dual stripline layer**	**Published range of values**
Dielectric constant Dk at 1 GHz	3.55	3.67	3.4-3.6
Dielectric loss tangent Df	0.005	0.006	0.004-0.006
Differential impedance Z0o	90.3Ω	88.6Ω	
Conductor roughness	0.15μm	0.15μm	

Baseline Via Model



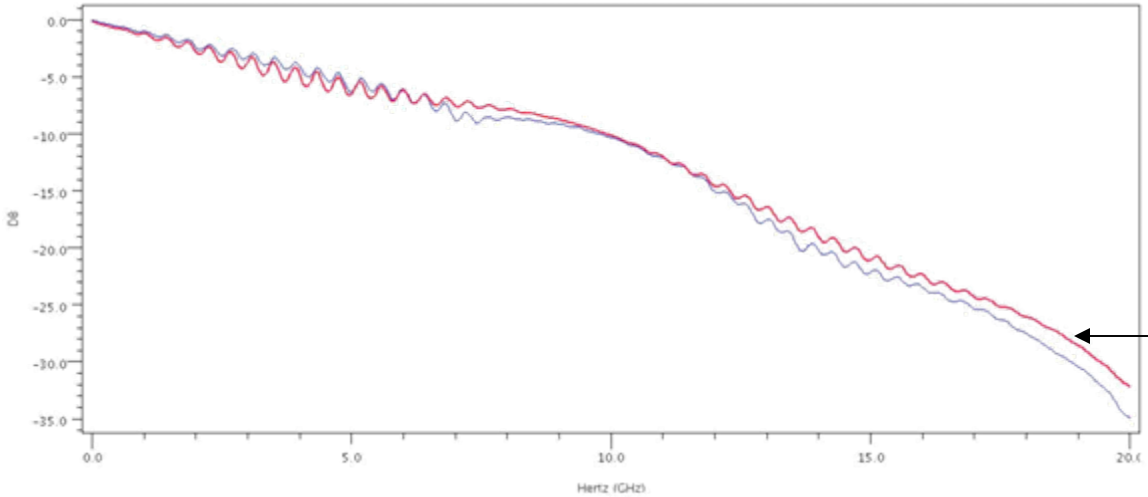
Donald Telian, Sergio Camerlo, Michael Steinberger, Barry Katz, Walter Katz, "Simulating Large Systems with Thousands of Serial Links", paper 8-WA3, DesignCon 2012, February 2012.

Baseline Correlation



TDR
(Time
Domain
Reflectometry)

Red: Model
Blue: Measured



Insertion
Loss

Model underestimates loss
at high frequencies

Reduce loss discrepancy

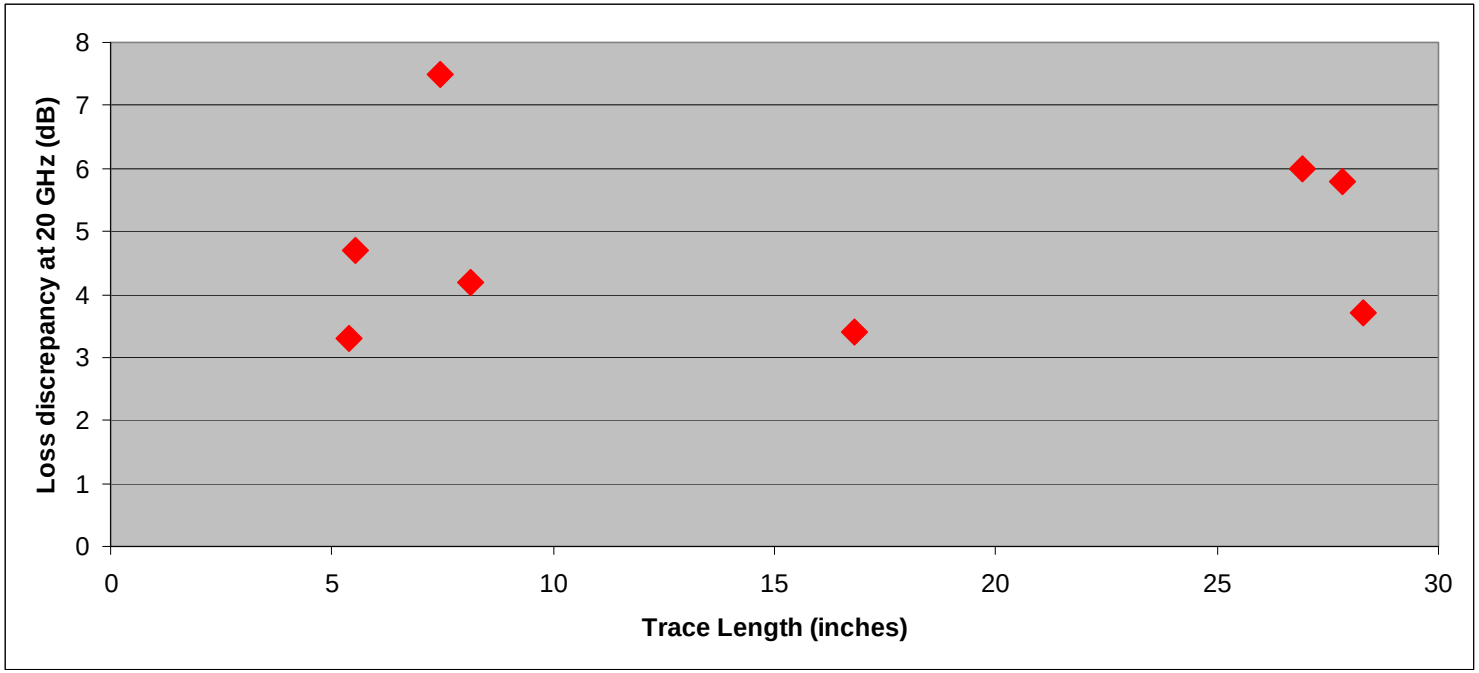
Hypotheses

- Transmission line losses
  - Increased dielectic loss tangent at higher frequencies
  - Increased conductor roughness losses at higher frequencies
  - Differential skew due to weave effects
- Via losses
  - Via barrel losses
  - Losses at transition from stripline to via

Predictions

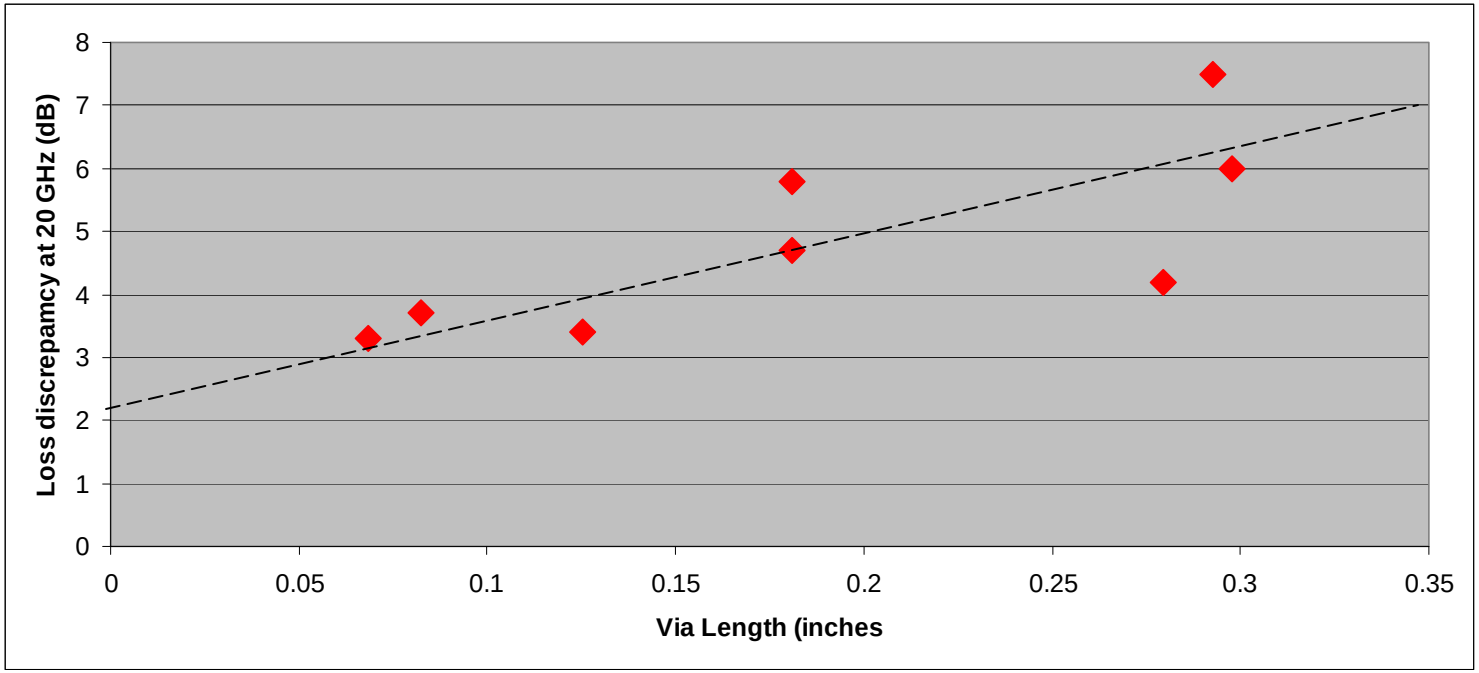
- Transmission line losses
  - Increased dielectic loss tangent at higher frequencies
    If so, loss discrepancy will be a linear function of trace length.
  - Increased conductor roughness losses at higher frequencies
    If so, loss discrepancy will be a linear function of trace length.
  - Differential skew due to weave effects
    If so, loss discrepancy will increase with trace length.
- Via losses
  - Via barrel losses
    If so, loss discrepancy will be a linear function of via length.
  - Losses at transition from stripline to via
    If so, loss discrepancy will be constant for all cases.

Loss Discrepancy vs. Trace Length



Original data set

Loss Discrepancy vs. Via Length



Original data set

And the answer is …

- Transmission line losses
  - ~~Increased dielectic loss tangent at higher frequencies~~
    ~~If so, loss discrepancy will be a linear function of trace length.~~
  - ~~Increased conductor roughness losses at higher frequencies~~
    ~~If so, loss discrepancy will be a linear function of trace length.~~
  - ~~Differential skew due to weave effects~~
    ~~If so, loss discrepancy will increase with trace length.~~
- Via losses
  - Via barrel losses
    If so, loss discrepancy will be a linear function of via length.
  - Losses at transition from stripline to via
    If so, loss discrepancy will be constant for all cases.

Continued Hypothesis Testing

- Via losses
  - Via barrel losses
    If so, loss discrepancy will be a linear function of via length.
    If so, then adding more loss to via barrel at high frequencies will improve correlation across a wide range of cases.
  - Losses at transition from stripline to via
    If so, loss discrepancy will be constant for all cases.
    If so, then adding some constant loss at high frequencies will improve correlation across a wide range of cases.

Empirical Model

Additional via series impedance per meter z(f)

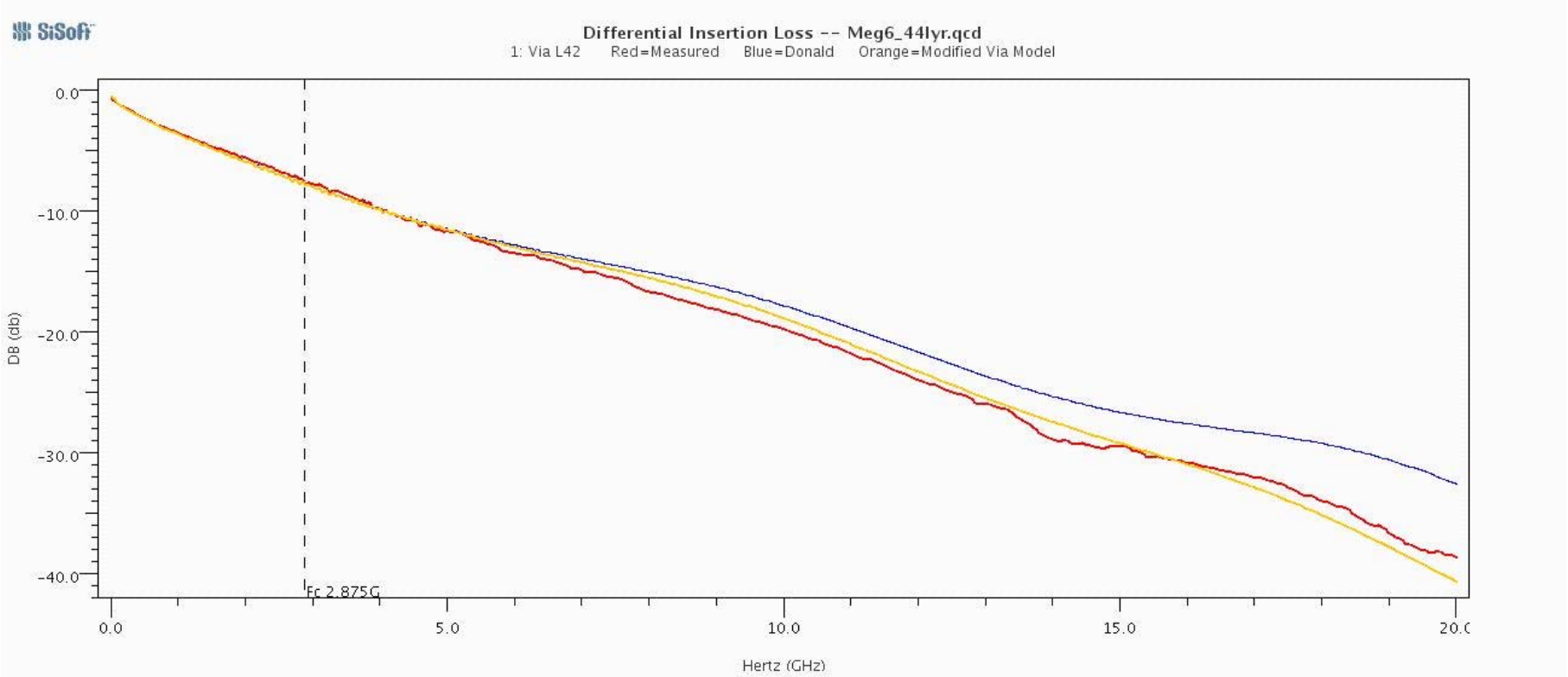
$$z(f) = (1 + j) r_v \left(\frac{f}{f_0} \right)^p$$

Via Length	r_v	p	f_0
0.298”	60Ω	3	5.0 GHz
0.293”	60Ω	3	5.0 GHz
0.280”	60Ω	3	5.0 GHz
0.181”	60Ω	3	5.0 GHz
0.125”	60Ω	3	5.0 GHz
0.083”	60Ω	3	3.5 GHz
0.068”	60Ω	3	3.5 GHz

A bit more loss for shorter vias

Baseline Case 1

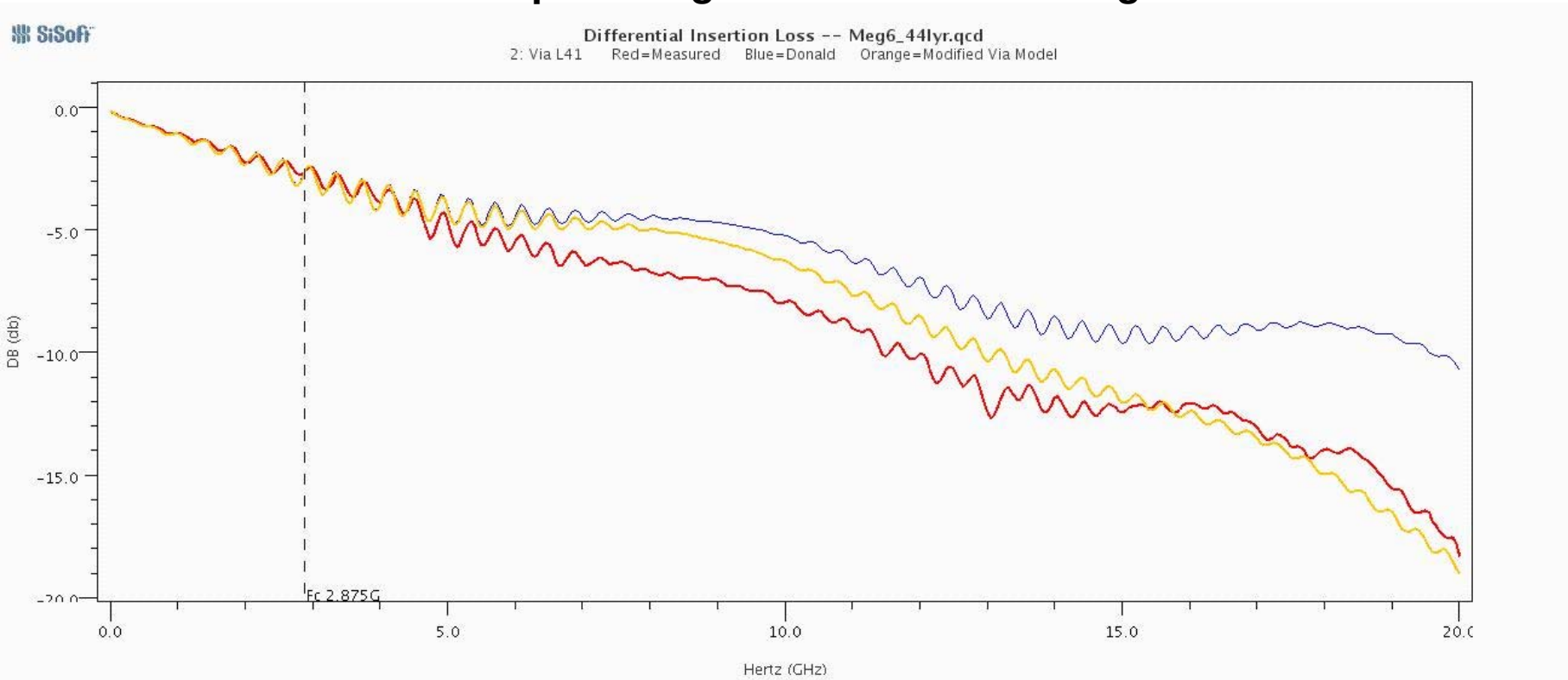
26.9” path length and 0.298” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 2

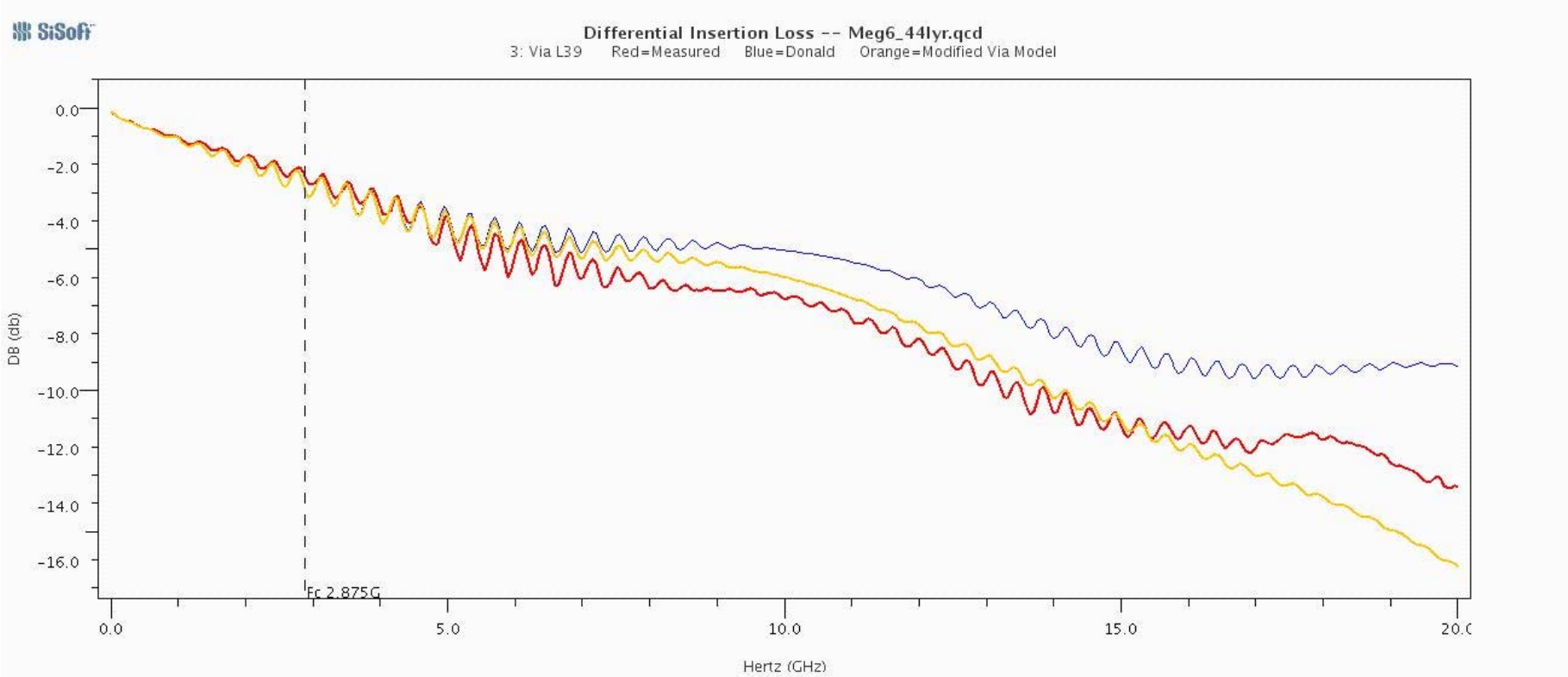
7.5” path length and 0.293” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 3

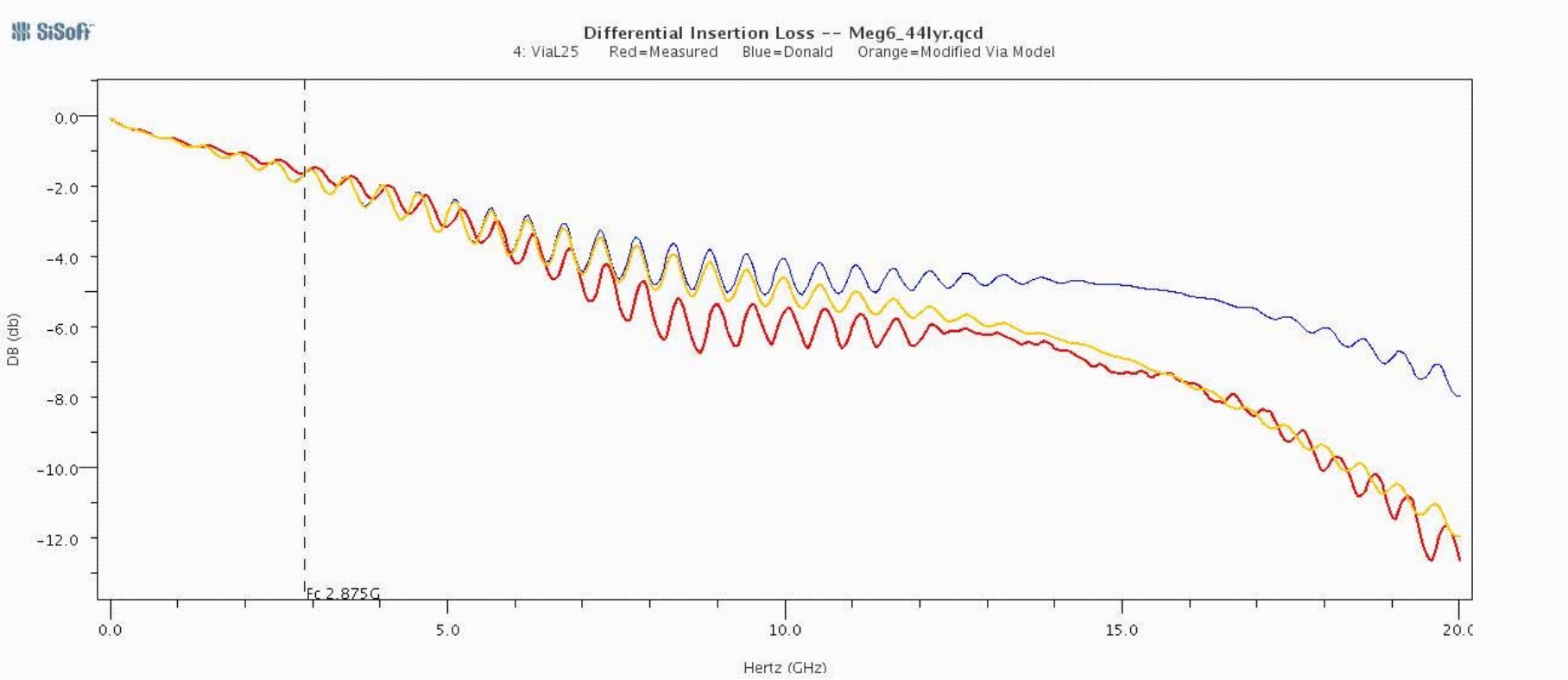
8.0” path length and 0.280” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 4

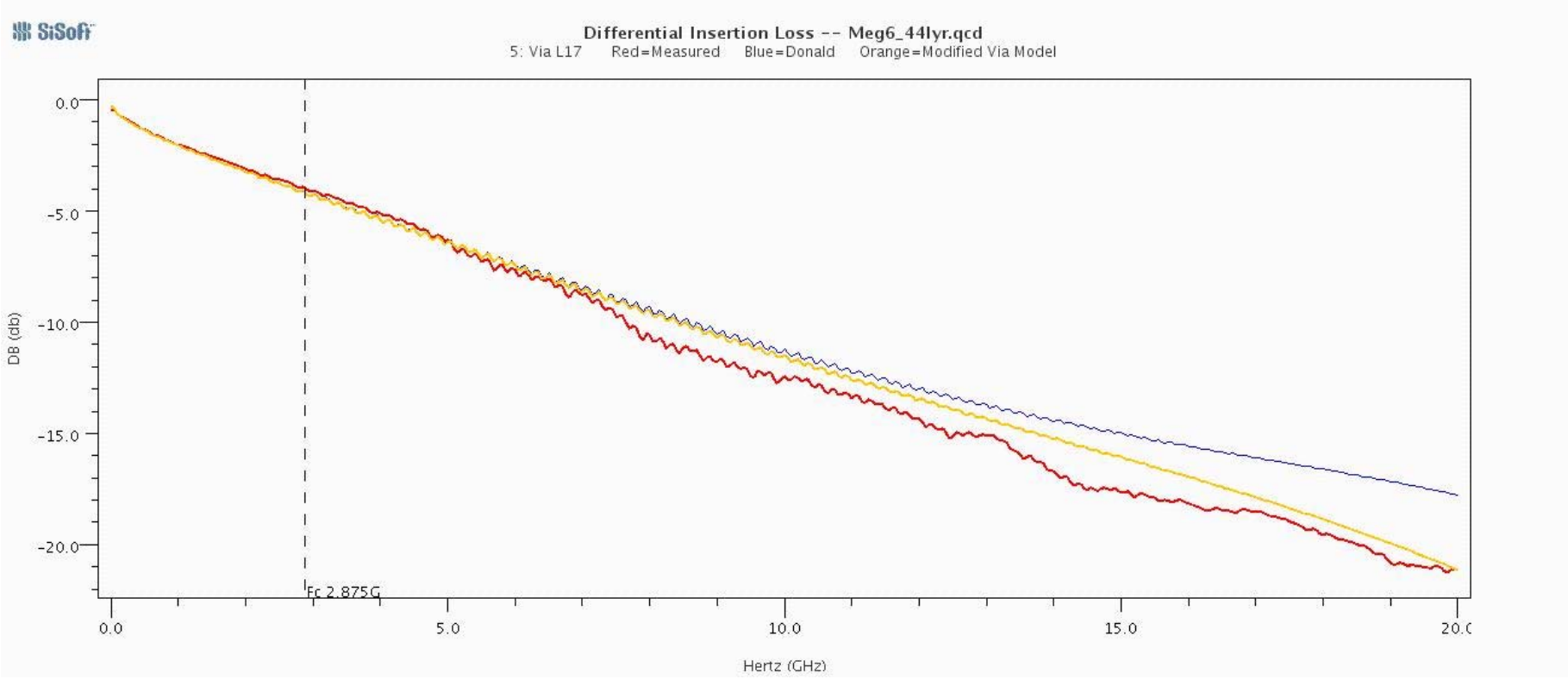
5.5” path length and 0.181” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 5

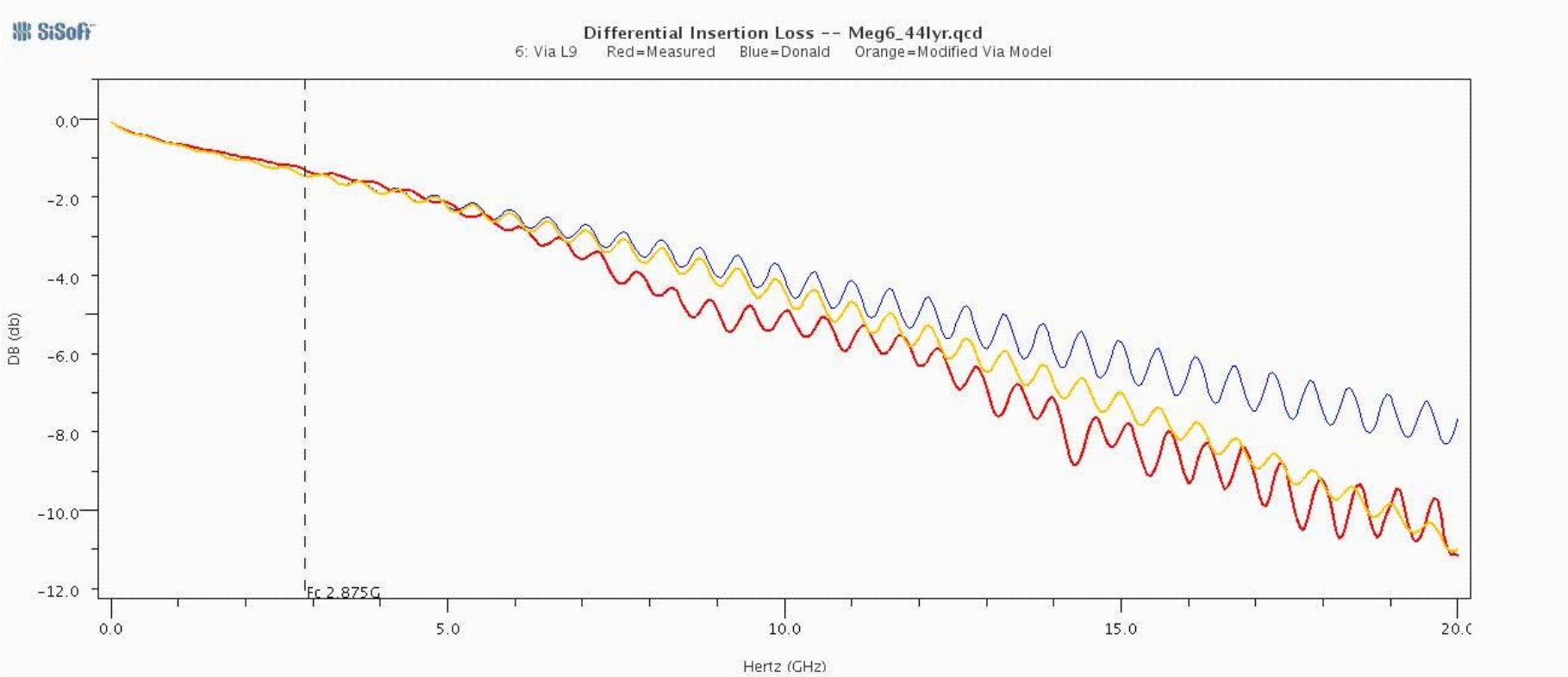
16.8” path length and 0.125” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 6

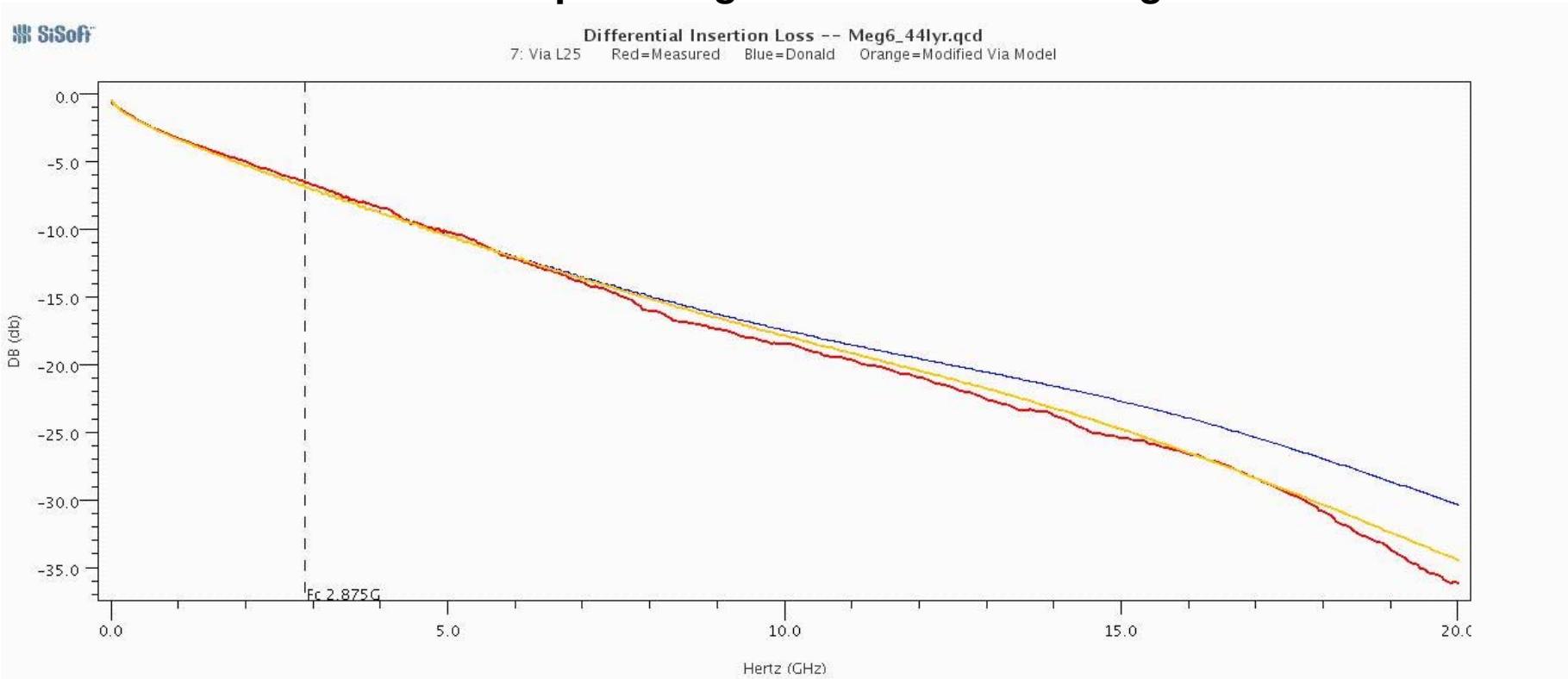
5.4” path length and 0.068” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 7

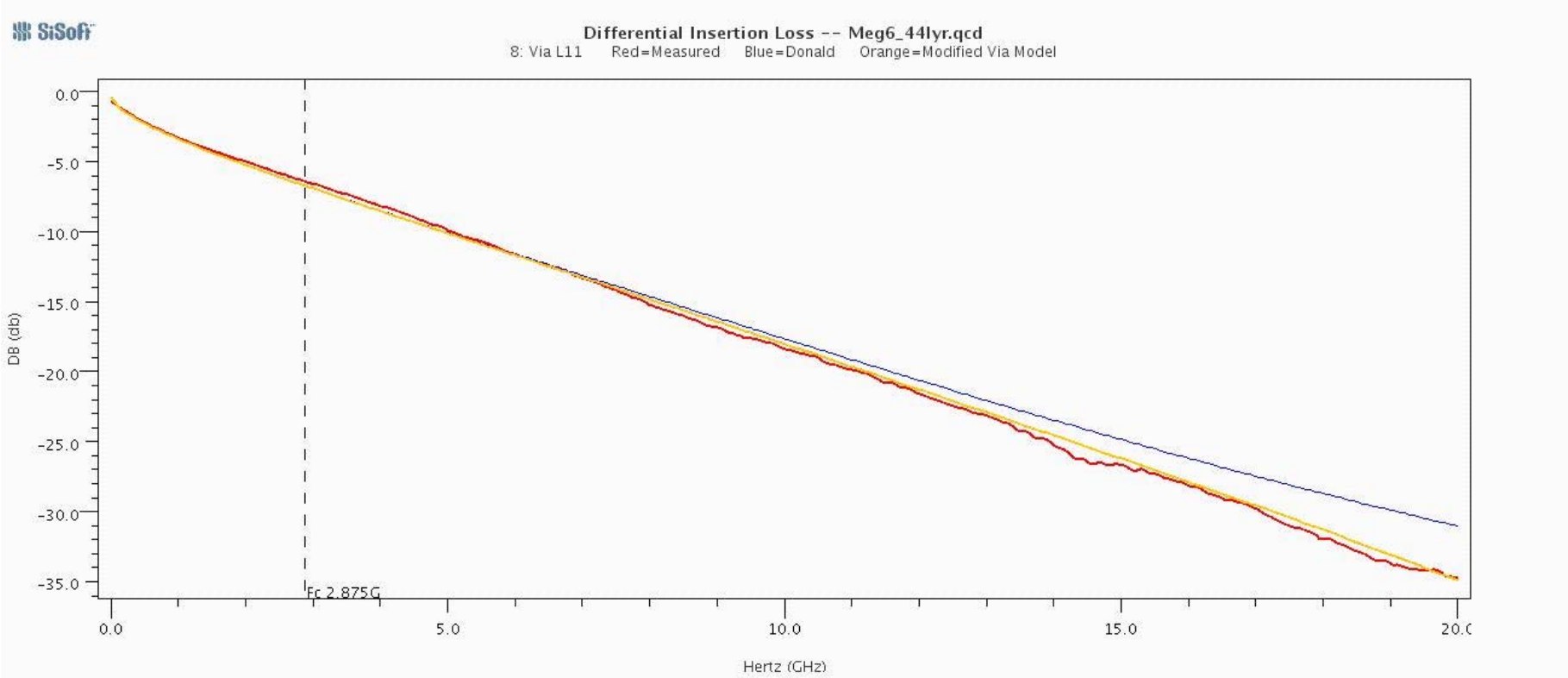
27.6” path length and 0.181” via length



RED: Measured BLUE: Baseline Model GOLD: Modified via model

Baseline Case 8

28.3” path length and 0.083” via length



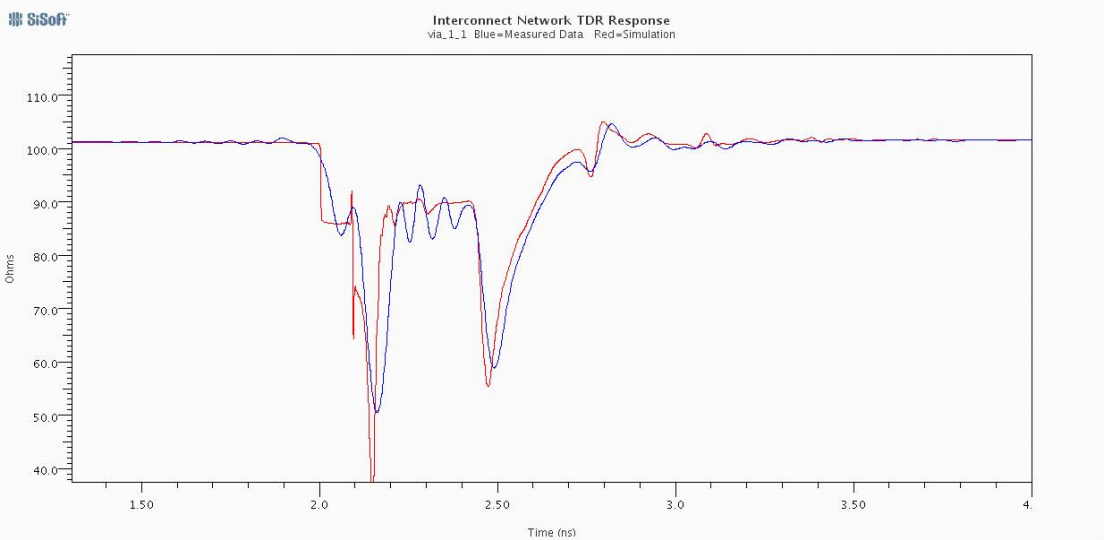
RED: Measured BLUE: Baseline Model GOLD: Modified via model

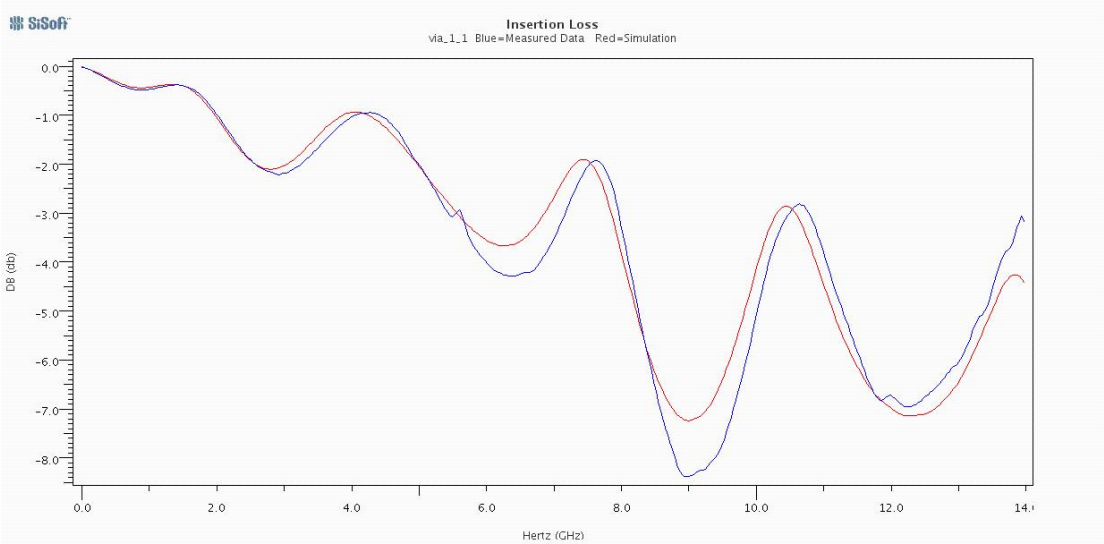
New Data: Via Stitch Board

Configuration	Total Length	Vias
1.1	1.34”	2
1.6	11.9”	8
4.1	2.2”	2
4.2	8.1”	2
4.3	12.0”	2

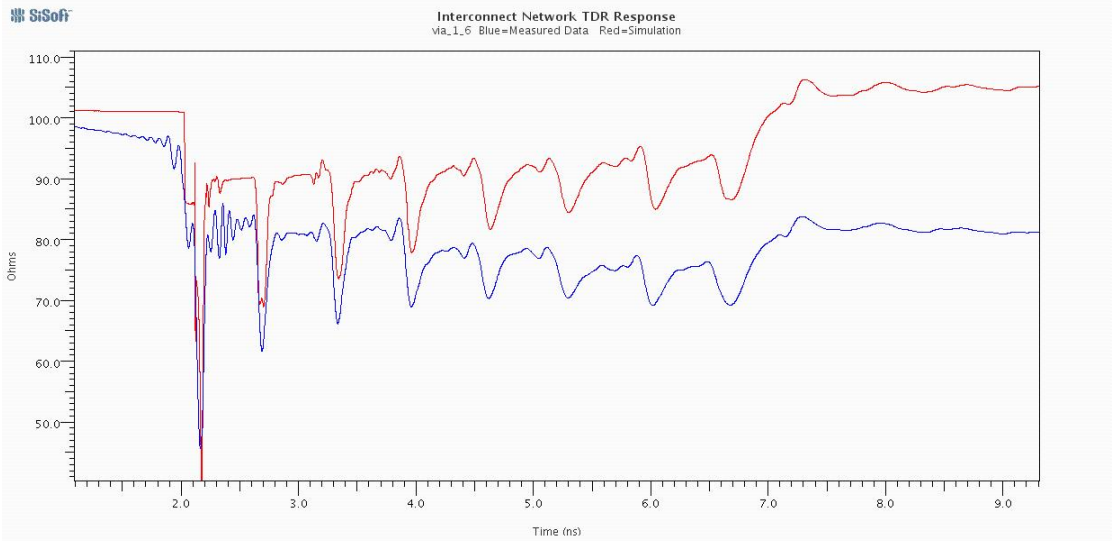
FR4 dielectric required different dielectric constant and dielectric loss tangent.
All other model parameters remained the same.

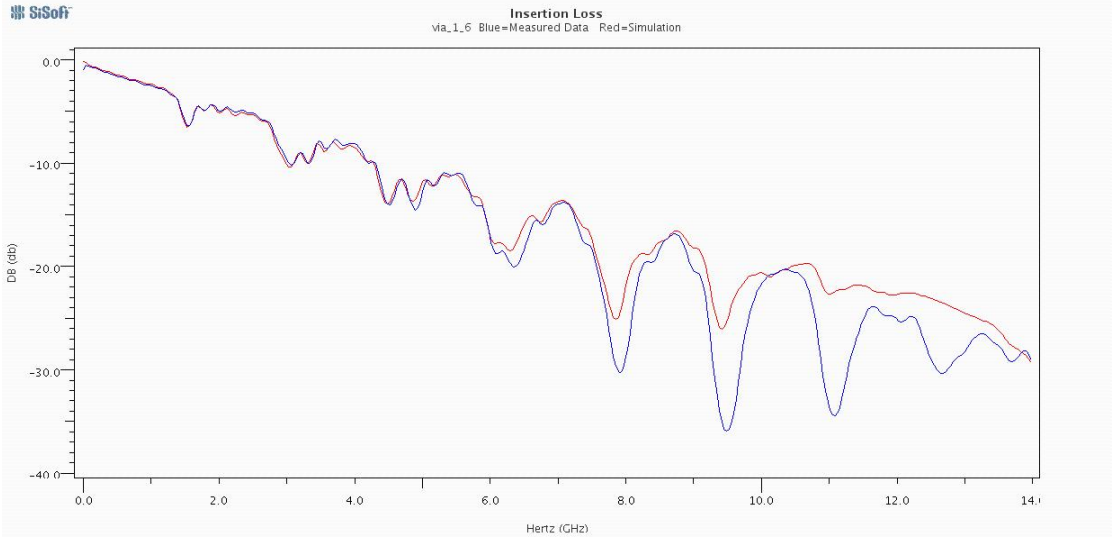
Configuration 1.1



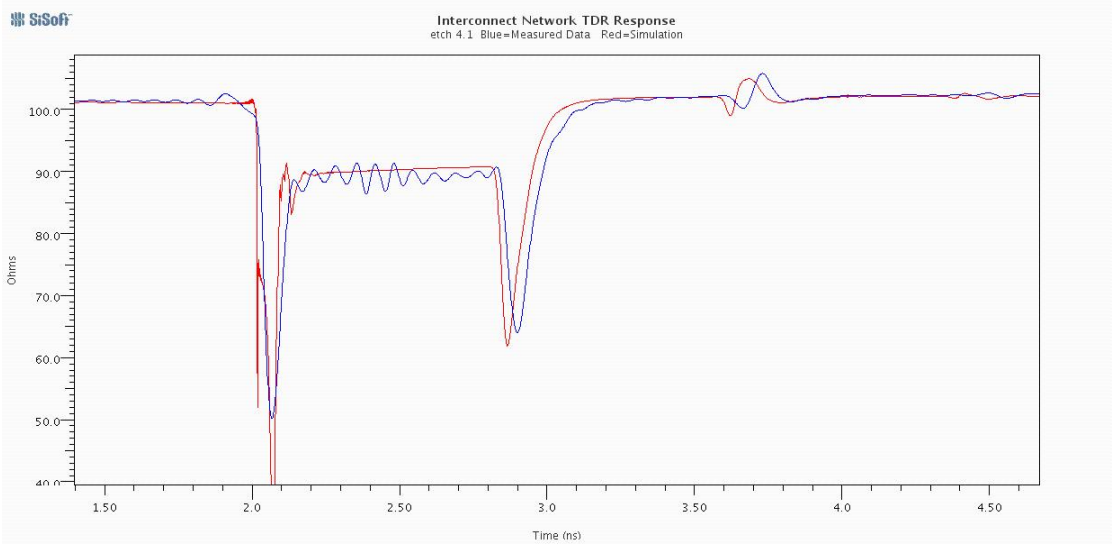


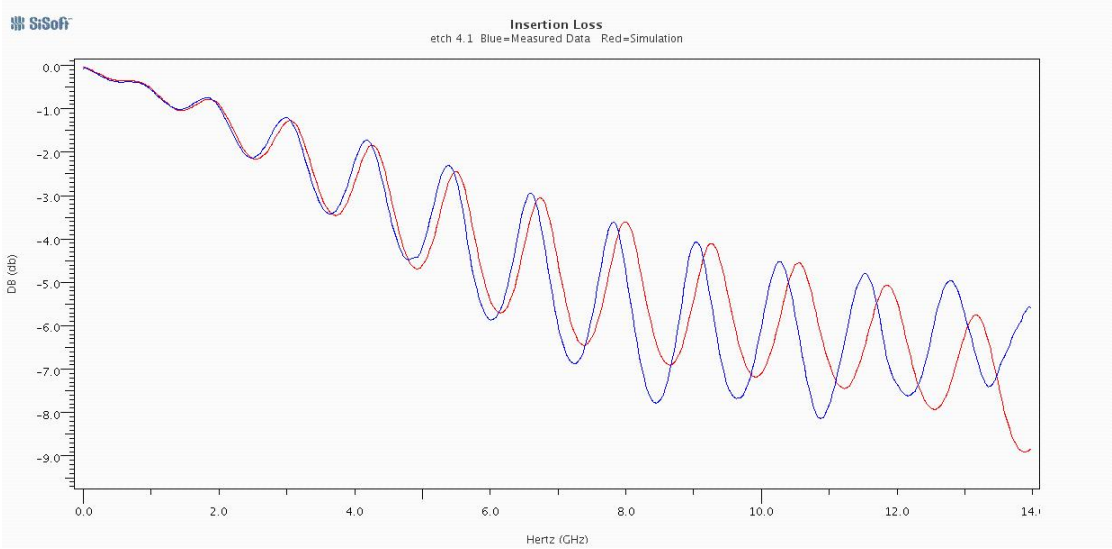
Configuration 1.6



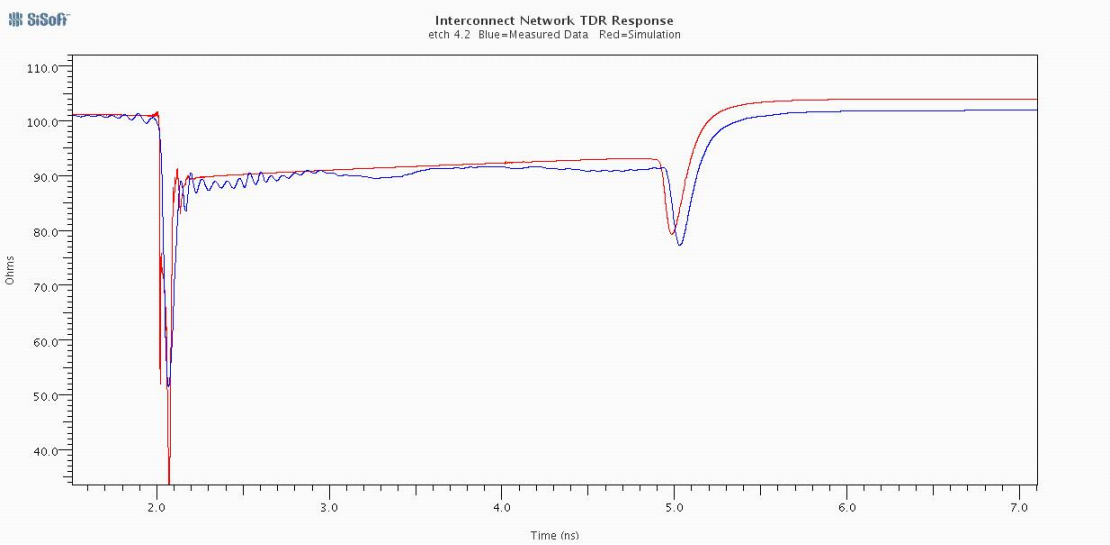


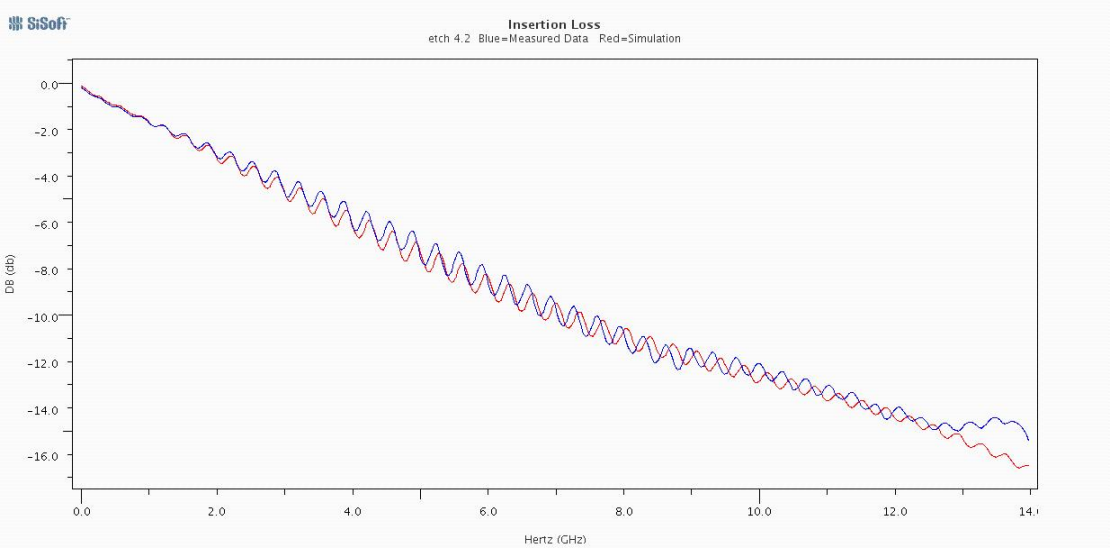
Configuration 4.1



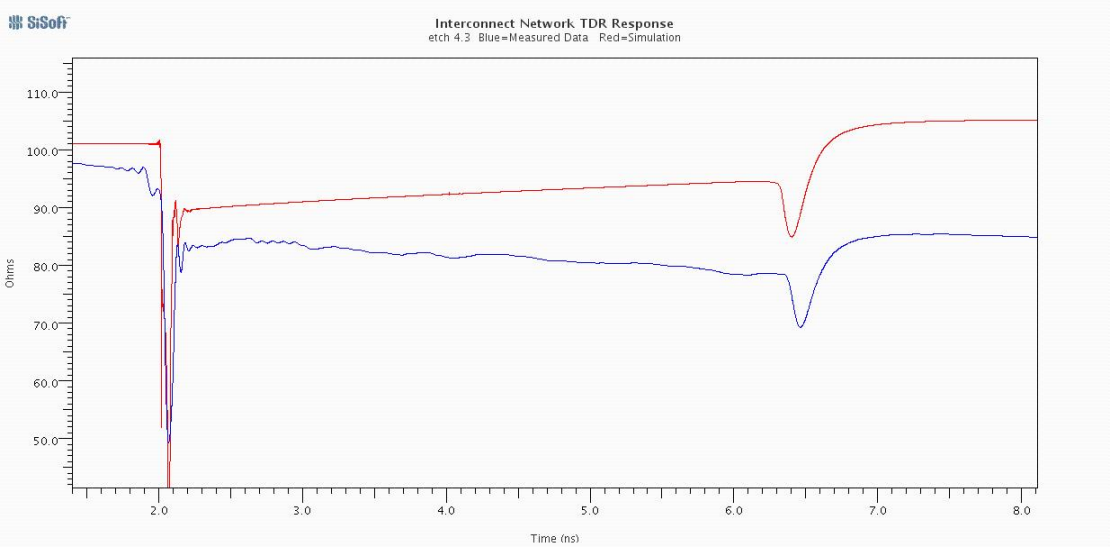


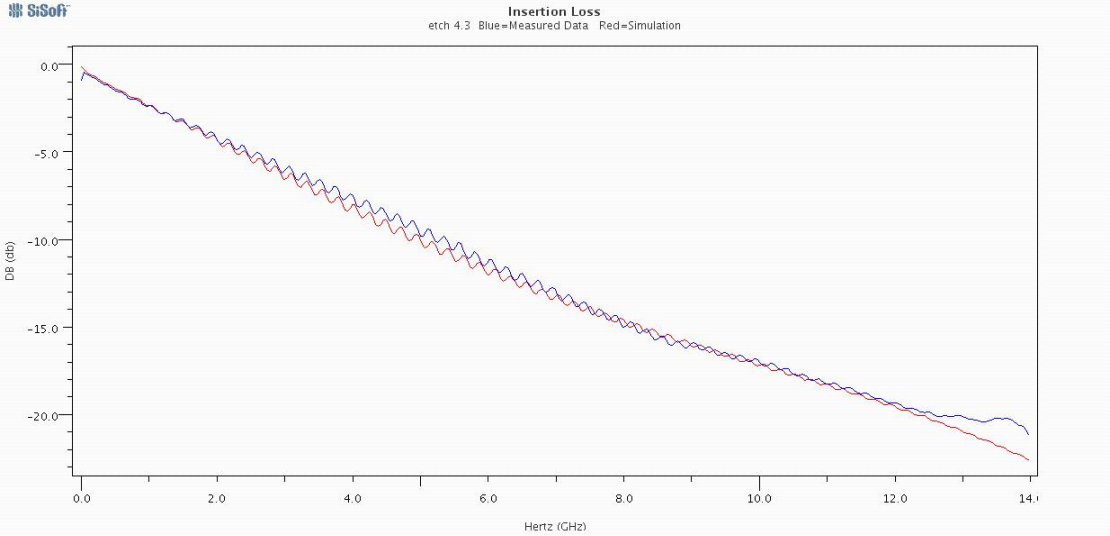
Configuration 4.2





Configuration 4.3



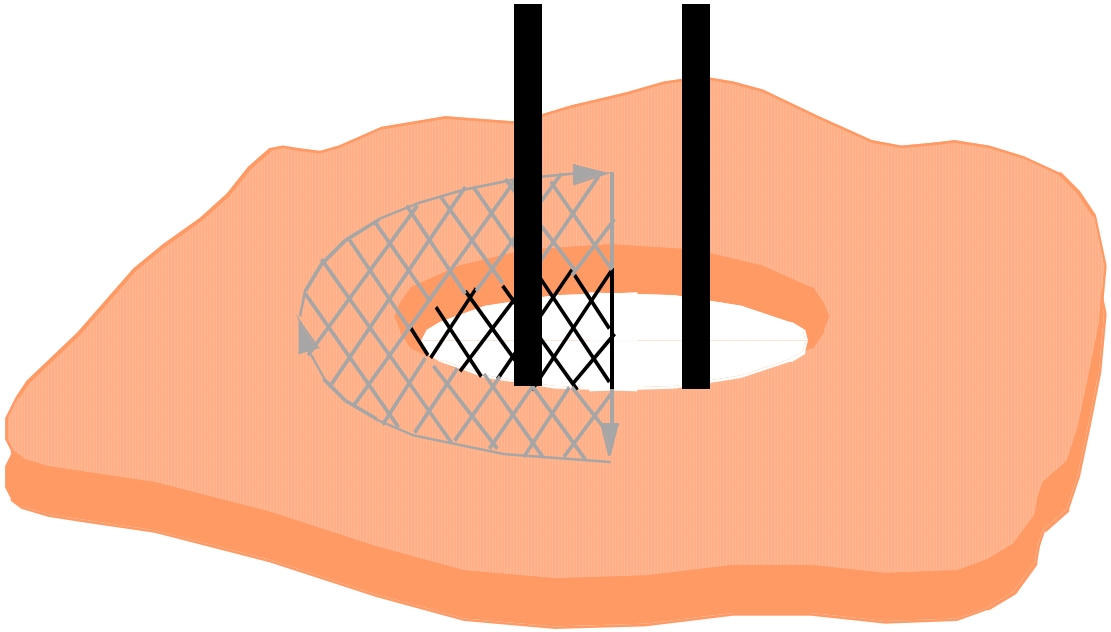


~~Continued~~ Hypothesis ~~Testing~~

- Via losses
  - Via barrel losses
    If so, loss discrepancy will be a linear function of via length.
    If so, then adding more loss to barrel at high frequencies will improve correlation across range of cases.
  - Losses at transition e to via
    If so, loss discrepancy onstant for all cases.
    If so, then adding some tant loss at high frequencies will improve correlation across a wide range of cases.
- Follow-on hypothesis: The losses occur in the ground return path.

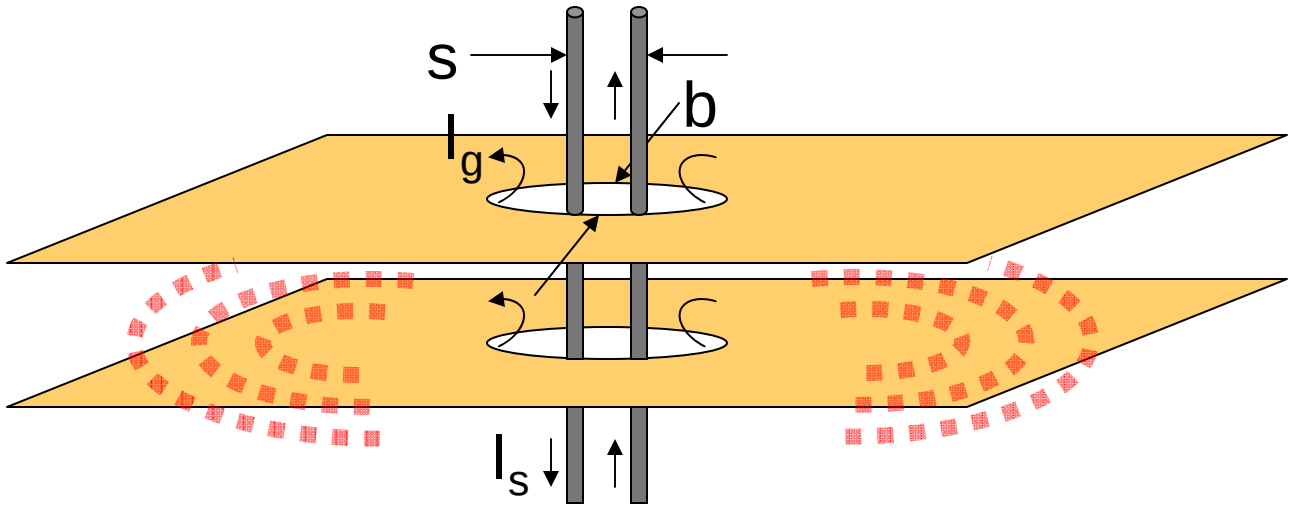
Let's start working on some physics!

Ground Currents in Differential Mode



Via Barrel Losses

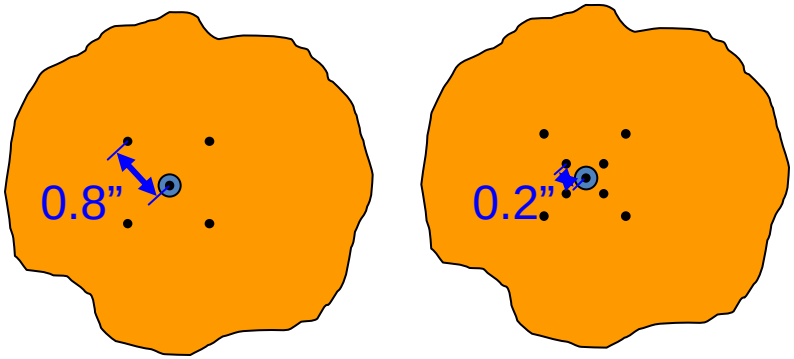
Energy is sprayed out between the ground planes.
The energy only returns
if the ground vias are closer than $\lambda/4$.



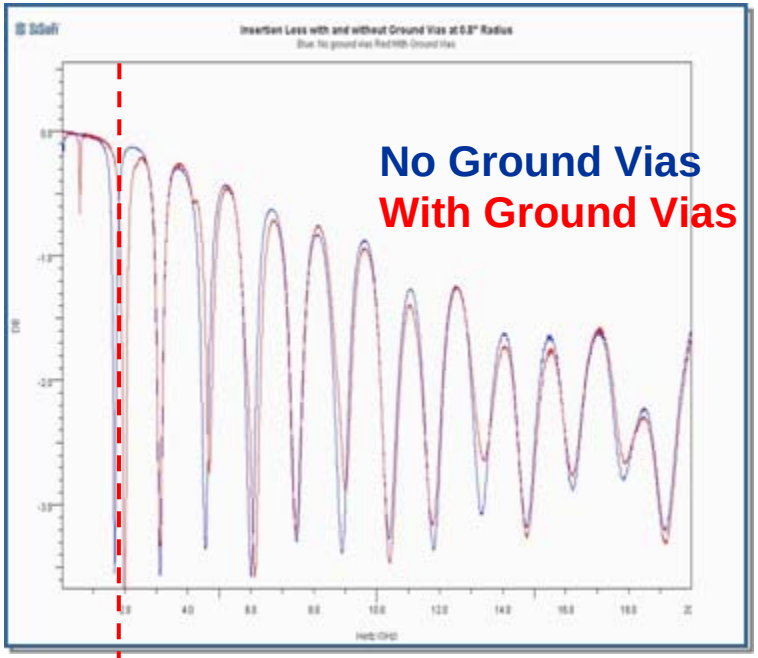
$$I_g = I_s\left(1 - \frac{2}{\pi}\operatorname{atan}\left(\frac{b}{s}\right)\right)$$

Loss is proportional to I_g^2

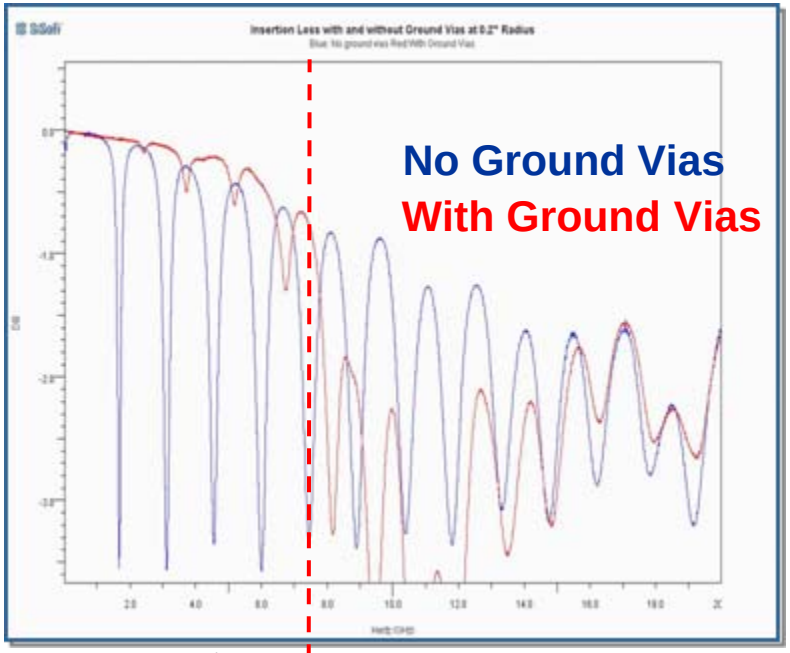
Ground Vias Closer Than λ/4



Chong Ding, et. al.,
“A Simple Via Experiment”,
paper 5-TP2, DesignCon2009,
February 3, 2009



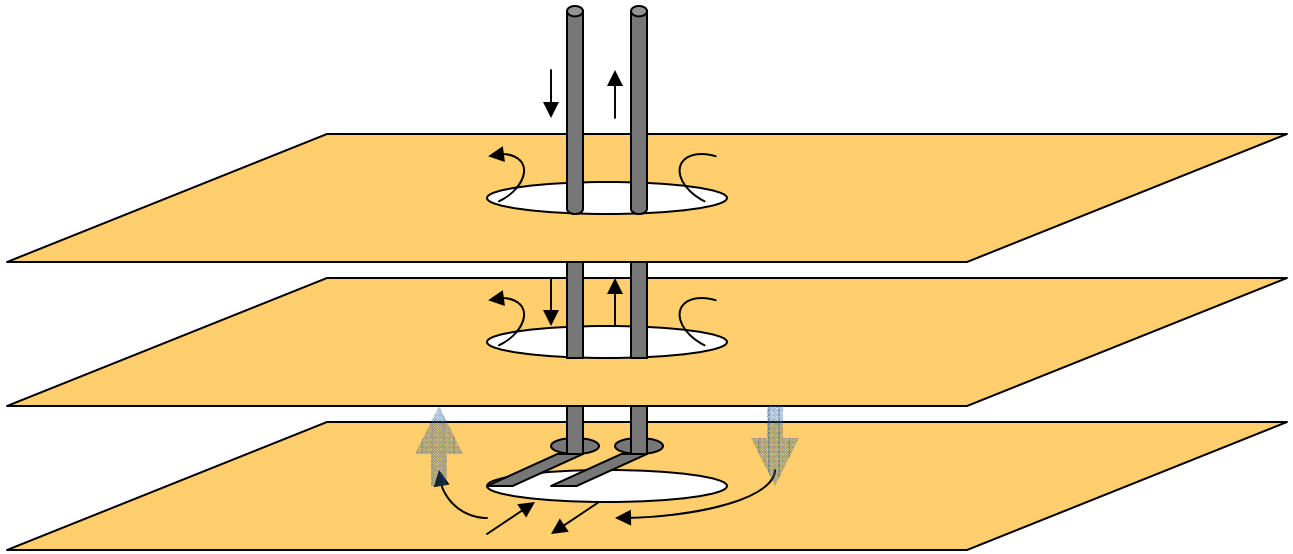
$\frac{\lambda}{4} = 0.8''$



$\frac{\lambda}{4} = 0.2''$

Via/Stripline Transition Losses

Current needs to get from under the stripline to the via antipad.



When ground vias are farther away than $\lambda/4$,
ground currents are inductively coupled
by higher order radial TEM waves.
This mechanism is not efficient.

In Conclusion …

- Empirical model of via losses is consistent with measured data.
- Analysis of ground path losses is qualitatively consistent with empirical model.
  - When ground vias are closer than $\lambda/4$, ground path losses are relatively low.
  - When ground vias are farther away than $\lambda/4$, ground path losses increase rapidly.
- PREDICTION: Maximizing via even mode impedance while maintaining matched odd mode impedance will reduce losses when ground vias are farther away than $\lambda/4$.