DesignCon 2015

CLOSING THE LOOP: WHAT DO WE DO WHEN MEASUREMENTS & SIMULATIONS DON'T MATCH?

UBM

Panelists

Alfred Neves, Wild River Technology
Steve Pytel, Ansys
Yuriy Shlepnev, Symberian
Doug Burns, SiSoft
Scott McMorrow, Teraspeed Consulting
Heidi Barnes, Keysight Technologies

Martin Rowe, moderator martin.rowe@ubm.com

Simulation and Measurement Correspondence – What is the DUT, and does it work in a airplane?

Alfred Neves, Wild River Technology

The New Boss, Manager "X"

Manager "X"

- A bit confused on how to build a cohesive, energized, low politics, confident signal organization
- Personally, we did not "get" each other
- Insisted on building the group with new grads from "his" University "X"

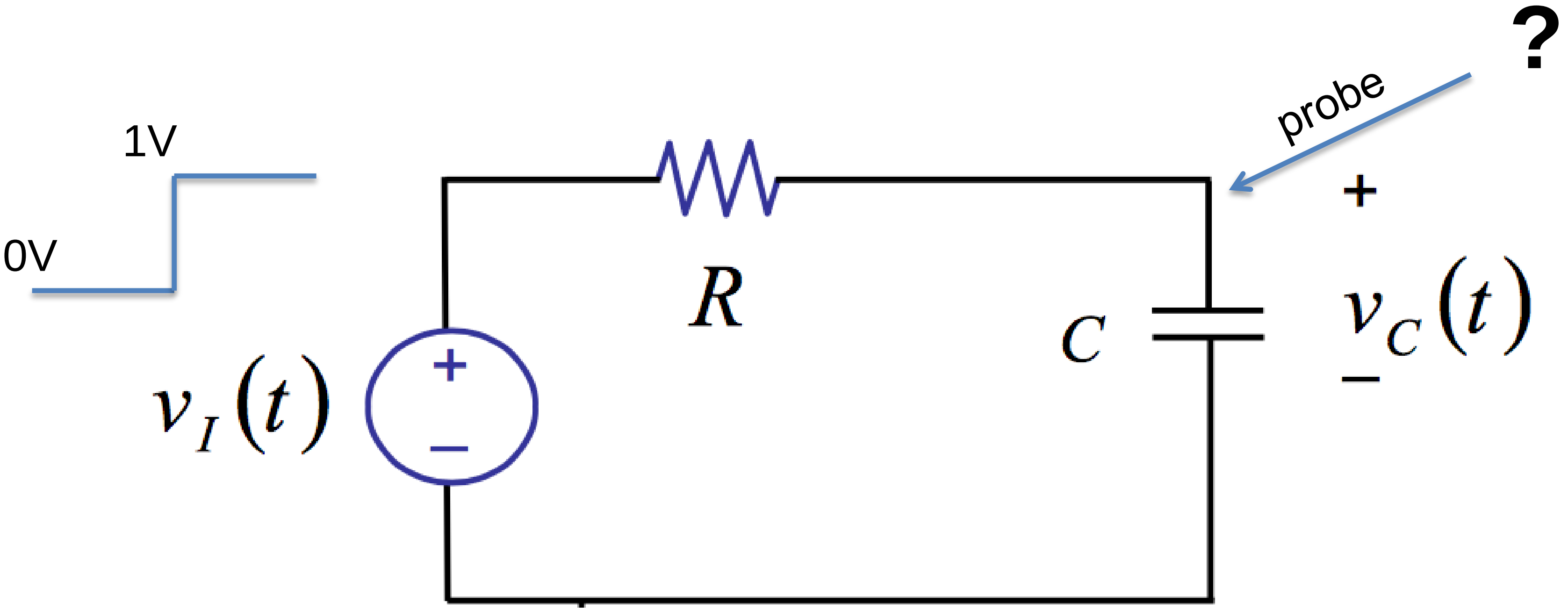
We had our differences..

He drove a $100k Porsche 911

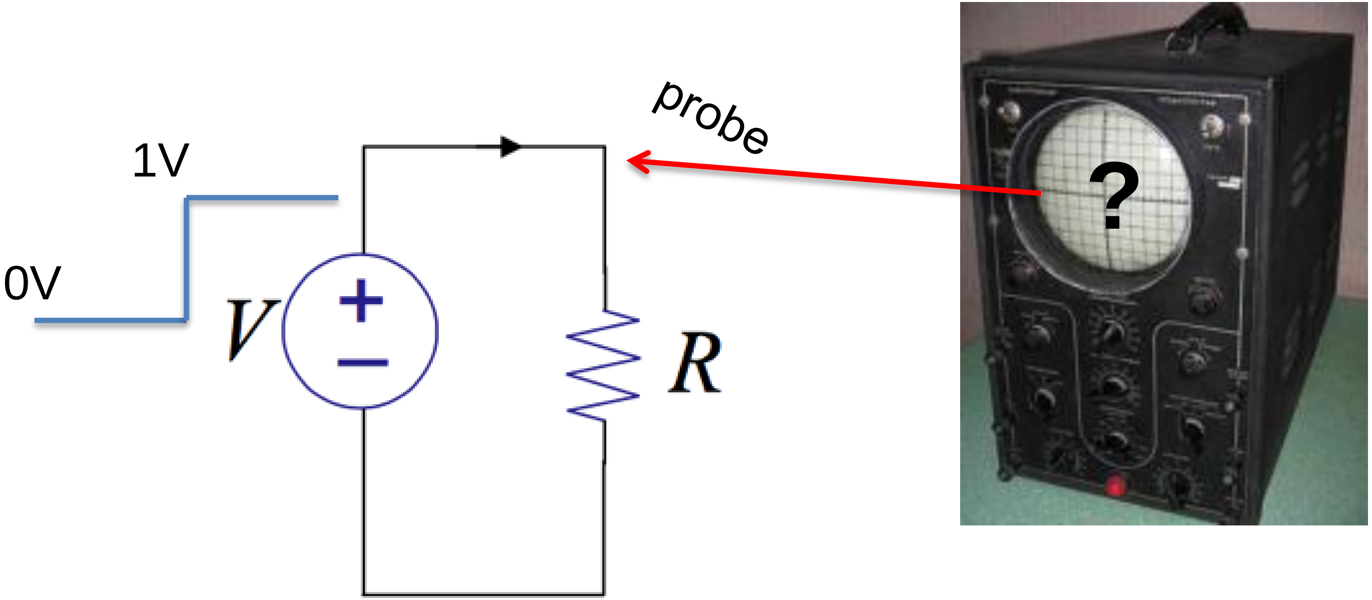
Cup holders were not included

I drove an old Jeep

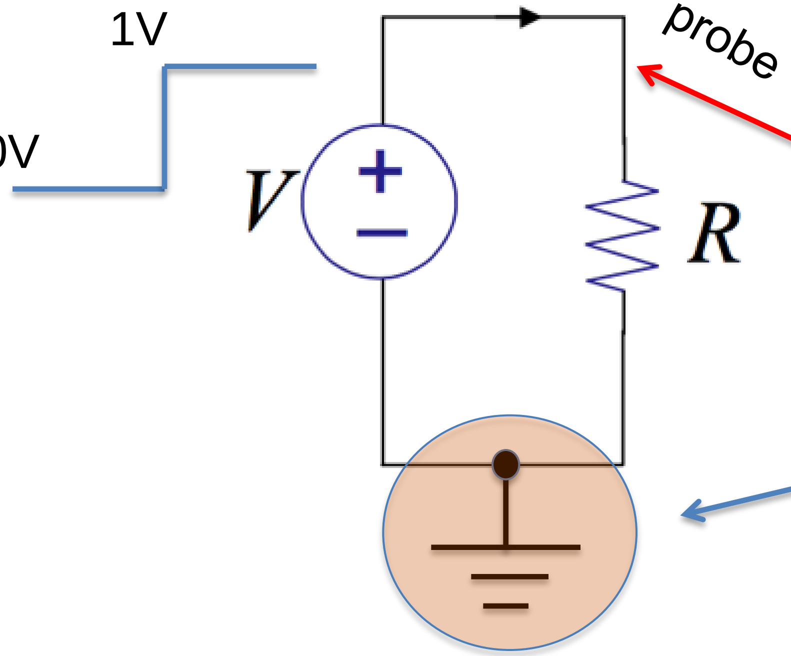
32 University "X"-ers in a row couldn't answer (assume probe is high impedance, latest generation 200 Gs/sec sampling oscilloscope)



After the 32nd I had a mental fit or “break” and reacted a bit irrationally with this semi-ridiculous question:

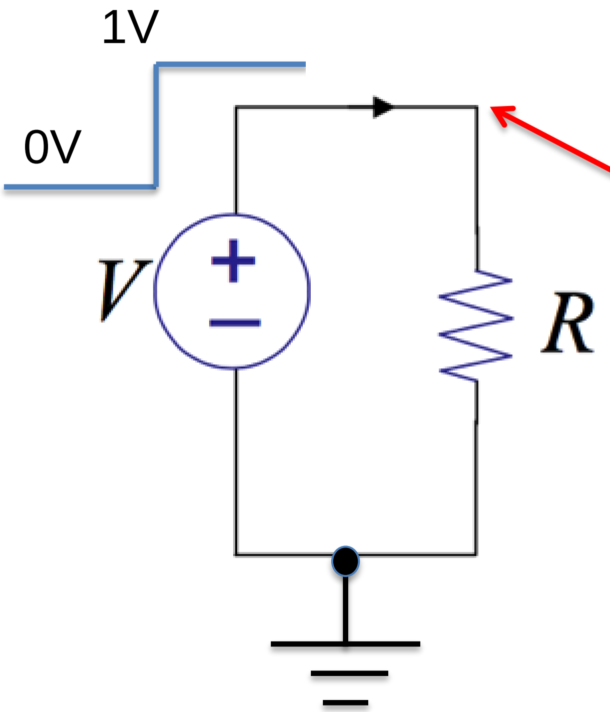


Interviewers Response: Your asking a trick question, you have no ground!



The Missing Ground

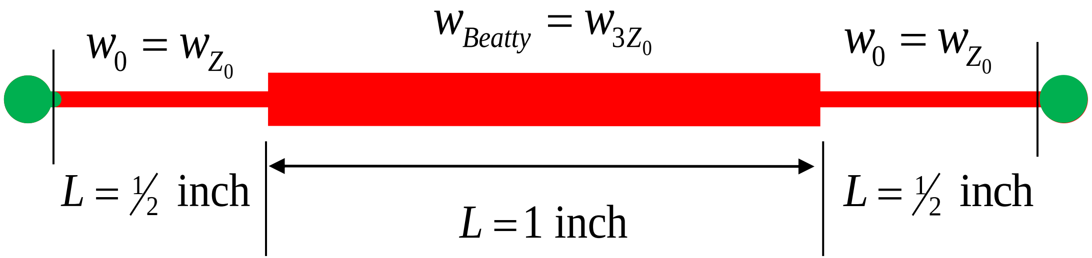
My Response: Ok. So, does the ground issue imply you couldn't make the measurement in an aircraft?

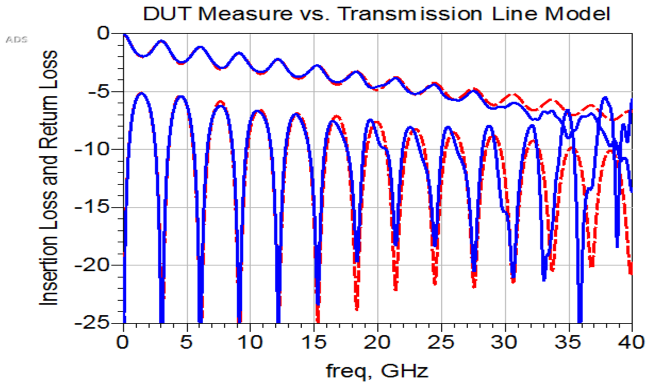


What the Virtual Seal Team 6 Team Learned

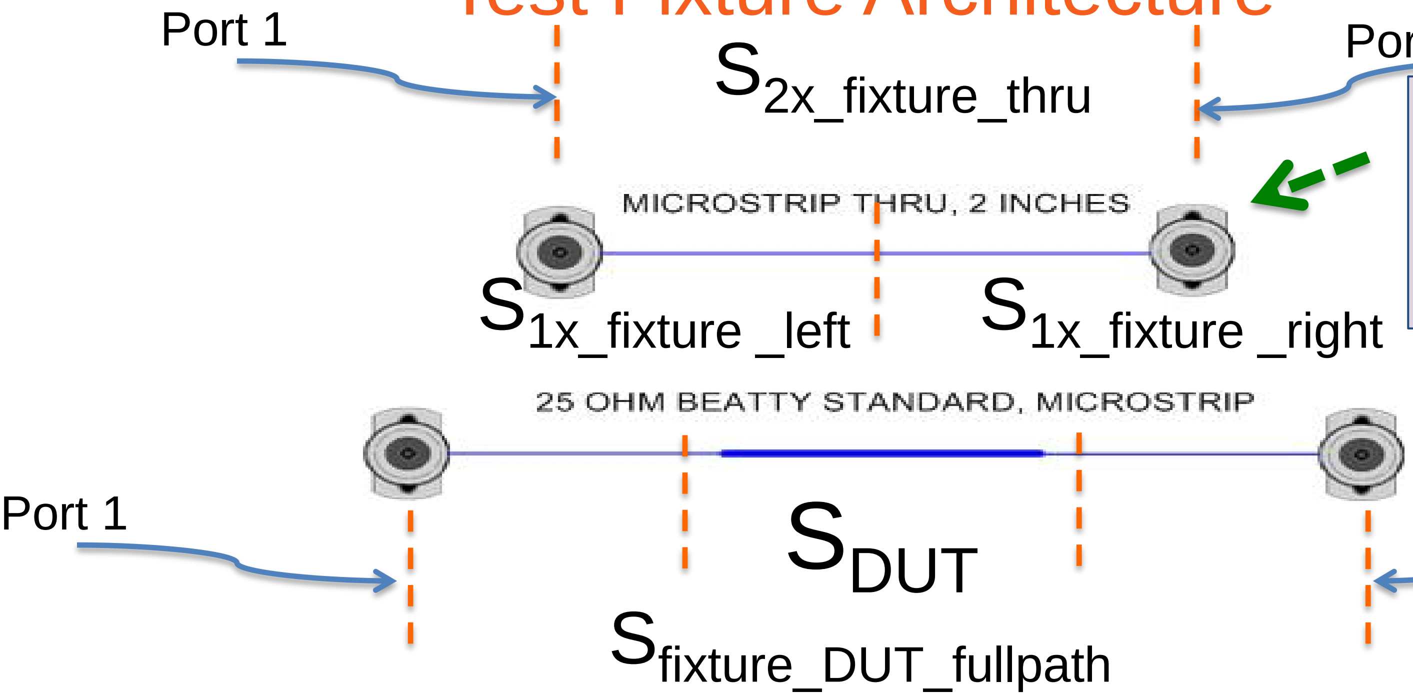
- **<u>Everything</u>** is hard for 32 Gbps level work!
  - Simulation (mesh, material identification)
  - Fabrication (etch, weave, non-homogeneity
  - Measurement and De-embedding

A Non-Trick Question: What part of Beatty Standard would you simulate – **What is the DUT?**





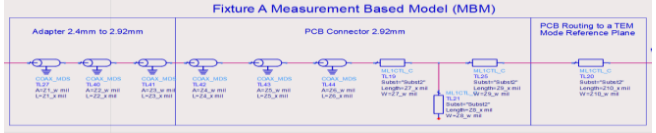
De-Embedding is about DUT Identification and Test Fixture Architecture



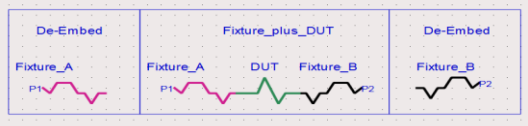
AFR requires one THRU structure, GMS (Simbeor) requires 2 lines

Model Workflow with Measure-Based Modeling

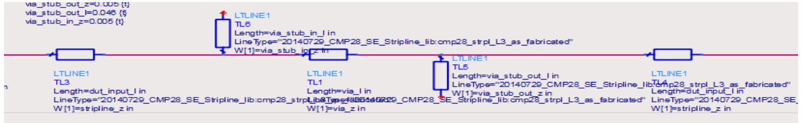
1 Fixture Model



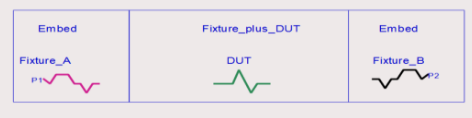
2 Fixture Removal from Measured Data



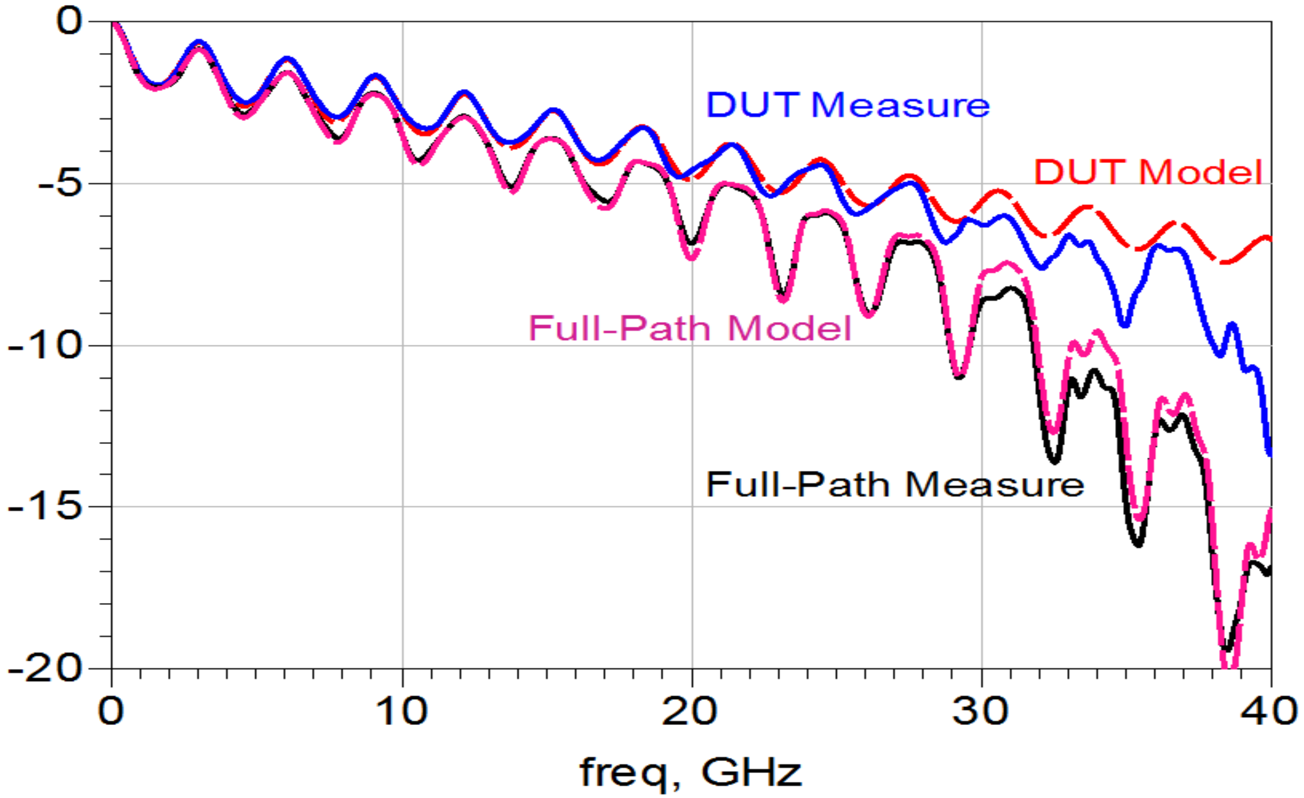
3 DUT Model



4 Full-Path Embed Fixture with DUT Model



Successful De-embedding and Full-Path Example



Thanks!

Sandy River, Portland Oregon

Al Neves
Chief Technologist
Wild River Technology
al@wildrivertech.com

CLOSING THE LOOP: WHAT DO WE DO WHEN MEASUREMENTS & SIMULATIONS DON'T MATCH?

STEVE PYTEL, ANSYS

"A *theory* is something nobody believes, except the person who made it. An *experiment* is something everybody believes, except the person who made it."

— Albert Einstein

"A *simulation* is something nobody believes, except the person who made it. A *measurement* is something everybody believes, except the person who made it."

— Paul Huray

1. Understand the Basic Technology

   Applies to both Test Equipment & Simulation Tools

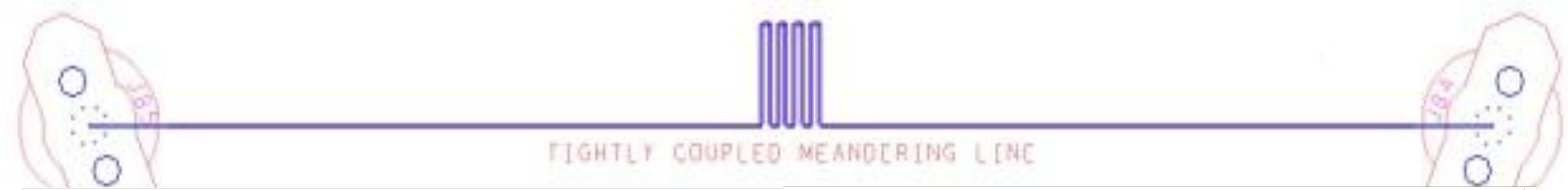
      VNA’s, Oscilloscopes, BERTs, …

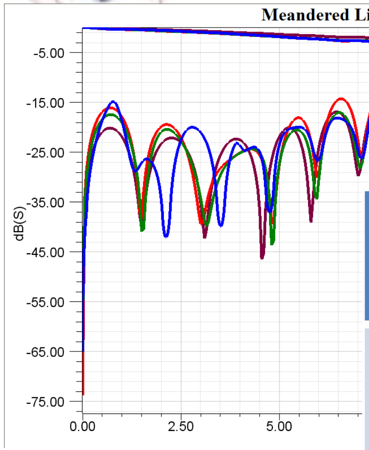
      3D, Hybrid, 2D, FEM, SPICE, …

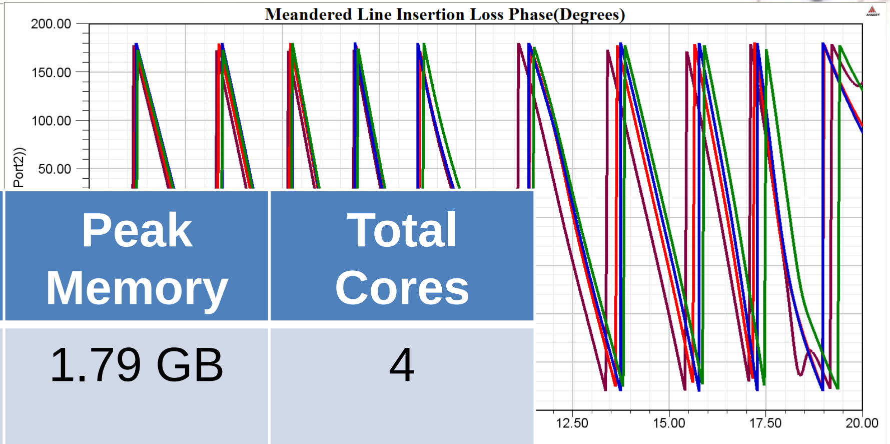
2. Understand the Assumptions

   Applies to both Test Equipment & Simulation Tools

   Material properties, Geometry, Ports, Probes, …



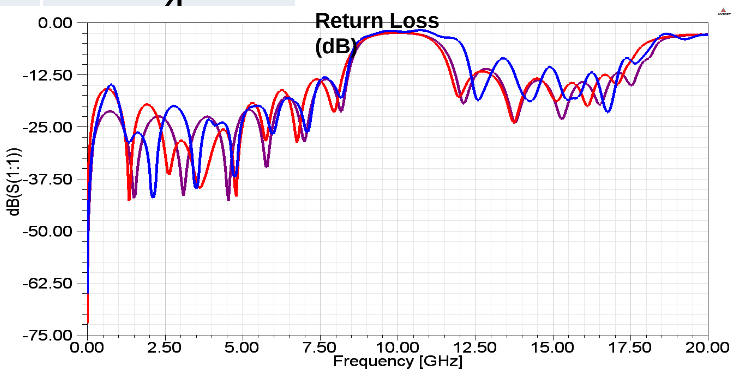




Simulation Method	Elapsed Time	Peak Memory	Total Cores
3D FEM	1hr 30m 7s	1.79 GB	4
Hybrid	11 s	54 MB	4
3D MoM	17m 53s	213 MB	[illegible]

3D FEM – red
Hybrid – purple
MoM – green
Measured –blue

Pytel et al, “Successful Practices for the Modeling of Printed Circuit Boards and Substrates Using Electromagnetic Field Solvers”, *43rd International Symposium on Microelectronics*, October 31 – November 4, 2010.



CLOSING THE LOOP: WHAT DO WE DO WHEN MEASUREMENTS AND SIMULATIONS DON'T MATCH?

YURIY SHLEPNEV, SIMBERIAN INC.

DesignCon 2015

UBM

What could possibly be wrong?

1. Manufacturing is messed up…
2. Measurements are messed up…
3. Modeling is messed up...

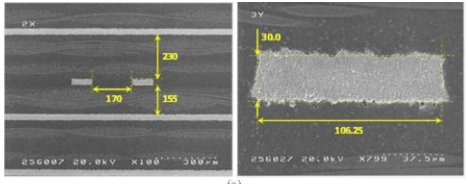
How to troubleshoot all those problems for 10 Gbps and higher data rates?

1. Manufacturing

- Adjustments by manufacturer must be figured out and accounted for in the analysis
  - Stackup adjustments
  - Etching and compensation for etching
  - Trace width and separation adjustments to “dial in the impedance”
- Random variations may require statistical analysis or manufacturer pre-qualification
  - Fiber Weave Effect
  - Random variations in layer thickness, trace width and separation, back-drilling…
  - The only published statistical data:
    Brist, G., “Design Optimization of Single-Ended and Differential Impedance PCB Transmission Lines,” PCB West Conference Proceedings, 2004
- Cross-sectioning may be required to identify/validate board geometry

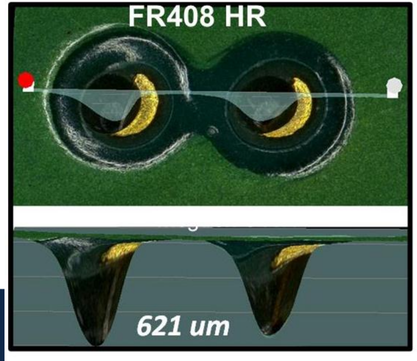
Example of cross-sectioning from: W. Beyene, Y.-C. Hahm, J. Ren, D. Secker, D. Mullen, Y. Shlepnev, Lessons learned: How to Make Predictable PCB Interconnects for Data Rates of 50 Gbps and Beyond, DesignCon2014

Stackup and cross-section is not as designed (adjusted by manufacturer):



(a)

Significant random variations in all back-drilling:



2. Measurements

- Use S-parameters measured with VNA with the bandwidth matching the signal spectrum and proper sampling
  - Read the manual or get training
  - Formally control quality of the measured S-parameters
- Use rational approximation of S-parameters for consistency of frequency and time domain analyses and accuracy control
  - Compare time-domain responses computed from S-parameters for consistency
- Calibration, de-embedding, probes or connectors may have issues…

Example of formal quality evaluation in Simbeor software for a subset of S-parameters measured for CMP-28 validation platform:

Touchstone Analyzer

C:\Repository\Simbeor\CMP-28_Simbeor_Kit_Rev4\CMP-28_Rev4\Touchstone_Files\1stc...

File name	Quality	Passivity	Reciprocity	Causality
cmp28_gnd_voids_p1J74_p2J75.s2p	99.5	100	99.4	-
cmp28_graduated_coplanar_p1J70_p2J69.s2p	99.7	100	99.5	-
cmp28_mstrp_2in_p1J1_p2J2.s2p	99.5	100	99.7	-
cmp28_mstrp_8inch_p1J4_p2J3.s2p	99.7	100	99.8	-
cmp28_mstrp_Beatty_25ohm_p1J25_p2J26.s2p	99.6	100	99.4	-
cmp28_mstrp_multiZ_p1J31_p2J32.s2p	99.6	100	99.3	-
cmp28_mstrp_p1J30_p2J29.s2p	99.6	100	99.8	-
cmp28_mstrp_resonator_p1J22_p2J22.s2p	99.7	100	99.7	-
cmp28_mstrp_whiskers_p1J68_p2J67.s2p	99.5	100	99.8	-
cmp28_strpl_2in_50ohm_p1J6_p2J5.s2p	99.6	100	99.1	-
cmp28_strpl_2in_Capacitive_p1J10_p2J09.s2p	99.5	100	99.5	-
cmp28_strpl_2in_Inductive_p1J12_p2J11.s2p	99.5	100	99.4	-
cmp28_strpl_8inch_p1J7_p2J8.s2p	99.6	100	99.7	-
cmp28_strpl_Beatty_25ohm_p1J28_p2J27.s2p	99.7	100	99.4	-
cmp28_strpl_resonator_p1J23_p2J24.s2p	99.6	100	99.4	-
cmp28_via_pathology_p1J65_p2J66.s2p	99.6	100	99.8	-

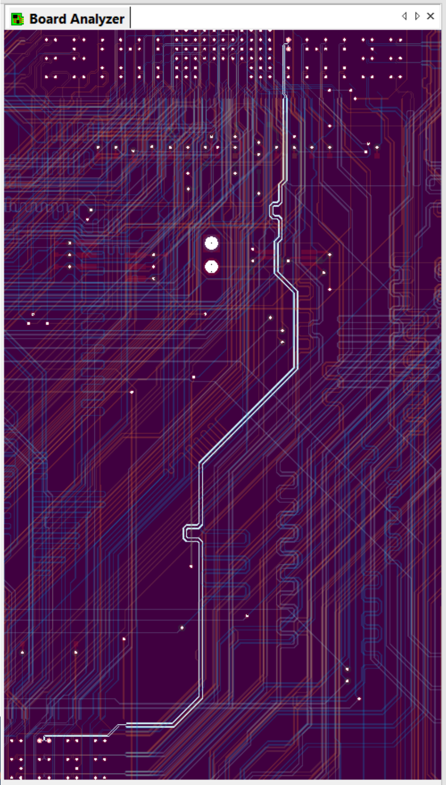
See more at Y. Shlepnev, “Reflections on S-parameter Quality”, IBIS Summit at DesignCon 2011, http://www.eda.org/ibis/summits/index-bytitle.htm

3. Modeling

- Serial interconnects are composed of traces (transmission lines) and transitions (discontinuities such as vias)
- T-Line models require:
  - Proper broadband material models: dielectrics, conductors and roughness – identify!
  - Localization or analysis with coupling
  - Full-wave models to account for dispersion in micro-strips
- Discontinuity models require:
  - Proper localization – verify and localize!
  - Full-wave 3D analysis with accurate numerical de-embedding

See more at Y. Shlepnev, “Decompositional Electromagnetic Analysis of Digital Interconnects”, IEEE Int. Symp. on Electromagnetic Compatibility (EMC2013), Denver, CO, 2013, p.563-568.

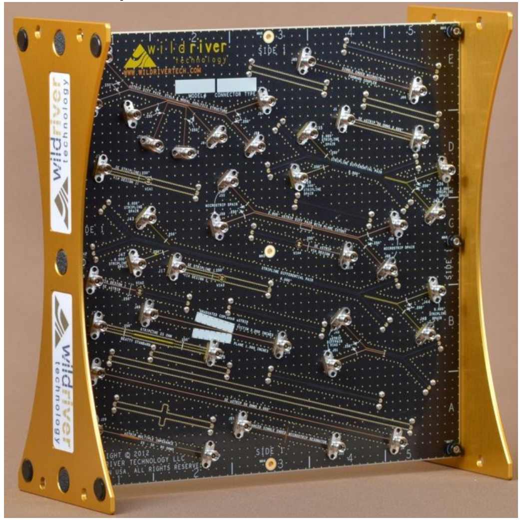
Typical BGA-to-BGA serial data link on PCB:



How to figure out the problem? Use validation platforms…

- Validation – independent checking or proving the validity or accuracy of manufacturing, models and measurements (preferably performed by disinterested parties);
- Include a set of structures to identify one material model at a time
  - Solder mask, core and prepreg, resin and glass, roughness, plating,…
- Include a set of structures to identify accuracy for transmission lines and typical discontinuities
  - Use identified material models for all structures on the board consistently
  - No tweaking - discrepancies should be investigated
- Compare both magnitudes and phases (or group delays) of all S-parameters and optionally TDR or eye diagrams computed from S-parameters

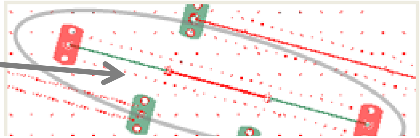
Example of validation platform: Wild River Technology CMP-28/32 Channel Modeling Platform for interconnect analysis to measurement validation up to 40/50 GHz or up to 28/32 Gbps:

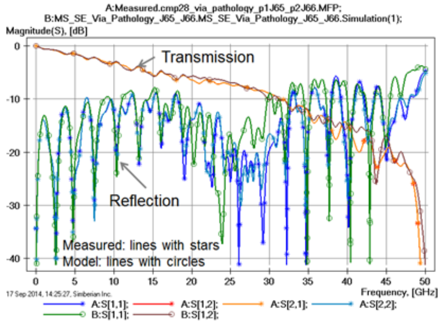


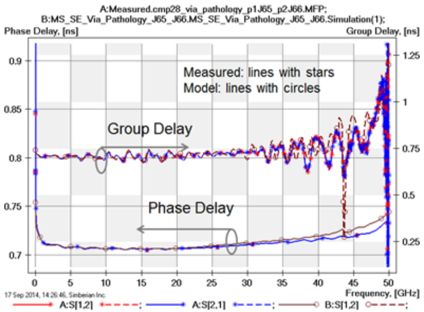
See more at: Y. Shlepnev, **Sink or swim at 28 Gbps**, The PCB Design Magazine, October 2014, p. 12-23.

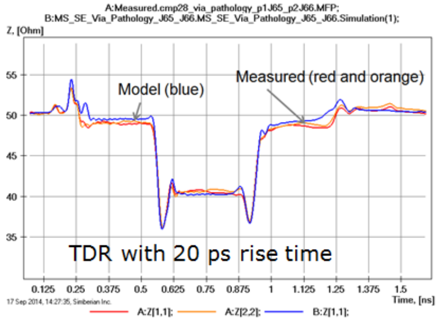
What is good match anyway?

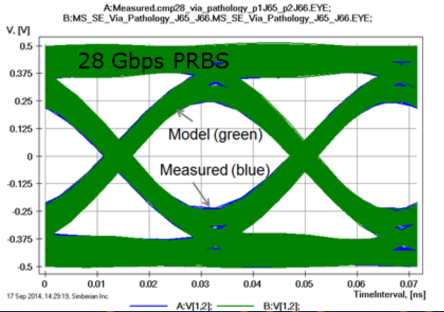
- Simple visual assessment of simulation to measurement correlation may be acceptable, but depends on experience of who is looking
- Feature Selective Validation (FSV) method can be used to formalize simulation to measurement correlation:
  - “IEEE 1597.1 Standard for Validation of Computational Electromagnetics Computer Modeling and Simulations.” Jun-2008.
  - A. P. Duffy’s papers at IEEE Transactions on EMC…











Analysis to measurement validation example from Simbeor EDA Kit for Wild River Technology CMP-28/32 Channel Modeling Platform

CLOSING THE LOOP:
WHAT DO WE DO WHEN MEASUREMENTS AND SIMULATIONS DON'T MATCH?"

Douglas Burns

Channel Simulations Are Like Mixed Drinks
The Ingredients Effect the Result

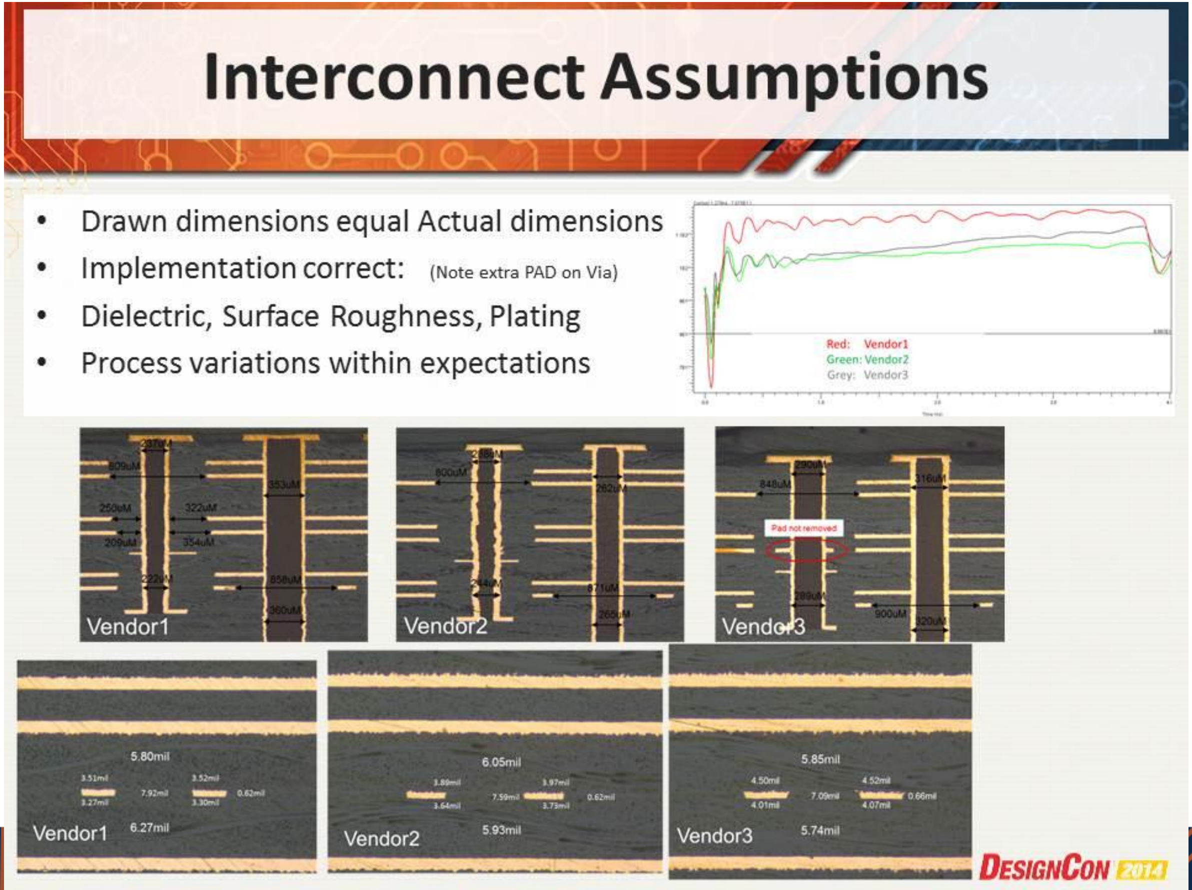
Top Shelf or Rotgut: What Is In Yours?

There are two types of S-parameters to consider: Measured and Modeled

- Measured data
  - Accurate for the specific condition measured
  - Does not reflect possible manufacturing variations
  - Most useful for calibrating modeled data
- Modeled data
  - Many ways to Generate
    - Easily model a range of manufacturing conditions
  - Requires calibration to ensure model represents reality

Review

- Last year we focused on ensuring physical structures were modeled correctly

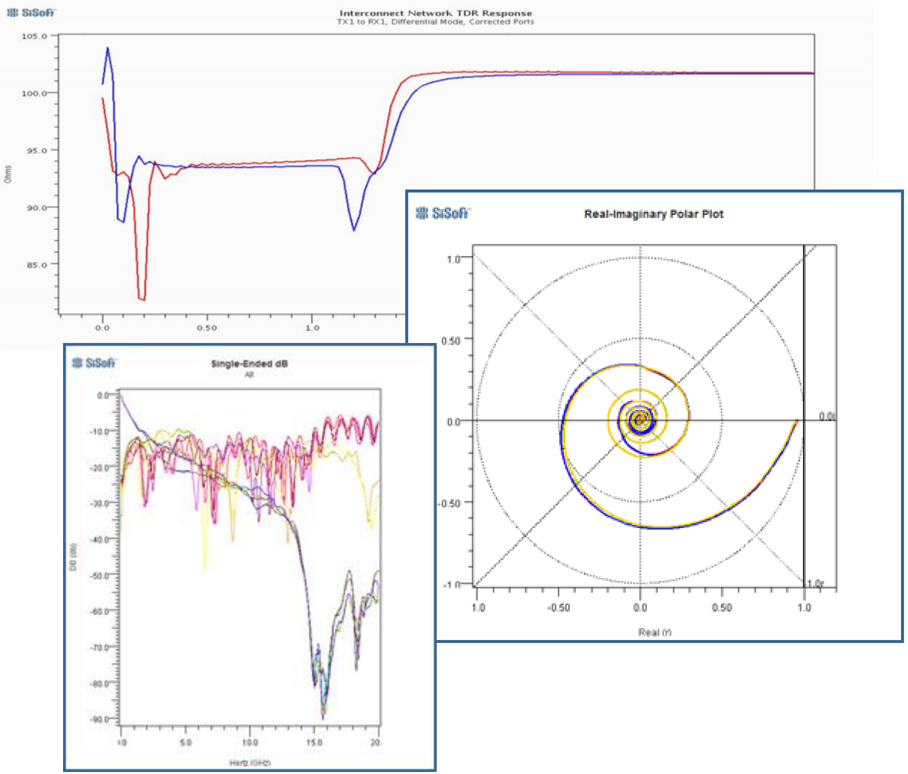


Now we focus on: Are the S-parameters good?

- Characteristics
  - Passive
    - We are modeling lossy elements; there should be no gain
  - Causal
    - Step response should show no output response before an input response
  - Proper Port Assignments
- Measured data
  - usually good, but always check, don't assume
- Modeled data
  - 50/50 chance, always needs a rigorous check

How do we check S-parameters?

- Time Domain Tests
  - TDR
  - TDT
- Frequency Domain Tests
  - Insertion Loss
  - Return Loss
  - Polar Plots



Detecting Issues

- Time Domain Tests
  - Provide insight on port assignments & examination of S-parameter for known channel features (etch, vias, etc)
- Frequency Domain Tests
  - Provides insight on DC/Low frequency behavior, causality
- Avoid Automatically Enforcing Passivity &/or Causality
  - Do you know what was changed and how?
  - Is the result real?
  - Know your data and what needs to be changed

More Information

- Designcon 2015 Paper
  - Getting Street-Smart about S Parameters
    - SiSoft Technical Staff
- Designcon 2010 IBIS Summit
  - “Quality metrics for S-parameter models”
    - Yuriy Shlepnev, Simberion
- SiSoft Elearning: http://www.sisoft.com/elearning/.
  - “S Parameter Causality: A Sampled Data Perspective”
    - Dr. Michael Steinberger and Todd Westerhoff, SiSoft
- EEWeb, Issue 16, 2011
  - *S Parameter Causality Correction:* **A Dissenting View**
    - Dr. Michael Steinberger, SiSoft

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Signal losses in PCBs

SCOTT MCMORROW
TERASPEED CONSULTING®
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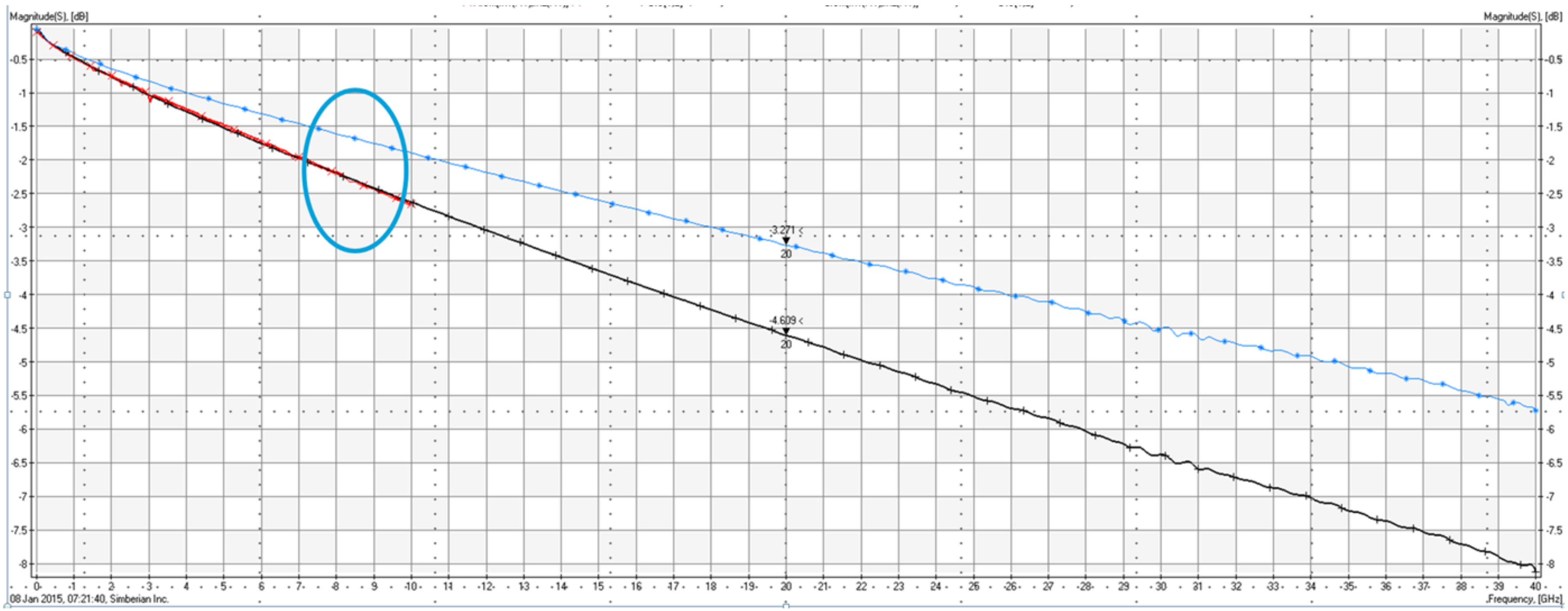
The Loss Problem



Epoxy Fiberglass Laminates

Fiberglass used in PCB materials create variations in the structural dielectric characteristics. Gaps and thickness variations across and between fiber bundles cannot be fully eliminated, thus contributing to anisotropic variation:

- **Expanded Weave -** Glass spread more than standard in one Direction
  - Open Weave is the same as Expanded
  - Open Filament is the same as Expanded

- **Spread Glass -** Glass Spread by a number of different ways
  - Mechanically Spread (MS) Glass – Glass is Mechanically spread in both the warp and fill directions.
  - Square Weave – Glass that has a balanced density and/or yarn Counts in warp and fill directions.
  - Flat Glass – Glass is made from fibers with little or no twist.

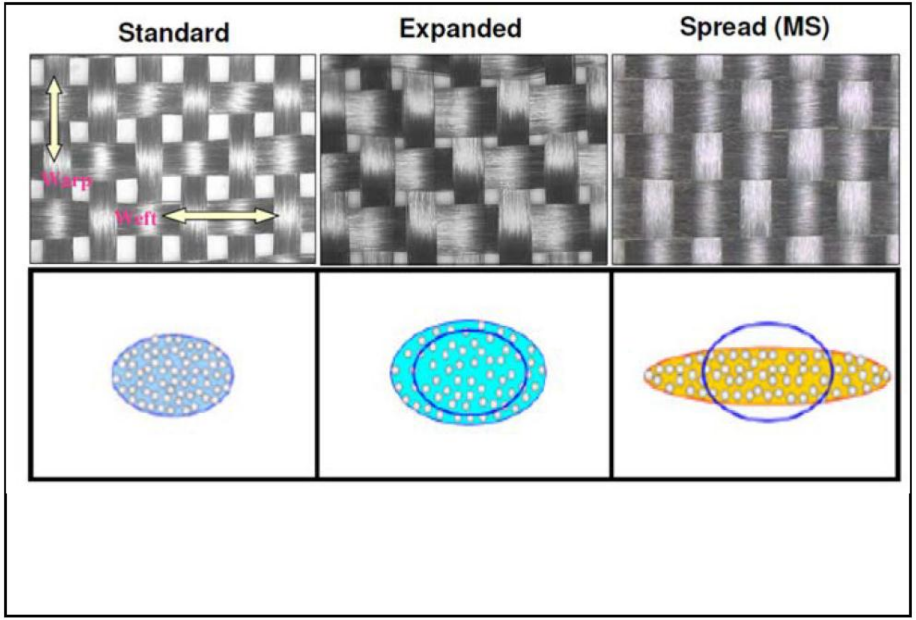
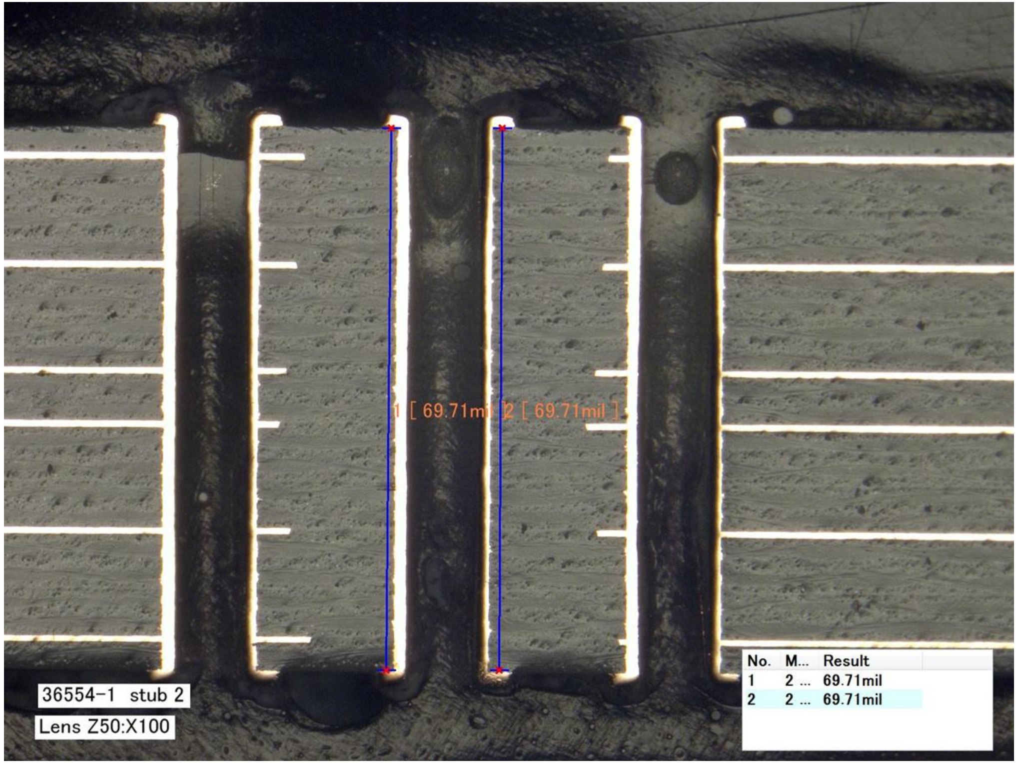


Fig 1: Common definitions and illustrations of glass styles

Via Microsection



PCB Materials as Linear Non-isotropic Dielectric Media

In PCB Media, the signal conductor is a copper foil surrounded by a permeating composite resin and a woven glass reinforced material.

- Electric fields are predominately in the vertical "X" direction, but also to a lesser extent in the "Y" direction.
- The relationship between the electric field and electric flux density can be written:

$$\begin{bmatrix} D_x \\ D_y \\ Dz \end{bmatrix} = \begin{bmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix} \cdot \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix}$$

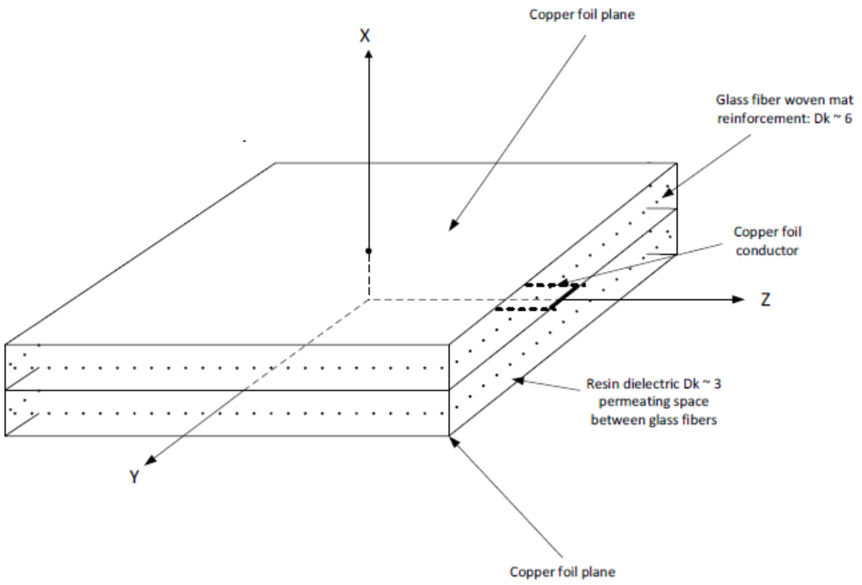
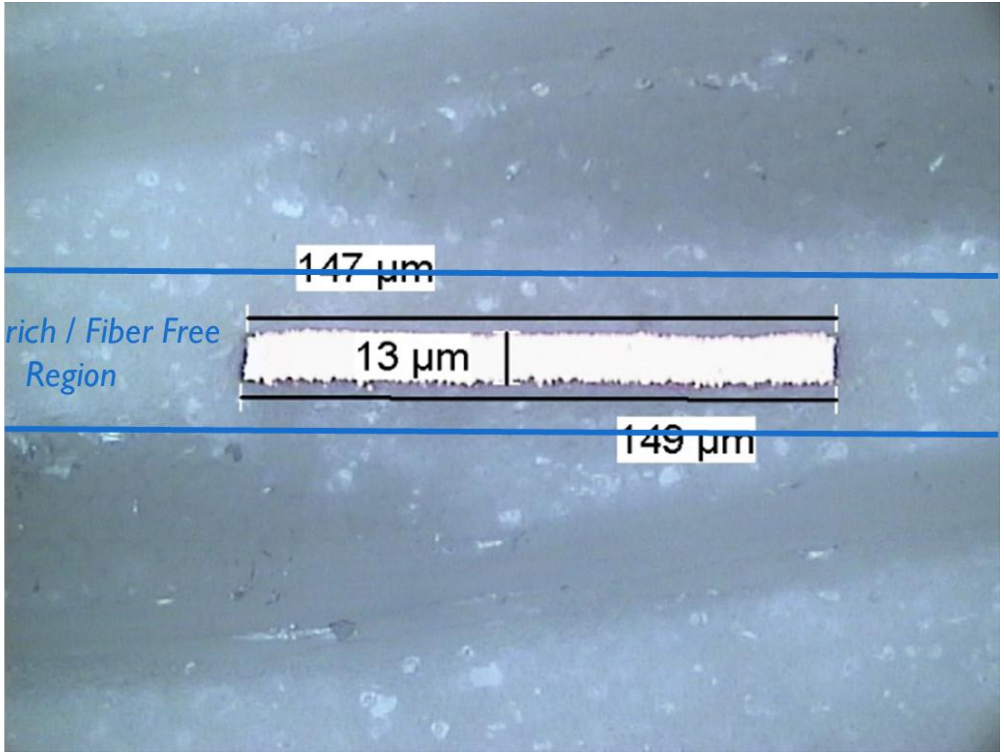
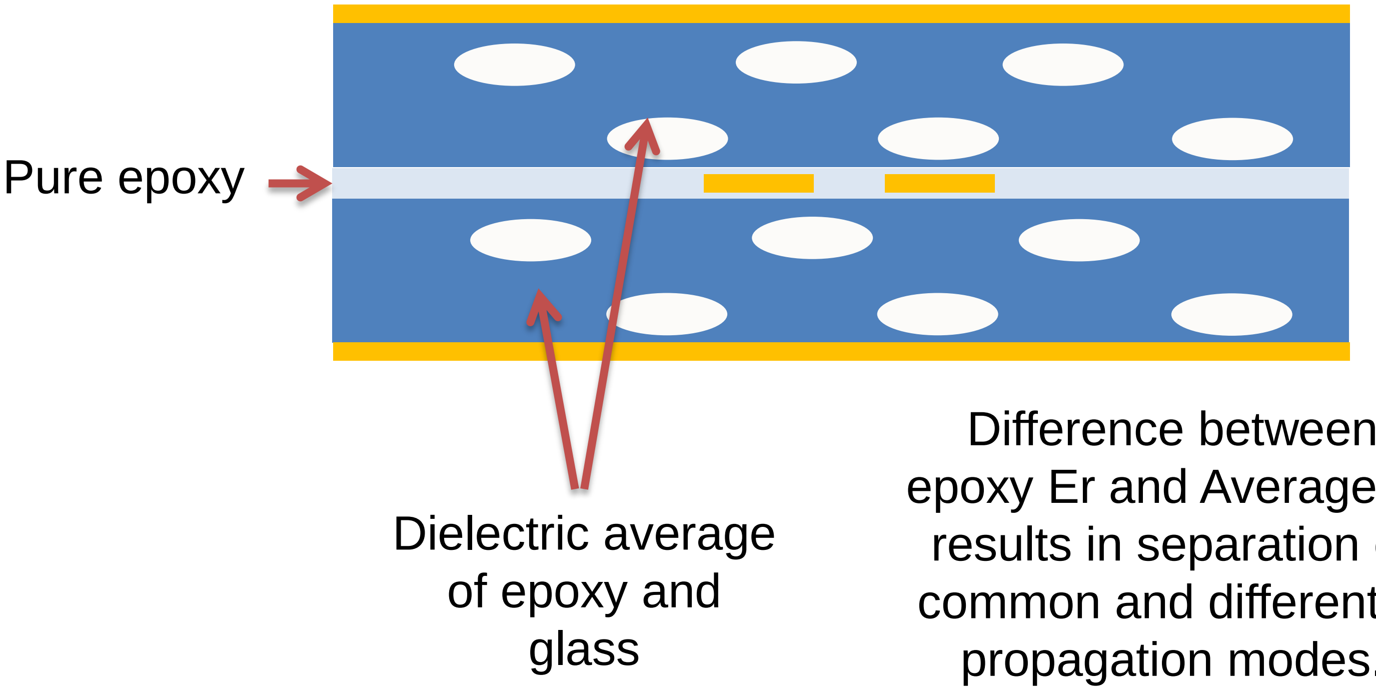


Fig 1: TEM stripline structure

Trace Microsection



Dielectric Mixture Modeling



Difference between epoxy Er and Average Er results in separation of common and differential propagation modes.

DesignCon 2015

Closing the Loop: What do we do when *PI* measurements and simulations don't match?

Heidi Barnes –
SI/PI EDA Applications at Keysight Technologies

Keysight Technologies

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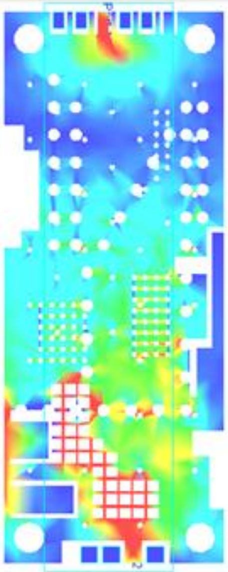
Engineering a Solution for Measurement and Simulation

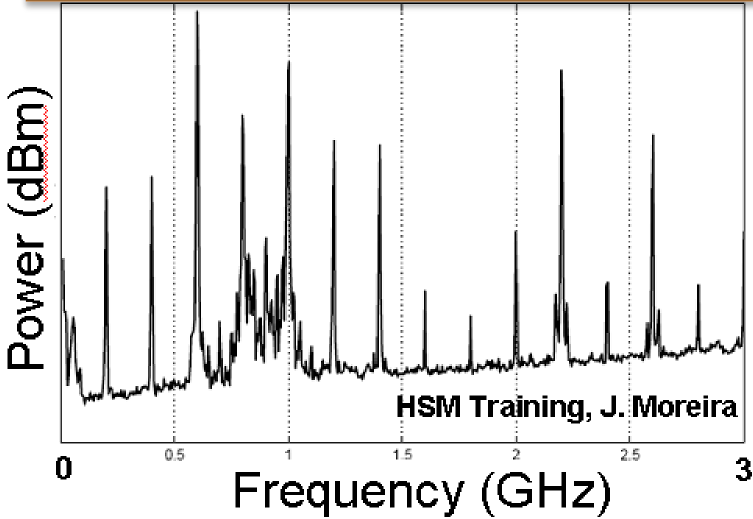
How many leaks to do you have in your Power Distribution Network?

Where is the leak?

Capacitor Location?

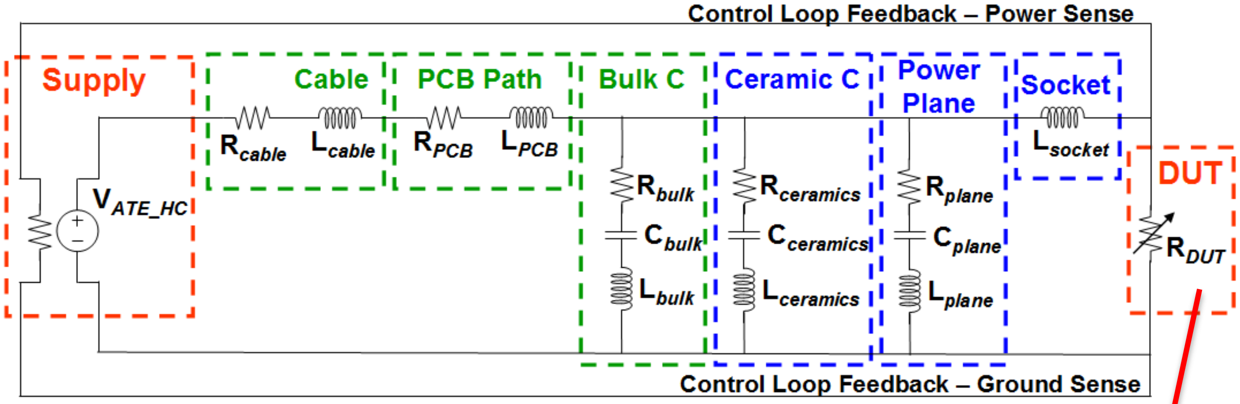


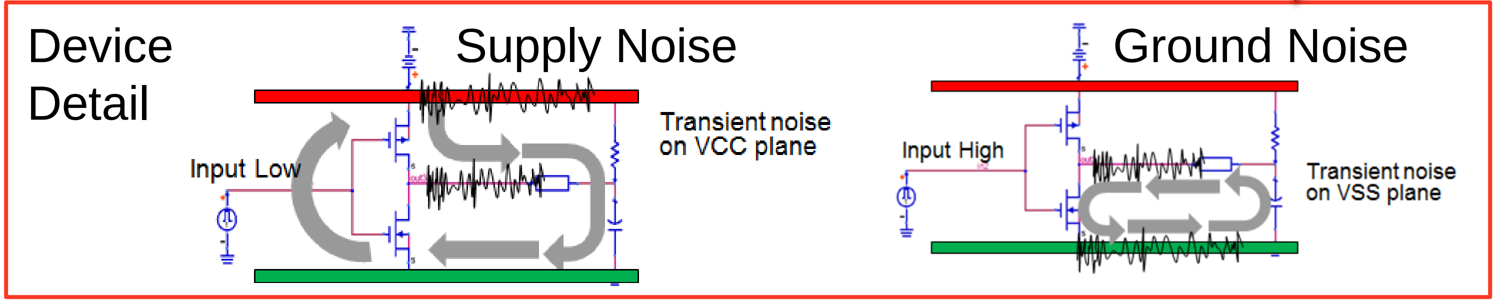
Device Power Spectral Density



What Does the Power Distribution Network Look Like?

The "Real World" PDN Network





Do you feel lucky?

- **Where did that multiple of 10's for capacitor loading come from?**
- **So why are we using a power plane and not a supply trace?**
- **Who said all capacitors were created equal?**
- **Do you believe in the magic of schematic grounds?**

Eric Bogatin's Rule #9: Never do a measurement or simulation without first anticipating what you expect to see.

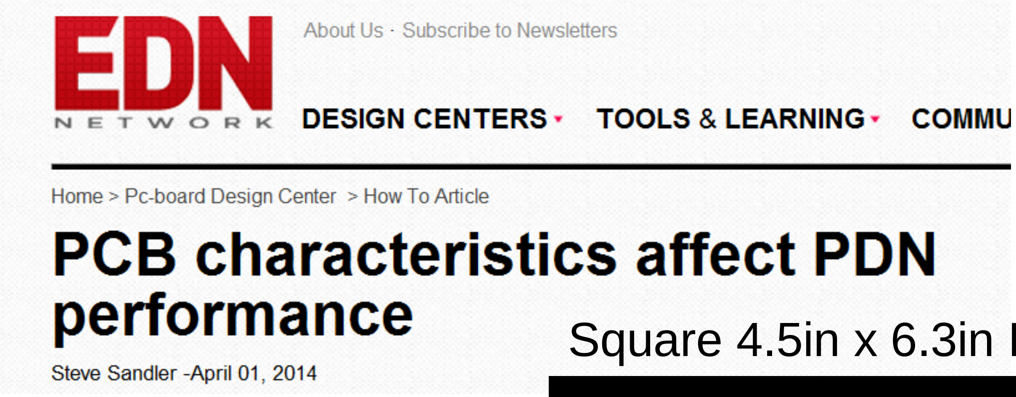
PDN Simulations and Measurements

- **IR Drop - Do I need sense lines?**
- **Supply Response Time – Do I have enough total C storage?**
- **L*di/dt voltage droop and kick – Is the PDN Z low enough?**
- **Supply Control Loop Stability – What is that Bode plot telling me?**
- **Plane Resonances – Are there Voltage Standing Waves from reflections?**

Biggest Challenge –

Breaking the problem down into manageable simulations and measurements to understand the fundamentals, and verify a robust design.

Can Your Simulation Match a Simple Square PDN?



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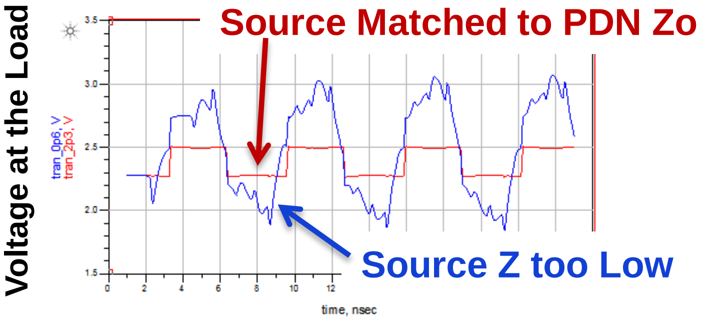
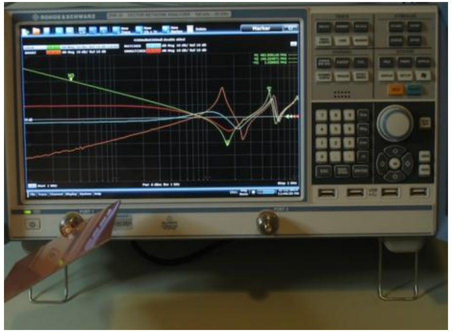
PCB characteristics affect PDN performance

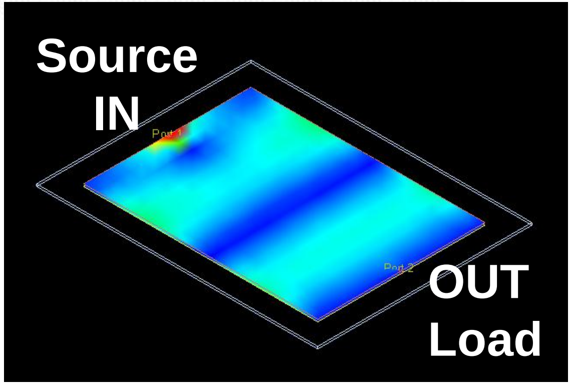
Steve Sandler -April 01, 2014



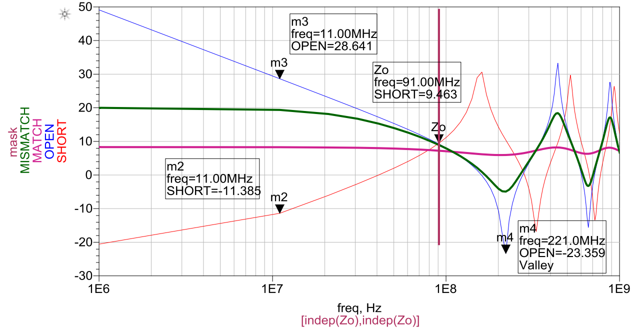
Square 4.5in x 6.3in PDN



Measure



EM Simulation



Open, Short, Load Simulation

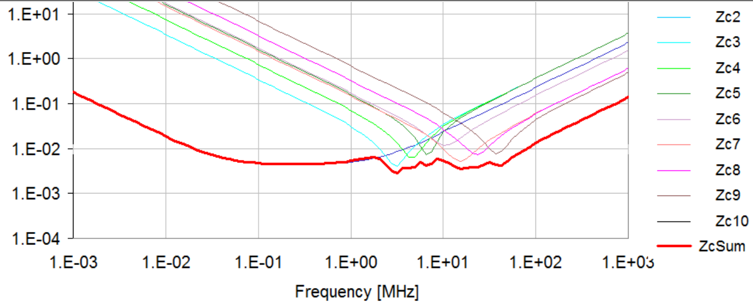
Does Your Simulation Include Supply Control Loop Stability?

EXAMPLE : Default Capacitors for a Single Supply with **4 Volt** and **40 Amp** Transients with 10% Voltage Ripple

Example high current power supply control loop stability requires:
max ESR=5 mΩ, Min Bulk C=637 µF, and Max Ceramics= 74 µF

Total // C	C1	C2	C3	C4	C5	C6	C7	C8
C [µF]:	880	4.7	2.2	1	0.94	1.1	0.5	0.235
ESR [Ω]:	0.0045	0.004	0.006	0.007	0.0115	0.0052	0.0072	0.0076
ESL [nH]:	0.375	0.6	0.6	0.6	0.25	0.1	0.1	0.08
Parallel Qty:	4	1	1	1	2	5	5	5
C [µF]:	220	4.7	2.2	1	0.47	0.22	0.1	0.047
ESR [Ω]:	0.018	0.004	0.006	0.007	0.023	0.026	0.036	0.038
ESL [nH]:	1.5	0.6	0.6	0.6	0.5	0.5	0.5	0.4
Package Type	D Tant	0805	0805	0603	0603	0603	0402	0402
Manufacturer	Kemet	Murata	Murata	Murata	TDK	Murata	Taiyo Yuden	Murata
Part Number	T520D227I	BR71C47	GRM21BR71A225KA	GRM188R71E105KA	C1608X7R1A4	GRM188R	EMK105B7104KV	GRM155R71A473KA01D

PDN Impedance

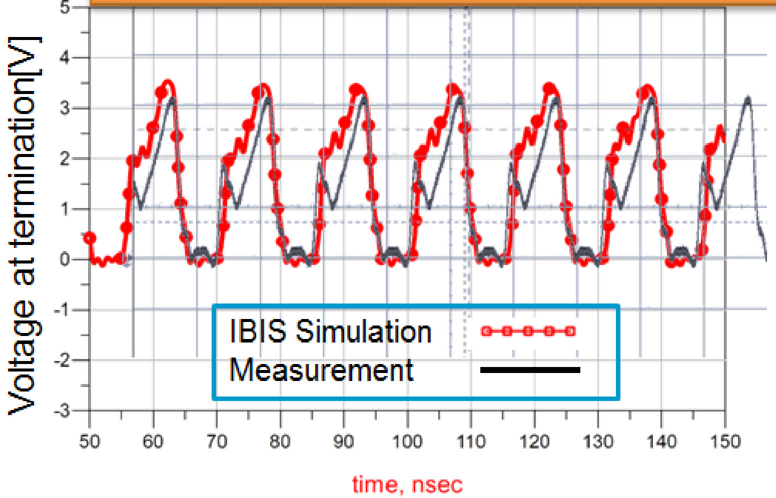


All ceramics and no bulk C can send your supply into oscillation!

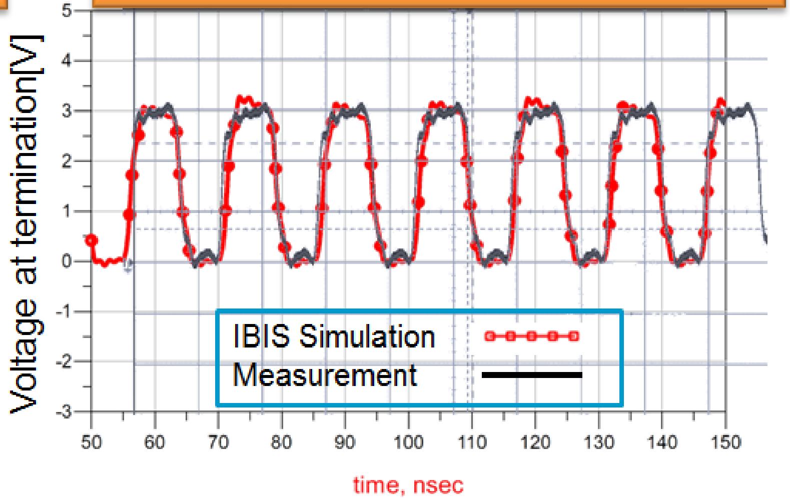
Understand the fundamentals to engineer a design that is fast to simulate and fast to measure!

Power Aware IBIS Simulations

No Decoupling Capacitors



With Optimized Capacitors



MWE2011-Workshop-04 Yokohama 2011/12/1

Mitsuharu Umekawa, "EMC Analysis for a PCB Mounted Switching regulator using Electromagnetic simulator"