BRING IT TO THE BOARD (PCB)

The device under test (DUT) board is sometimes overlooked as a critical element in test-and burn-in strategies. This session brings PCBs into the limelight. The first presentation will cover some of the challenges that various DUT layouts present, demonstrating to semiconductor and ASICS design engineers the importance of considering final test hardware when designing device layouts. Another important consideration, covered in the second presentation, is the importance of performing RF characterization and simulation in-house to accurately measure the materials' electrical performance.

Building Optimized Test PCB's Starts at the DUT
Joe Birtola—CMR Summit Technologies

This Paper

High Frequency PCB Material Characterization and Simulation
Ryan Satrom—Multitest

MARKET REPORT

As a bonus in this session, you'll get a look at the marketplace for test equipment and test consumables

Market Trends in Test Equipment and Test Consumables
John West—VLSI Research

HIGH FREQUENCY PCB MATERIAL CHARACTERIZATION AND SIMULATION

Ryan Satrom
Multitest

2013 BiTS Workshop
March 3 - 6, 2013

Agenda

- Importance of Characterization
- Characterization Project Scope
- Characterization Project Method
- Material Comparisons & Results
- Conclusions

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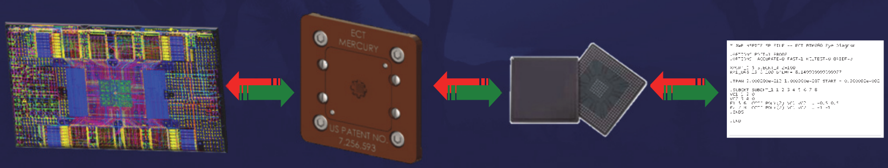
Importance of Characterization

- Multitest has run test interface simulations for about a decade
- Simulation provides confidence that the interface is designed correctly the first time
- Simulations include any or all of the following:
  - PCB (vias, components)
  - Contactor
  - Package
  - Device



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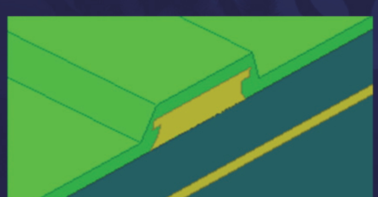
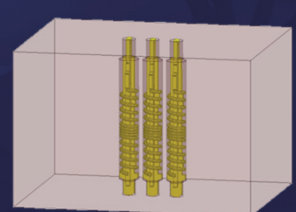
Importance of Characterization

- Reliable simulation results require accurate models
- Extensive simulation-to-measurement correlation for both PCBs and contactors is critical
- Correlation ensures models accurately represent physical design





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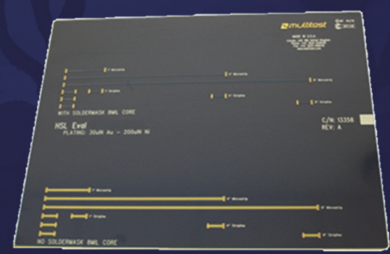
Importance of Characterization

- Test vehicles required to confirm model accuracy
- Vehicles must be created by target fabricator
- Hardware is fabricated using same techniques as end products
- Multitest manufactures both PCBs and contactors
- Test vehicles can be created quickly and easily

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Characterization Project Scope

- Extensive PCB materials project launched last year with the following goals:
  - Understand characteristics of multiple materials
  - Minimize differences between simulation and measurement
  - Understand contributing factors to PCB loss
  - Improve confidence in simulations beyond 20 GHz
- Study included mechanical reliability but this presentation discusses only electrical performance

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Characterization Project Method

- Fabricate boards from ten different PCB materials
- Each board includes:
  - Traces on two different core thicknesses
  - Both microstrip and stripline
  - One, four, and six-inch traces
  - Backdrill
- Via and pad geometries optimized through simulation

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Material Comparisons

Several material comparisons described:

1) Dielectric Constant (ε_R)
2) Loss Tangent/Dissipation Factor (dF)
3) Insertion Loss
4) Board-to-Board Repeatability
5) Copper Roughness
6) Soldermask – With vs. Without

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#1 – Dielectric Constant

Dielectric constant extraction

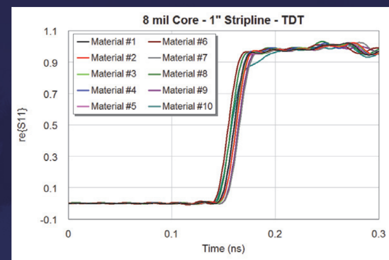
- Through measurements taken on one and six-inch stripline traces
- Signal velocity determined by difference between delay of the two traces

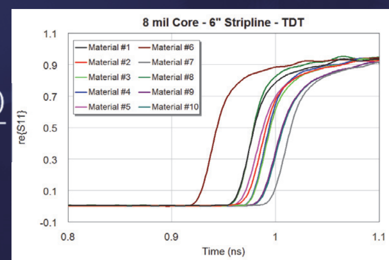
Equations:

$$v_{SIG} = 84.7 * \sqrt{\varepsilon_R}$$

$$v_{SIG}\left(\frac{ps}{in}\right) = \frac{DELAY_{6in}(ps) - DELAY_{1in}(ps)}{5in}$$

$$\varepsilon_R = \left[\frac{v_{SIG}}{84.7}\right]^2$$





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#1 – Dielectric Constant

Measured ε_R vs. spec (delta):

Measured ε_R Deviation from Spec	
Material #1	0.16
Material #2	-0.18
Material #3	-0.12
Material #4	-0.06
Material #5	0.02
Material #6	-0.04
Material #7	0.13
Material #8	-0.03
Material #9	0.36
Material #10	-0.07

- $|Difference|_{AVG}$ = 0.12
- $|Difference|_{MAX}$ = 0.36

4 mil vs. 8 mil core (delta):

Measured ε_R 4 mil vs. 8 mil Core	
Material #1	-0.04
Material #2	0.37
Material #3	0.15
Material #4	0.26
Material #5	0.18
Material #6	0.18
Material #7	0.34
Material #8	0.16
Material #9	-0.12
Material #10	0.12

- $|Difference|_{AVG}$ = 0.19
- $|Difference|_{MAX}$ = 0.37

Typical PCB ε_R values are between 3 and 4

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#1 – Dielectric Constant

Conclusions:

- **Measured ε_R and datasheet ε_R are different****
- **Thicker cores typically have a higher ε_R**

**One vendor actually specifies two values: Process specification Dk/ε_R and Design Dk/ε_R

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#2 – Loss Tangent

Loss tangent extraction

- Paths modeled in HFSS
- Models represent physical geometry as closely as possible

- Simulations executed with multiple loss tangent values to find best match to measured insertion loss

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#2 – Loss Tangent

Curve-Fit dF vs. spec (delta):

Curve-Fit dF Deviation from Spec	
Material #1	0.007
Material #2	0.003
Material #3	0.006
Material #4	0.004
Material #5	0.003
Material #6	0.003
Material #7	0.005
Material #8	0.002
Material #9	0.009
Material #10	0.006

- $|Difference|_{AVG}$ = 0.005
- $|Difference|_{MAX}$ = 0.007

4 mil vs. 8 mil core (delta):

Curve-Fit dF 4 mil vs. 8 mil Core	
Material #1	-0.005
Material #2	-0.002
Material #3	-0.002
Material #4	0.001
Material #5	0.000
Material #6	-0.002
Material #7	-0.002
Material #8	0.000
Material #9	-0.003
Material #10	-0.005

- $|Difference|_{AVG}$ = 0.002
- $|Difference|_{MAX}$ = 0.005

Typical dF values are between 0.002 and 0.02

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#2 – Loss Tangent

Conclusions:

- Simulated loss tangent values significantly higher than datasheet specifications
- Thinner core materials will typically have a larger simulated loss tangent
- Higher loss tangent mainly attributed to copper roughness
  - Unable to accurately model this geometry
  - Critical at higher frequencies

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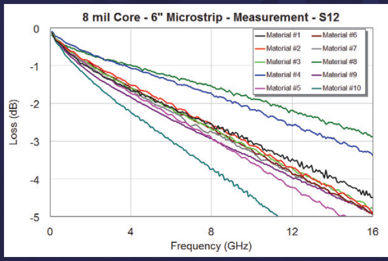
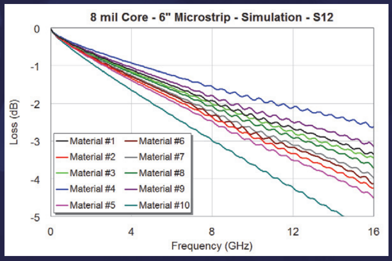
#3 – Insertion Loss

- Plots compare simulations using datasheet ε_R and dF to VNA measurements





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#3 – Insertion Loss

Simulation/measurement (4 mil)

Insertion loss delta:

4 mil core	Measurement vs. Datasheet Delta			
	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.9 dB	1.6 dB	3.0 dB	3.7 dB
Material #2	0.0 dB	0.2 dB	1.0 dB	2.0 dB
Material #3	1.1 dB	1.8 dB	3.1 dB	4.3 dB
Material #4	0.2 dB	0.7 dB	1.5 dB	2.4 dB
Material #5	0.3 dB	0.5 dB	1.3 dB	2.4 dB
Material #6	0.8 dB	1.2 dB	2.1 dB	2.9 dB
Material #7	0.8 dB	1.3 dB	2.4 dB	3.4 dB
Material #8	-0.6 dB	-1.1 dB	-1.6 dB	-2.9 dB
Material #9	1.3 dB	2.2 dB	3.4 dB	4.7 dB
Material #10	1.1 dB	1.8 dB	3.3 dB	4.2 dB
Average	**0.6 dB**	**1.0 dB**	**1.9 dB**	**2.7 dB**

Simulation/measurement (8 mil)

Insertion loss delta:

8 mil core	Measurement vs. Datasheet Delta			
	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.7 dB	1.6 dB	2.8 dB	-0.9 dB
Material #2	0.3 dB	1.1 dB	2.3 dB	-1.0 dB
Material #3	0.8 dB	1.9 dB	3.1 dB	-0.5 dB
Material #4	0.3 dB	1.2 dB	2.3 dB	-1.3 dB
Material #5	0.6 dB	1.4 dB	2.6 dB	-1.3 dB
Material #6	0.5 dB	1.3 dB	2.2 dB	-1.9 dB
Material #7	0.7 dB	1.4 dB	2.4 dB	-1.6 dB
Material #8	-0.6 dB	-0.7 dB	-0.5 dB	-4.4 dB
Material #9	1.3 dB	2.4 dB	3.8 dB	0.5 dB
Material #10	0.9 dB	1.9 dB	3.2 dB	-0.5 dB
Average	**0.6 dB**	**1.4 dB**	**2.4 dB**	**-1.3 dB**

- Expected difference from data sheet specifications:
  - Up to 1 dB at 10 GHz
  - About 1 to 2.5 dB at 20 GHz

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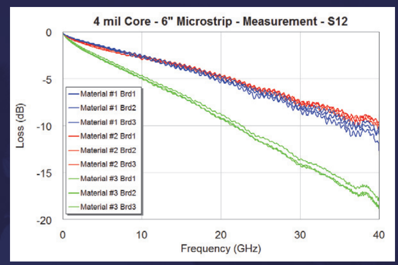
#4 – Board-to-Board Repeatability

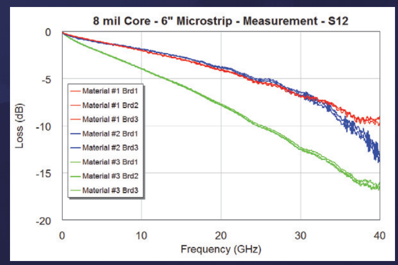
- Three boards fabricated with each of three different materials
- Results show difference between the same trace on each board
- Traces are six inches

Microstrip traces:

Microstrip (4 mil core)				
Freq	**10 GHz**	**20 GHz**	**30 GHz**	**40 GHz**
Material #1	0.1 dB	0.2 dB	0.3 dB	0.6 dB
Material #2	0.2 dB	0.2 dB	0.3 dB	0.3 dB
Material #3	0.2 dB	0.4 dB	0.5 dB	0.7 dB
Average	**0.2 dB**	**0.3 dB**	**0.4 dB**	**0.5 dB**

Microstrip (8 mil core)				
Freq	**10 GHz**	**20 GHz**	**30 GHz**	**40 GHz**
Material #1	0.0 dB	0.0 dB	0.1 dB	0.3 dB
Material #2	0.1 dB	0.1 dB	0.3 dB	0.6 dB
Material #3	0.1 dB	0.1 dB	0.2 dB	0.3 dB
Average	**0.1 dB**	**0.1 dB**	**0.2 dB**	**0.4 dB**





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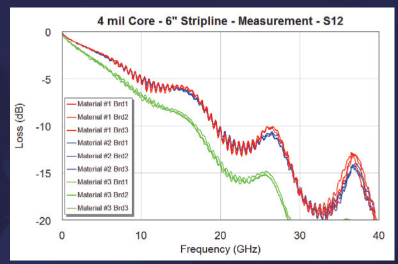
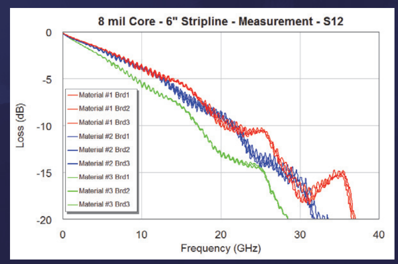
#4 – Board-to-Board Repeatability

Stripline traces:

Stripline (4 mil core)				
Freq	**10 GHz**	**20 GHz**	**30 GHz**	**40 GHz**
Material #1	0.1 dB	0.2 dB	0.4 dB	0.7 dB
Material #2	0.1 dB	0.2 dB	0.3 dB	0.5 dB
Material #3	0.2 dB	0.4 dB	0.6 dB	0.5 dB
Average	**0.1 dB**	**0.3 dB**	**0.4 dB**	**0.6 dB**

Stripline (8 mil core)				
Freq	**10 GHz**	**20 GHz**	**30 GHz**	**40 GHz**
Material #1	0.1 dB	0.4 dB	0.7 dB	1.8 dB
Material #2	0.1 dB	0.4 dB	0.9 dB	1.9 dB
Material #3	0.1 dB	0.1 dB	0.2 dB	0.3 dB
Average	**0.1 dB**	**0.3 dB**	**0.6 dB**	**1.3 dB**





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#4 – Board-to-Board Repeatability

- Conclusions (based on 6” trace length):
- Measured board-to-board differences:
  - A few tenths of a dB up to 20 GHz
  - As much as 2 dB up to 40 GHz
- Impact proportional to trace length
  - Expect twice the impact with twice the length
- Differences likely caused by variations:
  - Trace width
  - Core thickness
  - Fiberglass weave

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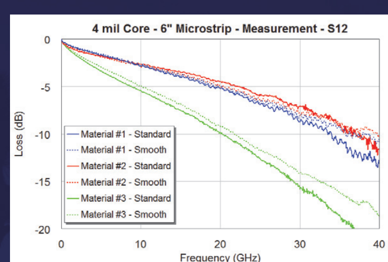
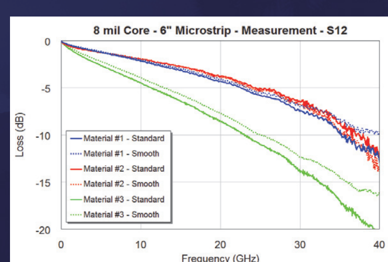
#5 – Copper Roughness

- Three boards of different materials fabricated with standard copper
- Three more fabricated with smoother copper

Microstrip traces:



Microstrip (4 mil core)				
Freq	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.1 dB	0.2 dB	0.6 dB	2.0 dB
Material #2	-0.2 dB	-0.4 dB	-0.4 dB	0.8 dB
Material #3	0.5 dB	0.7 dB	1.6 dB	3.2 dB



Microstrip (8 mil core)				
Freq	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.1 dB	0.2 dB	0.6 dB	1.9 dB
Material #2	0.0 dB	-0.1 dB	-0.3 dB	-1.0 dB
Material #3	0.5 dB	0.8 dB	1.6 dB	3.2 dB

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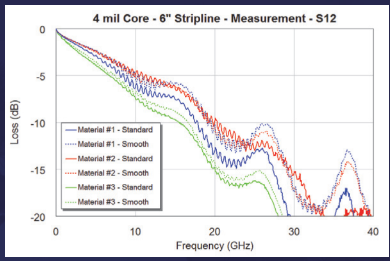
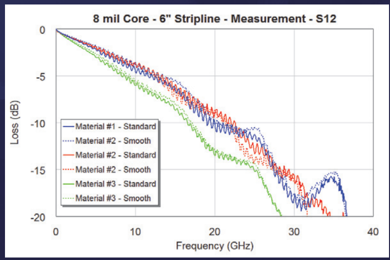
#5 – Copper Roughness

Stripline traces:

Stripline (4 mil core)				
Freq	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.9 dB	2.0 dB	3.7 dB	5.3 dB
Material #2	-0.2 dB	-0.2 dB	0.2 dB	3.1 dB
Material #3	0.5 dB	0.7 dB	1.4 dB	3.2 dB

Stripline (8 mil core)				
Freq	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.5 dB	0.6 dB	0.8 dB	0.9 dB
Material #2	-0.2 dB	-0.6 dB	-1.3 dB	-2.1 dB
Material #3	0.4 dB	0.3 dB	0.6 dB	0.3 dB





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#5 – Copper Roughness

Conclusions (based on 6" trace length):

- Measured difference between copper profiles
  - As much as 1 dB up to 20 GHz
  - As much as 3-4 dB up to 40 GHz
- Impact proportional to trace length
- Measurements only compared two copper profiles
  - Future studies will compare more
- Impact due to copper roughness is presently neither well-defined nor readily modeled
  - Must be better defined and understood in order to accurately predict performance

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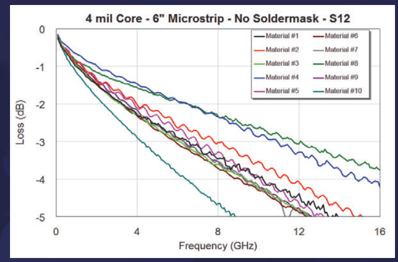
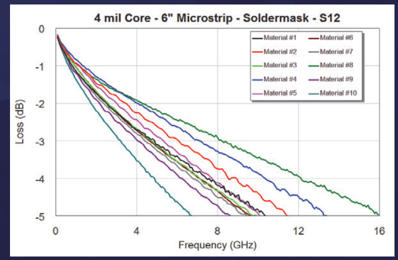
#6 – Soldermask Impact

- Boards included identical traces with and without soldermask

4 mil core:

4 mil core	Difference due to Soldermask			
	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.9 dB	1.6 dB	2.2 dB	2.6 dB
Material #2	0.8 dB	1.8 dB	2.9 dB	4.0 dB
Material #3	0.8 dB	1.5 dB	2.4 dB	3.2 dB
Material #4	1.1 dB	1.9 dB	2.8 dB	3.5 dB
Material #5	0.9 dB	1.7 dB	2.4 dB	3.1 dB
Material #6	0.9 dB	1.7 dB	2.4 dB	2.7 dB
Material #7	1.0 dB	1.6 dB	2.4 dB	3.1 dB
Material #8	0.8 dB	1.5 dB	2.5 dB	3.5 dB
Material #9	1.3 dB	2.1 dB	2.9 dB	3.3 dB
Material #10	1.1 dB	2.0 dB	2.9 dB	3.6 dB
Average	**1.0 dB**	**1.7 dB**	**2.6 dB**	**3.3 dB**





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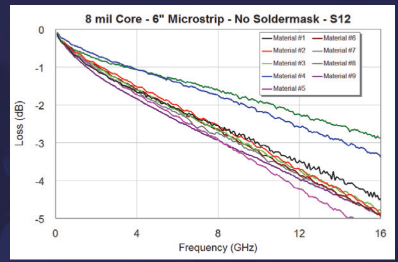
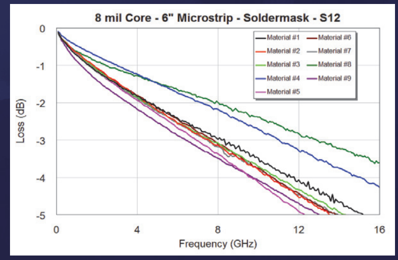
#6 – Soldermask Impact

8 mil core:

8 mil core	Difference due to Soldermask			
	10 GHz	20 GHz	30 GHz	40 GHz
Material #1	0.5 dB	1.0 dB	1.5 dB	2.0 dB
Material #2	0.7 dB	1.2 dB	1.8 dB	2.4 dB
Material #3	0.5 dB	0.9 dB	1.4 dB	1.8 dB
Material #4	0.6 dB	1.1 dB	1.8 dB	2.4 dB
Material #5	0.6 dB	1.1 dB	1.6 dB	2.2 dB
Material #6	0.5 dB	1.0 dB	1.6 dB	2.2 dB
Material #7	0.5 dB	0.9 dB	1.4 dB	2.0 dB
Material #8	0.5 dB	0.9 dB	1.4 dB	1.8 dB
Material #9	0.6 dB	1.2 dB	1.8 dB	2.1 dB
Average	**0.6 dB**	**1.0 dB**	**1.6 dB**	**2.1 dB**





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#6 – Soldermask Impact

Conclusions (based on 6" trace length):

- Measured impact of soldermask:
  - As much as 1 dB of difference up to 20 GHz
  - As much as 3-4 dB up to 40 GHz
- Impact larger for thinner cores
- Impact proportional to trace length
- Exclusion of soldermask should be considered for critical high-speed paths

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Conclusions

- Datasheet specifications are insufficient for accurate high frequency PCB design
- Confidence in high frequency performance requires extensive material characterization
- Much data presented here, but time insufficient to expand on conclusions and describe path forward
- Intend to follow this with presentation(s) here next year or at other industry conferences

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