Introduction and Comparison of an Alternate Methodology for Measuring Loss Tangent of PCB Laminates

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AGENDA

- Introduction
- The Capacitance Gradient Method (CGM)
- Laminate Study
  - Subject, purpose, scope
  - Copper-clad laminates: Low Frequency
  - Bare laminates: High Frequency
  - Unreinforced laminates
  - Composite test results
- Potential sources of errors
- Conclusions, acknowledgement

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INTRODUCTION

- Laminate loss is becoming more important
- Df measurement options
  - direct impedance measurements
  - resonance-based methods
  - wide-band model-based signature tests
- Multitude of IPC standards for Df testing
- No agreed-upon method followed by the majority
  - Data (if available) may be conflicting and confusing

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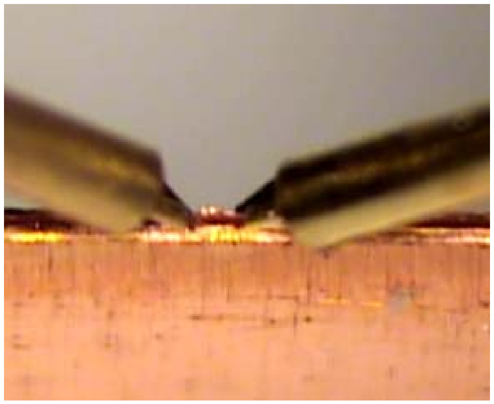
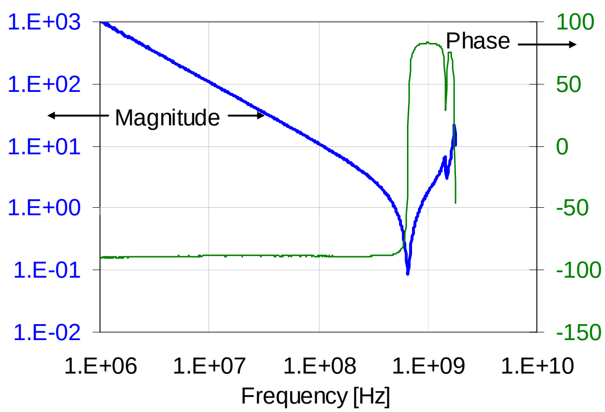
THE CAPACITANCE GRADIENT METHOD (1)



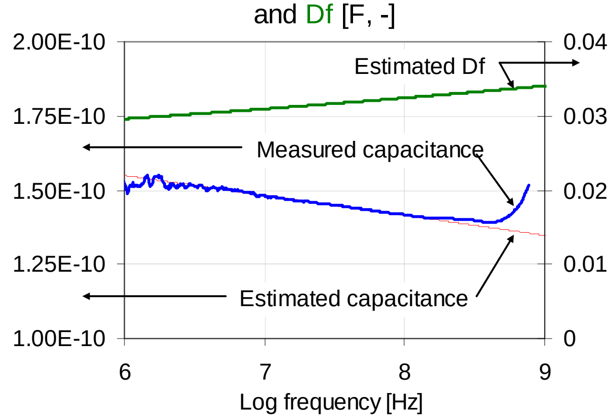
Impedance magnitude and phase [ohm, deg]



What is it and what are the steps

- Df derived from change in Capacitance with frequency
- Measure the impedance of a CCL (Copper Clad Laminate) DUT sample
- Extract capacitance vs frequency
- Establish the trendline of C(f)
- Calculate Df(f) from Wideband Debye model

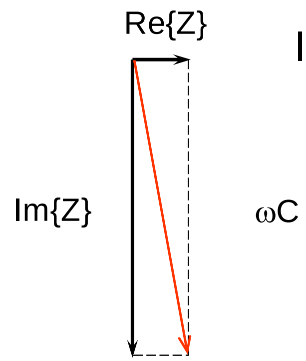
Measured and estimated capacitance and Df [F, -]



THE CAPACITANCE GRADIENT METHOD (2)

The theory behind it

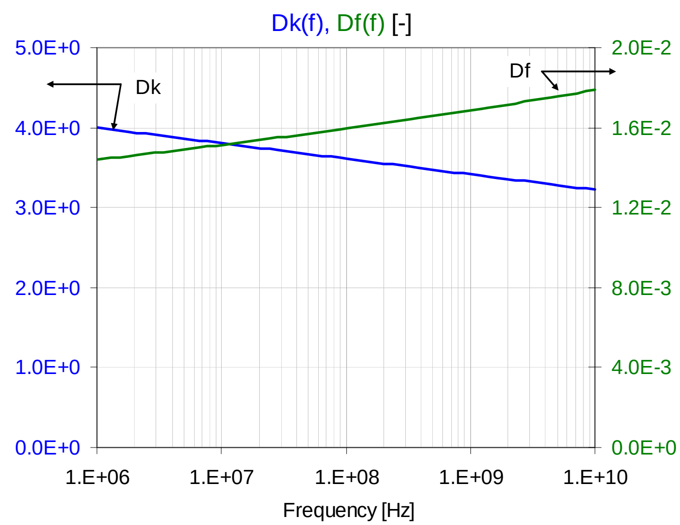
- Capacitance can be extracted from Im{Z}
- The real and imaginary parts of impedance are linked through causality constraints
- Integral wide-band Debye model needs only one Df(fo) point to define the entire curve
- Df is proportional to the slope of Dk



Impedance Vector

Integral Wide-band Debye model:

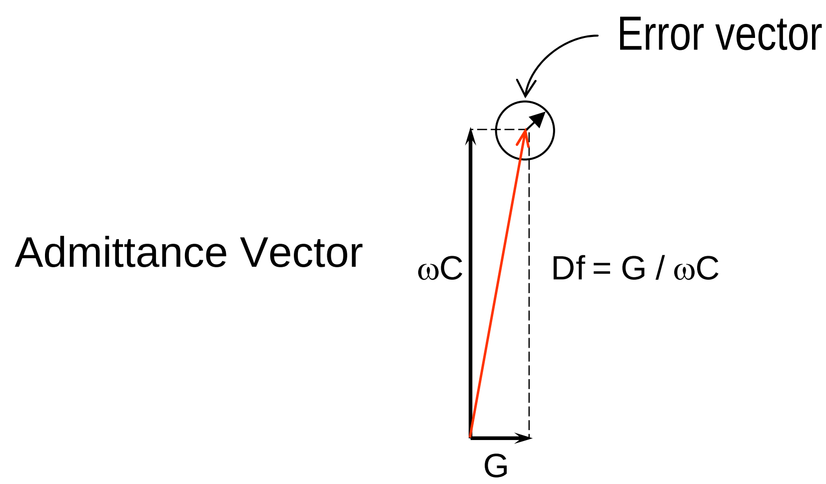
$$\varepsilon_r(\omega) = \varepsilon_\infty' + \frac{\Delta\varepsilon'}{m_2 - m_1} \ln \frac{\omega_2 + j\omega}{\omega_1 + j\omega} \frac{1}{\ln(10)}$$

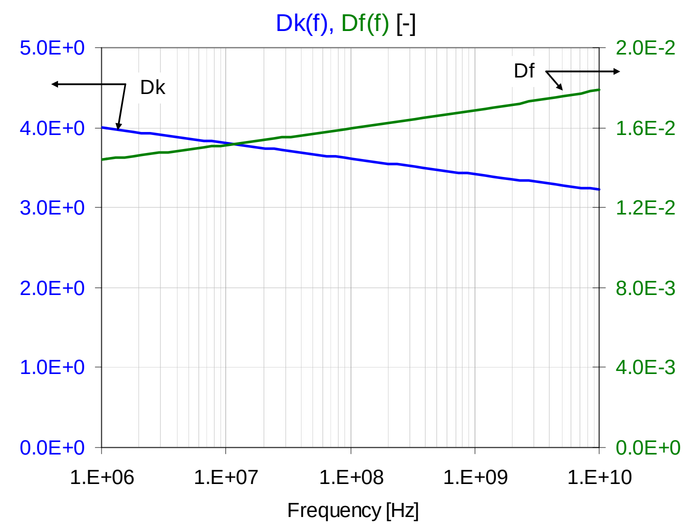


THE CAPACITANCE GRADIENT METHOD (3)

Assumptions, benefits

- Relies on Wideband Debye model: >> input data is OK from any limited frequency band
- C(f) is closer related to the magnitude of Y, relative measurement error is usually lower
- C(f) is measured in a convenient low frequency band >> there are fewer error factors

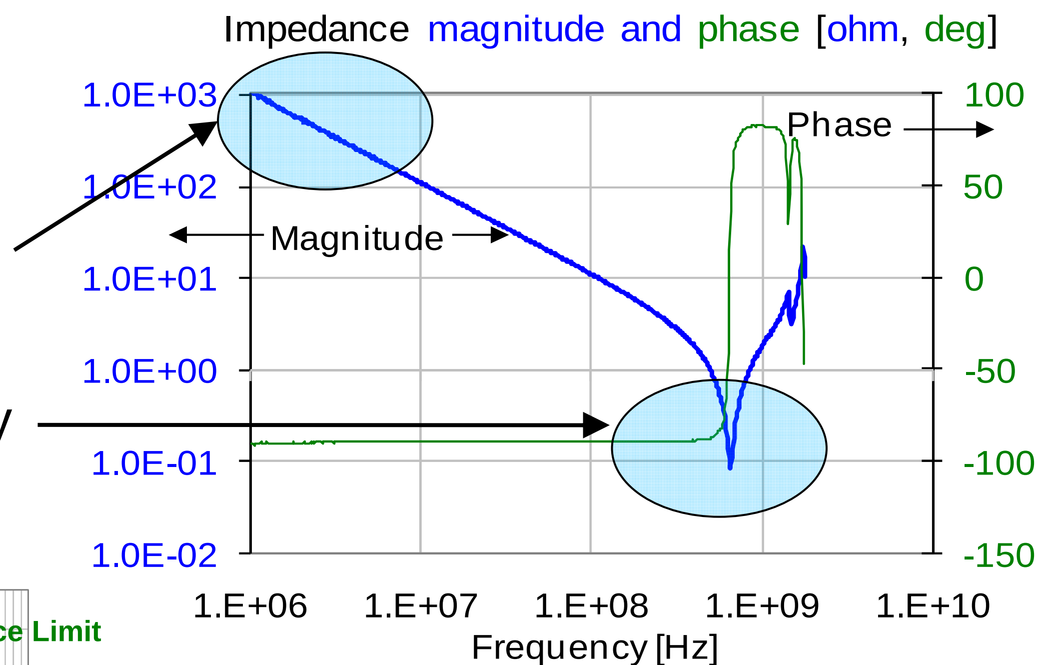


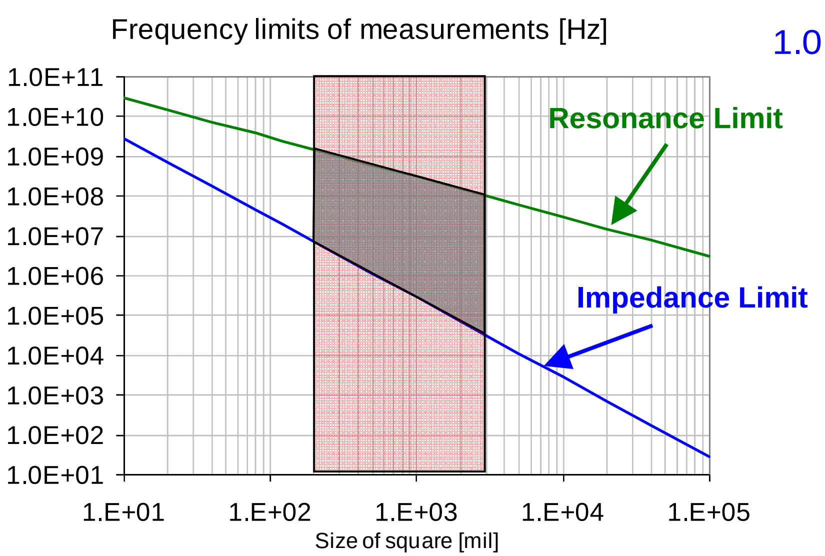


THE CAPACITANCE GRADIENT METHOD (4)

Limitations

- Does not work if/where Wideband Debye model is not valid
- Lowest frequency is set by impedance limit
- High-frequency limit is set by lowest resonance frequency





- DUT size limitation
- Effective working area

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LAMINATE STUDY: Subject, purpose, scope (1)

- Subject
  - Df (no Dk)
- Purpose
  - Correlate CGM against other methods
  - Find a Df test method that fits our needs
- Scope
  - Glass-reinforced laminates
  - 45% - 55% glass-resin ratio
  - 4-5 mil thickness
  - One glass style

LAMINATE STUDY: Subject, purpose, scope (2)

Material	Thickness (mil)	Glass Style	Resin Content (%)	Vendor Df	Freq (GHz)	Method (IPC)
Laminate A FR408HR	5.0	#2116	55	0.0072 0.0086 0.0093	0.1 1.0 10.0	2.5.5.3 2.5.5.9 2.5.5.5
Laminate B R1566V	5.0	#2116	55	0.012 0.012 0.018	0.001 1.0 10.0	2.5.5.9 2.5.5.9 2.5.5.5
Laminate C LGC-451HR	4.0	#2116	44	0.0118 0.0124 0.159	0.001 1.0 10.0	2.5.5.9 2.5.5.9 2.5.5.13
Laminate D 370HR	4.0	#2116	46	0.0150 0.0161 0.0250	0.1 1.0 10.0	2.5.5.3 2.5.5.9 2.5.5.5

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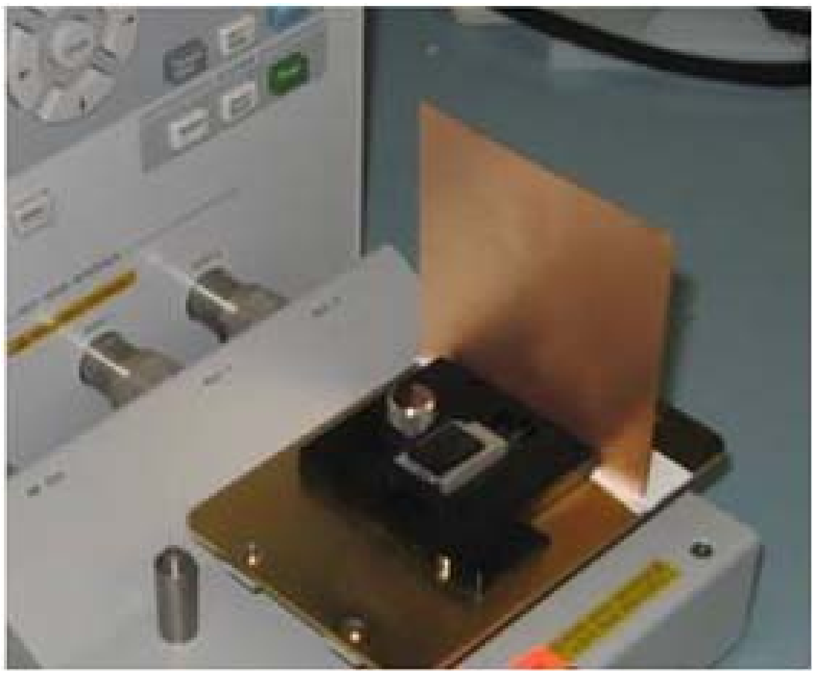
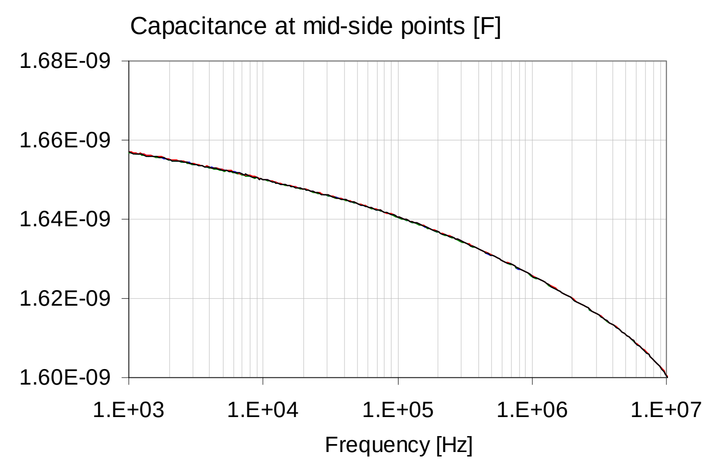
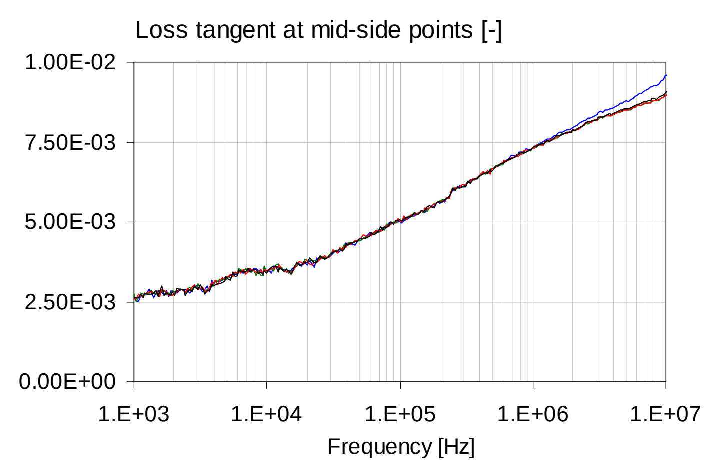
COPPER CLAD LAMINATES: Low Frequency (1)

- Laminate A measured with E4294A Impedance Analyzer and 16192A SMD (Surface Mount Device) fixture
- Measurements taken on unconditioned samples

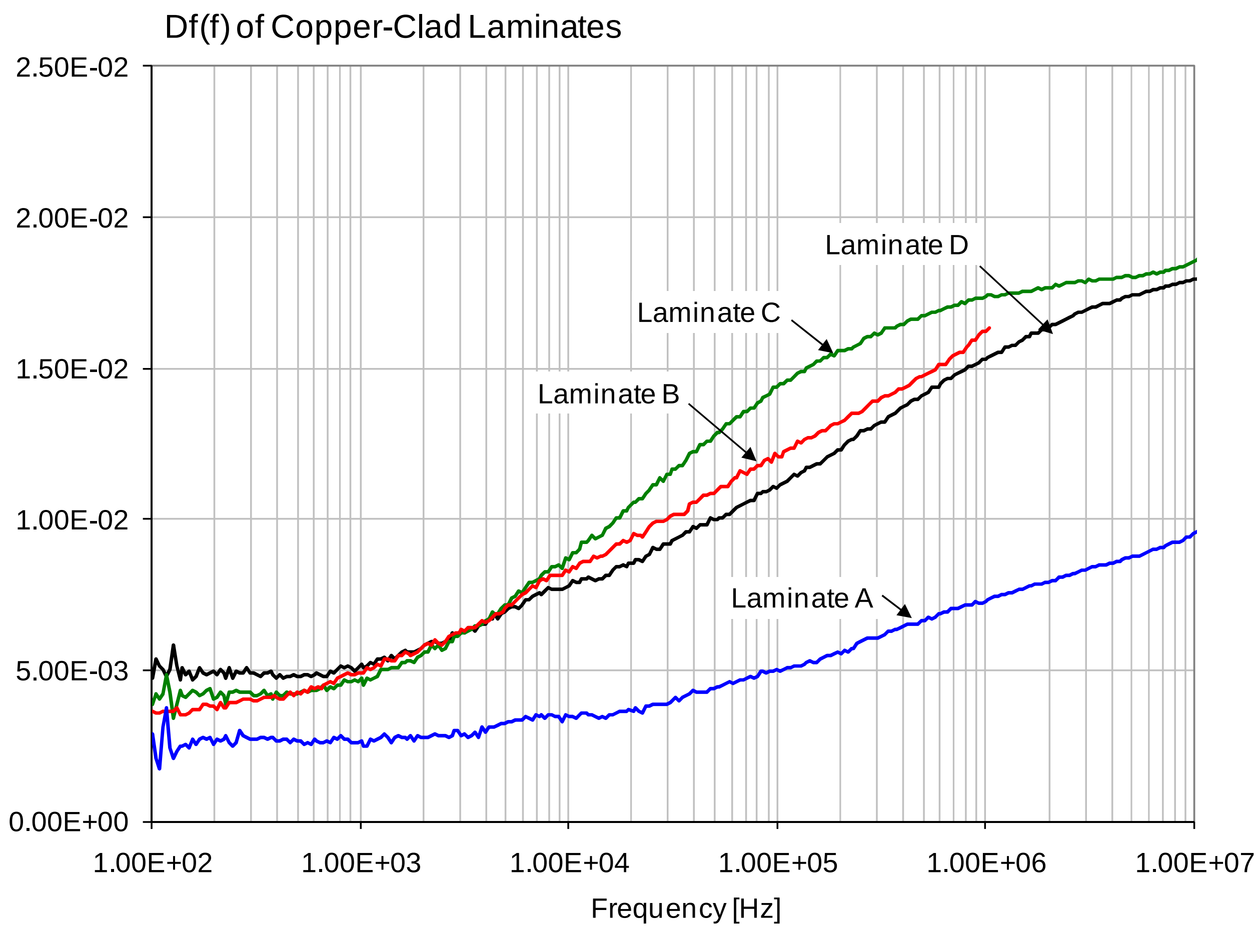






COPPER CLAD LAMINATES: Low Frequency (2)

Comparing the four laminates



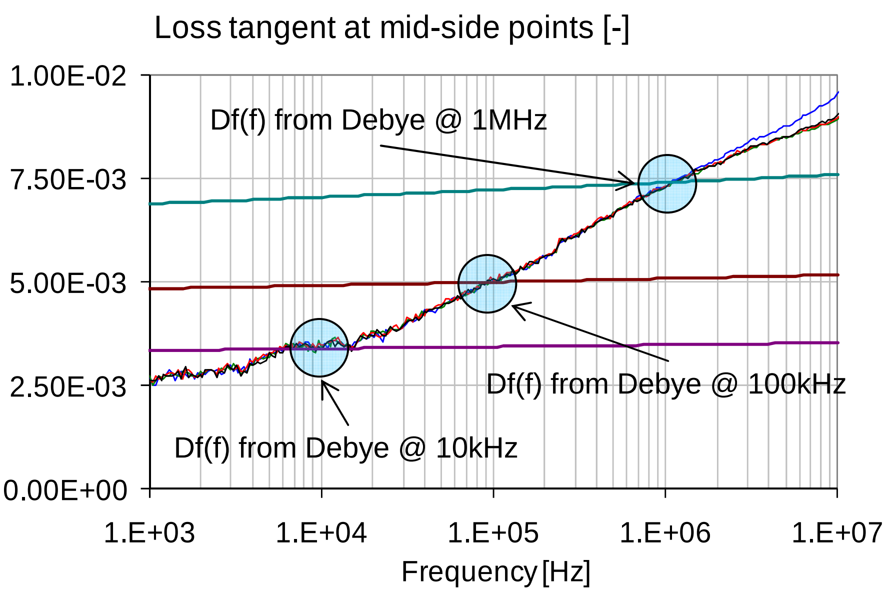
COPPER CLAD LAMINATES: Low Frequency (3)

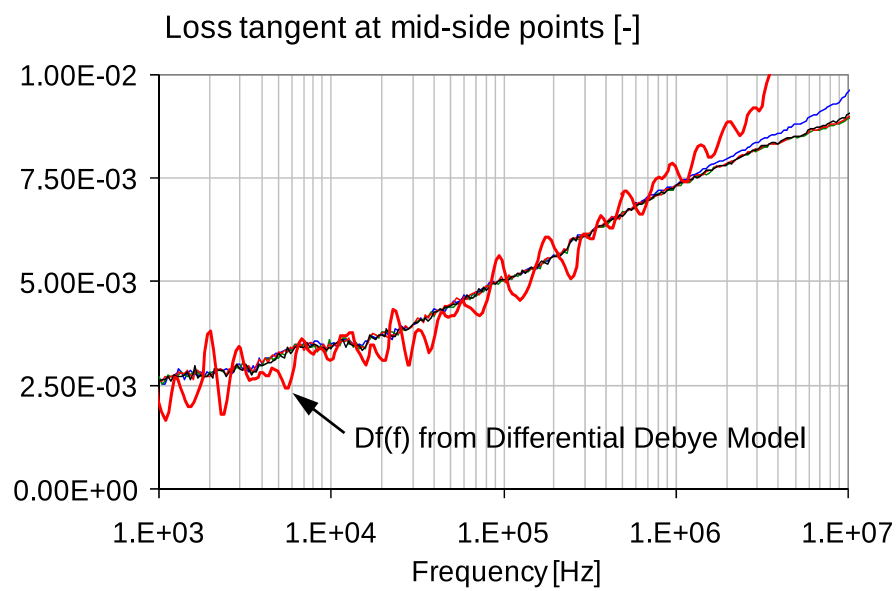
Laminate A, 3"x3" size

Correlation to Integral Wideband Debye model is poor

Differential form of Wideband Debye model correlates well

$$Df(f) = \frac{C(f) - C(f+\Delta f)}{C(f)} \frac{a}{\ln\left(\frac{f+\Delta f}{f}\right)}; \quad a = \frac{\pi/2}{\ln(10)}$$





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BARE LAMINATES: High Frequency

Instrumentation for 1MHz – 1GHz:
E4991A and 16453A fixture (Parallel Plate)

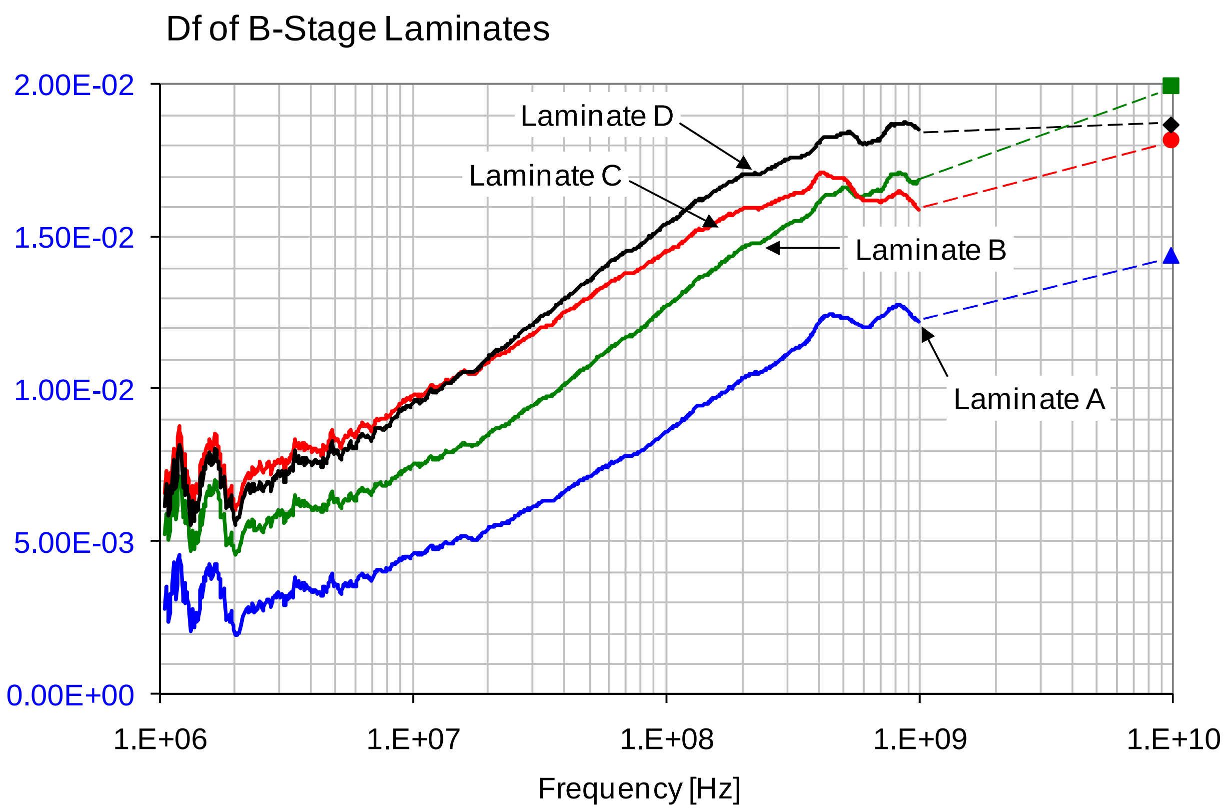
- Bare laminate sample
- Fixture creates plate capacitor
- C(f) and D(f) directly measured

Instrumentation for 10GHz:
E8363A and 85072A Split Cylinder Resonator (SCR)

- Cylinder Q is measured with/without DUT
- Dk and Df are calculated from shift of resonance frequency and Q

B-STAGE BARE LAMINATES: High Frequency (1)

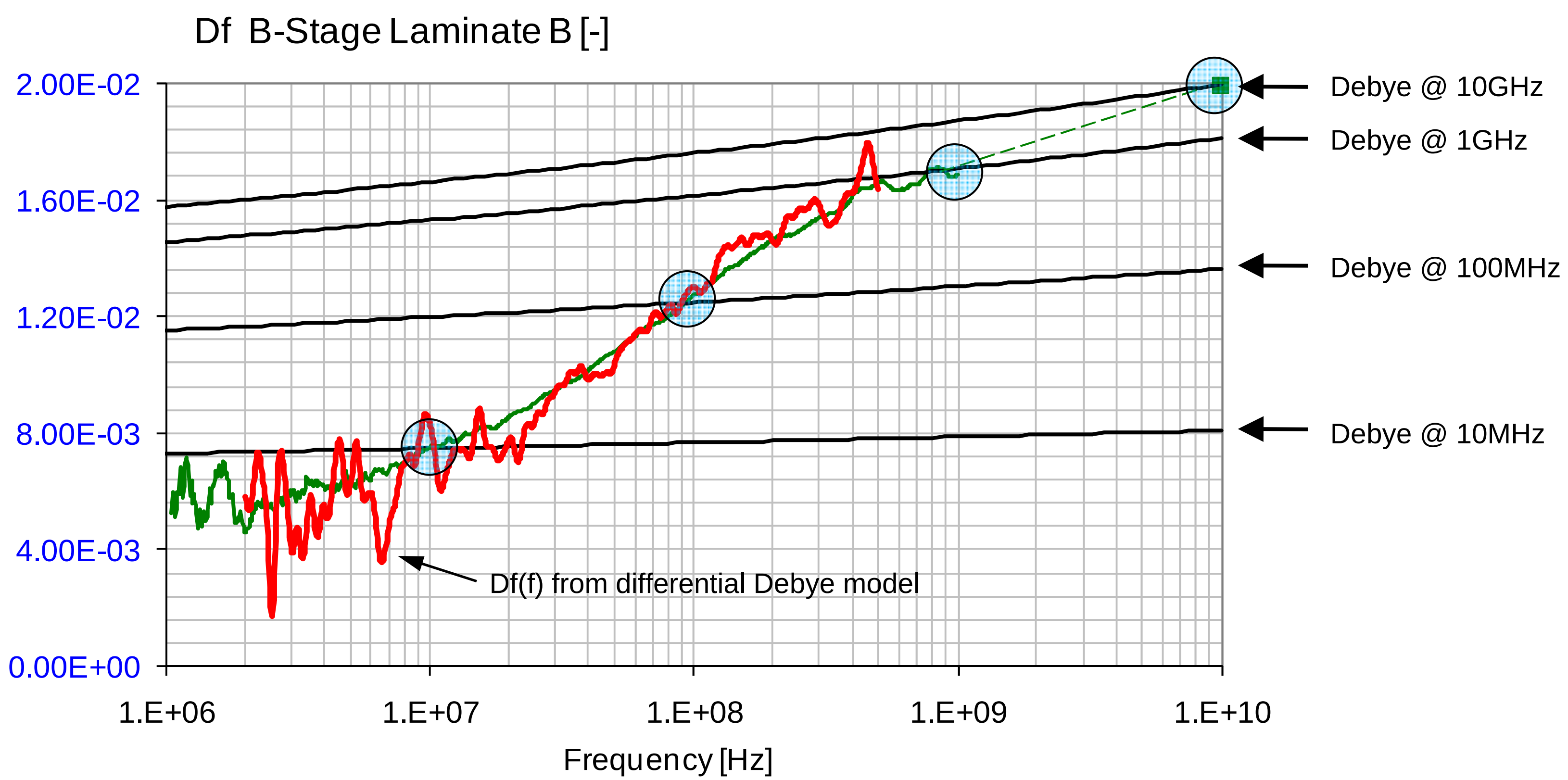
- All 4 laminates measured with PP and SCR
- Measurements taken on unconditioned samples



- B-stage: not fully cured resin
- Df < 1% under 1MHz
- All laminates show similar trends
- Significant changes in slope
- Dashed line indicates frequency range with no data

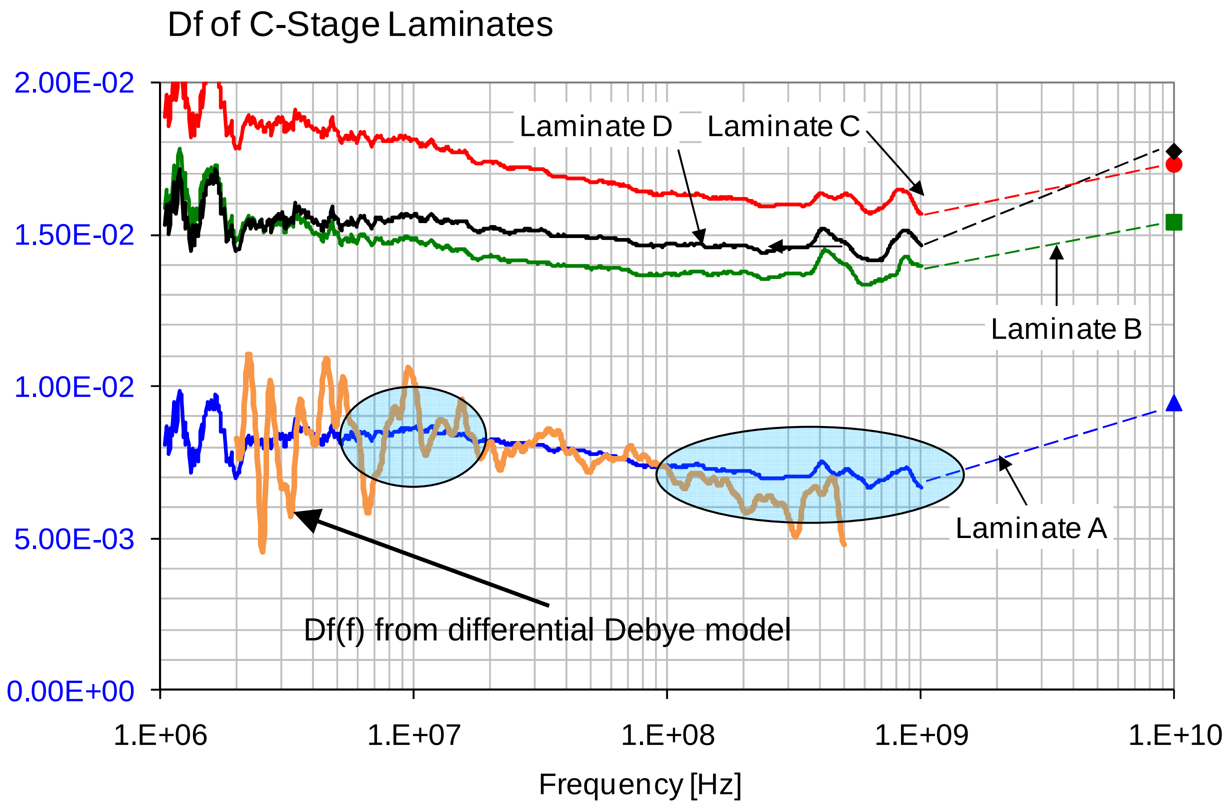
B-STAGE BARE LAMINATES: High Frequency (2)

- Integral Wideband Debye model does not match
- Differential Debye model correlates well



C-STAGE BARE LAMINATES: High Frequency

- All 4 laminates measured with PP and SCR
- Measurements taken on unconditioned samples

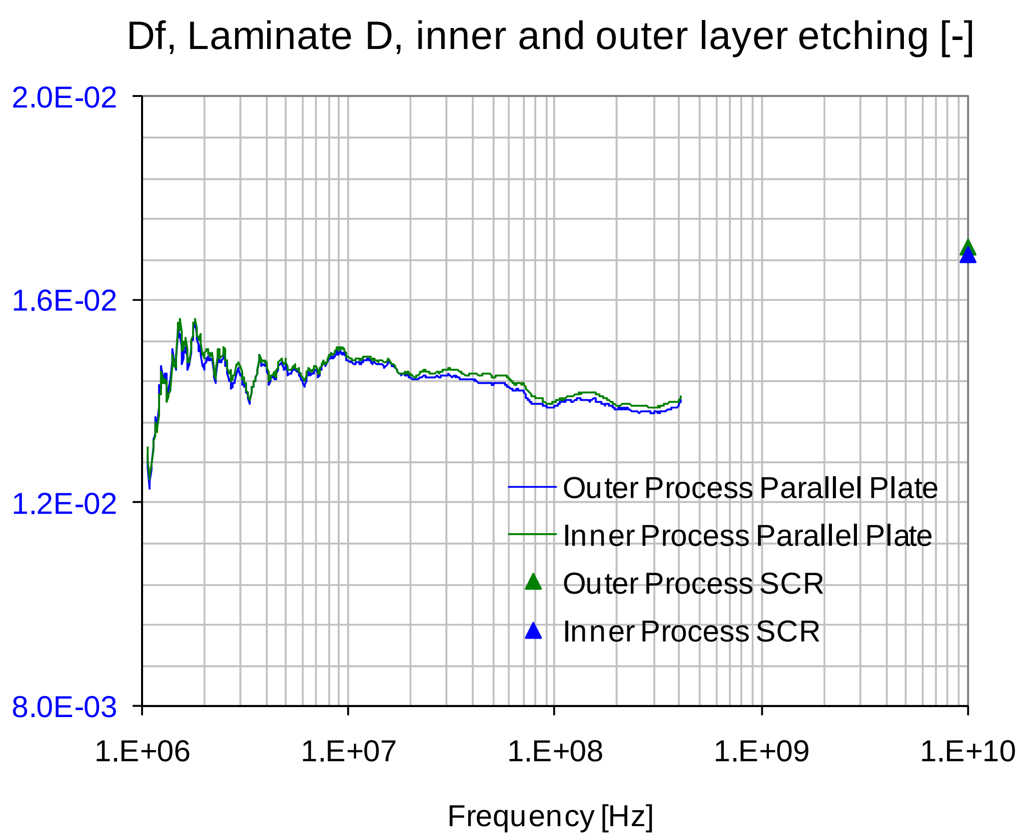


- C-stage: fully cured resin
- Trend significantly different
- Multiple inflection points
- Neither integral Wideband Debye nor Differential Debye model correlates well

C-STAGE BARE LAMINATES: Etching

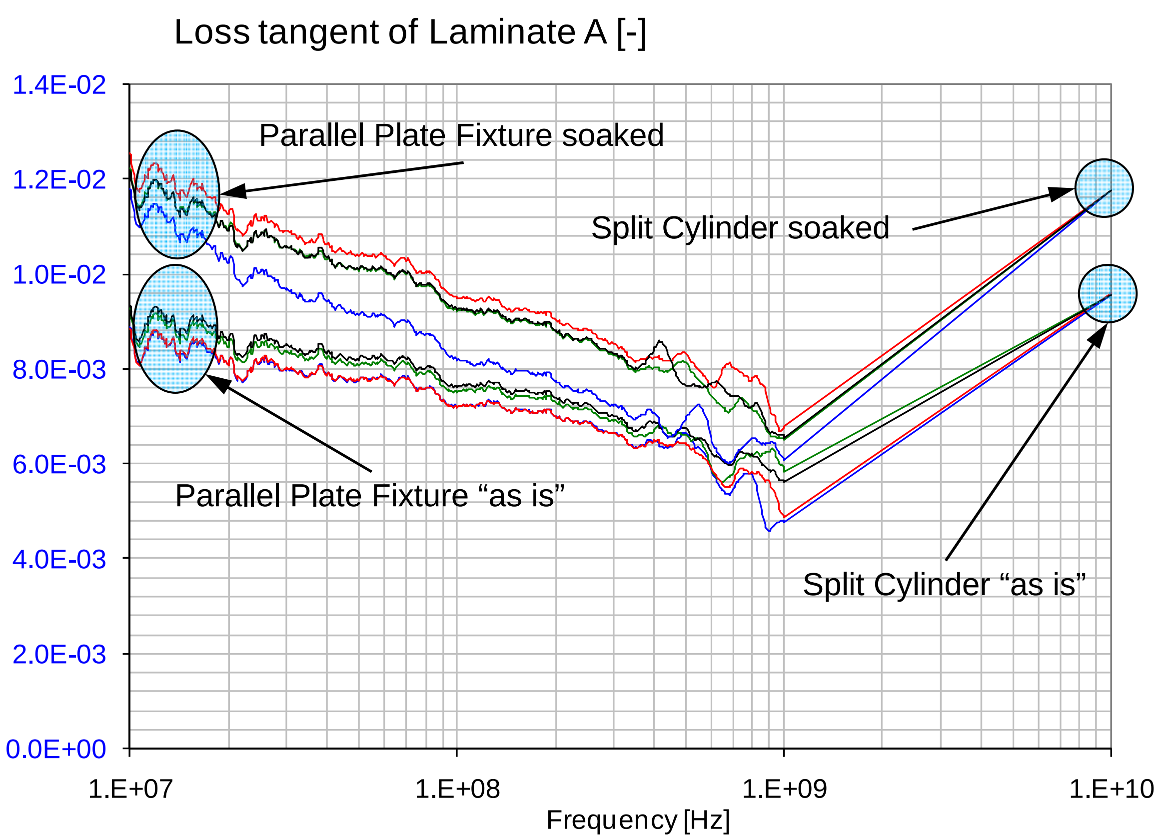
Etching Experiment

- Why did trend change from B-stage to C-stage?
- C-stage were etched cores
- Impact of inner vs. outer layer etching process is minimal



C-STAGE BARE LAMINATES: Soaking

- Is moisture responsible for Df(f) signature?
- Qualitative measurements by Parallel Plate and SCR methods

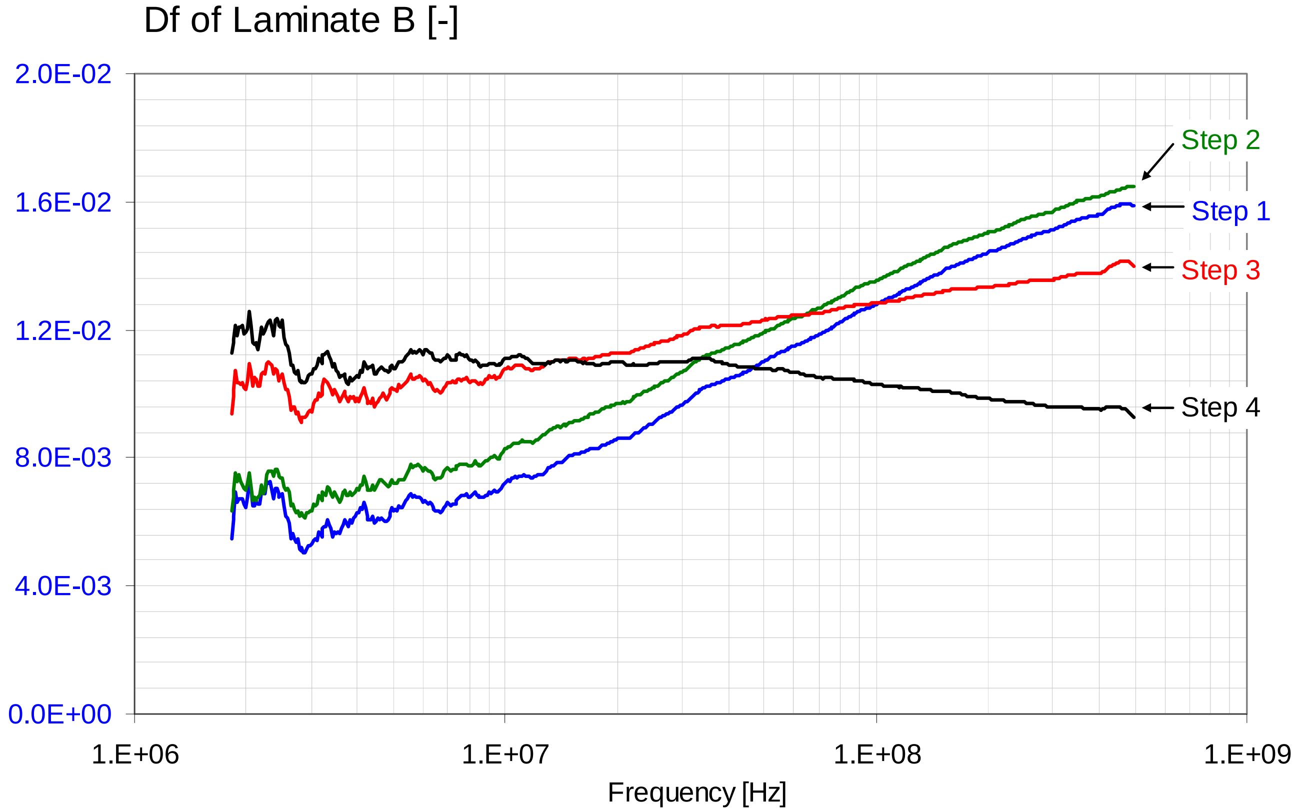


- 2 Hour Soak in pressure cooker
- Moisture absorption increases Df but doesn't change trend

C-STAGE BARE LAMINATES: Baking

Step 1 → **Step 2** → **Step 3** → **Step 4**

30min @ 110C | 2 hours @ 110C | 14 hours @ 110C | 2 hours @ 185C



- Baking DOES change Df signature
- Step 4 shows previous C-stage trend
- Additional baking had no effect

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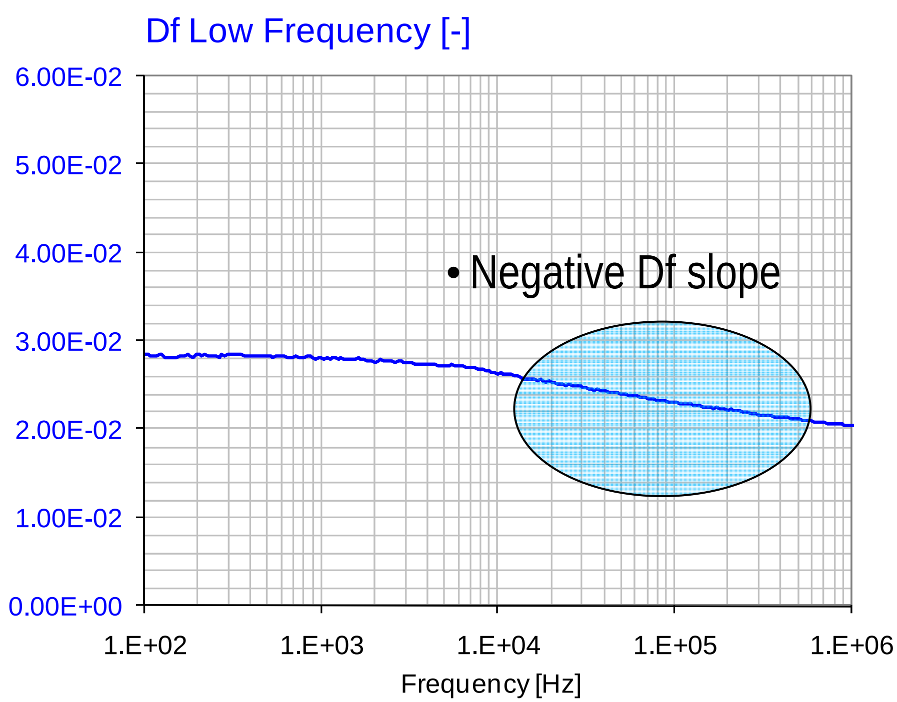
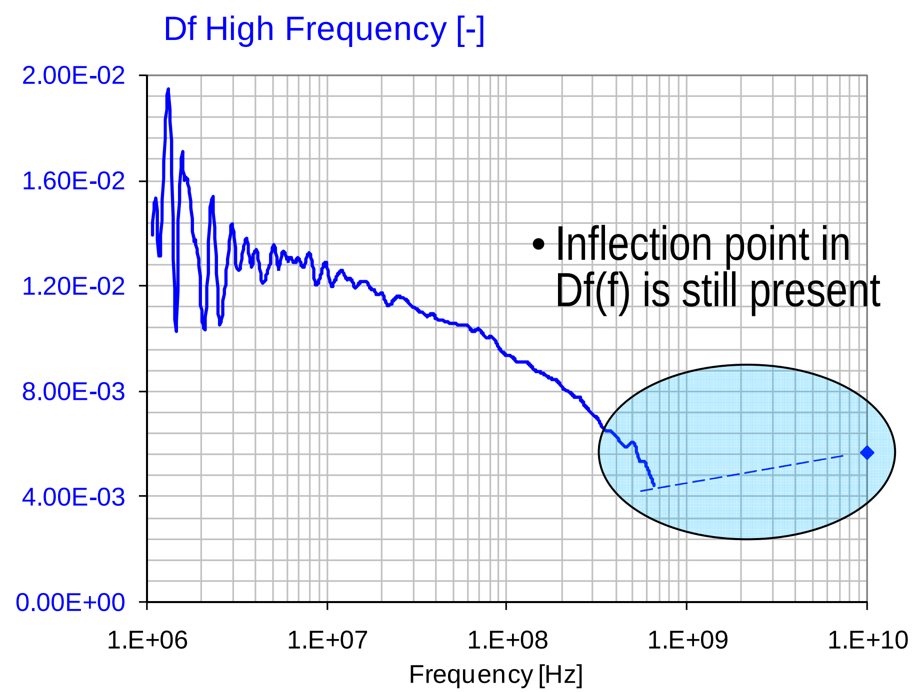
UNREINFORCED LAMINATES (1)

Purpose: checking to see if difference in field orientation shows up in isotropic laminates as well

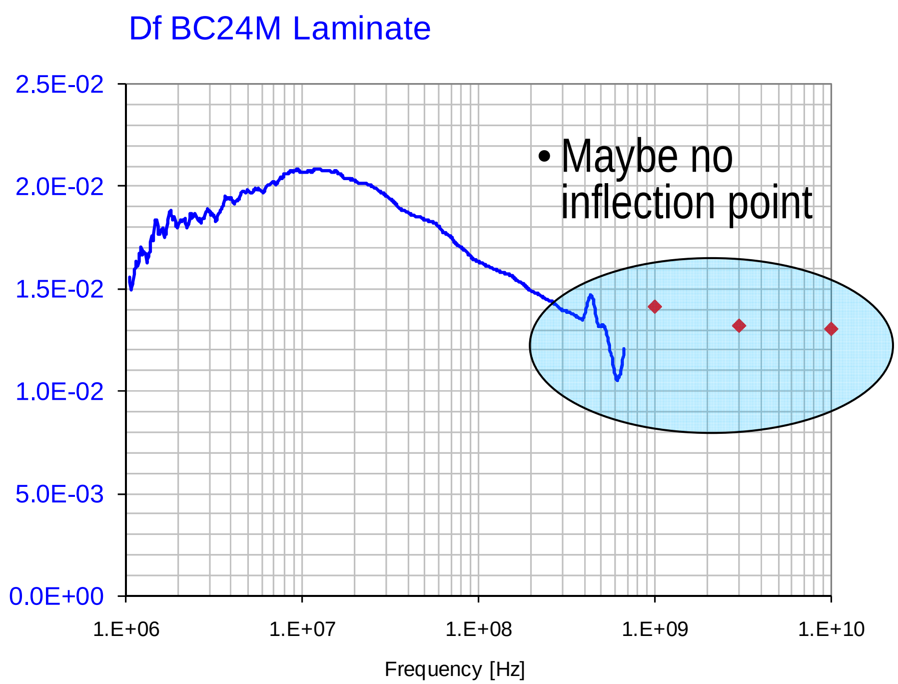


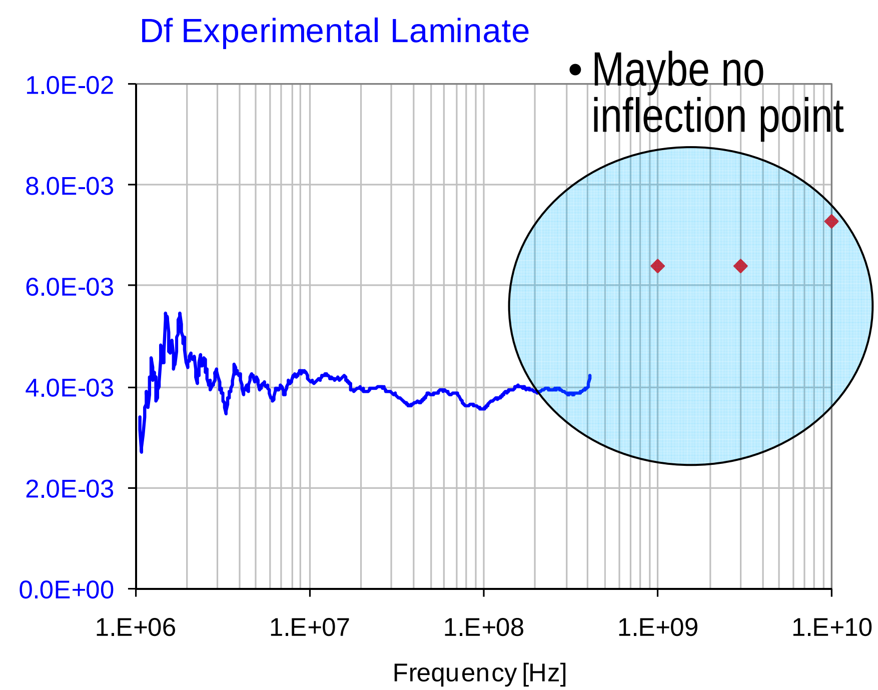


Low and high-frequency Df signature of DuPont FR0121A acrylic laminate

UNREINFORCED LAMINATES (3)

Df of Oak Mitsui Technologies BC24M 1/1 (left graph) and experimental laminate (right graph). Blue data points: SUN Microsystems; red data points: courtesy of Oak Mitsui Technologies.





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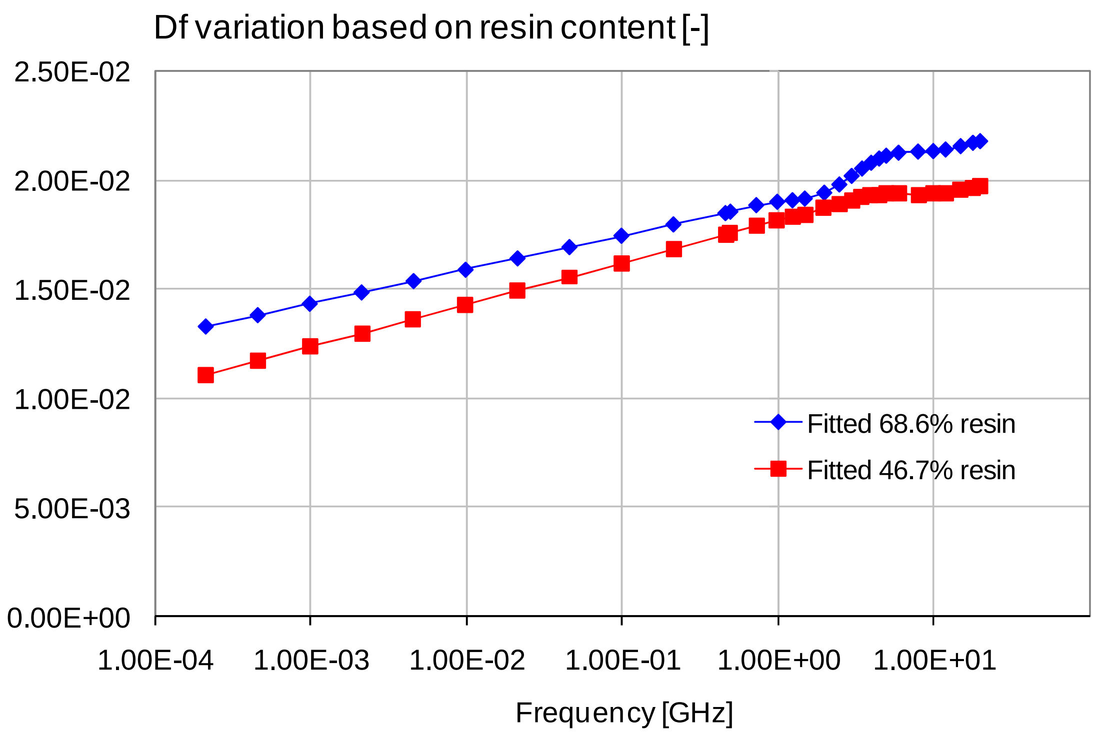
COMPOSITE TEST RESULTS (1)

Df of Laminate B for two different resin contents, measured with Short Pulse Propagation (SPP) method. Data courtesy of Compeq.

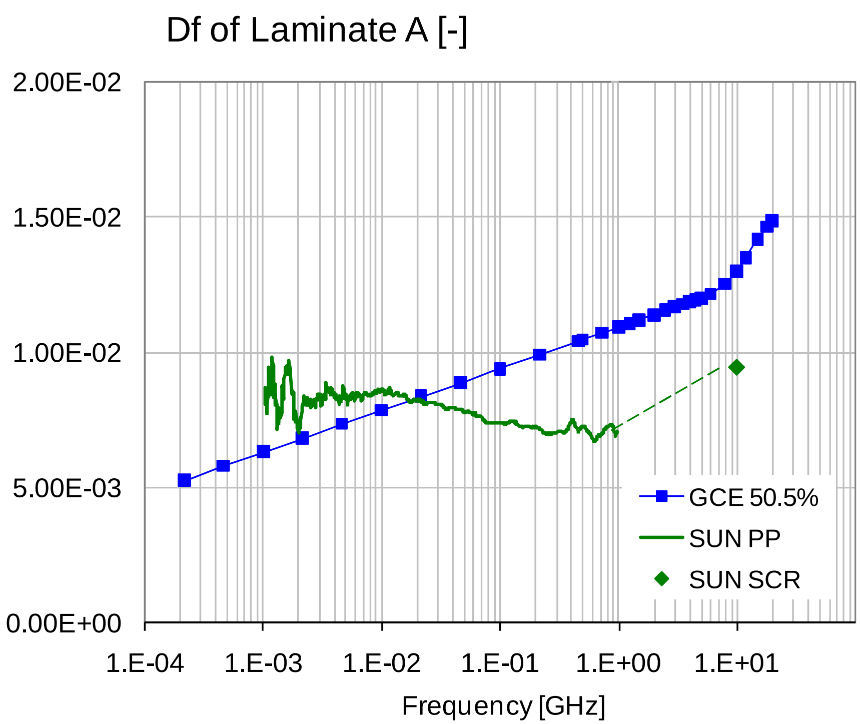


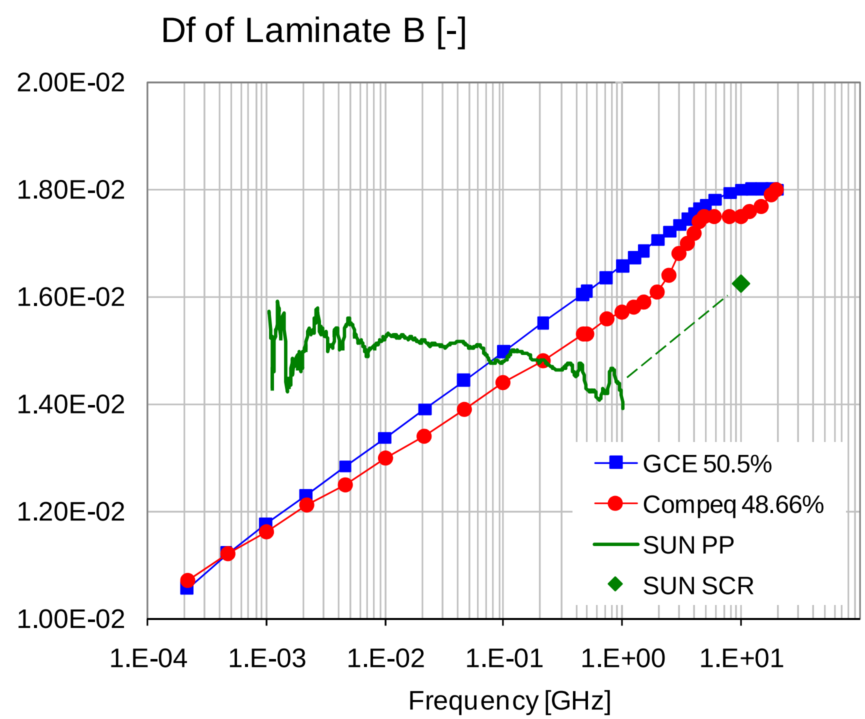
SPP:

- Laminated interconnect is measured with a narrow pulse
- Different length traces are measured
- Complex propagation constant is calculated from far-end received pulse
- From cross section data, DC resistance and field-solver data, a first order model is created
- R(f), L(f), C(f) and G(f) are fitted to match measured response

COMPOSITE TEST RESULTS (2)

Df of Laminate A (left graph) and Laminate B (right graph) with different measurement methods. SPP data courtesy of Compeq and GCE





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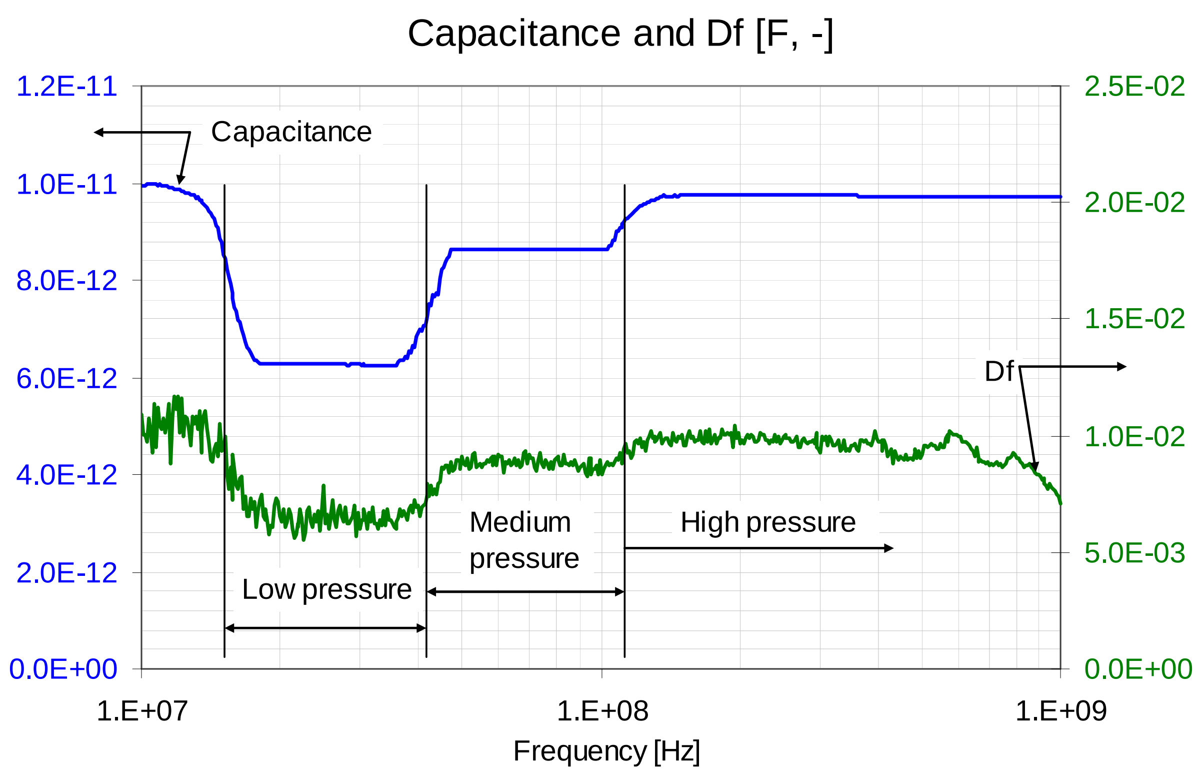
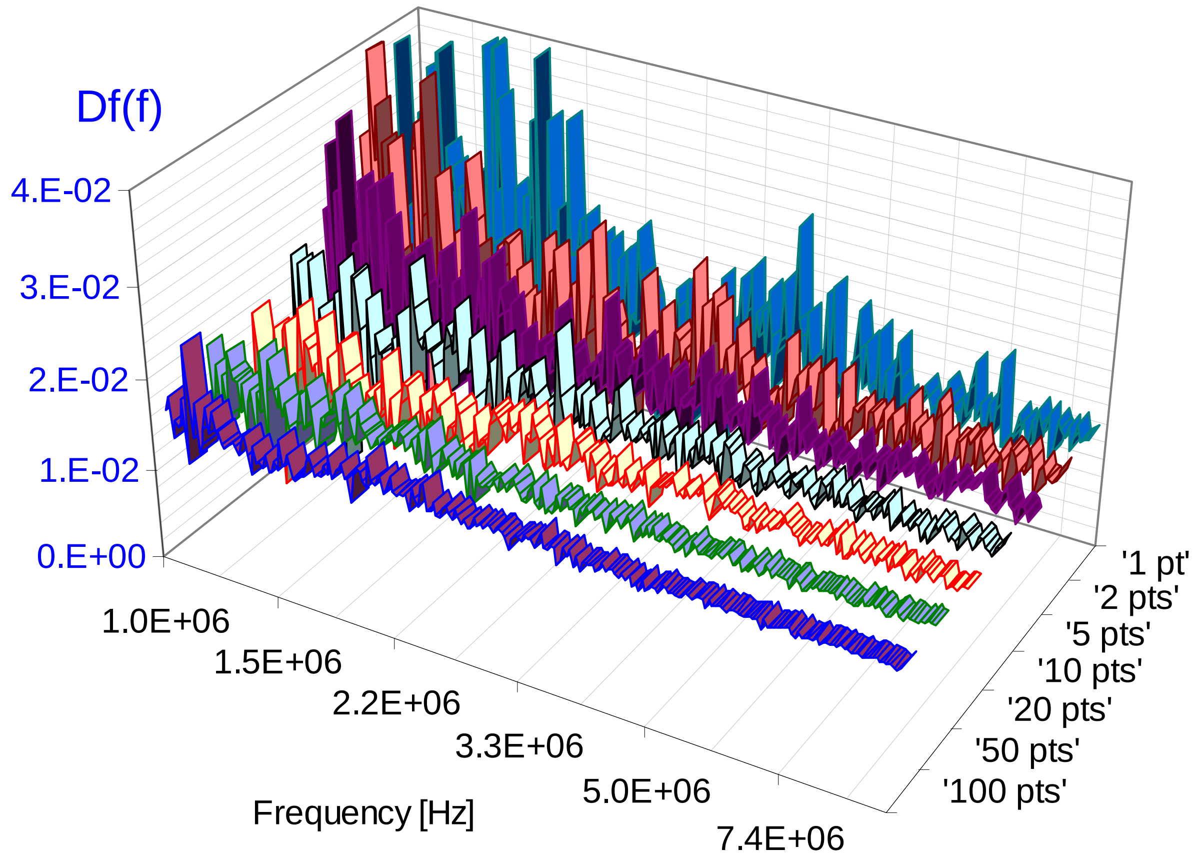
POTENTIAL SOURCES OF ERRORS (1)

Impact of electrode pressure of 16453A fixture on the measured capacitance and Df



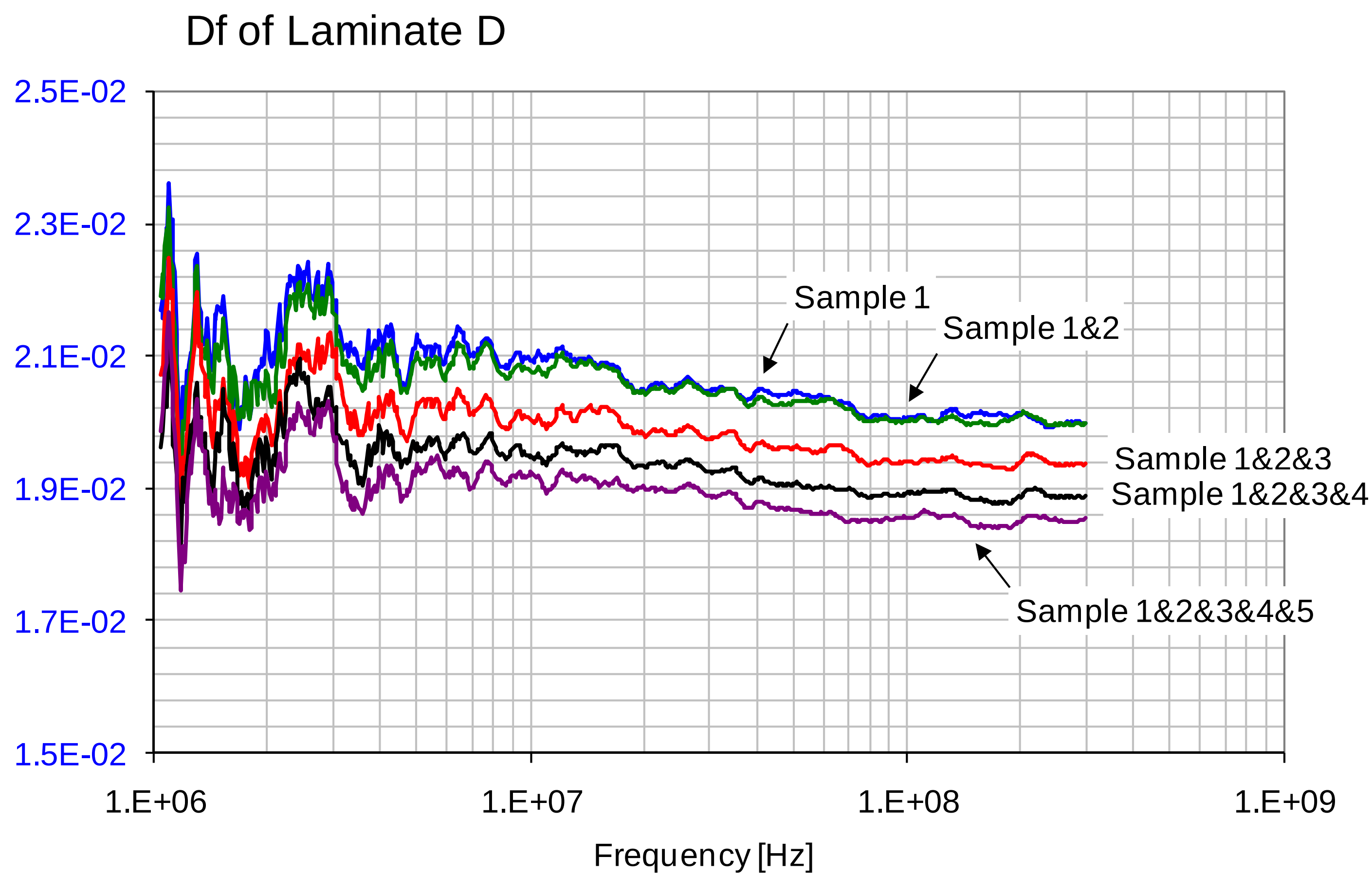
POTENTIAL SOURCES OF ERRORS (2)

Impact of point averaging in E4991A Impedance Analyzer



POTENTIAL SOURCES OF ERRORS (3)

Impact of stacking on Df. Laminate D samples were measured in 16453A Parallel-Plate fixture.



SUMMARY AND CONCLUSIONS

- Wideband Debye model does not match measured data
- Multiple inflection points on Df(f) curves
  - CGM can not be used to extrapolate to higher frequencies with no data
- Differential Wideband Debye model matches measured Df data wherever capacitance can be extracted reliably
  - CGM can be used within the measured frequency range to cross-correlate data
- Short Pulse Propagation, Parallel-plate and Split-cylinder methods provide different results

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