High Frequency Dk and Df Test Methods Comparison
High Density Packaging User Group (HDP) Project

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Abstract

The High Density Packaging (HDP) user group working on high frequency test methods, used for speeds above 2.0 GHz, is developing a way of comparing how sensitive each of the various high frequency test methods are in measuring the effect of moisture content on a laminate material's dielectric constant and loss. In the completed Phase 1 of this work[1], higher moisture content appeared to cause as much as a 20 percent increase in loss with some test methods. The Phase 2 project work was needed to a develop an effective method of determining the moisture content in high frequency test coupons. Variations in the test board material resin content/construction and copper foil surface roughness/type were minimized in this work.

Introduction

Currently there are many standard IPC laminate material Dk and Df test methods, and no industry commonality in the actual methods used to evaluate high frequency laminate materials for dielectric loss (Df) and dielectric constant (Dk). As the industry moves to higher clock speeds, the differences between the types of test methods are critical to understand, including the signal path being measured and other factors affecting the relevancy of the measurements taken.

Phase 1 of this project [1] showed strong Dk and Df data correlations between high frequency test methods that were of the same type. However, differences in moisture content were found to contribute up to a 20 percent difference in the measured Df values of some laminate materials tested.

In Phase 2 of this project, a method of consistently evaluating the sensitivity of high frequency Dk and Df test measurements to moisture content was developed. The goal was to be able to control the moisture content before testing Dk and Df, and if possible also accurately measure the moisture content in the representative test coupons.

Project Plan

This Phase 2 project used one lower loss laminate material known to absorb significant amounts of moisture without having any fillers capable of releasing water or moisture into the material during thermal excursions or at higher temperatures. This laminate material was one of the laminate materials used in Phase 1, and the same board construction was used in Phase 2. Two of the three types of high frequency test methods were used, In-Plane and Z-Direction, to test the selected test coupons at various frequencies (2 GHz, 10 GHz, and up to 30 GHz if possible). The test methods selected and used in Phase 2 were SUM-DISK, SUM-PLATE, SPDR-Transverse Magnetic, and Tri-Plate Resonator. However, multiple test facilities were not used for the same test method to determine the repeatability.

Four different levels of moisture preconditioning were used to achieve four difference levels of moisture content:

- As-Is or As-Received
- Temp 85C & 85% RH
- Temp 30C & 85% RH
- Baked Dry

Project goals included:

a) Using weight gain test coupons to quantify the percent moisture content in the material resulting from each of the four conditioning environments.
b) Determining the sensitivity of loss measurements with moisture content for each type of test method.
c) Develop a test protocol that could be used by the industry for measuring the effect of moisture content on a laminate material's electrical characteristics.

Test Board Design

The test board construction used was the same as for Phase 1, having six layers total, inner layers half-oz RTF copper foil, and finished test board thickness of 0.0313 +/- 0.0022 inches thickness glass-glass. For test coupons with traces, the trace width was either 0.0055 inches or slightly adjusted to meet 50 ohms characteristic impedance, depending upon the location (one of each per test board).

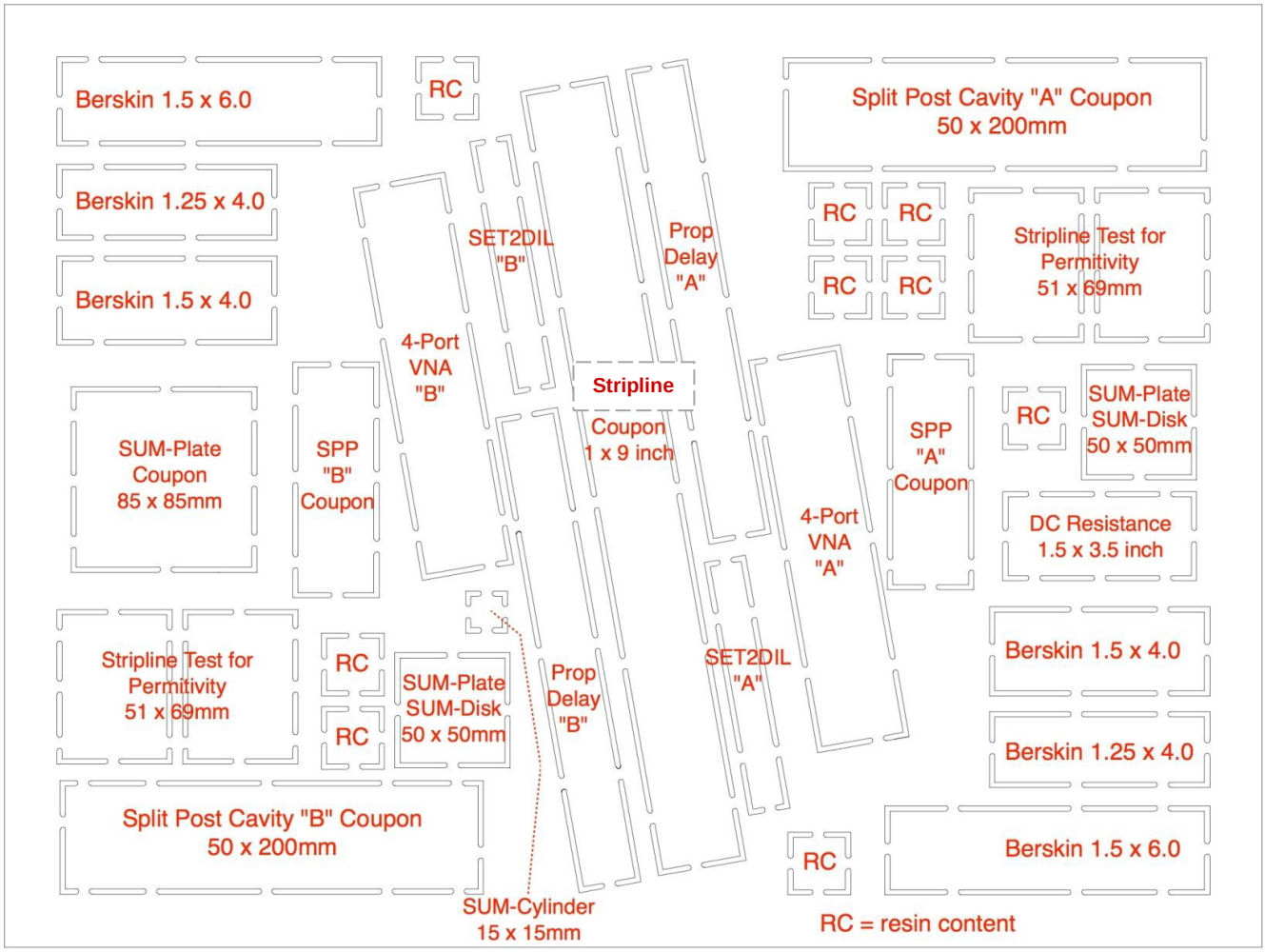

Figure 1: Phase 2 Test Board Layout

Of the three Z-Direction high frequency test methods (Tri-Plate Resonator, SUM-DISK, Bereskin), the SUM-DISK test method (coupon 50mm x 50mm, no soldermask) was selected as representative and tested, and the TRI-PLATE RESONATOR test method (coupon 2.0 x 8.0 inches, no soldermask) was selected as representative and tested.

No trace or conductor based (a.k.a. stripline) high frequency test methods were selected for this Phase 2 testing (Stripline, 4-Port VNA, SPP, SET2DIL).

Of the four In-Plane high frequency test methods (SUM-PLATE, SUM-CYLINDER, SPDR-Transverse Electric, SPDR – Transverse Magnetic), the SPDR – Transverse Magnetic test method (coupon 1.25 x 4.00 inches) was selected as representative and tested, and the SUM-PLATE test method (coupon 50mm x 50mm, no soldermask) was selected as representative and tested.

Experimental

The four different moisture levels or contents were determined by the following preconditions:

1) As Received
2) High Moisture Preconditioning (85% R.H. and 85 C for 168 hours)
3) Medium Moisture Preconditioning (85% R.H. and 30 C for 168 hours)
4) Dry Bake (125 C for 168 hours)

The 1.0 inch x 1.0 inch "resin content" coupons were used as the weight gain test coupons and included with the Dk and Df test coupons for each preconditioning by each test facility. A micro-balance was used to weigh these coupons shortly after each preconditioning.

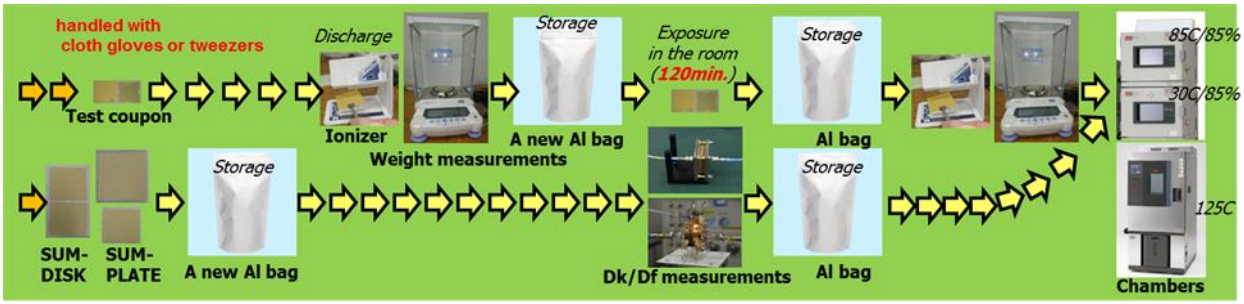

Figure 2: Process Flow for Weight Gain/Loss and Dk/Df Measurements

A classification was proposed to explain the statistical correlations between the high frequency test methods, which is shown in Figure 3 for the Dk extraction test methods.

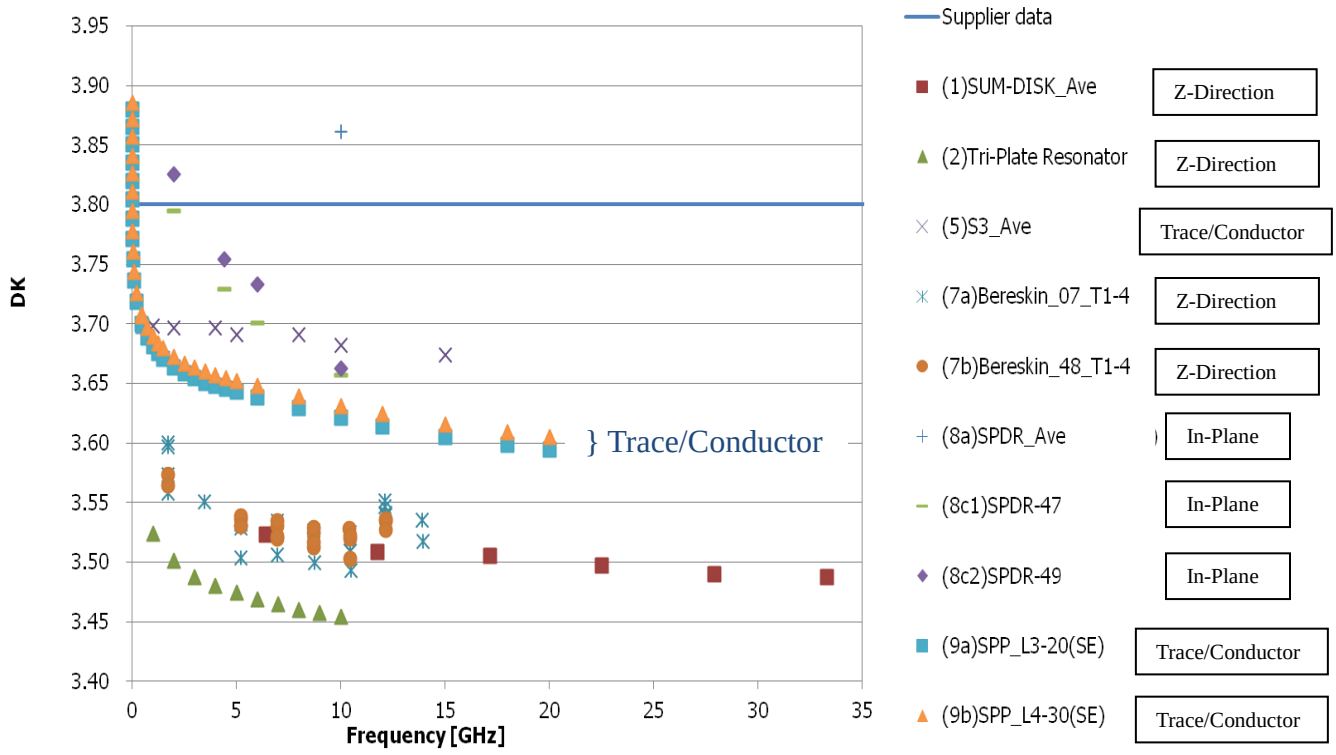

Figure 3 – Comparison of Dk Results by Test Method (for single material)

The Dk extraction test results shown in Figure 3 show Z-Direction measurements all lower than the Trace/Conductor measurements. Also the In-Plane measurements are all higher than the Trace/Conductor measurements.

Sample Preparation

The test board and coupon designs were updated to accommodate the latest high frequency test fixtures. The test board design package was sent to the PCB fabricator for the manufacture of the test boards. The test boards were then shipped to the author, where the required test coupons were removed and sent to each of the test facilities.

Results

All test facilities found the 1 inch x 1 inch weight gain test coupons were difficult to measure with sufficient accuracy, indeed the test coupon weight changes were barely detectable. The following chart shows representative weight gain test coupon results, when they were achieved. The bare laminate coupons increased in weight by at most 0.15 percent after 168 hours at 85C and 85% R.H. (blue line), and slightly less after 168 hours at 30C and 85% R.H (green line). After baking the coupons dry, some facilities measured an unexpected increase in the weight of these thin test coupons after additional baking (orange line). This phenomenon is currently not well understood.

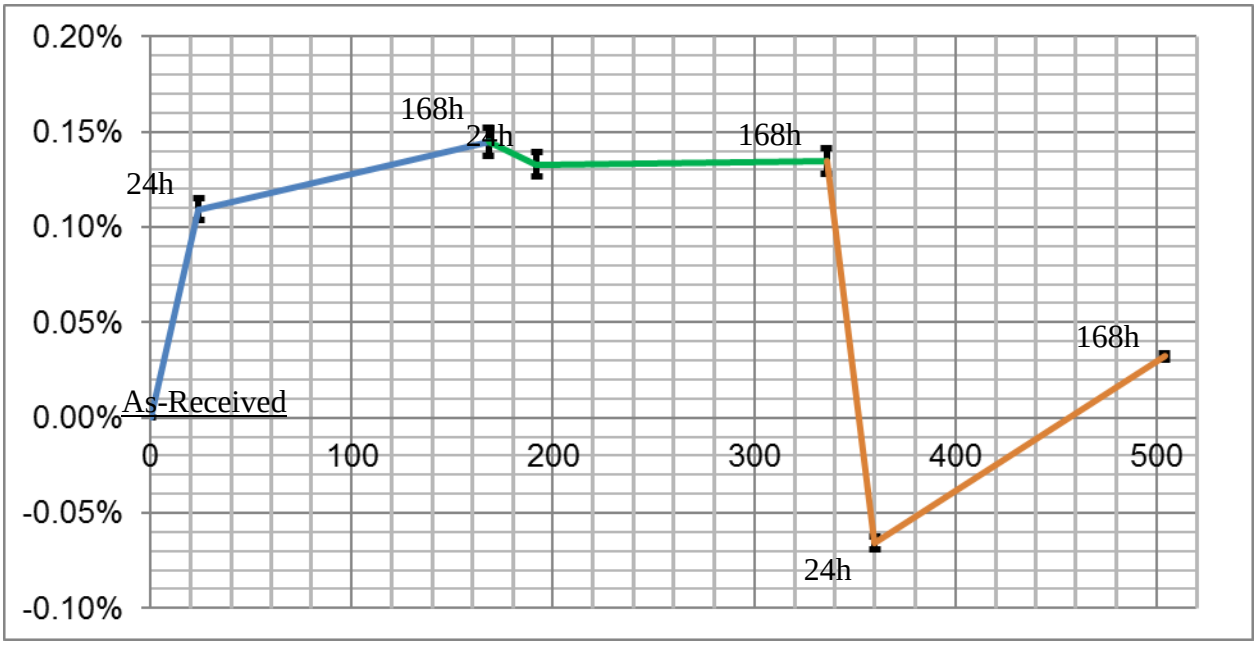

Figure 4: Relative Weight Change = (measured – as received) / (as received)

All test facilities found the high frequency testing of the dielectric constant (Dk) to show very little change with moisture content. However, the In-Plane test method SPDR-Transverse Magnetic was slightly more sensitive to moisture than the SUM-PLATE test method. Also the Z-Direction test method Tri-Plate Resonator was slightly more sensitive to moisture than the SUM-DISK test method. As expected the In-Plane high frequency test methods measured a higher Dk than the Z-Direction high frequency test methods, typically about 7 percent higher.

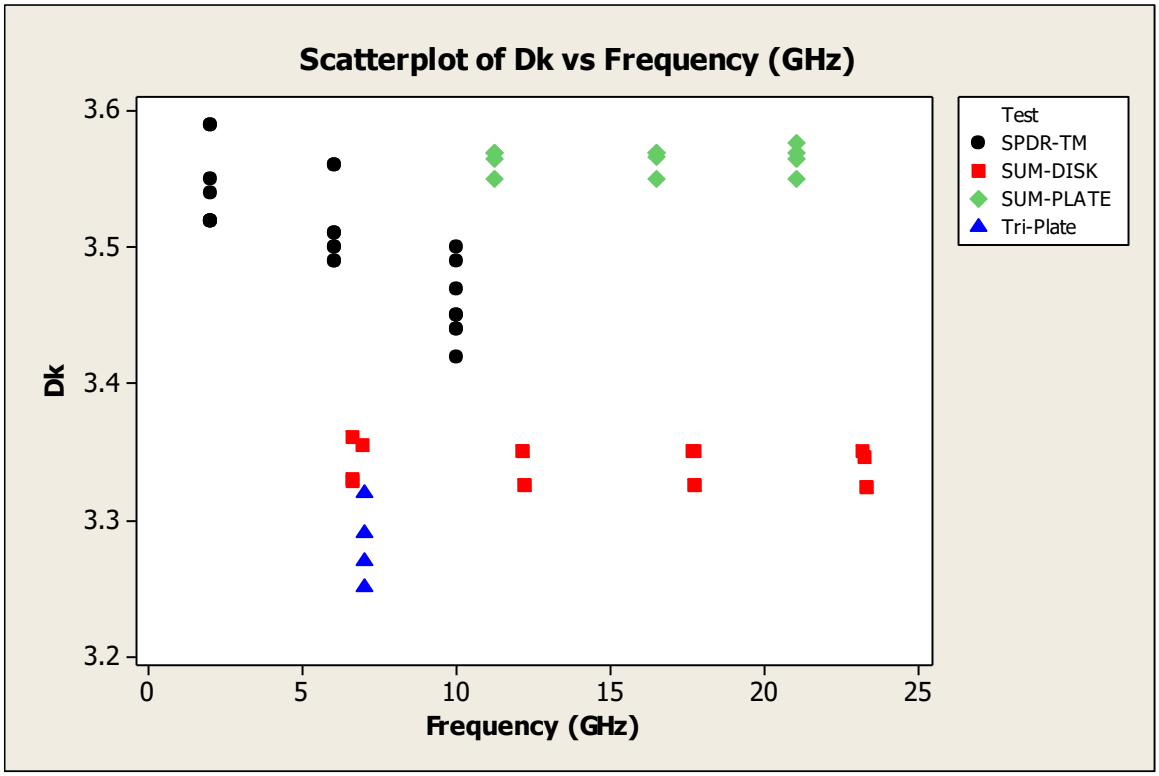

Figure 5: Dk versus Frequency

The following is the same chart, but with greater detail.

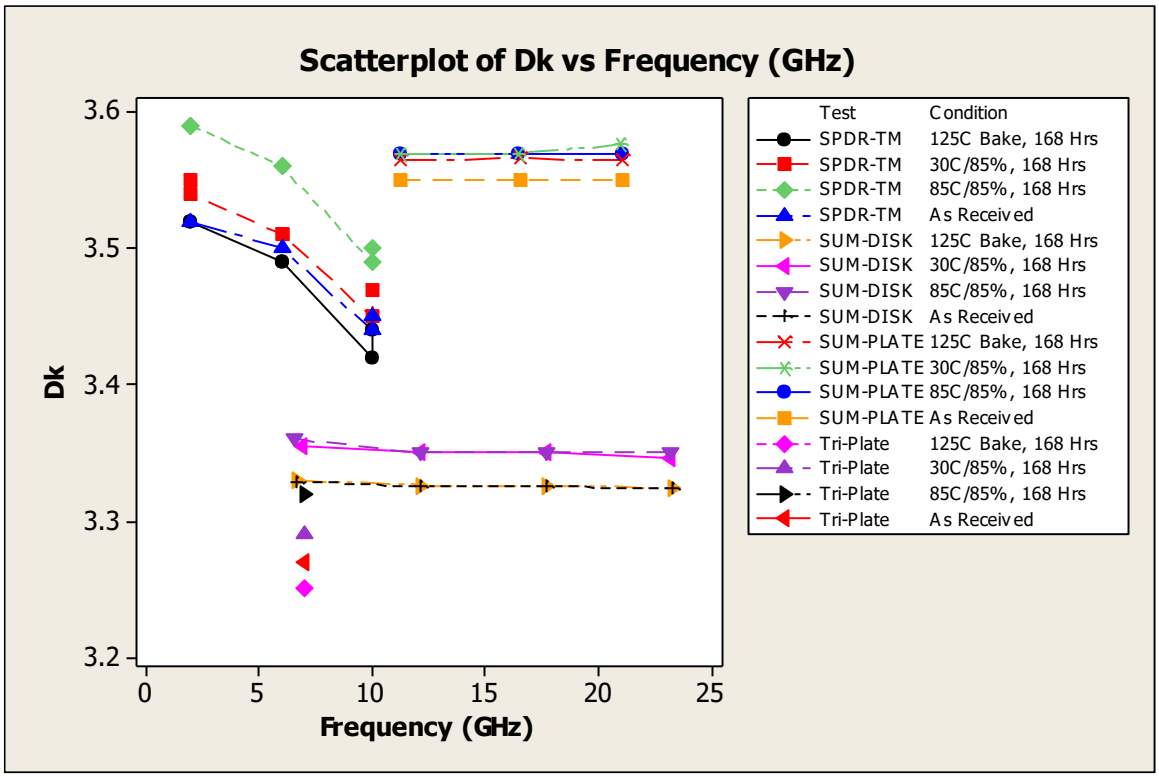

Figure 6: Dk versus Frequency versus Moisture Content

As expected, the Z-Direction Df test methods were less sensitive to frequency than the In-Plane test methods. All test facilities found the high frequency testing of the loss or dissipation factor (Df) to show very significant change with moisture content, in some cases a 40 percent increase. The SPDR-Transverse Magnetic In-Plane test method going from 2 GHz to 10 GHz had the same increase in loss as going from a low to a high moisture content. At higher frequencies the SUM-DISK Z-Direction test method going from 7 to 23 GHz showed less than half the loss as going from a low to high moisture content.

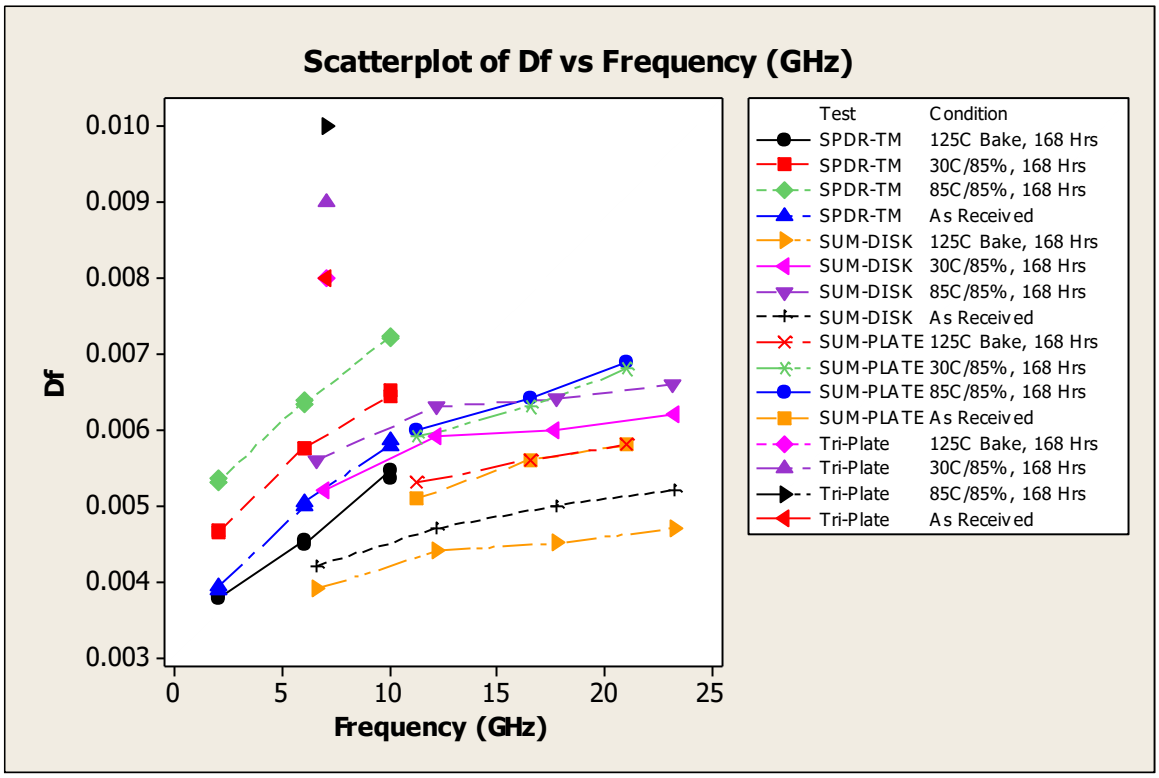

Figure 7: Df versus Frequency versus Moisture Content

Surprisingly, the as-received measurements were nearly always very close to the Baked Dry measurements, and the 85C/85% R.H. measurements were very close to the 30C/85% R.H. measurements.

Conclusions and Comments

These high frequency Dk/Df extraction test methods can be used to show the impact of moisture content. Because the moisture content impact on loss is so significant, one of these test methods in combination with a standard laminate material could be used to indicate a dielectric material's moisture content with greater sensitivity than the weight gain test coupon method used.

As preparation for a Phase 3 project evaluating the sensitivity of all the high frequency test methods to moisture content, this Phase 2 project established a baseline of comparison for all subsequent testing. The ability to measure additional moisture content levels has been established in order to conduct further testing using additional laminate materials having different moisture content characteristics.
Since these measurements have shown very similar Dk and Df values for both the As-Received and

Dry Bake samples, it may be that the board laminate material moisture content in most applications is typically not high enough to significantly affect loss. However, in high temperature and humidity field environments such as 30C and 85% R.H., the increase in loss is potentially quite significant.

Recommendations/ Future Work

Proceed with a Phase 3 project to evaluate the relative sensitivity of each of the high frequency test methods to moisture content, using additional laminate materials to provide additional laminate material moisture content levels generated by 85% R.H. conditioning.

Consider adding an additional environmental condition of having test boards exposed to an actual worst case field condition for 168 hours, if an on-site high frequency testing capability can be made available.

Acknowledgements

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Brian Wright of Keysight	4-Port VNA testing
Michael Gay of Isola	Bereskin Stripline testing
Kevin Zhang of Shengyi	SPDR, Transverse Electric testing
Joe Smetana of Nokia	Data analysis
Brian Butler of Introbotix	4-Port VNA, SPP, SET2DIL testing
Rick Hinkle, T. Senese of Panasonic	Supplier of laminate material used for testing
Shunichi Kikuchi, Akiko Matsui, and Kazuhiro Kanai of Fujitsu	Data analysis, and SUM-DISK, SUM-PLATE testing
Scott Hinaga, David Senk of CISCO	S-3 testing
Mike Freda of Oracle Corp.	
Test board design manufactured by Sanmina-SCI, San Jose	
Jack Fisher of HDP	Project Facilitator

References

1. K.Sauter and J. Smetana, ”High Frequency Loss Test Methods for Laminate Materials Comparison (a High Density Packaging User Group/HDPUG Project),” , IPC Apex-Expo 2015, SanDiego, CA.

High Frequency Dk & Df Test Methods Comparison

A High Density Package User Group (HDP) Project

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High Frequency Test Methods and Moisture

- In Phase 1 of this project, higher moisture content showed as much as a 20 percent increase in loss with a small increase in Dk using high frequency test methods
- In Phase 2 of this project, the purpose was to identify an effective way of determining moisture content in high frequency test coupons
- In Phase 3, high frequency test methods will be evaluated for their sensitivity to moisture content

Test Plan

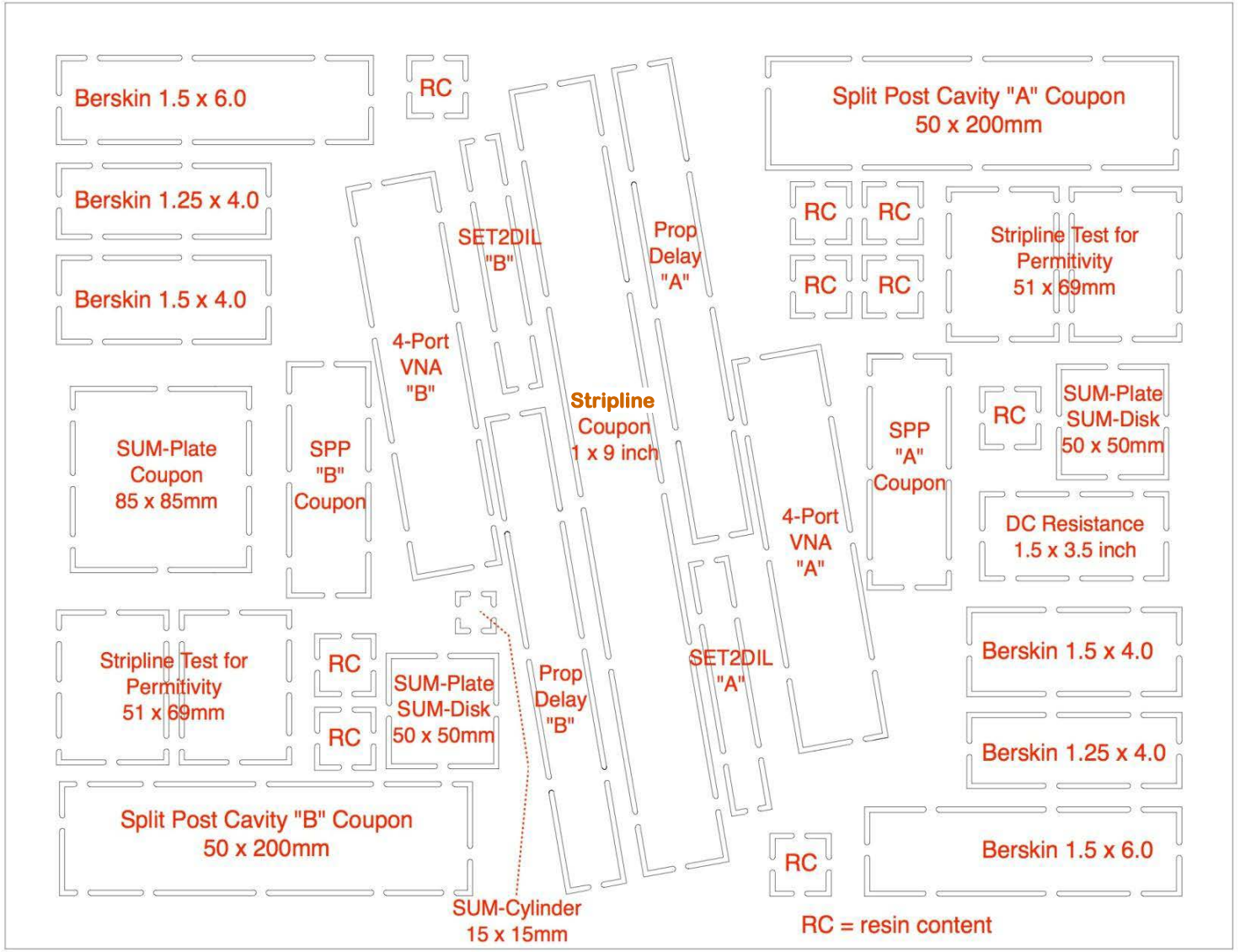
Four different levels of moisture preconditioning were used to achieve four levels of moisture content:

- *As-Is or As-Received*
- *Temp 30 C and 85 percent RH*
- *Temp 85 C and 85 percent RH*
- *Baked Dry (125 C for 168 hours)*

Test Board Design

- Overall board thickness 0.0313 +/- 0.0022 inches
  - *6 layers total, inner layers ½-oz RTF copper foil*
  - *SUM-DISK, 50 mm x 50 mm*
- The 1.0 x 1.0 inches test coupons were used as weight gain test coupons, some with copper thieving on the inner layers and some without any copper features on any layer (weight gain test coupons were included with the Dk & Df test coupons for each preconditioning step)

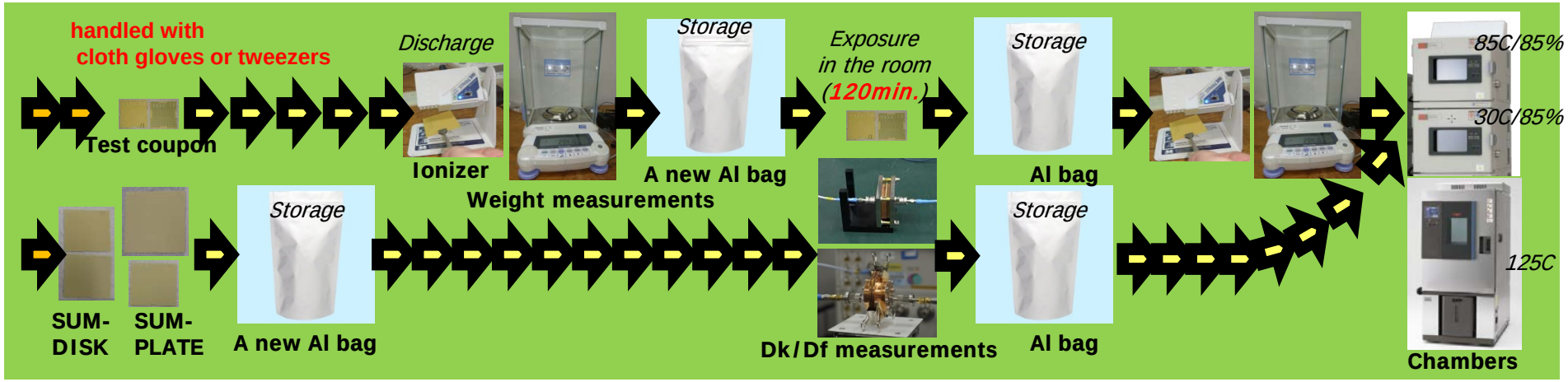
Test Board Layout



Test Coupons

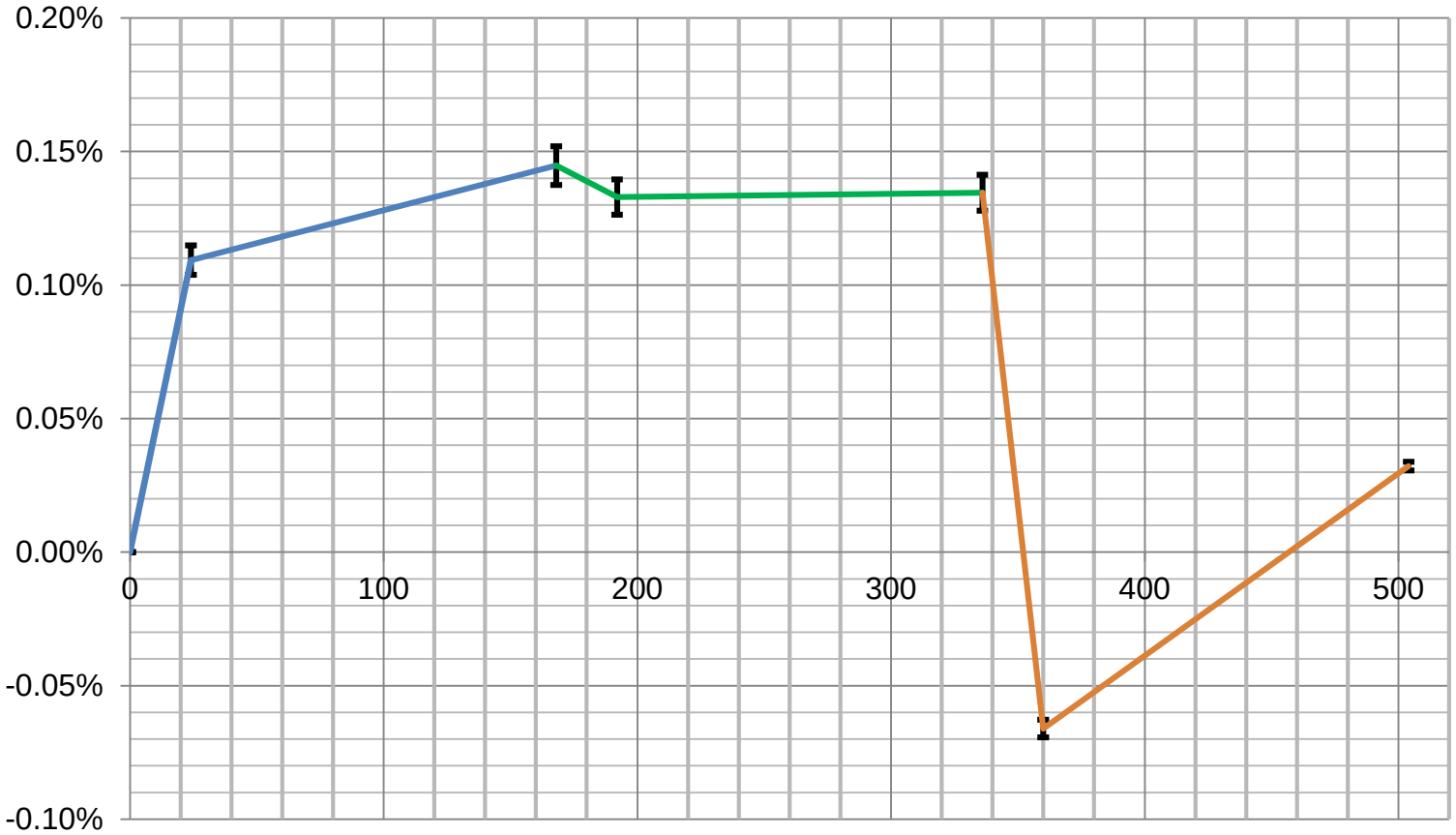
- Z-Direction Test Coupons
  - *Tri-plate Resonator*
  - *SUM-DISK, 50 mm x 50 mm*
- Trace/Conductor Based
  - *None (SPP, Stripline, 4-Port VNA, SET2DIL)*
- In-Plane Test Coupons
  - *SPDR – Transverse Magnetic*
  - *SUM-PLATE, 50 mm x 50 mm*

Weight Gain Coupon Testing



All facilities found the 1 inch by 1 inch weight gain test coupons difficult to measure with sufficient accuracy.

Results - Weight Gain Coupon Testing

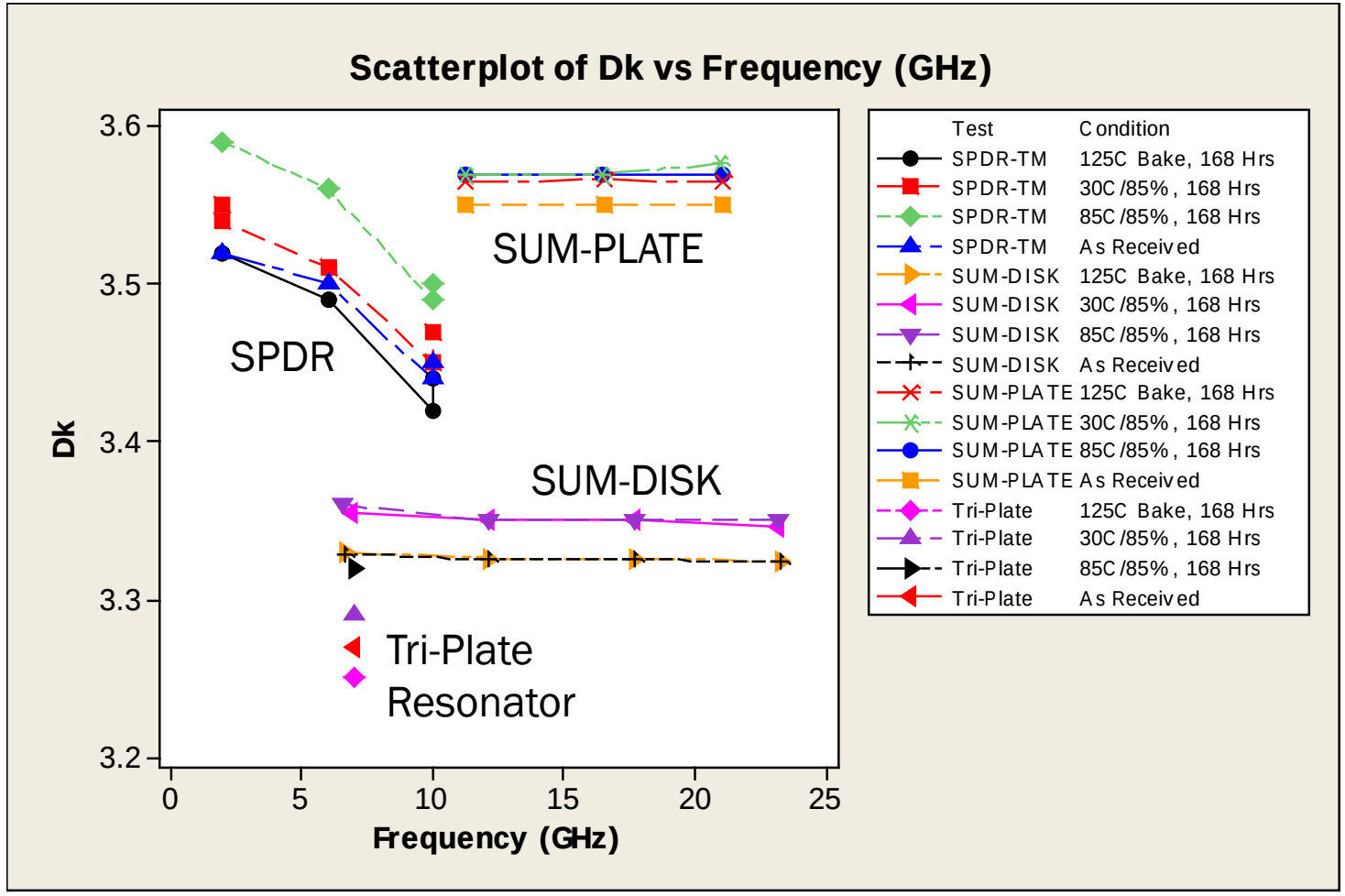


Note: After baking the coupons dry, some measured a slight unexpected increase in weight from 24 to 168 hours, This phenomenon is not currently understood.

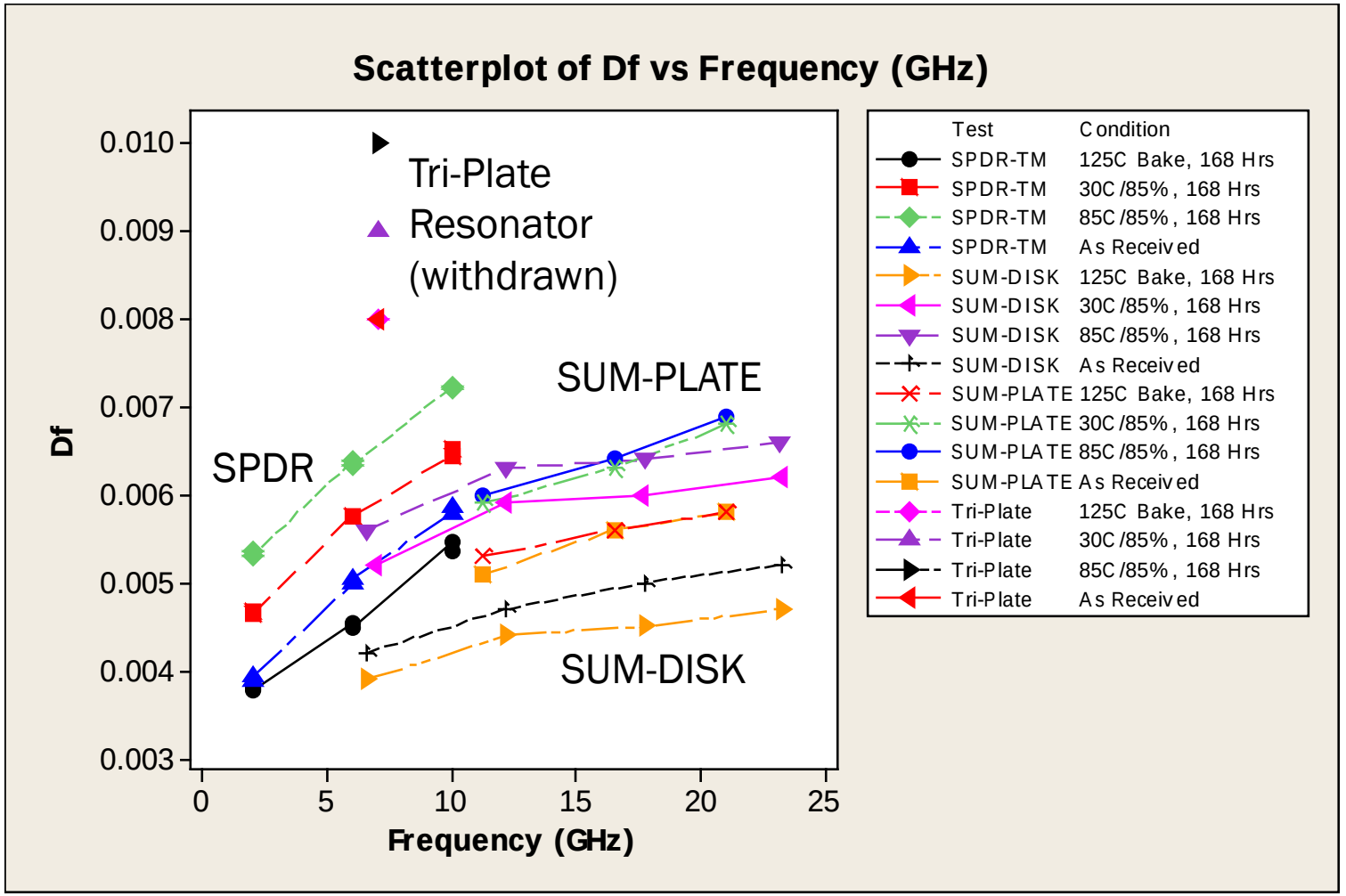
Results - Weight Gain Coupon Testing, cont.

- All testers found these weight gain test coupons difficult to measure with sufficient accuracy
- The test coupon weight changes were barely detectable
- No significant weight gain difference between 30C & 85%RH and 85C & 85%RH
- No significant weight gain difference between As-Received and Baked Dry

Results – High Frequency Testing - Dk



Results – High Frequency Testing - Df



Results – High Frequency Dk & Df Testing

- The test method most sensitive to moisture was SPDR-TM (Dk increase ~ 2%, Df increase ~43%)
- The test method least sensitive to moisture was SUM-PLATE (Dk increase ~1%, Df increase ~28%)
- The SUM-DISK and SUM-PLATE test methods showed similar Dk and Df results for the 30C & 85%RH and 85C & 85%RH conditioning, and also showed similar Dk and Df results for the As-Received and Baked Dry conditioning

Conclusions & Comments

- These high frequency Dk/Df extraction test methods can be used to show the impact of moisture
- High frequency Df measurement is very sensitive to moisture content regardless of the test method used
- The coupon size used for the weight gain test coupons may have been too small to provide sufficient accuracy and repeatability

Recommendations

1. Proceed with a Phase 3 project to compare the sensitivity of each high frequency test method to moisture content, using SPDR-TM and SUM-DISK high frequency Df measurements to indicate relative moisture content.
2. Consider adding an additional environmental condition of having test boards exposed to an actual field case condition for 168 hours, if an on-site high frequency testing capability can be made available.

Acknowledgements

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