# Behavior of Materials in the Manufacturing Environment

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Abstract

This study was conducted to understand seven materials reliability, behavior of Dielectric constant and Dissipation factor over medium to high frequencies. A modified version of HDPUG design was used for evaluation. This test board contains IST, CAF, Thermal Cycling and Impedance (both Micro Strip and Strip line) coupons. In addition to these we added HATS coupons. Materials were chosen from FR4 family and selection was made based upon our present and future needs. Dielectric constants of these materials ranged from Dk 3.6 to Dk 4.2, as published, at 10GHz. This document shows the effect of Dk and Df values from 10GHz to 20GHz and also shows their performance for lead free assembly process when tested using IST and HATS test methods. In addition CAF testing was done on five of the seven materials.

Introduction:

As signal speeds are getting higher, a better understanding of material performance is required. Materials which were good at low frequencies may not be good for higher frequencies. The goal of this study was to:

1. Compare Material reliability using HATS and IST test methods.
2. CAF analysis of these materials.
3. Study insertion losses for materials chosen and do a comparison of these materials for frequencies between 1GHz – 20 GHz.

A modified HDPUG design, shown below (Fig 2) was adopted as a test vehicle. To keep the testing manageable, thermal cycling and Water absorption coupons were not tested. However, HATS coupons were added to the panel design. The stack up used is shown below in Fig 1..

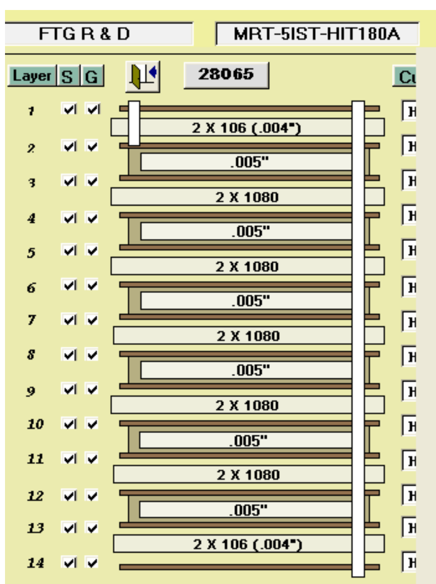


**Fig. 1**

Board Design

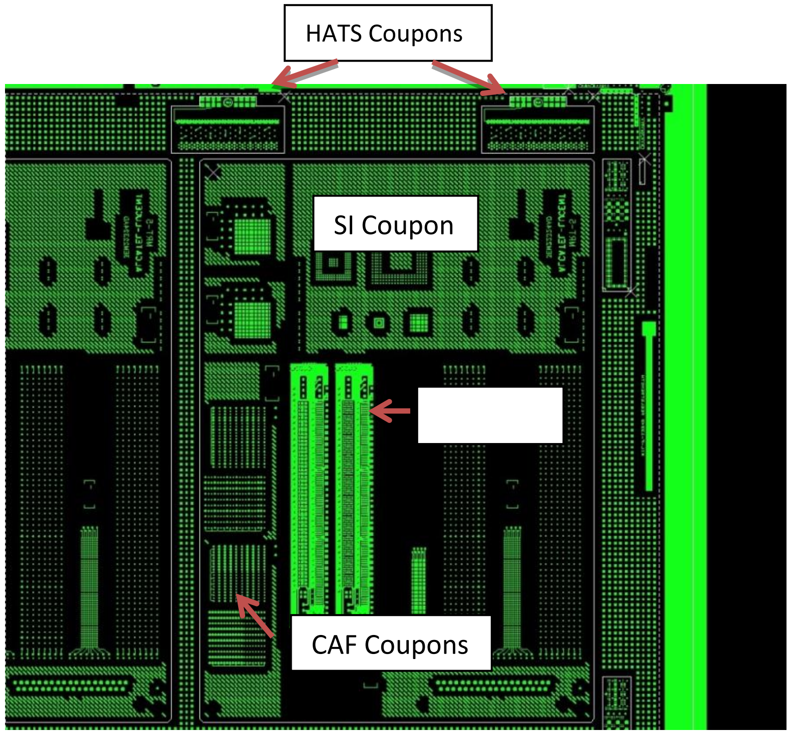


**Fig. 2**

Material for test was supplied free of cost by each material supplier. Materials were given a code name for the study. Each material supplier will have cross reference to their material only. Table 1, below, gives the detail of the material properties as published on technical data sheets. All material tested are rated by their manufacturers as lead free assembly compatible material. Materials ranged from a Dk of 3.7 to 4.7 and were in Tg range of $170^0 – 210^0$C.

**Table 1**

| R& D NEW MATERIAL TESTS | | | | |
|---|---|---|---|---|
| **MATERIAL** | **TG – $^0$C** | **Dk** | **Df** | CTE 'z' PPM / $^0$C |
| A | 170 | 4.0 | 0.010 | 34 |
| B | 171 | 4.4 | 0.010 | 33 |
| C | 170 | 4.7 | 0.018 | 50 |
| D | 200 | 3.7 | 0.008 | 40 |
| E | 180 | 4.0 | 0.012 | 50 |
| RA | 200 | 3.7 | 0.009 | 55 |
| RB | 210 | 3.7 | 0.009 | 65 |

All samples were produced using the same equipment and within a close time frame window. No process abnormalities were seen during processing period.

Test parameters selected are given below:

**HATS Preconditioning and Test Parameters:**

**Test Conditions:**

- 6 coupons for each material type to be cycled through 6X @ 260°C assy. simulation.
- Test temperatures for cycling to be (-) 40°C temperature to (+)145°C, 15 minutes @ temperature and transition time is 30 seconds.
- Test cycles to be 1,000. Cycles or a change of 10% in resistance, whichever comes first.
- Testing done by Integrated Reliability Test Systems, Inc. (IRTS)

**HATS Test Analysis;**

All coupons showed no signs of delamination after preconditioning. During hats testing all materials met the set criteria of 1,000 cycles without the exception of Material 'RA' which had an average of 941 cycles for net 2 and 900 cycles for net 4. Material 'B' had an anomaly where there were spikes of 6% change in resistance between 600 and 800 cycles and after that the coupon went back to less than 0.2% change. Below are the charts for Material 'A' (Fig. 3) (showing change in resistance for a typical good coupon), Material 'RA' (Fig.4) and Material 'B' (Fig.5).

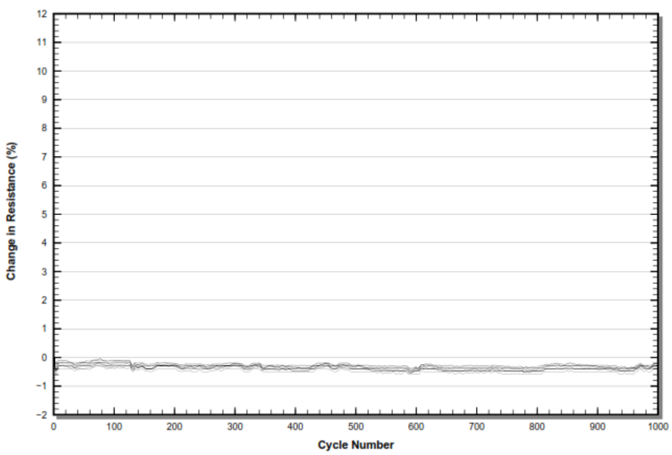


**Fig. 3**

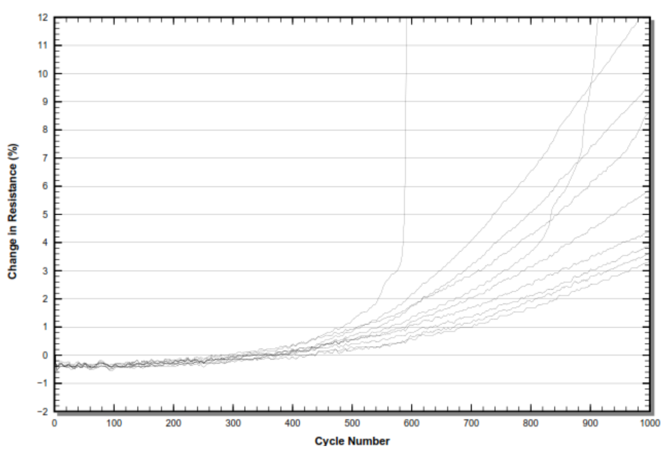


**Fig. 4**

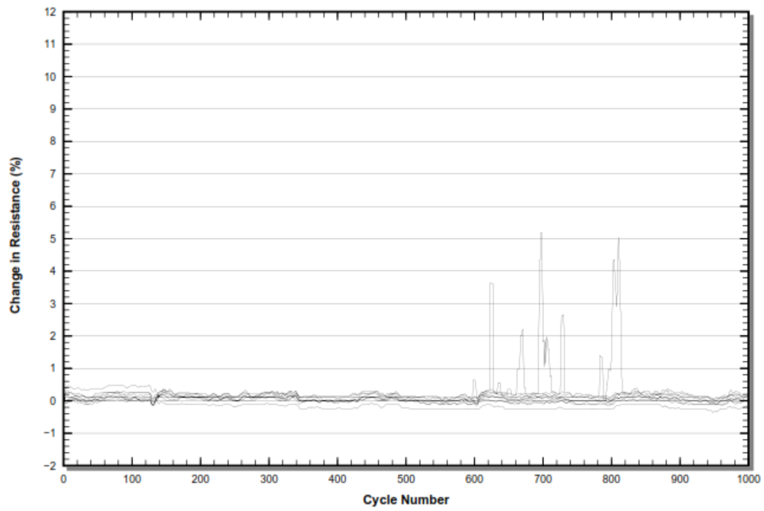


**Fig. 5**

**IST Testing:**

**Preconditioning& Test Conditions**

- 6 coupons for each material type will be cycled through 6X @ 260°C assy.
- Test the coupons for failure, any failure to be recorded.
- Capacitance readings will be taken before preconditioning, after preconditioning and at the end of cycling.
- Any change in capacitance > (-)6.5% will be considered a failure.
- Test temperatures cycling will be room temperature to (+) 1500°C in 3 minutes +/- 5 seconds and cooling in approximately 2 minutes.
- Test cycles will be 1,000. Cycles or a change of 10% in resistance, whichever comes first.
- Testing done at PWB Interconnect.

**Test Results:**

**Capacitance Analysis:**

Six sections for each of the seven materials tested showed various degree of % change in capacitance value. Material 'A'&'B' showed excellent results with a maximum of (-) 4.13% and (-) 3.46% change in capacitance. Results for material 'C' and 'D' had a maximum of (-) 5.40% and (-) 5.05% change, which is still considered acceptable below the maximum allowable percentage change of (-) 6.5%. Material 'RA' showed signs that material degradation had started but percentage change was still below the maximum allowable range. However, Material 'E' and 'RB' were at (-) 7.02% and (-) 8.59%. In both of these cases material damage was observed. See Table 2 for typical capacitance results for 0.8mm (0.032") test coupon.

**Table 2**

| % Capacitance Change in Picofarads - Group A .032" / 0.8mm after 6x260$^0$C | | | | | | | |
|---|---|---|---|---|---|---|---|
| Layer | A | B | C | D | E | RA | RB |
| 2/4 | -4.13% | -2.84% | -5.40% | -5.05% | -7.02% | -6.26% | -6.59% |
| 4/6 | -2.67% | -2.59% | -4.08% | -3.89% | -7.02% | -5.50% | -7.13% |
| 6/7 | -1.61% | -1.60% | -2.98% | -3.13% | -6.70% | -4.15% | -6.10% |
| 7/8 | -1.69% | -1.92% | -2.84% | -3.14% | -5.71% | -4.52% | -8.59% |
| 8/9 | -1.57% | -1.64% | -2.92% | -3.18% | -6.67% | -4.20% | -6.04% |
| 9/11 | -2.78% | -2.66% | -4.11% | -3.60% | -7.05% | -5.57% | -7.08% |
| 11/13 | -3.98% | -3.46% | -4.95% | -4.00% | -6.74% | -5.82% | -5.99% |

**Table 3**

| % Capacitance Change in Picofarads - Group A -1.0mm (0.040") after 6x260$^0$C | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Layer** | **A** | **B** | **C** | **D** | **E** | **RA** | **RB** |
| **2/4** | -5.02% | -4.56% | -6.01% | -1.89% | -7.33% | -6.48% | -3.62% |
| **4/6** | -3.24% | -3.90% | -4.46% | -2.51% | -6.77% | -6.20% | -3.68% |
| **6/7** | -1.98% | -1.96% | -3.17% | -2.46% | -5.46% | -4.81% | -3.62% |
| **7/8** | -1.96% | -2.49% | -3.07% | -2.86% | -5.66% | -5.26% | -3.59% |
| **8/9** | -1.82% | -1.95% | -3.12% | -2.71% | -5.43% | -4.83% | -3.49% |
| **9/11** | -3.20% | -3.64% | -4.47% | -2.50% | -6.79% | -6.06% | -3.67% |
| **11/13** | -4.85% | -4.62% | -5.73% | -1.51% | -7.00% | -5.93% | -3.69% |

It was observed that if test coupons have retained moisture then we will see an improvement in capacitance value for the outer layers as the test progresses. This was particularly evident in case of Material 'E' which showed an improvement in capacitance value between 6x260°C and at the end of test measurements. Since all materials were stored under the same conditions, it leads us to believe that material is more hydroscopic. Also, 0.8mm pitch showed early capacitance failure for material 'RA' indicating that either the material bond was compromised during drilling or that the material bond strength was not the best.

**IST Test Analysis;**

A summary of test results is shown below in Table 4. The data shown is cycles to failure for 6 coupons of each material type. Any failure that was process related has been taken out.

**Table 4**

| .032" / 0.8mm Via to Via Spacing | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | **A** | **B** | **C** | **D** | **E** | **RA** | **RB** |
| 1 | 3000 | 3000 | 1162 | 1587 | 1847 | 232 | 1108 |
| 2 | 3000 | 3000 | 1738 | 839 | 2847 | 355 | 981 |
| 3 | 3000 | 3000 | 1329 | 1074 | 731 | 149 | 1313 |
| 4 | 3000 | 3000 | 487 | 1042 | 1573 | 160 | 482 |
| 5 | 3000 | 3000 | 1437 | 792 | 2557 | 151 | 804 |
| 6 | 3000 | 3000 | 1793 | 1078 | | 241 | |
| | | | | | | | |
| **Mean** | 3000 | 3000 | 1324 | 1069 | 1911 | 215 | 892 |
| **Std Dev** | 0 | 0 | 476 | 282 | 837 | 80 | 315 |
| **Min** | 3000 | 3000 | 487 | 792 | 731 | 149 | 482 |
| **Max** | 3000 | 3000 | 1793 | 1587 | 2847 | 355 | 1313 |

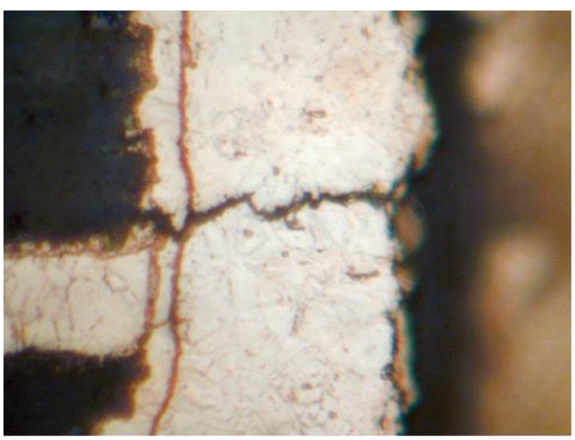

**Fig. 6**

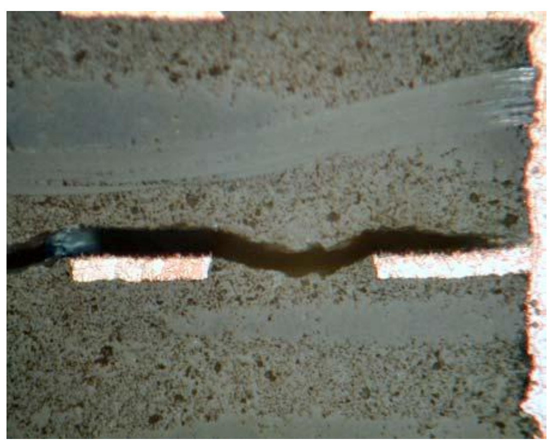

**Fig. 7**

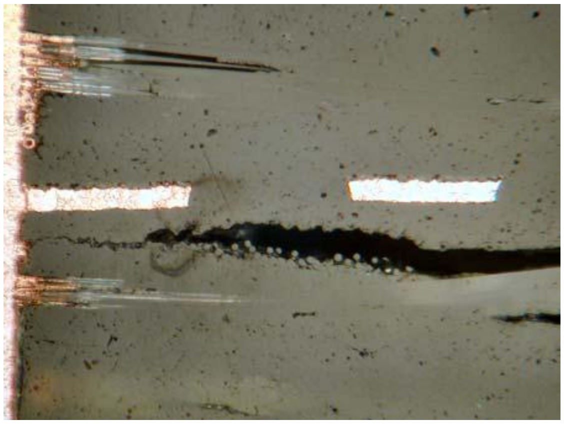

Fig. 8

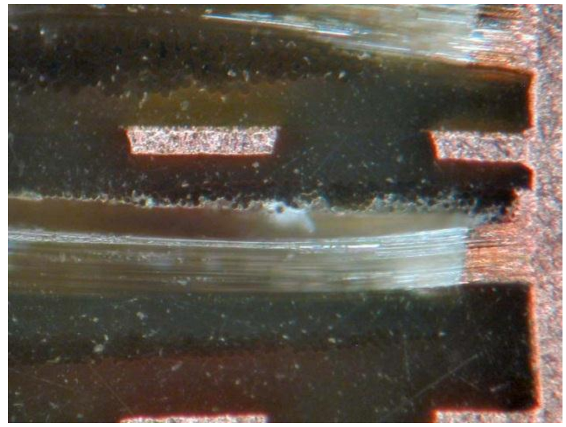

Fig. 9

In our IST results Material ‘RB’ showed good cycles to failure but when sectioned we saw the extent of damage to the material. The degree of delamination seen in Fig.10 below agrees with the results seen in capacitance measurements of these coupons. The material had degraded to a stage where further cycling would not have had any further degradation.

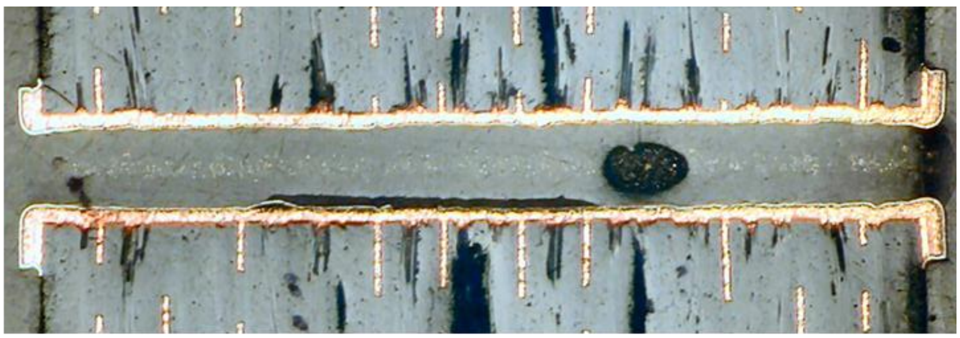

**Fig.10**

## CAF Preconditioning and Test Parameters

### Test Methods

1. Testing was carried out in accordance with IPC-TM-650 Method 2.6.25, Conductive Anodic Filament (CAF) Test.
2. 100 Volts DC bias was applied to each circuit through a 1 mega-ohm series resistor. Voltage drop across the resistor was measured daily in each sample with a high-impedance voltmeter, without removing or altering the applied bias.
3. The test method allows for two humidity levels. The more aggressive environmental condition option of 85°C (+/-2°C) and 87% (+3/-2%) relative humidity was chosen for this test.

In all, 30 coupons were tested. No coupons were tested for Material ‘A’ and ‘D’. For Materials ‘B’, ‘C’, ‘E’, ‘RA’ and ‘RB’ 3 coupons each for grid size 40mm (16mil) and 50mm (20) were tested in accordance with IPC-TM-650, method 2.3.25. Below is a summary of the results for the 30 coupons tested.

**Table 5**

| Material | Hole wall to Hole wall 20mil | | | | Hole wall to Hole Wall 16mil | | | |
|---|---|---|---|---|---|---|---|---|
| | Coupons tested | Coupons failed | Min. Hrs. | Max. Hrs | Coupons tested | Coupons failed | Min. Hrs. | Max. Hrs |
| B | 3 | 1* | 120 | >500 | 3 | 1** | 24 | >500 |
| C | 3 | 2** | 24 | >500 | 3 | 2 | 24 | >500 |
| E | 3 | 0 | >500 | >500 | 3 | 2 | 24 | >500 |
| RA | 3 | 3 | 24 | 48 | 3 | 3 | 24 | 24 |
| RB | 3 | 3 | 24 | 24 | 3 | 3 | 24 | 48 |

* - Failure due to surface contamination, see Fig. 11
** - Failure mode could not be found for one 'B' and one 'C' material.

**Fig.11**

Fig. 12 and Fig. 13, below, show the Typical CAF failures seen on failed coupons.

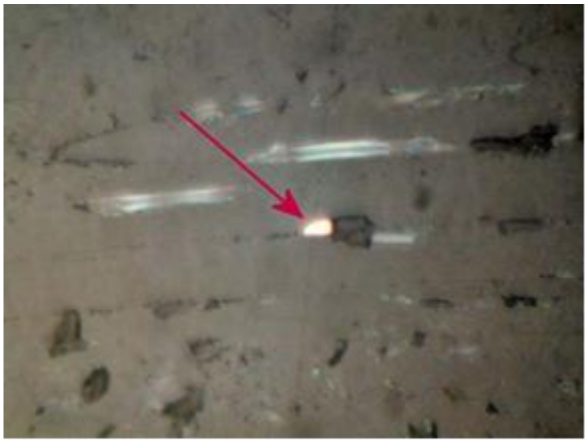

**Fig. 12**

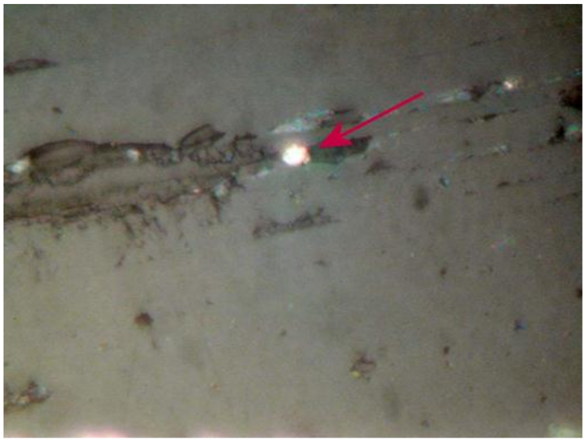

**Fig. 13**

CAF data above shows that the CAF failures increase as the pitch reduces. Coupons at 16 mil pitch had 16% higher failures as compared to 20 mil pitch. The failure rate is influenced by both the material and the drilling process. Since this exercise was to compare different materials under the same manufacturing conditions, we evaluated the degree of failures for each material. It is also important to see that materials 'E', 'RA' and 'RB' had 100% failures. These results are in line with IST and Capacitance results. Those materials which had poor performance for IST and Capacitance also showed poor results for CAF.

**Signal Integrity (Overall Insertion loss)**

**Test Conditions;**

- Conductor Length: 5 inches
- Impedance: 50 ohms
- Materials: RA, RB, A, B, C, D and E
- Equipment Used: Agilent VNA N5230
- Testing done at ITEQ labs

**Test Results:**

**Insertion Losses for Micro Strip Line**

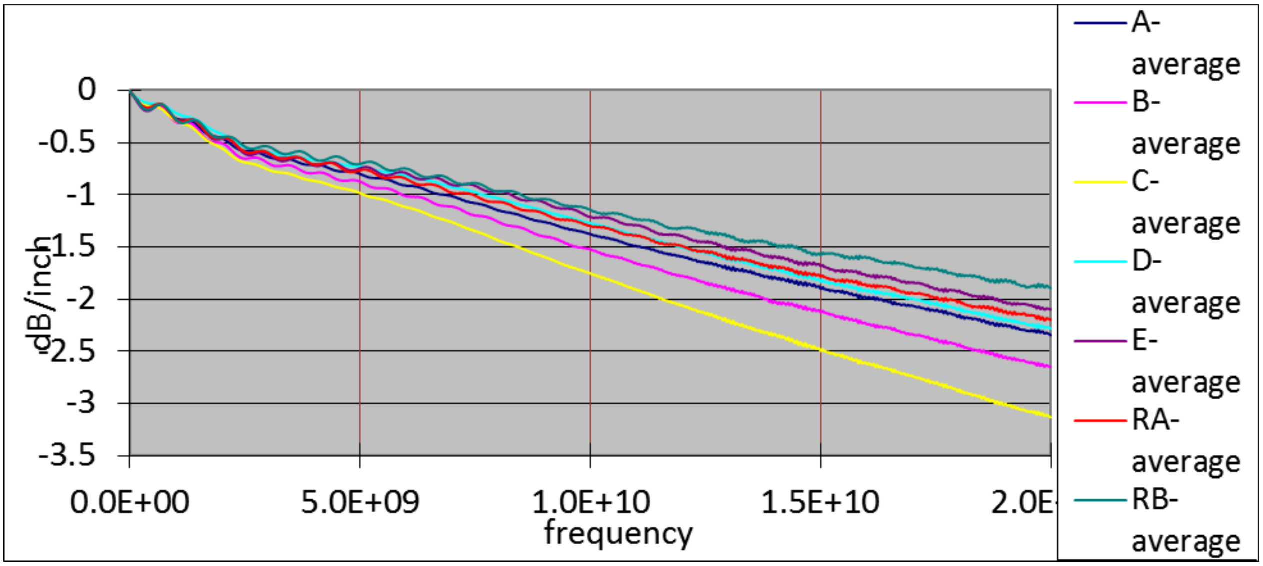


**Fig. 14**

Figure 14 shows that a clear separation is seen between materials as the frequency increases from 10GHz to 20GHz. Material ‘RB’ still has the lowest Df value at (-) 1.894dB/inch at 20GHz. Percentage change for Material ‘RB’ was the lowest at 66%. Material ‘C’ had the highest percentage change at 79%.

The same was true for the Strip Line. Material ‘RB’ had the lowest Df value at (-) 1.939dB/inch and Material ‘C’ had the highest Dk loss at (-) 3.376dB/inch.  Materials ‘A’ and ‘RB’ had the lowest percentage change at 87%.  Materials ‘E’ and ‘RA’ had the highest percentage change at 94%.

**Insertion Losses for Strip Line**

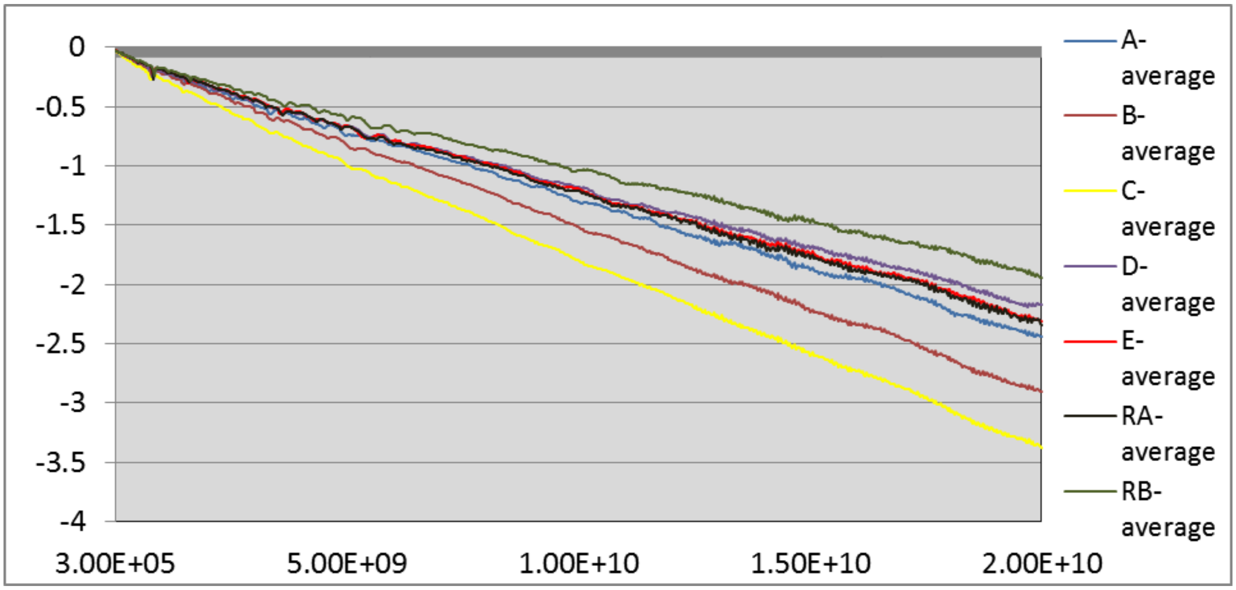


**Fig. 15**

**Table 6**

| Materials | Delay time @ 10GHz (ps) | |
|---|---|---|
| | Micro-strip line | Strip-line |
| A | 706 | 878 |
| B | 700 | 858 |
| C | 707 | 855 |
| D | 673 | 801 |
| E | 671 | 813 |
| RA | 672 | 810 |
| RB | 658 | 797 |

**Observations based on SI Data :**

1. Published and actual Df and Dk values were found to be very close.
2. Insertion losses for both Strip and micro – strip line of materials tested are in a small band width below 10GHz. However, the gap widens as we move towards 20GHz.
3. Percentage change in Df value ranged from 7.3% for material 'C' to 17.9% for material 'RA" as the frequency increases from 10GHz to 20GHz.
4. Percentage change in Dk values for materials is below 1.5% as the frequency increases from 10GHz to 20 GHz
5. There is a direct relationship between Dk and delay time. Material 'RB' with a Dk value of 3.7 has the lowest delay time.

**SI results Conclusion**

1. By the insertion loss measurement, material 'RB' has the best signal integrity. We can classify these materials as below:

-- signal integrity (overall insertion loss):

RB (the best) > RA~E~D > A > B >C

2. Evaluation based upon delay time and Dk and Df extraction, the material ( in order of Dk and Df value ) are;

Dk -- RB (the lowest) < RA~E~D < A~B~C
Df -- RB (the lowest) < D < RA~E < A < B< C

**Project Summary:**

Below Table 6 gives a summary of all the test result. It should be noted that some of the values are averaged for ease of data review. However, this is still representative of actual test results. Based on the test data available the a suitable material can be selected to fit individual needs.

**Table 6**

| Material | HATS Cycles | % Change in Capacitance | IST Cycles | CAF Cycles | | Dk @20GHz | Df @ 20GHz |
|---|---|---|---|---|---|---|---|
| | | | | 0.5mm | 0.4mm | | |
| A | 1,000 | (-)2.25 | 3,000 | Data Not Available | | 4.24 | 0.0155 |
| B | 1,000 | (-)2.38 | 3,000 | 500 | 1 out of 3 below 500 | 4.09 | 0.0207 |
| C | 1,000 | (-)3.89 | 1,324 | 1 out of 3 below 500 | 2 out of 3 below 500 | 4.04 | 0.025 |
| D | 1,000 | (-)3.71 | 1,069 | Data Not Available | | 3.57 | 0.0130 |
| E | 1,000 | (-)6.70 | 1,911 | 500 | 2 out of 3 below 500 | 3.68 | 0.0145 |
| RA | 960 | (-)5.15 | 215 | 24 | 24 | 3.62 | 0.0151 |
| RB | 1,000 | (-)6.79 | 892 | 24 | 24 | 3.53 | 0.0109 |

Data has shown that, among the materials tested, materials that had least insertion losses performed poorly for reliability. The materials selection process should take all aspects of material performances into account when selecting a material. With that in mind, material 'D' would be the best performing material in Dk range of 3.57, @ 20GHz, followed closely by material 'B' with Dk of 4.09 and material 'A' at 4.24 Dk. However if a variation of 0.52in Dk value, @ 20GHz, can be compensated by design, then material 'B' becomes the best overall choice.

Similar studies are planned for Polyimide, RF and thermally conductive materials.

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