Presented at IPC Printed Circuits Expo® 2002
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# Using Personal Digital Assistants from Alaska to Zanzibar the Dielectric Constant and Dissipation Factors of Non-Woven Aramid/FR4 Laminates For a Range of Temperature, Frequency and Humidity

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**Abstract**

Permittivity and dissipation factor ($D_k$ and $D_f$) are effects of polarization of different components of the dielectric substrate material when subjected to an electrical field. Reliable design of PDAs to be used at very low temperature (-5 °C) and very high temperature (60 °C) with different amounts of humidity, require knowledge of range of $D_k$ and $D_f$ within this domain. A database of these important design parameters for PWBs, has been developed for THERMOUNT® RT materials. Effects of variations in the level of moisture (bone dry to completely saturated at various relative humidity levels), testing temperature (-5 °C to 60°C) and testing frequencies (500 MHz to 1.5 GHz) on $D_k$ and $D_f$ are reported. A very reliable design of PWB can be accomplished with this database.

## Introduction

Miniature equipment with high functionality such as Personal Digital Assistants (PDAs) is used under extreme environmental conditions. IPC-9701[1] defines the worst case "use environments" for this type of product to be 0 °C to 60 °C. Printed wiring boards (PWBs) for these PDAs are designed to meet the requirements of miniaturization at these extreme environmental conditions, with high density interconnect (HDI), utilizing 50-150 µm blind microvia holes.[2] These types of PWBs require stringent impedance control to optimize power input/output and signal integrity. This program was originated to provide a database of permittivity ($D_k$) and dissipation factor ($D_f$) of the dielectric material, which affect the impedance, for the PWB designers.

Permittivity and dissipation factor, of a dielectric material, are dependent on temperature, frequency of incoming signal and material content (e.g. moisture, trace elements, etc.). The dielectric polarizations, which exist in the material, force the permittivity and the loss tangent factor of the insulating material to be a function of signal frequency.[3] The two most important phenomena are dipole polarization due to polar molecules and interfacial polarization caused by in homogeneities in the material. Thus moisture level in a dielectric substrate will significantly affect the electrical properties. The permittivity is determined by an atomic or electronic polarization, at the highest frequency. The permittivity has its maximum value at zero frequency and each succeeding polarization, dipole or interfacial, adds its contribution to permittivity. Both permittivity and dissipation factor exhibit local maxima due to each polarization. Rate of polarization and movements of free ions/electrons are strong functions of testing temperature. Thus the electrical properties ($D_k$ and $D_f$) of the insulating substrate of PWBs are functions of level of moisture, frequency and temperature.

The objective of this project is to define the phenomenological relationships between the electrical properties of a dielectric substrate (aramid/ epoxy with different moisture levels) and the testing environment (testing temperature and frequency).

## Scope

*Test*

Microtek Laboratory conducted all the tests according to IPC-TM-650[4] method 2.5.5.4, using a Hewlett-Packard Impedance Analyzer 4291A. This instrument measures $D_k$ and $D_f$ reliably from 1 MHz to 1.5 GHz. To suit the objective of the test, we collected some extra data points (e.g. specimen weight before and after testing).

We tested coupons under two moisture conditions (bone dry and saturated at 85 °C/85% RH). The test condition consisted of three temperatures (-5/5 °C, 25 °C and 60°C), and three frequencies (500 MHz, 1 GHz and 1.5 GHz). The saturated specimens were tested at 5 °C for low temperature tests to avoid delaminating due to freezing.

We tested a fully populated test matrix with 9 different test conditions, two moisture conditions and one set for material from two different vendors. In all we tested 108 specimens.

*Material*

We tested composite laminates of epoxy and nonwoven reinforcement (100% aramid). The reinforcement is transversely isotropic in properties. The author's material is manufactured from para-aramid and meta-aramid floc/binders. One laminator from the USA, and one laminator from Europe, provided the laminates. The nominal thickness of the 3.0N710 reinforcement is 0.0029" (72 µm). These are impregnated with high $T_g$ epoxy in MEK solvent and laminated to a thickness of 0.06" (1.5 mm).

*Moisture Absorption*

Two inch by two inch specimens (5 cm x 5 cm) were first brought to "bone-dry" condition by placing those in an oven at 105 °C for 24 hours.

In a humidity chamber, set at 85 °C and 85%RH, eighteen sets of specimens (54 specimens - 3 in each set) were exposed for saturation with moisture. Six (6) specimens from each set were measured for weight gain, at 24 hours intervals[4]. When the average weight gain, of the last three measurements, was less than 1% of the total weight gain, the set was considered "fully saturated".

The following effects were considered:

1. Effect of TEST TEMPERATURE on $D_k$ and $D_f$ of saturated and "bone-dry" laminates. We measured $D_k$ and $D_f$, of the bone dry specimens at -5, 25, and 60 °C. The saturated specimens were tested at 5, 25, and 60 °C. This was repeated for the three testing frequencies (0.5, 1 & 1.5 GHz).
2. Effect of TESTING FREQUENCY on $D_k$ and $D_f$
   We measured $D_k$ and $D_f$ at 500 MHz, 1 GHz and 1.5 GHz. Although the machine was rated at 1.8 GHz, the reliable maximum limit was deemed to be 1.5 GHz. The specimens were tested at two (2) levels of moisture - bone-dry and fully saturated at 85% RH (maximum moisture content). The testing temperature, was selected as discussed above.
3. Effect of SATURATION LEVEL on $D_k$ and $D_f$
   All the tests were conducted at two moisture level of the specimen - bone-dry and fully saturated (85 %RH). The tests were conducted at ambient condition for moisture (~50% RH).

**Experimental Details**

In general, ASTM D 150 (IPC-TM-650 method 2.5.5.3) was followed. Three specimens were tested from each material Group A & B for each test. We tested a total of 108 specimens, 54 each from each vendor, for 18 test conditions.

IPC-TM-650 does not define moisture absorption as a standard test. ASTM D5229[5] was followed for moisture exposure. Details of the procedure for moisture exposure has been described before. We used an electronic balance (± 0.00005 gms) to weigh the specimens. Each specimen was cooled to room temperature, in a closed vessel, prior to weighing.

The specimens were taken out of the "humidity chamber," cooled, weighed and placed in the analyzer (HP 4291A). Specimens were allowed to stabilize in the machine for 2-5 minutes. After stabilization and testing, the specimens were cooled and weighed again. The maximum difference between "before" and "after" moisture content was ~0.06% (negligible). The average of these two weights, before and after test, is used for calculating Table 1 the moisture content of a specimen during the test

**Discussion of Results**

The differences of measured values of electrical properties ($D_k$ and $D_f$) for different materials and different specimens (within a test condition) were negligible. The data, as reported in Table 1 and in all the Figures 1-5, are averages of six specimens. The $D_f$ measurements are less reliable as evident from higher coefficient of variation.

*Moisture Absorption*

The moisture absorption by the composite laminates is graphically displayed in Figure 1. The exposure started with bone-dry specimens. As received, the specimens had average moisture content of 0.66%. The maximum moisture absorbed (saturated) by the laminates was 1.89 %. We also reported equivalent moisture absorption of glass/FR-4 laminates.

*Effect of Testing Temperature*

The dielectric constant ($D_k$), increases with increase in testing temperature Figure 2. As the testing temperature increased from 5°C to 60°C, $D_k$ increased by ~10%. $D_k$ increases non-linearly and monotonically as a function of the temperature. With higher moisture content, the overall slopes became steeper.

The dissipation factor ($D_f$), in general, increases with increase in testing temperature Figure 3. However, the correlation is not as strong as that of permittivity ($D_k$). In most cases, it is not amonotonic increase. With the increase of testing temperature, from 5°C to 60°C, $D_f$ increased 50 - 100%. Effect of temperature is less at lower frequency. The Saturated specimens showed less variation due to temperature.

*Effect of Testing Frequency*

Three frequencies, 0.5 GHz, 1 GHz & 1.5 GHz, were selected for this test. Specimens were tested in the same tester (HP4291A) for the range of frequencies. The tests were conducted on bone dry specimens and specimens saturated with moisture at 85 % RH.

The dielectric constant ($D_k$), in general, *decreased* with increase in test frequency Figure 4. With testing frequency increasing from 0.5 GHz to 1.5 GHz, the $D_k$ decreased ~5% (maximum).

The dissipation factor ($D_f$), in general, decreased with increase in frequency Figure 5. As before, these are not monotonic relations. Saturated specimens exhibited higher $D_f$ than bone-dry specimens. Coefficient of variation is higher at higher frequencies

*Effect of Specimen Moisture Content*

Laminates with two levels of moisture , bone-dry & and fully saturated (85% RH) were tested for each test condition.

Both the permittivity ($D_k$) and the dissipation factor ($D_f$), in general, increases with increase in moisture content. The effect of moisture, in general, is *reduced* as the frequency is increased.

**Summary**

We have measured the effect of changes in temperature, frequency and moisture content on the dielectric constant and dissipation factor of PWB laminates constructed from composite of aramid reinforcement and high $T_g$ epoxy resin.

We found that the properties were statistically equivalent within and between batches of specimens from two laminators) . The results are reported as an average of six specimens. The maximum moisture absorption was ~2% at saturation (85% RH).

The $D_k$ of the substrate increased monotonically with increase in the temperature and the moisture content of the specimen. Increase in frequency decreased the $D_k$ of the substrate, following a log-linear function.

The dielectric constant ($D_k$) of the laminate (aramid/epoxy) varied from 3.34 to 3.98, due to simultaneous wide variations in *moisture content* (0% to 2%), testing *temperature* (5 °C to 60 °C) and testing *frequency* (0.5 GHz to 1.5 GHz).

The $D_f$ of the substrate increased with increase in the test temperature and the moisture content of the specimen, displaying a possible local maximum. $D_f$ changed more as a fraction of its minimum value, compared to $D_k$. Increased test frequency decreased the $D_f$ of the substrate and also reduced the effect of moisture.

A commercial laboratory measured the reported properties on specimens provided by commercial laminators. In general, we found that aramid/epoxy composites behaved *consistently* under different test conditions. Data for $D_k$ and $D_f$ as a function of moisture, temperature and frequency will provide design engineers latitude in designing the optimum PWB's with aramid reinforcement /epoxy substrate.

The laminates, from prepregs, developed by the author, can be used confidently for HDI PWBs in avionics, communications and other electronic industries, where *consistence* of electrical properties at high frequencies and high temperatures is important[6].

**Acknowledgement**

I would like to thank Polyclad Laminates for providing the materials for test. I extend my gratitude towards my teammates at DuPont Advanced Fibers Systems for their active and continuous support of the project.

**References**

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**Table 1 -Averaged Specimen Data for $D_k$ and $D_f$ at Different Testing Conditions ( PWB Laminates With Aramid Paper - 3N710/epoxy - 47/53 - 0.06" Thick)**

| Humidity(% RH) | Saturation level (%) | Frequency (MHz) | Temperature (C) | Average Moisture | Average $D_k$ | Std Dev $D_k$ | Average $D_f$ | Std Dev $D_f$ |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 500 | -5 | 0.00% | 3.38 | 0.026 | 0.0123 | 0.00058 |
| 0 | 0 | 500 | 25 | 0.00% | 3.44 | 0.032 | 0.0213 | 0.00058 |
| 0 | 0 | 500 | 60 | 0.00% | 3.63 | 0.038 | 0.0223 | 0.03300 |
| 0 | 0 | 1000 | -5 | 0.00% | 3.39 | 0.01 | 0.016 | 0.001 |
| 0 | 0 | 1000 | 25 | 0.00% | 3.42 | 0.025 | 0.019 | 0.00058 |
| 0 | 0 | 1000 | 60 | 0.00% | 3.51 | 0.0058 | 0.033 | 0.000 |
| 0 | 0 | 1500 | -5 | 0.00% | 3.34 | 0.015 | 0.010 | 0.001 |
| 0 | 0 | 1500 | 25 | 0.00% | 3.40 | 0.017 | 0.010 | 0.00058 |
| 0 | 0 | 1500 | 60 | 0.00% | 3.51 | 0.0012 | 0.031 | 0.001 |
| 85 | 100 | 500 | 5 | 1.94% | 3.73 | 0.000 | 0.030 | 0.00058 |
| 85 | 100 | 500 | 25 | 1.93% | 3.73 | 0.00058 | 0.03 | 0.00058 |
| 85 | 100 | 500 | 60 | 1.91% | 3.98 | 0.015 | 0.033 | 0.000 |
| 85 | 100 | 1000 | 5 | 1.90% | 3.63 | 0.026 | 0.029 | 0.0012 |
| 85 | 100 | 1000 | 25 | 1.96% | 3.72 | 0.015 | 0.028 | 0.0010 |
| 85 | 100 | 1000 | 60 | 1.95% | 3.88 | 0.015 | 0.044 | 0.00058 |
| 85 | 100 | 1500 | 5 | 1.97% | 3.59 | 0.035 | 0.034 | 0.0032 |
| 85 | 100 | 1500 | 25 | 1.95% | 3.71 | 0.021 | 0.026 | 0.002 |
| 85 | 100 | 1500 | 60 | 1.93% | 3.78 | 0.0058 | 0.037 | 0.00058 |

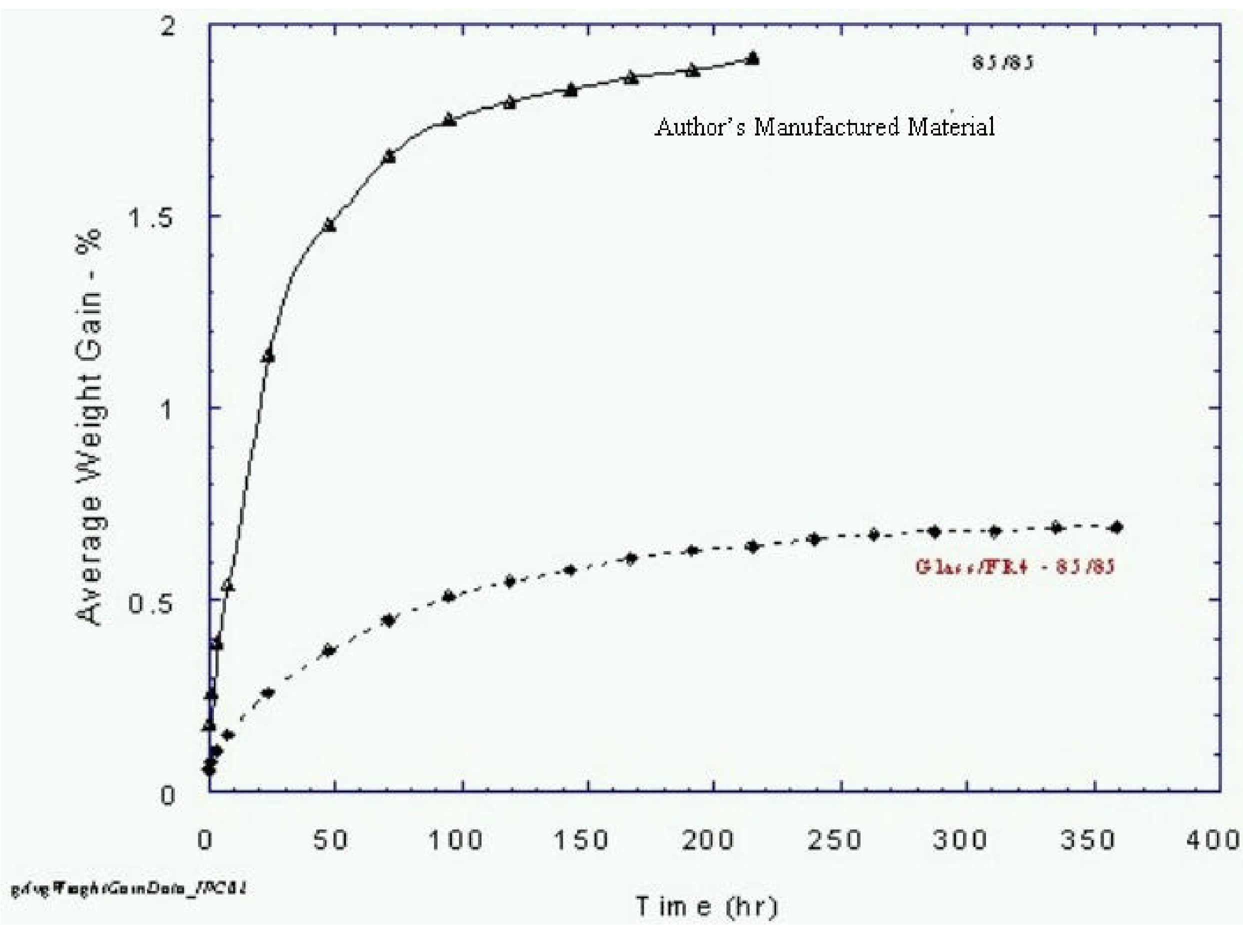


**Figure 1 - Rate of Moisture Absorption of PWB Laminates With Aramid Paper (3N710/Epoxy - 47/53 - 0.06" Thick)**

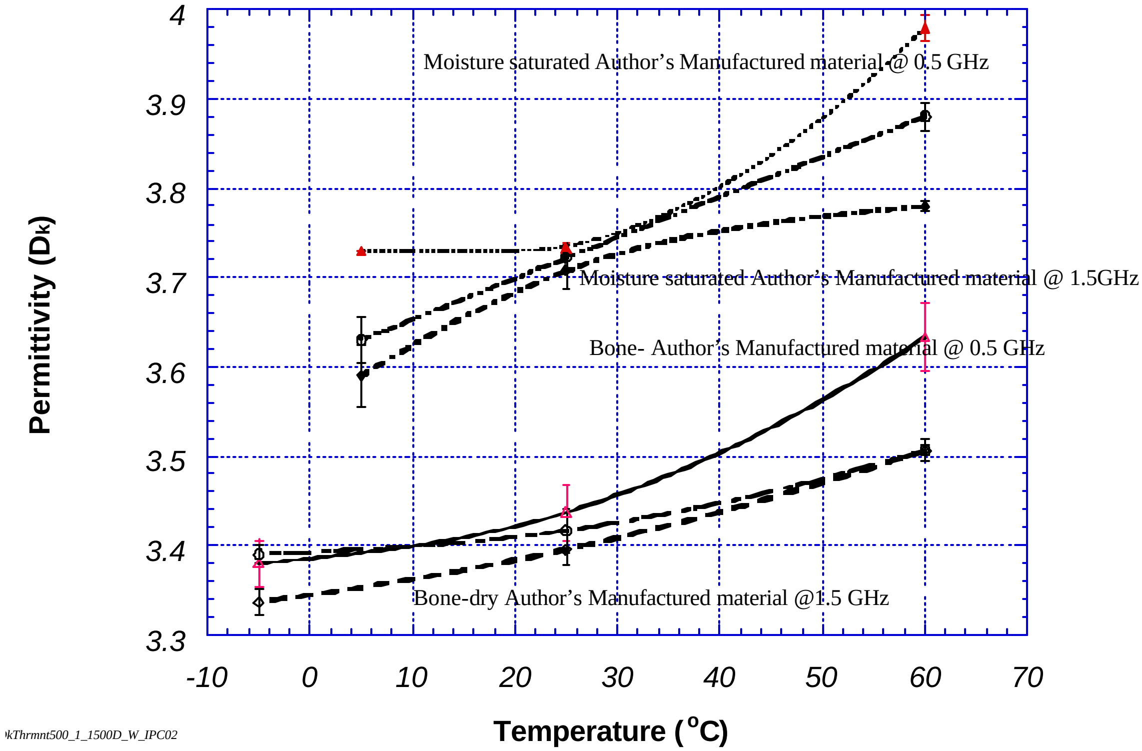


**Figure 2 - Permittivity ($D_k$) as a Function of Testing *Temperature* With Varying Moisture in the Specimen and Testing Frequency (3N710/Epoxy – 47/53 – 0.06" Thick)**

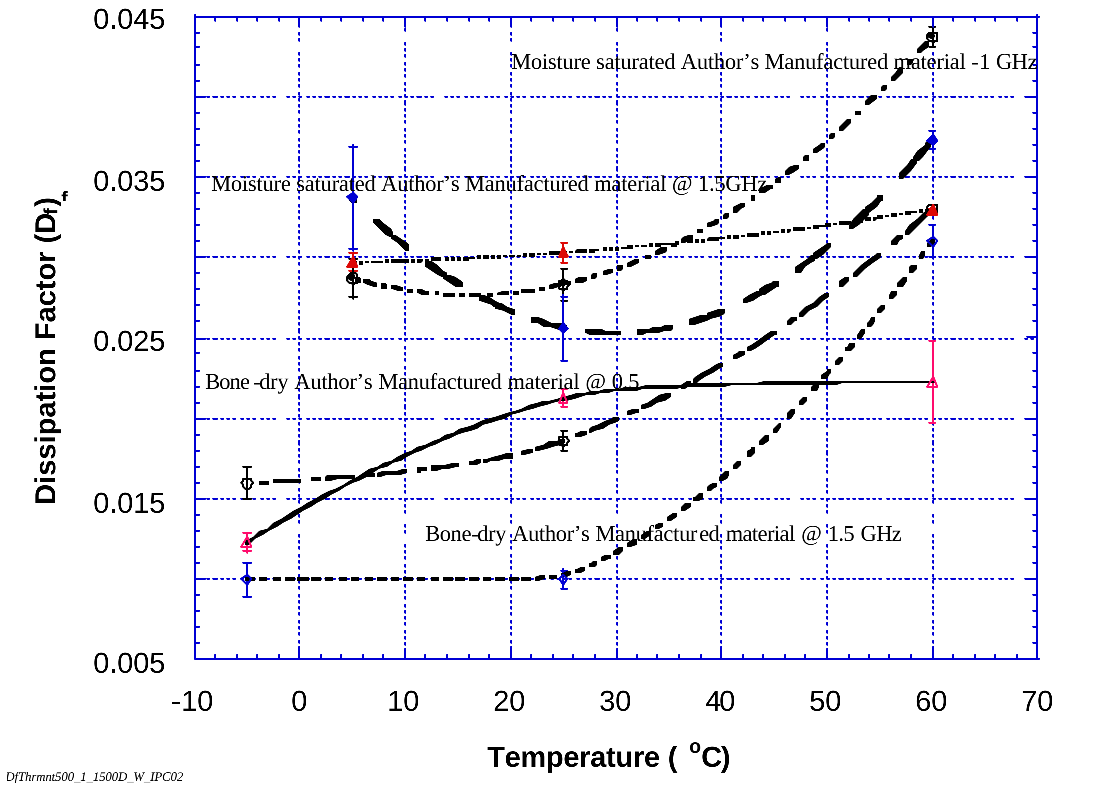


**Figure 3 - Dissipation Factor ($D_f$) as a Function Of Testing *Temperature* (3n710/Epoxy - 47/53 - 0.06" Thick, Testing Frequency 1 mhz)**

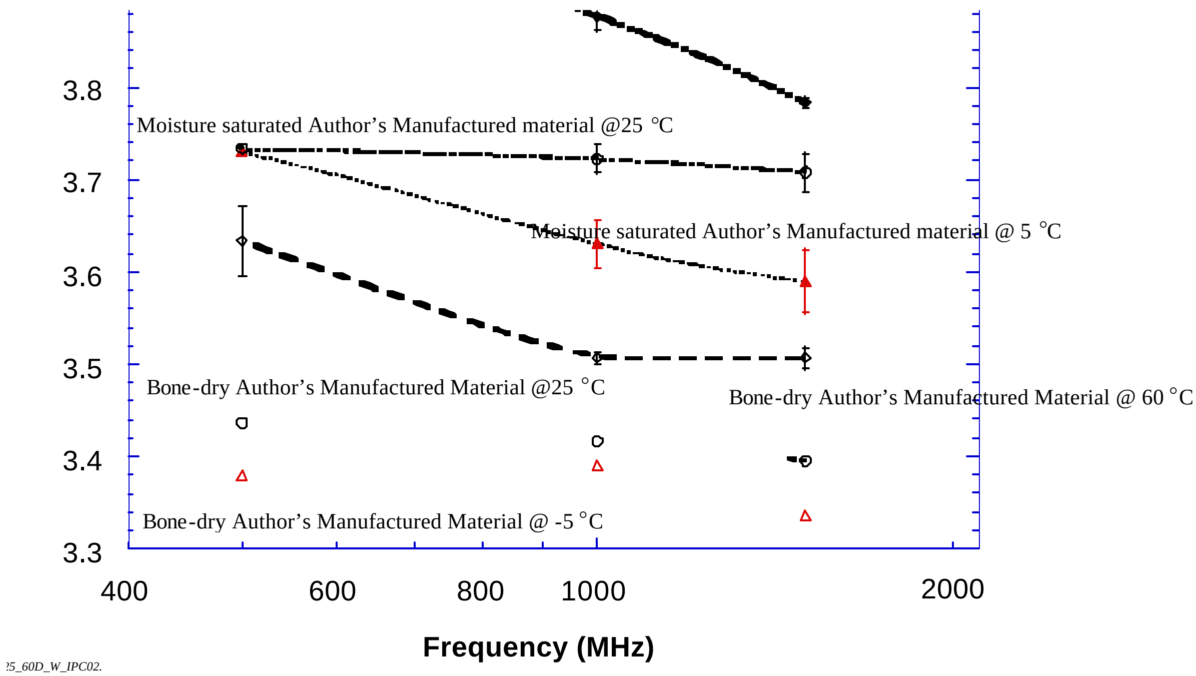


**Figure 4 - Permittivity as a Function of Testing *Frequency* (3N710/Epoxy - 47/53 - 0.06")**

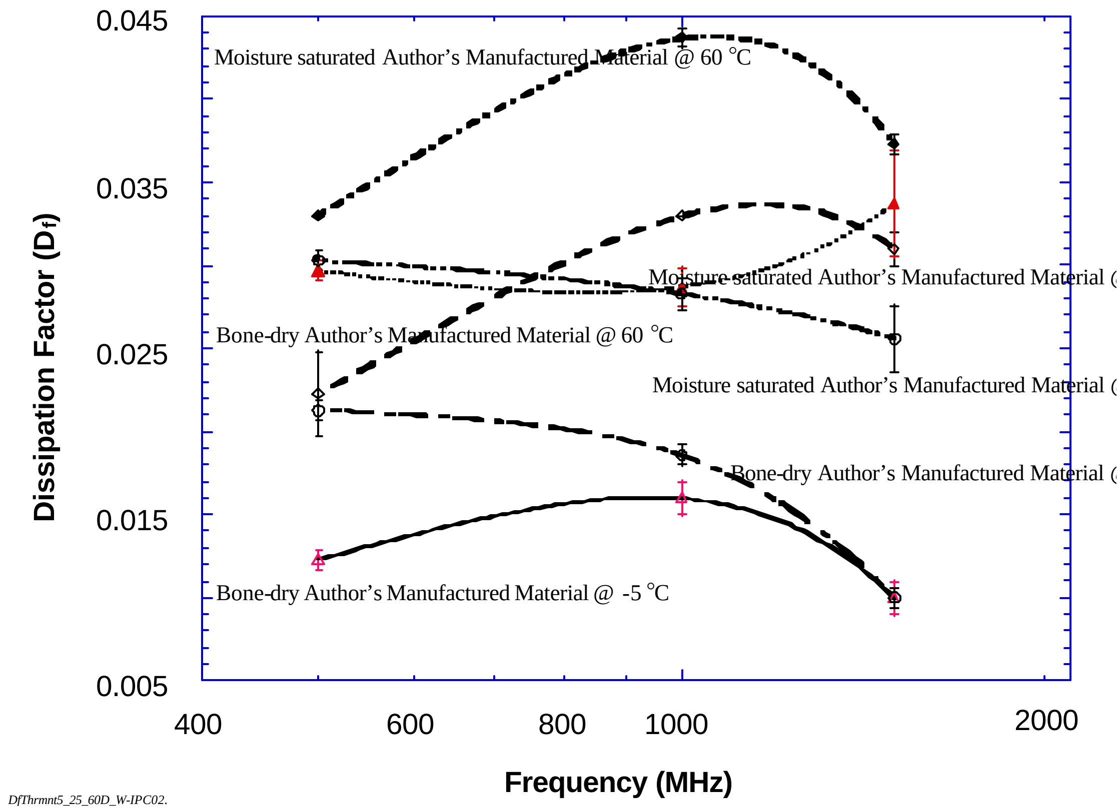


**Figure 5 - Dissipation Factor as a Function Of Testing *Frequency* (3N710/Epoxy - 47/53 - 0.06")**