New Developments in High Frequency Dielectric Measurements of PWB Materials Part II: Applications of the Bereskin Method to PWB Materials

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Abstract

A relatively easy and repeatable technique is presented for measuring the Dielectric Constant and Dissipation Factor (DK/DF) of PWB materials for frequencies in the range of 1.5 GHz to 12 GHz. The technique is based on a stripline method utilizing only a signal generator and two power meters as described in Part I of this paper. A repeatability and a Gage R&R studies were performed using PWB substrates and yielded satisfactory results up to 12 GHz. Data from this method for an extruded Polysulfone sample were compared to two other techniques with good agreement. Dielectric Constant and Dissipation Factor were measured for various PWB substrates and the effects of resin content and temperature were evaluated. It was found that resin content affects DK more so than DF and both properties increased with temperature, although DK to a much smaller extent than DF.

Introduction

In our continued quest to apply new techniques to the measurement of Permittivity (Dielectric Constant, DK) and Loss Tangent (Dissipation Factor, DF) of PWB base materials, we are hereby introducing such a technique developed by A. Bereskin (see Part I). This technique is capable of measuring DK and DF of PWB base materials from about 1.5 GHz to about 12 GHz, depending on the base material composition.

As stated in our previous publication on this subject (1), ideally any technique chosen to measure DK and DF should:
1-be accurate and repeatable
2-be easy to learn and use
3-require little or no sample preparation
We will demonstrate that, as applied to PWB base materials, the Bereskin method meets all the above requirements.

Experimental

The equipment and measurement protocol are described in Part I of this paper. All samples (except for the polysulfone) were etched copper clad laminates of approximately 4"L x 1.5" W. The conductor copper strip was 3.5"L x 0.25" W x 0.002" thick. All samples were baked at 105 ^{o}C for 2 hours then equilibrated at 25 ^{o}C and 50% RH for a minimum of 2 days prior to testing.

Repeatability Study

An equipment variation study was done on a pure polysulfone sheet of 0.063" thickness. Polysulfone was chosen because its dielectric properties are in the same range as most laminates, but unlike laminates, it has a very low moisture absorption. Two different operators tested the same polysulfone sample ten times, at three different frequencies, over a period of three days. The results are shown in Table 1.

Table 1 - Repeatability Study on pure Polysulfone

Frequency (GHz)	1.9	5.7	9.5
DK	2.97±0.005	2.97±0.005	2.96±0.005
DF	0.0047 ±0.0001	0.0057 ±0.0002	0.0062 ±0.0003

The data in Table 1 indicate a very good repeatability with average Relative Standard Deviations of 0.17% for DK and 3.5% for DF.

Gage Repeatability and Reproducibility Study (GAGE R&R)

A gage R&R (2) is the analysis of the variation of measurements of a gage (repeatability) and the variation of measurements by operators (reproducibility). Repeatability is the variation observed when an operator measures the same sample with the same gage several times. Reproducibility is the additional variation observed when several operators use the same gage to measure the same sample. Two important results of the gage R&R study are the %RR and the Discrimination indices. The %RR index is defined as the ratio of the variation due to the measurement error to the total process variation i.e. addresses what percent of the process variation is taken up by the measurement error. An acceptable ratio is less than 30%. The Discrimination index is the ratio of the variation due to sample to the measurement system variation multiplied by 1.41 and represents the number of non-overlapping confidence intervals that will span the range of product variation. It can be thought of as the number of groups within the process data that the measurement system can discern. An acceptable Discrimination index should be above 2. An index of 2 is equivalent to a go/no go gage.

Table 2, summarizes the results of the Bereskin method Gage R&R study by two operators with three trials each using ten different laminate samples with a DK and DF range of 1.12 and 0.009 respectively.

Table 2 - Gage R&R Study on Laminates

	DK		DF	
Freq. (GHz)	1.7	9	1.7	9
%RR	2	7	15	34
Discr. Index	62	19	9	4

The results in Table 2 indicate acceptable %RR and Discrimination indices for DK at both frequencies and for DF at the lower frequency of 1.7 GHz. At the relatively high frequency of 9 GHz, the %Gage and Discrimination for DF begin to reach borderline values, indicating that the method could benefit from some improvement. A potential improvement might be to automate the determination of the -3 dB frequencies on each side of the resonance frequency (see Part I). Another improvement would be to add a crystal oven to the frequency generator in order to eliminate frequency drift.
However one should be aware of the inherent limitations with relatively high loss materials (such as some of the FR4 laminates with DF of about 0.01 and higher). For such materials, the bandwidth of the resonance frequency at 9 GHz could be as high as a few hundred MHz, as compared to less than 20 MHz for pure PTFE (DF of 0.00015). The relatively broad bandwidth for high loss materials increases the error in measuring the exact location of the resonance frequency and thus increases the error in measuring DF (see Part I).

Comparison to Other Techniques

A pure polysulfone sample tested for DK and DF at various frequencies in our laboratory by the Bereskin method was also tested by the Resonant Re-entrant Cavity technique (3) at the 3M Laboratory (4). These data were compared to historical data obtained at MIT using a waveguide technique (5). The results summarized in Table 3, indicate very good correlation between the Bereskin method and the other two techniques for pure polysulfone.

Table 3 - Comparison of the Bereskin Method to Other Techniques

Freq.(GHz)	2.0	2.5	5.0	6.0	8.0	8.5	9.5
Bereskin	**DK**: 2.97			2.96	2.96		2.96
	DF: 0.0047			0.0063	0.0063		0.0062
Re-entrant		3.02		3.00			
Cavity		0.0053		0.0061			
MIT		2.99	2.99			2.98	
Waveguide		0.0050	0.0056			0.0061	

Laminates Data

Comparison of Various Laminates

Figures 1-2 show a comparison of DK and DF for several laminates of identical construction (2116 glass, 40% resin content, 0.040" thick) at frequencies between about 2 GHz and 12 GHz. The modified epoxy resin is an FR4 material formulated for a high Tg (180 ^{o}C) and low DK, whereas the multifunctional epoxy has a Tg of 170 ^{o}C. The BT-Epoxy is a high Tg (180 ^{o}C) with a low DF and the Polyimide is a high Tg (270 ^{o}C) high temperature applications material. A rise in DF between 6 and 7 GHz (Fig. 2) was observed for all samples containing woven glass. This observation is consistent with published data on FR4 laminates (6). Since this rise in DF was absent for the polysulfone extruded resin sample, one might safely assume that this phenomenon could be attributed to a weak resonance effect of the woven glass present only in the laminate samples.

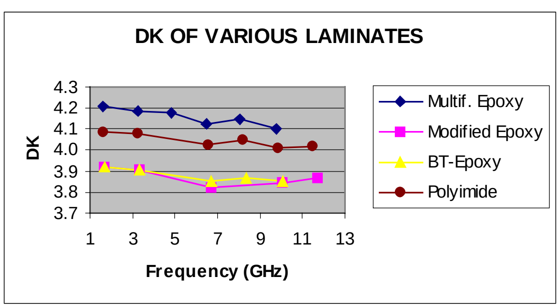


Figure 1

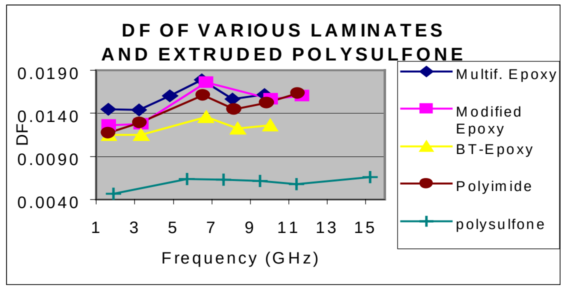


Figure 2

Effect of Resin Content

The effect of retained resin (resin content), on the dielectric properties of a high Tg (170 ^{o}C) FR4 multifunctional epoxy resin laminate, was investigated at various frequencies. It can be seen from Figure 3 that DK has a significant inverse relationship with resin content. At 50% resin content the DK is on average 3.8 and at 35% resin content the DK is on average 4.3 (11% increase) . DF, on the other hand, is almost independent of resin content (Figure 4). This relationship was also reported by Emstad (7) for a PPO-Epoxy laminate.

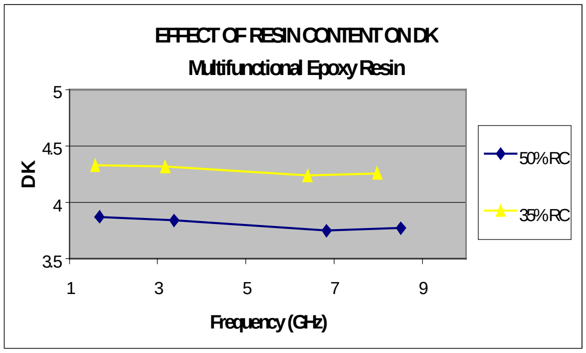
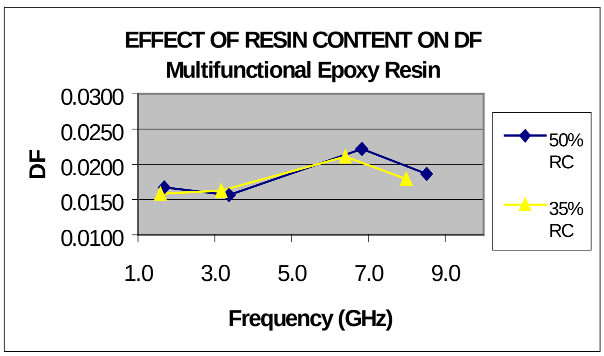


Figure 3

Figure 4



Effect of Temperature

Data were collected at various frequencies at 25 ^{o}C and at 60 ^{o}C (heated sample holder) for a high Tg (180 ^{o}C) modified epoxy resin (39% resin content). The results shown in Figures 5-6, indicate that DK increases on average by about 1%, whereas DF increases by about 10% as a function of temperature. This increase with temperature is consistent with published experimental data (5,8,9) and the Debye and other theoretical models for Dielectric Constant and Dissipation Factor (10).

Figure 5

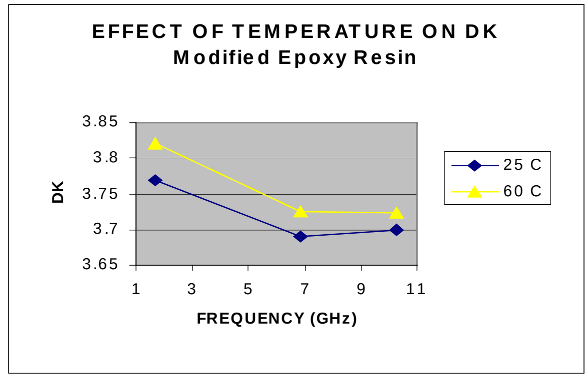
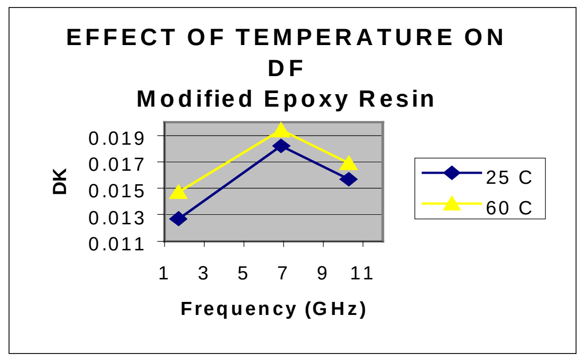


Figure 6



Conclusion

The Bereskin method as applied to the measurement of DK and DF of PWB base materials is relatively accurate and precise in the region of about 1.5 GHz to about 12 GHz. It requires minimal sample preparation and is simple to use. Perhaps this technique will provide some standardization for dielectric measurements of PWB materials in the frequency region of about 1.5 GHz to about 12 GHz.

Work continues on extending this method to higher frequencies by using a shorter conductor strip and on automation in order to improve its precision and reduce test time.

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This paper was presented at IPC Expo '99 in Long Beach, CA - March, 1999.