High Frequency Dielectric Constant and Dissipation Factor Performance of Electronic PWB Substrates

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Abstract
Design of printed wiring boards allowing devices to function at increasing signal transmission rates is a difficult task. As operating frequencies increase beyond one Gigahertz the availability and accuracy of Dielectric Constant and Dissipation Factor data for PWB substrates becomes very limited. To improve the availability of dielectric data on PWB substrates, Cookson Electronics PWB Materials and Chemistry Sector worked with the Electronics Manufacturing Technology Branch of NAVSEA to develop reliable test capabilities and evaluate various substrates. The test technique utilized the "Waveguide Slab" method (1) to measure the Dielectric Constant and Dissipation Factors of various substrate materials between 4 and 18 GHz. Results of the testing of these substrates will be presented. Substrates tested include FR-4, Thermally Stable Epoxy, Aramid reinforce epoxy, halogen free, Polyimide, BT, and other low DK/low DF materials. Information about the testing procedure and accuracy will also be discussed.

Sample Preparation:
Unclad laminates were produced from reinforced prepreg by placing the appropriate number of plies of prepreg between tedlar release film and stainless steel separator plates and curing the prepreg in a press at elevated temperature and pressure. Cure times were varied according to the requirements for the specific material processed. Sample thickness' of 0.030 inches to 0.032 inches were produced. For 2116 based laminates the measured resin content was 49% to 51% by weight resin. For 7628 based laminates the resin content was 41 to 43% by weight resin.

Samples were milled to the appropriate dimension to form square test specimens. Afterward they were cleaned and stored for a minimum of 24 hours in the laboratory at 40% RH to assure uniform moisture content prior to testing.

The following samples were tested: All samples were prepared from Cookson Electronics PWB Materials (Polyclad) products. Additional samples have been prepared and will be tested using the same techniques in the near future.

Table 1 - Laminate Samples Tested

Matrix Resin	Product Designation	2116 E-Glass	7628 E-Glass	Other
140C Tg Dicy FR-4	140-Dicy	X		
175C Tg Dicy FR-4	175-Dicy	X		
175C Tg Non-Dicy FR-4	175-Non-Dicy	X		
175C Tg Non-Dicy Inorganic Filled FR-4	175 Filled FR4	X	X	
145C Tg Halogen Free Dicy FR-4	145-HF	X		
160C Tg Halogen Free Dicy FR-4	160-HF	X		
Thermosetting UL-94HB Polyimide	PI-HB	X	X	
Thermosetting UL-94V1 Polyimide	PI-V1	X	X	
Thermosetting UL-94V0 Polyimide	PI-V0	X	X	
Thermount Reinforced 165 Tg FR-4	Aramid Epoxy			X
Low DK Epoxy Based UL-94V0	Low DK Epoxy	X	X	
Low DK Epoxy Based Organic Filled UL94V0	Low DK Filled	X	X	
Low DK APPE	APPE	X		

Testing Techniques and Equipment
Various methods were researched to determine the Relative Permittivity (Dielectric Constant, DK) and Loss Tangent (Dissipation Factor, DF) of bulk unclad PWB materials. The Waveguide Slab (ws) method was determined to be the most appropriate for this effort. This method lends itself well to the measurement of bulk material without the need to establish striplines on the specimens resulting in less specimen preparation time. The required fixtures are relatively inexpensive to acquire and machine to accept the material specimens. The measurement technique was based on a work described in a paper

by R.A. York, R.C. Compton (1). Testing was performed using a Hewlett Packard 8510C Vector Network Analyzer with waveguide calibration kits for each type of waveguide used for the fixtures. Four waveguides were required to span the frequency range from 4 GHz to 18 GHz. Algorithms were developed to extract the Relative Permittivity and Loss Tangents utilizing specimen and waveguide fixture dimensions, s-parameters of the empty fixture, and s-parameters of the waveguide fixture with the specimen inserted.

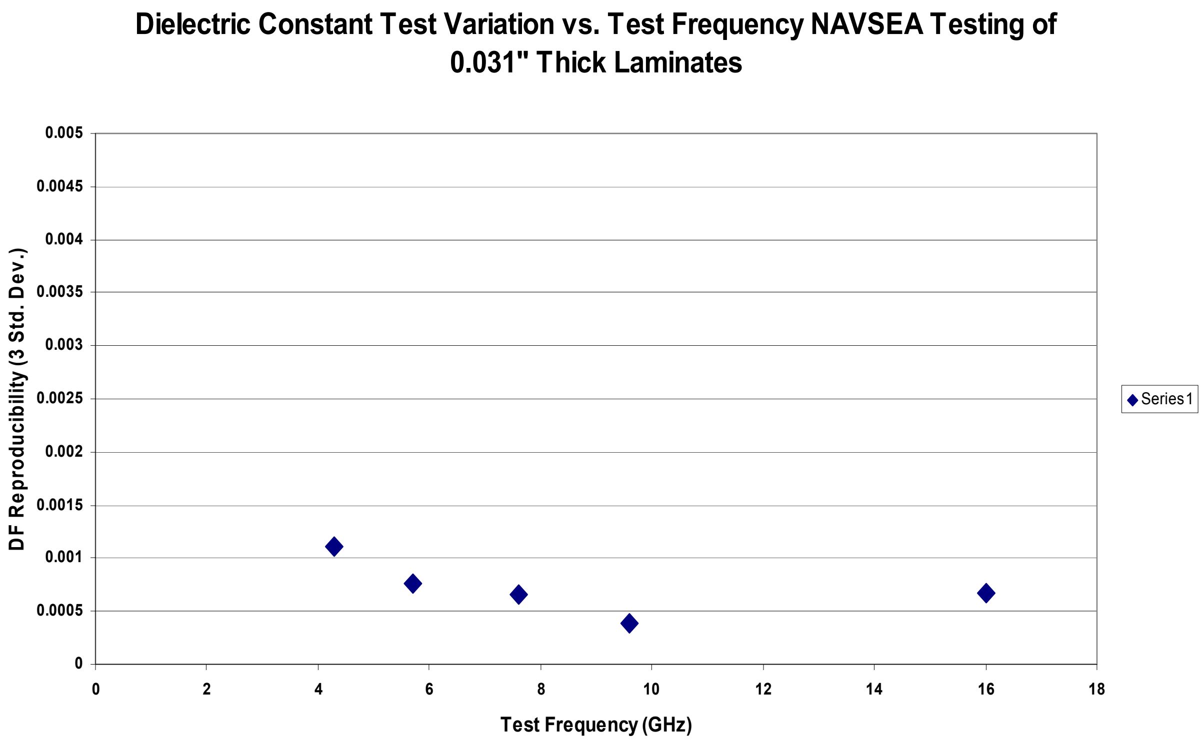


Figure 1 -

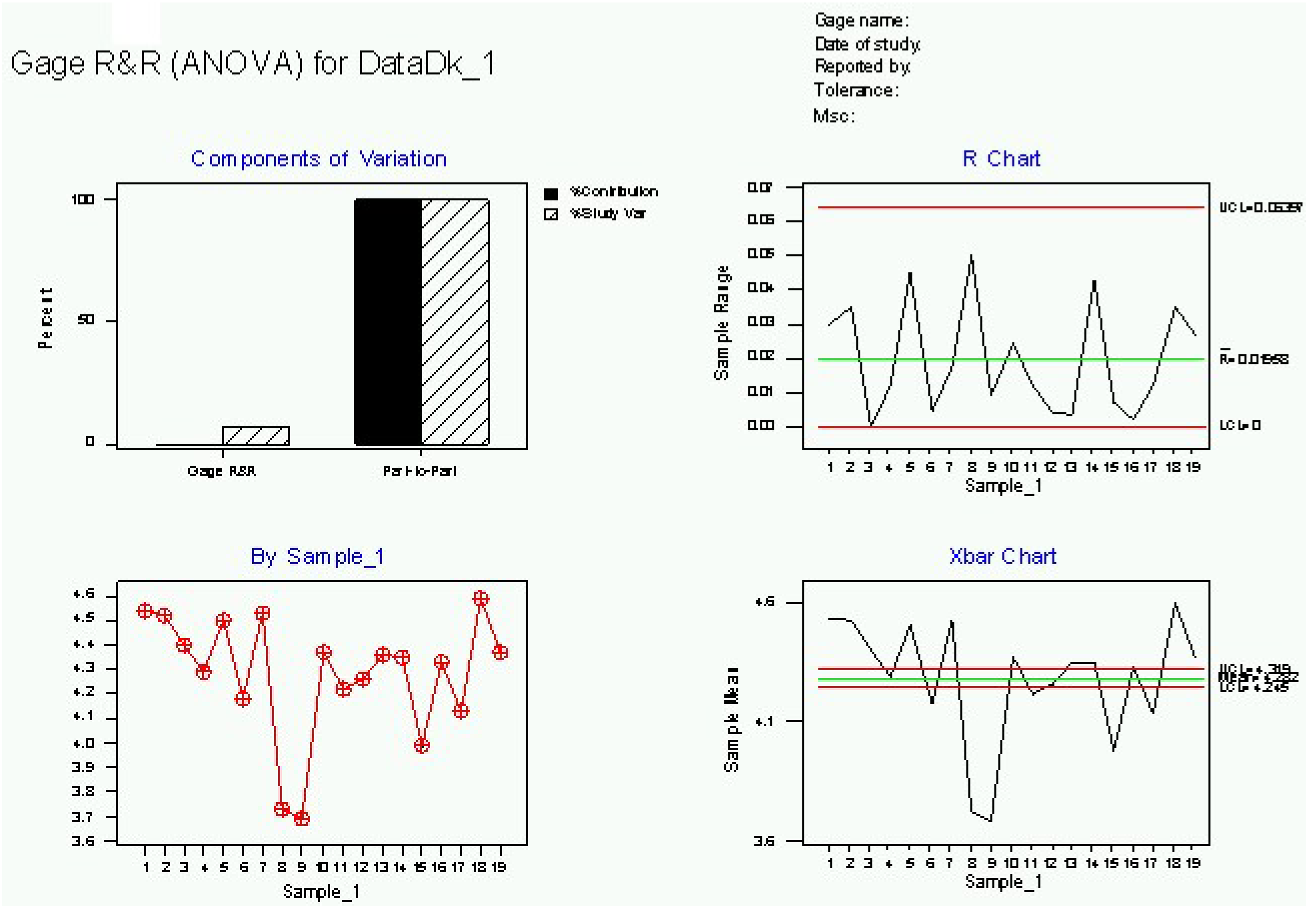


Figure 2 -

Test Repeatability:
Each sample type was tested twice at each frequency in order to determine the repeatability of the test method and equipment. Minitab analysis of the date was performed. Since only one operator performed all of the testing complete gage R&R information could not be generated. The reproducibility of the Dielectric Constant was less than +/- 3 sigma of 0.07 and frequency independent. The reproducibility of the Dissipation Factor was less than +/- 3 sigma of 0.0012 and also frequency independent. Reproducibility test results are shown figures 1 through 3.

Results and Discussion
Dielectric Constant and Dissipation Factor results for various PWB substrates tested between 4GHz and 16 GHz are shown in Figures 4 to 11.

A wide range of Dielectric Constant and Dissipation Factor performance can be selected from the available reinforced thermoset PWB substrates. For all FR-4 epoxy products at 50% resin content and including several types of curing agent, flame retardant, and/or fillers the dielectric constant varied by less than 0.3 at 4 GHz and 0.2 at 16 GHz. The Dissipation Factor had larger variation from 0.014 to 0.022 within the 4 to 16 GHz frequency range. For Polyimides the performance of the HB, V1, and V0 products were very similar. The dielectric constant and Dissipation Factor are slightly lower than the epoxy based FR4. The "low DK and low DF" products tested have significantly lower DK and DF values. The products that are formulated with combinations of epoxy and low DK thermosets have DK values of about 4.0 with DF values of about 0. 008 to 0.01. Products produced using Asahi thermosetting polyphenylene ether resins have very low DK and DF properties of 3.8 to 3.6 for DK and 0.006 to 0.008 for DF. Aramid reinforced epoxies can have very low DK values of about 3.6 to 3.5 but unfortunately also have very high DF values of about 0.025. As expected the Dielectric Constant of the thermoset materials evaluated decreased slightly and the Dissipation Factor increased with increasing frequency.

The use of higher resin content constructions can lower the dielectric constant by about 0.02 for most products when using 2116 based constructions as compared with 7628 based constructions. The dissipation factor is not significantly affected by the resin content.

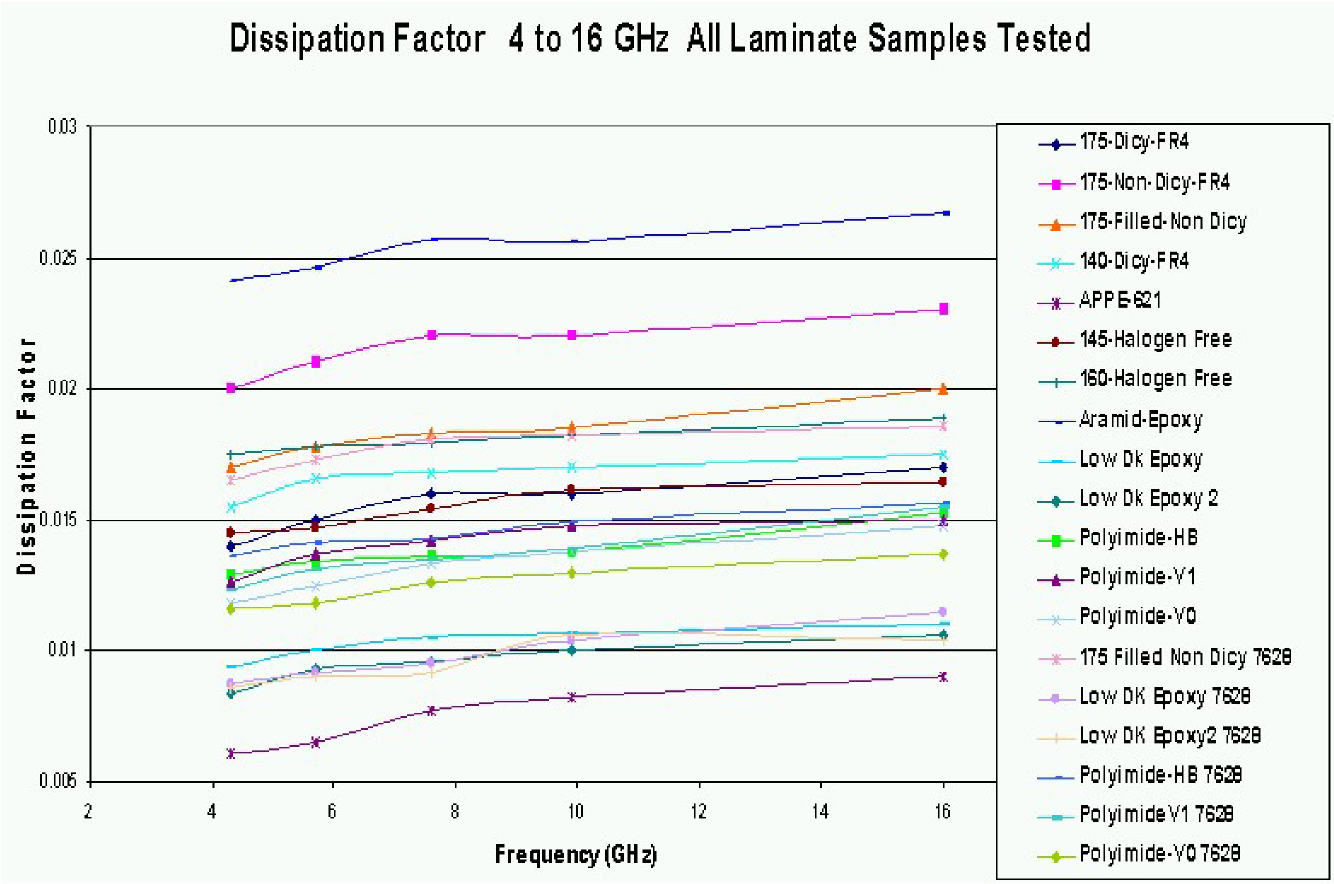


Figure 4

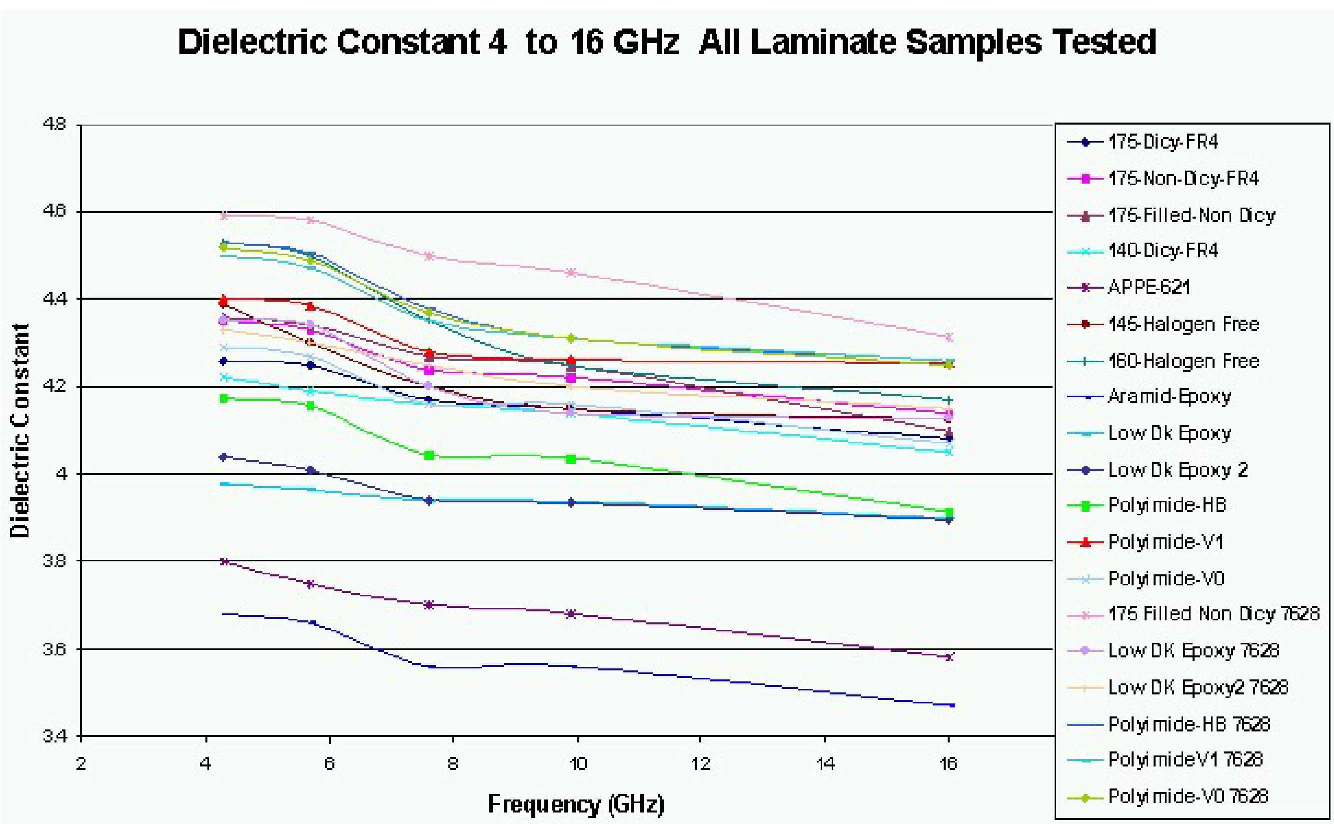
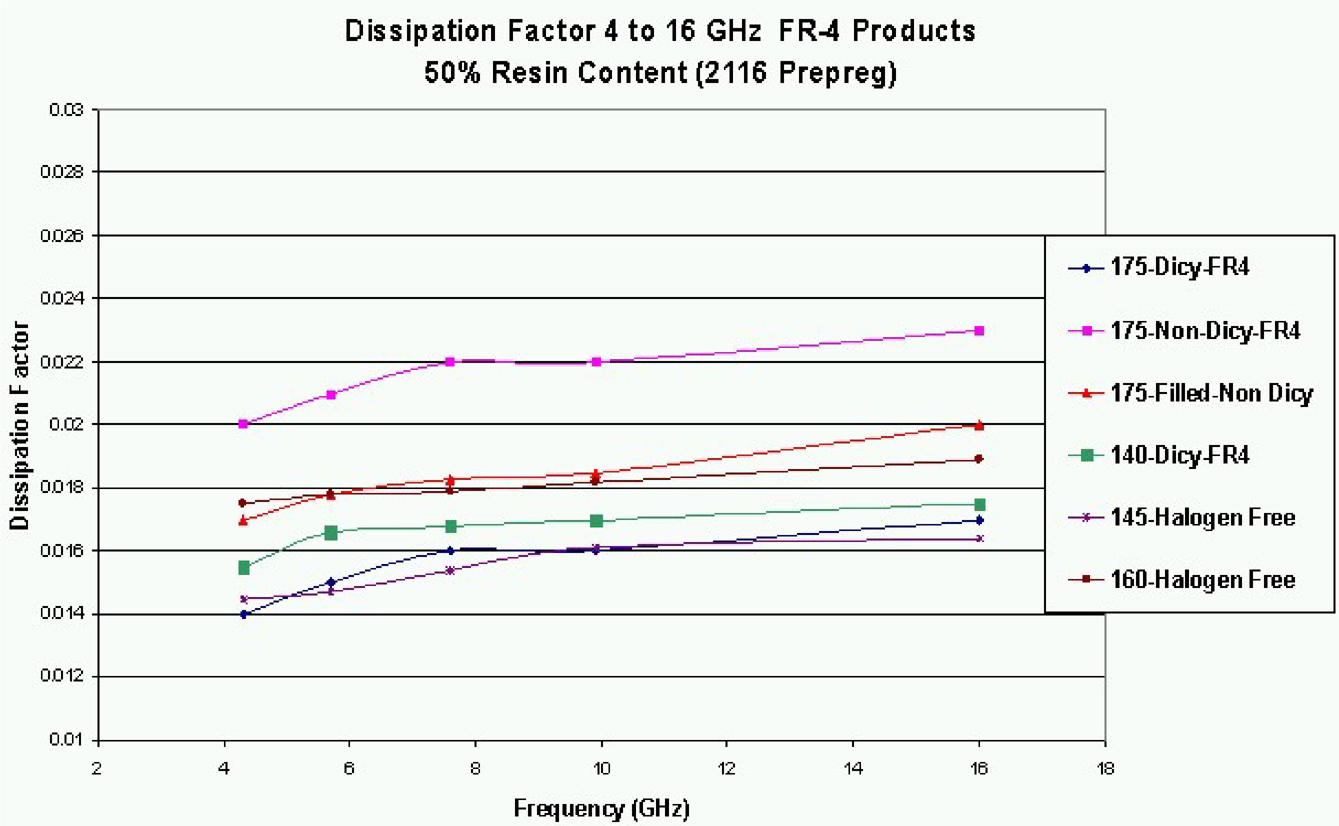


Figure 5



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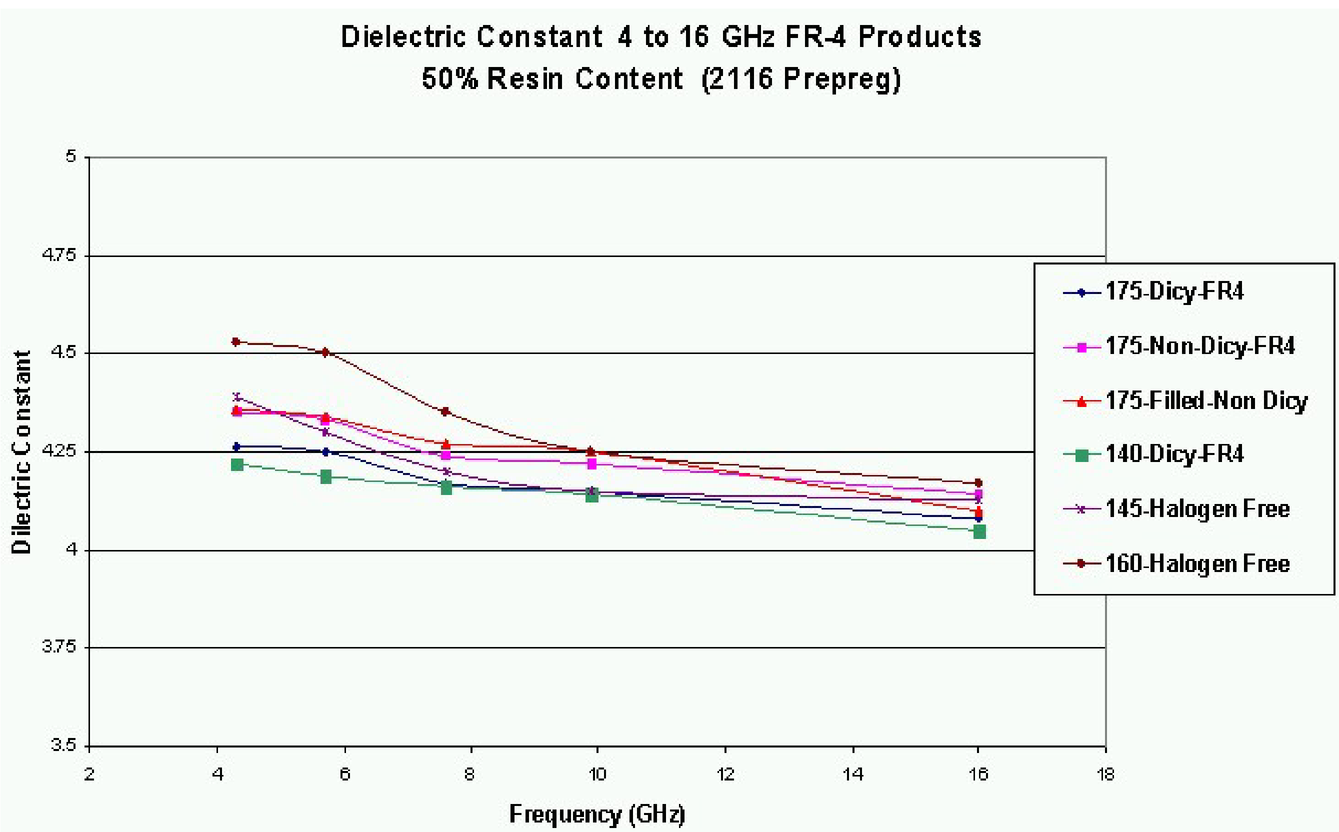

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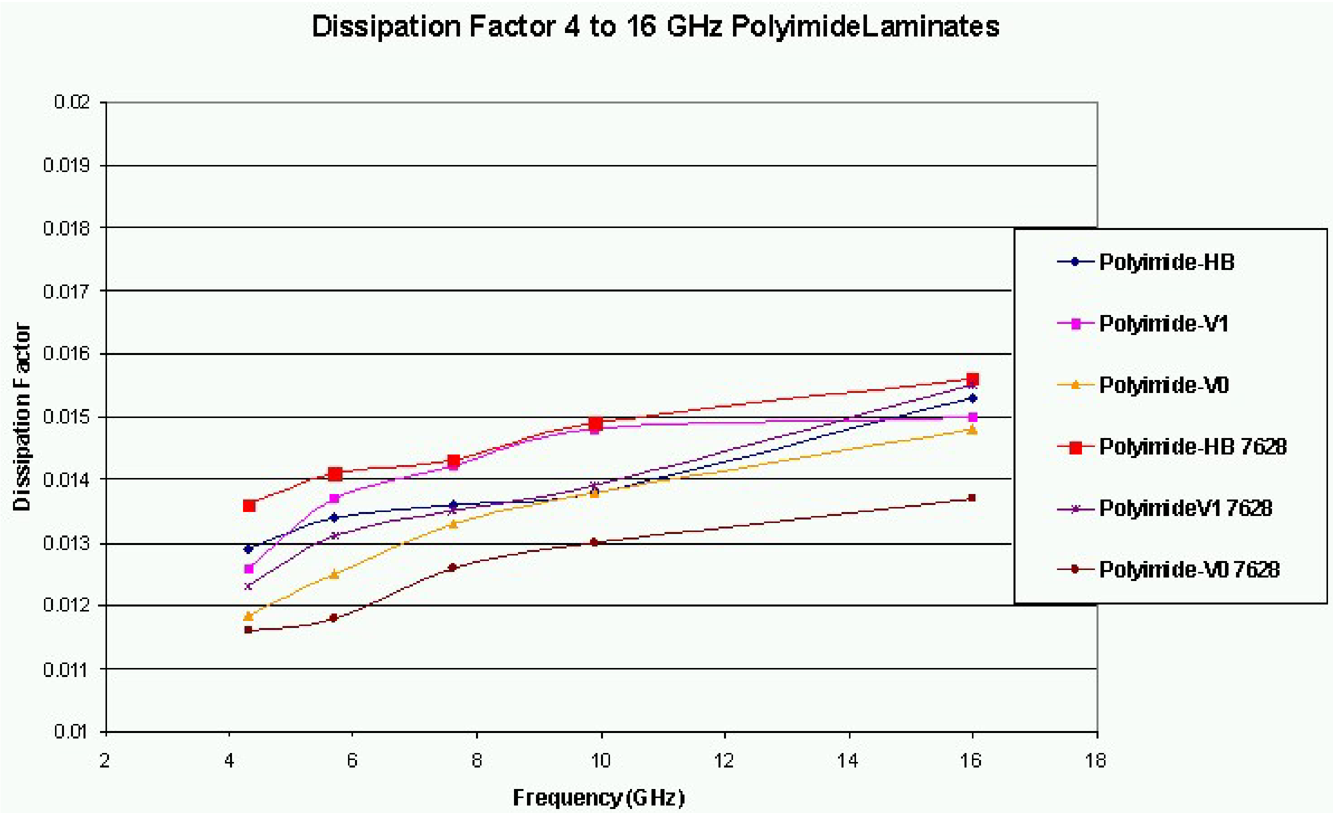

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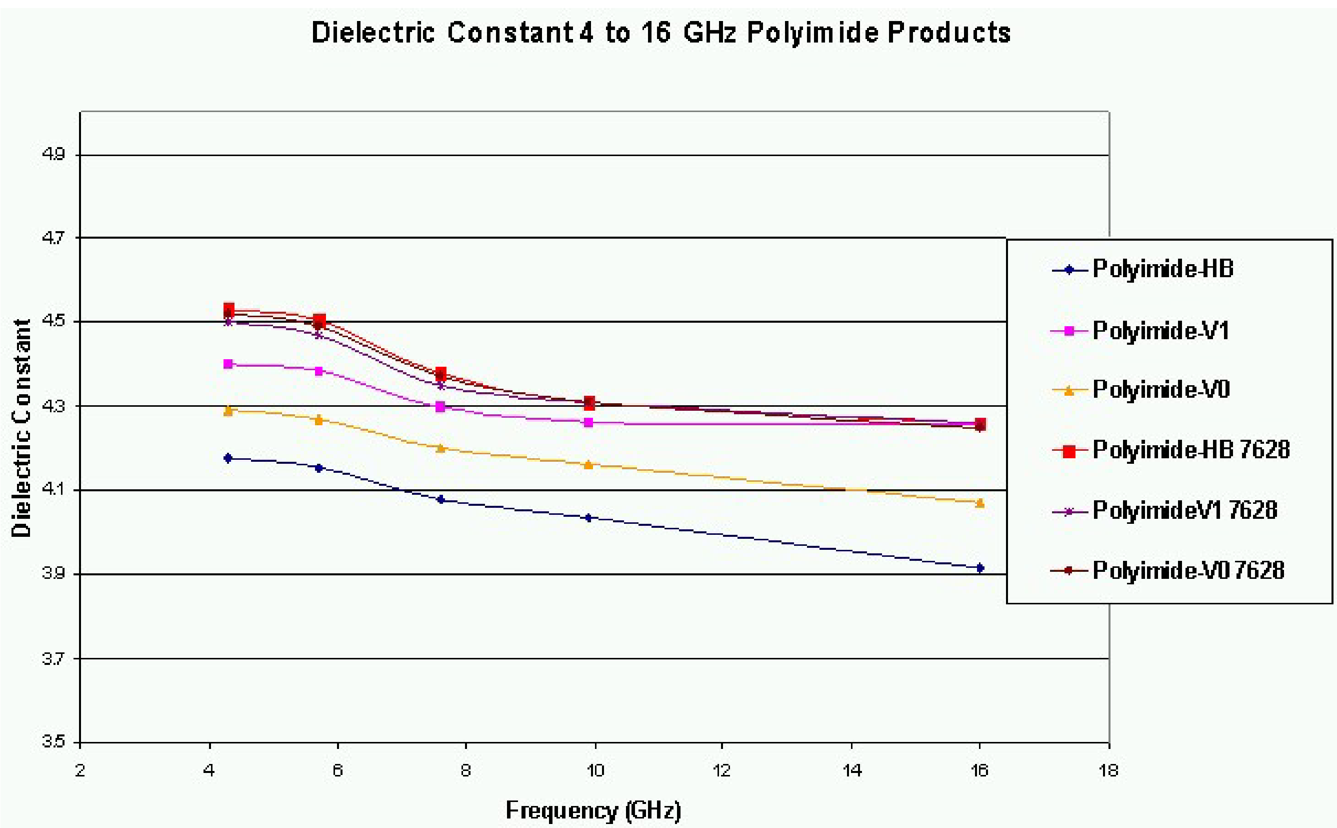

Figure 9

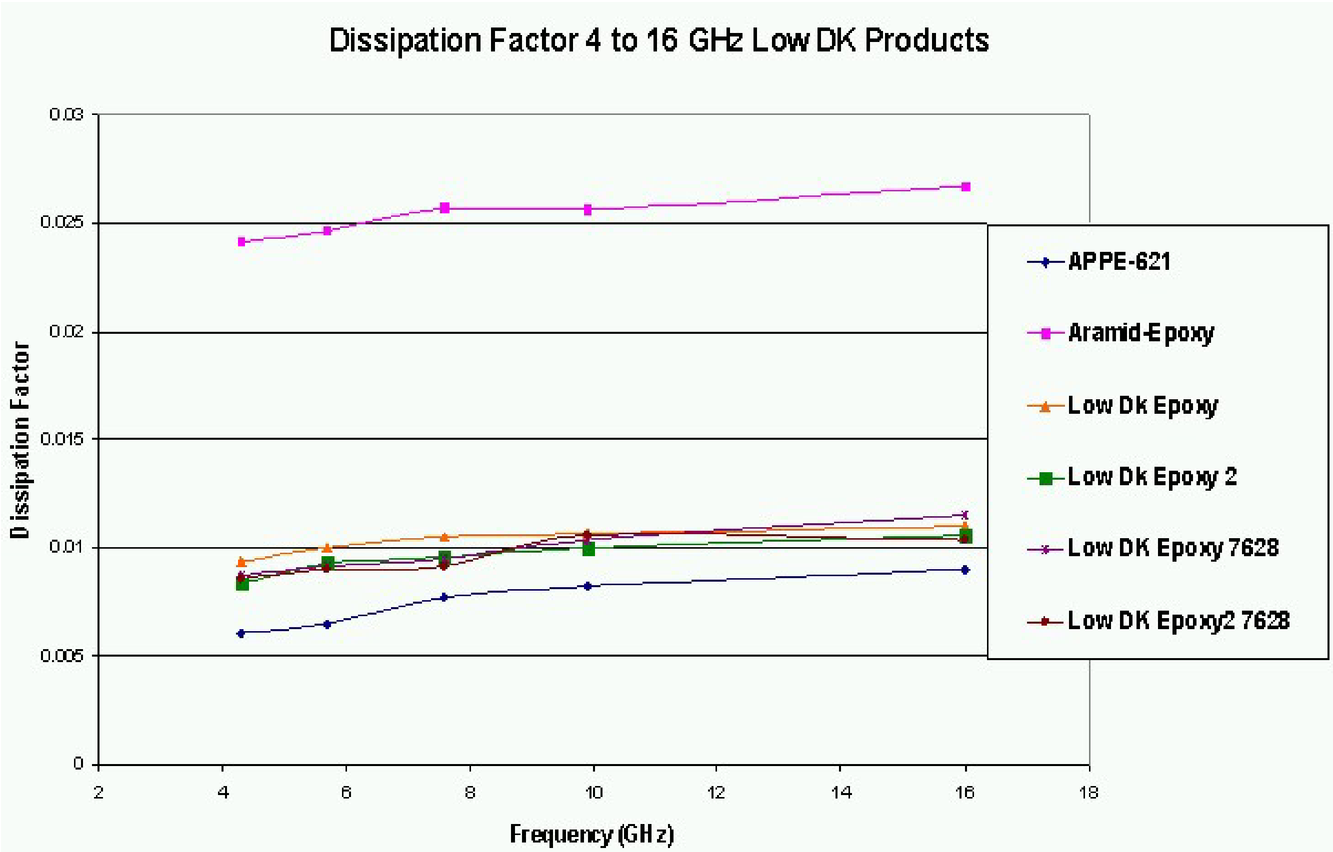

Figure 10

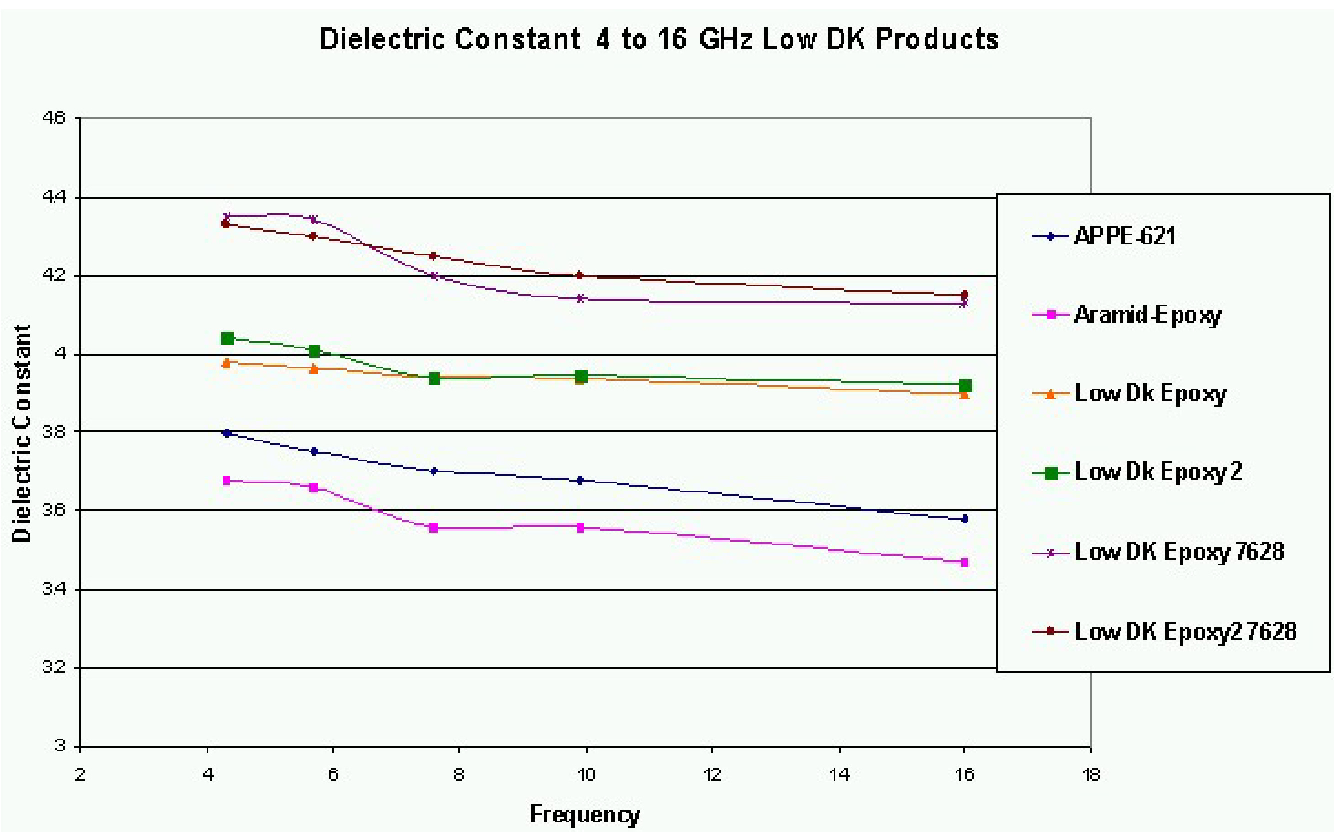

Figure 11

Conclusions:
The Waveguide Slab method of measuring the bulk dielectric properties of PWB substrates is both accurate and cost effective. Use of this technique clearly differentiated the performance of various PWB substrates.

A broad range of PWB substrate dielectric performance can be obtained to meet current and future PWB requirements

Additional testing of higher resin content materials and products will provide useful data for product dielectric constant modeling and devise optimization.

The Dielectric Performance testing capabilities established at the Navy "NAVSEA" Electronics Manufacturing Technology Branch in Crane, Indiana are well suited to support the electrical interconnect industry in the United States.

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References:
(1) R.A. York, R.C. Compton, "An Automated Method for Dielectric Constant Measurements of Microwave Substrates," Microwave Journal, Technical Notes, March 1990

Word File: IPC Dielectric Properties at high frequency 8-18-03
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