Dielectric Constant and Dissapation Factor of Fr4 Laminates Produced Using Specific Vendors of Fiberglass Yarn

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Currently there is not a specification within the IPC for the DK and DF of E-Glass reinforcements and there is no requirement to report the DK and DF of the glass formulation used to produce E-glass yarn. Without a specification, performance of reinforced PWB substrates can be subject to significant variation depending on the supplier of the fiberglass cloth. In an effort to understand the impact on the electrical performance of PWB substrate materials related to the choice of fiberglass yarn manufacturer, FR4 laminates were produced using fiberglass cloth woven with yarns from specific vendors and tested for their dielectric performance.

In IPC document IPC-EG-140 section 3.4.8 the composition of E-glass electrical grade glass fiber is specified in table 1:

Table 1

Compound	Composition by weight	Dielectric Constant
B2O3	5-10%	>10
CaO	16-25%	11.8
Al2O3	12-16%	>9
SiO2	52-56%	3.9
MgO	0-5%	10
Na2 and K2O	0-2%	13
TiO2	0-0.8%	>20
Fe2O3	0.05-0.4%	14.2
F2	0-1.0%	15

Significant variation in composition is allowed for many of the compounds. Most of the compounds used to formulate E-Glass have dielectric constants greater than 10. Only Silicon Dioxide has a DK lower than 5. Obviously, if the ratio of SiO2 to the other much higher DK compounds changes even a small amount, the resulting dielectric constant of the glass composition can increase significantly. With the increasing use of controlled impedance designs, and the need for tighter performance tolerances, these allowed variations in the composition of the glass formulation could significantly affect device performance.

To determine the influence of glass cloth supplier on laminate DK and DF, laminates were produced at production scale in the Polyclad manufacturing facility in Franklin, NH using cloth woven from specific suppliers of E-glass yarn. To minimize manufacturing variation, all of the samples were made consecutively from the same batch of Non-Dicy, filled, thermally stable FR4 resin. The treater used to manufacture the prepreg was adjusted to produce the targeted dielectric thickness and the consecutive lengths of 1080 E-glass cloth impregnated and partially cured to form prepreg. These prepregs were then laminated into fully cured composites. Four fiberglass cloth weavers provided E-glass cloth produced entirely from specific yarn manufactures. One roll of lower DK "D-Glass" cloth was also produced and laminated for comparison. The basis weights of the cloth provided were measured and within measurement error determined to be the same.

These laminates were tested for DK and DF at 1 MHz using the "two fluid cell test method" IPC TM-650 2.5.5.3. Differences in the dielectric performance of the substrates are reported below in table 2. The DK of the fiberglass reinforcement was also calculated using a rule of mixtures equation.

Table 2

Glass Vendor-Cloth Weaver	Laminate DK	Std Deviation	Calculated Fiberglass DK	Laminate DF
A-1	4.593	0.030	7.52	0.0180
B-1	4.590	0.026	7.50	0.0178
B-2	4.567	0.010	7.37	0.0190
C-1	4.653	0.010	7.86	0.0185
D-3	4.34	0.020	6.43	0.0160
E-4 (D-glass)	4.18	0.030	5.42	0.0162

Observations:
Laminates produced using yarn vendors A, B, and C had very similar DK and DF values. The differences are within the variations from test and resin content. Laminate produced using E-glass yarn vendor D had significantly lower DK and DF values. The performance was close to that observed for laminate produced using D-glass. D-glass is known to have a higher SiO2 content and lower DK and DF properties when compared with E-glass.

The dissipation factors measured for laminate produced using vendors A, B, and C were also very similar. While there is more variation, this is the result of higher test equipment variation. Again, laminate using vendor D and the "D" glass had significantly lower dissipation factors as compared to A, B, and C.

Conclusions:
Without reducing the variation to the formulation or the specification for the DK and DF of E-glass and establishment of test procedures to measure DK and DF accurately, there is indeed significant opportunity for variations in the dielectric performance of laminate and PWBs related to the fiberglass cloth source.

Three major suppliers of E-fiberglass had very similar dielectric performance.

Supplier (D) had DK and Df performance significantly lower than the other three sources tested.

Measurement of these same laminates at higher test frequencies is planned for the future to provide additional insight into the influence of fiberglass yarn formulation on electrical performance of substrates.

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