System Operating Environment Effect on PCB Material Electrical Property

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Abstract**—The purpose of this paper is to consider the impact of humidity and temperature on the electrical properties of printed circuit boards (PCBs). PCB base materials are glass reinforced thermosetting laminates using a variety of resin systems with different loss characteristics.**

Test results indicate humidity has little impact on electrical properties of inner layer. It is difficult for moisture to penetrate into the PCB due to barriers created by copper ground planes.

Conversely, temperature has a significant influence on PCB's electrical properties. Increasing temperature from 20 to 80 degrees C has a limited impact on dielectric constant (< 3%) for all material types: standard loss, middle loss, low loss and ultra-low loss materials. The impact of increased temperature, 20 to 80 degrees, on loss tangent is more significant. Increasing temperature from 20 to 80 degrees C will influence loss tangent according to material type ranging from 10.4% for ultra-low loss to 38.7% for standard loss materials.

Keywords—Humidity; Temperature; Signal integrity; Loss tangent ; dielectric constant

I. Introduction

The market trend for Personal Communications Services (PCS) and Wireless Local Area Networks (WLAN) server, switch and storage devices is to operate at higher frequencies. Signal integrity becomes increasingly more important at higher frequency levels. The CPU generates heat increasing the PCB temperature. Humidity is a variable considering different operating environments. Therefore the impact of temperature and humidity on signal integrity should be considered.

II. Material Property And Test Vehicle

Material Property

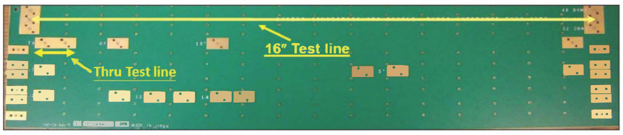
Four material types were selected to test the range of PCB material loss segments from low end (standard loss) to high end (ultra-low loss). Materials are classified according to insertion loss: standard loss, middle loss, low loss and ultra-low loss. Table I lists the material grades and product characteristics.

TABLE I. Materials And Properties

Category	Material	Tg by DSC	Resin Type
Ultra Low Loss	IT-968	185°C	Polyphenylene Ether Blend
Low Loss	IT-150DA	170°C	Styrene Maleic Anhydride Copolymer Blend
Middle Loss	IT-170GRA1	175°C	Modified Phenol Novolac + Phosphorus Epoxy Blend
Standard Loss	IT-180I	175°C	Phenol Novolac + Brominated Epoxy Blend

Test Vehicle

The test vehicle is Cisco's standard SI TV design [1]. The six layer stack up is shown in Figure 1 with the through test line of 590 mils and the trace length of 16 inches. Layers 1, 3, 4 and 6 are ground planes. Single ended traces are on layer 5 with differential pairs are on layer 2. The connector launches are from layer 1 to layer 5 and layer 6 to layer 2. Insertion loss measurements are taken. Permittivity and loss tangent values are extracted by two line method [2].



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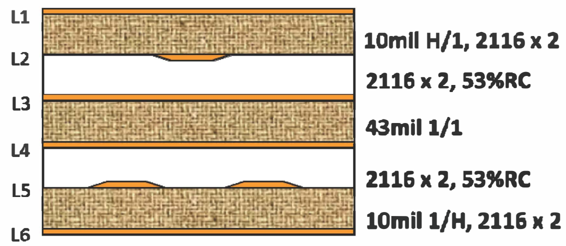


(b)

Fig. 1. (a)Test Vehicle (b) TV Stackup

III.

IV. Measurement And Result

A. The Moisture Effect

All test vehicles are pre-baked for 24 hours at 120ºC. After baking the samples are stabilized for 24 hours at room temperature (23˚C) and 55% RH. VNA measurements are taken after the stabilization period to collect scattering parameters of thru line and 16 inch traces before exposure to moisture [3].

The test vehicles are then placed into a chamber for two weeks at 85ºC and 85% RH. At the end of the two-week high temperature and high humidity exposure period the test vehicles are stabilized at room temperature for 1 hour at 23ºC and 50-55% RH. VNA measurements are taken to measure the moisture effect.

A two-line method is used to calibrate cables, SMA and via effects. Insertion loss results are shown in Figure 2. Solid curves represent insertion loss before exposure to moisture. Dotted curves represent insertion loss after exposure to moisture. The results conclude there is no significant insertion loss difference between before and after exposure to moisture. This is true for the four resin types. It should be noted solid copper ground planes create a barrier preventing moisture from penetrating into the inner layers.

Although the strip-line design of the TV prevents moisture uptake by the material, it should be noted that moisture absorption effects on external (micro-strip) layers were not studied. As these layers are protected from the external environment only by solder resist, Dk and Df degradation due to moisture may be more significant than in the strip-line example studied here.

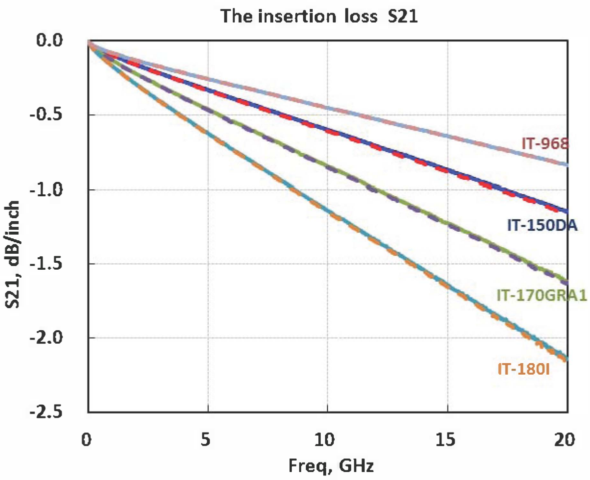


Fig. 2. The measurement result of with and without moisture

B. The Temperature Effect

The temperature effect test setup is demonstrated in Figure 3. The C1 to C4 cable length inside the cabinet is kept equal to ensure cable properties do not influence the insertion loss values at elevated temperatures. Before recording the insertion loss at specific temperatures, the insertion loss (IL) of DUT should be stable; the delta IL should be less than 0.02dB at 10GHz to ensure the temperature at DUT arrives the target temperature. Record the S-parameters of DUT at different temperatures from -20ºC ~ 100ºC at 20ºC increments.

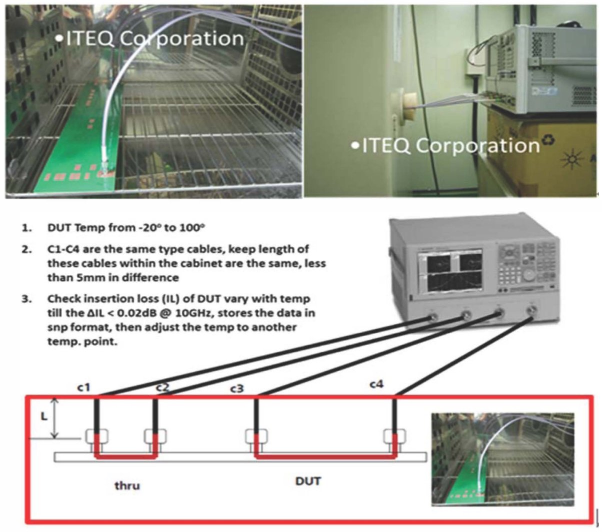


Fig. 3. Temperature Effect Test Setup

The temperature effect test results are shown in Figure 4. Insertion loss increases for each material type as temperature increases. The temperature effect on insertion loss is greatest for standard loss material. The temperature effect is reduced at each lower loss level. The ultra-low loss material is the most stable.

Temperature effect test results are plotted in Figure 4. Test values are listed in Table II.

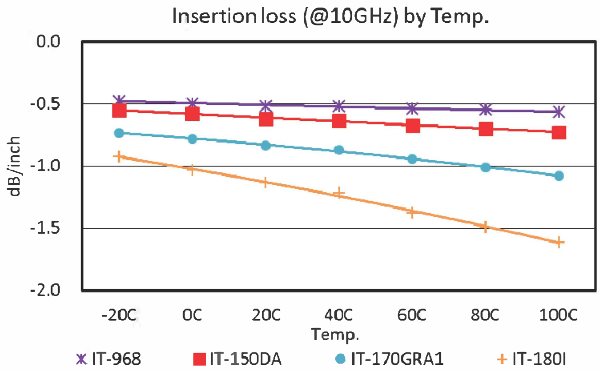


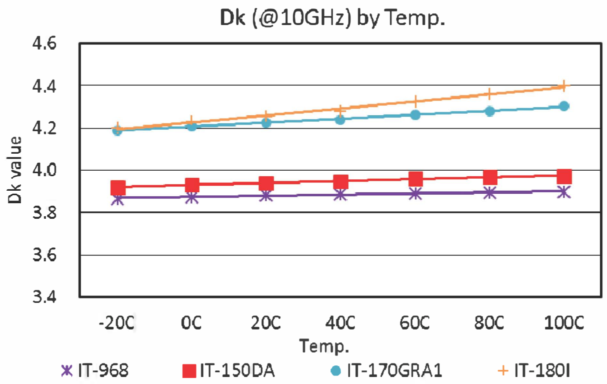
Fig. 4. Insertion Loss (10GHz) by Temperature.

TABLE II. SUMMARY OF INSERTION LOSS

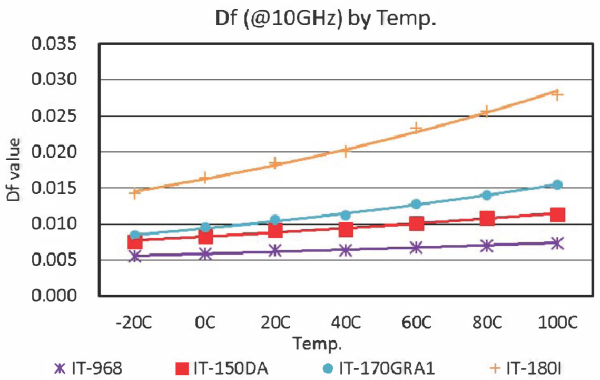
Material	-20°C	0°C	20°C	40°C	60°C	80°C	100°C	Loss Δ @ 20C-80C
IT-968	-0.48	-0.50	-0.52	-0.52	-0.54	-0.55	-0.57	6.0%
IT-150DA	-0.55	-0.58	-0.62	-0.65	-0.67	-0.70	-0.73	13.0%
IT-170GRA1	-0.73	-0.78	-0.84	-0.87	-0.95	-1.01	-1.08	20.2%
IT-180I	-0.93	-1.03	-1.13	-1.21	-1.38	-1.49	-1.61	31.7%

Permittivity (Dk) and Loss Tangent (Df) values at 10GHz from 20°C to 100°C are extracted and plotted in Figure 5 [4]. Test values are listed in Table III.

Both permittivity & loss tangent increase with temperature. Permittivity variation is more stable with a maximum variation less than 3%. Loss tangent is impacted to a more significant degree at higher temperatures with a range of 10.4% to 38.7%. Ultra-low loss material is most stable. The temperature impact increases at each higher loss level. Lower loss resin systems are more stable.



(a)



(b)

Fig. 5. (a) Permittivity (10GHz) by Temp. (b) Loss tangent (10GHz) by Temp.

TABLE III. PERMITTIVITY & LOSS TANGENT @ 10GHZ BY TEMPERATURE

Material	Dk @-20C	Dk @0C	Dk @20C	Dk @40C	Dk @60C	Dk @80C	Dk @100C	Dk△ @ 20-80C
IT-968	3.87	3.88	3.88	3.89	3.89	3.90	3.90	0.4%
IT-150DA	3.92	3.93	3.94	3.95	3.96	3.97	3.97	0.7%
IT-170GRA1	4.19	4.21	4.23	4.24	4.26	4.28	4.30	1.3%
IT-180I	4.20	4.23	4.26	4.28	4.32	4.36	4.40	2.5%

Material	Df @-20C	Df @0C	Df @20C	Df @40C	Df @60C	Df @80C	Df @100C	Df△ @ 20-80C
IT-968	0.0055	0.0059	0.0064	0.0065	0.0068	0.0070	0.0074	10.4%
IT-150DA	0.0076	0.0083	0.0091	0.0094	0.0102	0.0108	0.0113	18.7%
IT-170GRA1	0.0084	0.0095	0.0106	0.0112	0.0128	0.0141	0.0154	32.3%
IT-180I	0.0142	0.0164	0.0184	0.0201	0.0234	0.0256	0.0279	38.7%

V. CONCLUSION

Moisture does not impact the insertion loss (SL) in part because ground planes provide a barrier preventing moisture penetration into the PCB.

Electrical properties of PCB materials are very sensitive to temperature change. Permittivity and loss tangent increase at elevated operating temperatures. Temperature change has a greater influence on loss tangent.

Material type according to loss class is also significant. Lower loss materials are more stable than higher loss materials.

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