DesignCon 2019

Thermoelectric Performance of Copper Clad Laminate

Cheng Wei Huang PhD, Nanya Plastics
Email: cw.huang@npc.com.tw

Mark Shields, Nanya Plastics
Email: markshields@nanya-na.com

Abstract
The demand for higher frequency and faster data transmission rates is rapidly increasing. A consequence of this trend is a higher operating temperature environment.

For high frequency copper clad laminates, the relationship between temperature and electrical performance has been investigated. Tests measured material stability from room temperature to 80°C. Resin types tested included epoxy, phenolic, hydrocarbon, polyethylene ether and polytetrafluoroethylene. There is a correlation between electrical performance and operating temperature.

The paper will present thermal-electrical performance results of standard loss, mid loss, low loss and ultra low loss material types.

INTRODUCTION

The global 5G infrastructure market is experiencing intense interest with significant investment driving materials evaluation for future deployment. 5G technology covers a broad spectrum that includes VR/AR, cloud computing, autonomous driving, high-quality videos, low latency, etc that requires extremely high throughput, data transfer speed, and efficiency. The Internet of Things (IoT) will require a supercharged 5G wireless network. IoT will connect billions of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators and connectivity enabling these items to connect, collect and exchange data. 5G devices will be designed with high speed capability and good thermal management. High-end server, switch and storage device CPUs will generate more heat increasing the PCB temperature along with potential high humidity environments. As a result, the impact of temperature and humidity on loss performance must be considered.

MATERIAL PROPERTIES AND TEST VEHICLE

Ten materials, spanning the range from low-end standard loss to high-end ultra low loss, were selected for the test. Materials are classified according to insertion loss. Table I lists the material resin types and product characteristics.

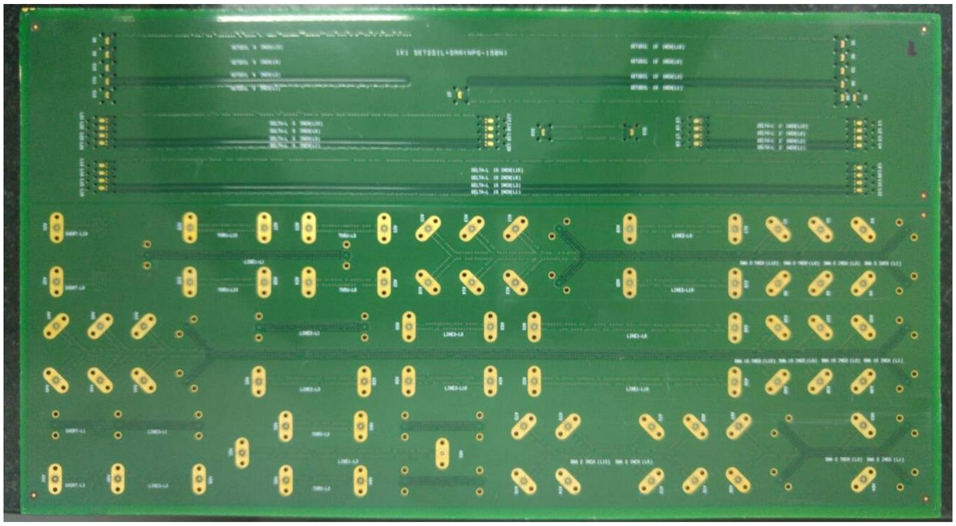
TABLE I. MATERIALS AND PROPERTIES

Loss Class	Sample No.	Halogen Free	Tg °C	Resin Type
Ultra Low Loss	1	No	230 (DMA)	Polyphenylene Ether Blend + Hydrocarbon
	2	Yes	220 (DMA)	Polyphenylene Ether Blend + Hydrocarbon
	3	No	-	Polytetrafluoroethylene
	4 LD	Yes	220 (DMA)	Polyphenylene Ether + Modified Epoxy Blend (w/ LD glass)
Low Loss	4	Yes	220 (DMA)	Polyphenylene Ether + Modified Epoxy Blend
	5	Yes	170 (DSC)	Modified Phenol Novolac + Phosphorus Epoxy Blend
Mid Loss	6	Yes	170 (DSC)	Modified Phenol Novolac + Phosphorus Epoxy Blend
	7	No	150 (DSC)	Phenol Novolac + Epoxy Blend
	8	Yes	170 (DSC)	Phenol Novolac + Epoxy Blend
Standard	9	Yes	150 (DSC)	Phenol Novolac + Epoxy Blend

TEST VEHICLE

Intel's standard Delta L design was chosen as the test vehicle with differential pairs trace lengths of 5 and 10 inches. Figure 1 shows the twelve layer stack up (76 mil). Layer 10 is the signal layer from which measurements were taken. Equipment used is an Agilent E5071C with Intel Delta L software.

FIGURE 1. TEST VEHICLE & STACKUP



Layer	Type	Material	Thickness
			0.50
L1	Signal Layer	Copper Foil 0.5 oz	1.90
		2.7mil Prepreg	2.70
L2	Plane Layer	Power/Ground 1.0 oz	1.30
		5.0mil Core	5.00
L3	Signal Layer	Signal 1.0 oz	1.30
		10mil Prepreg	10.00
L4	Signal Layer	Signal 1.0 oz	1.30
		5.0mil Core	5.00
L5	Plane Layer	Power/Ground 1.0 oz	1.30
		3mil Prepreg	3.00
L6	Signal Layer	Signal 1.0 oz	1.30
		11.0mil Core	11.00
L7	Signal Layer	Signal 1.0 oz	1.30
		3mil Prepreg	3.00
L8	Plane Layer	Power/Ground 1.0 oz	1.30
		3.0mil Core	3.00
L9	Signal Layer	Signal 1.0 oz	1.30
		10mil Prepreg	10.00
L10	Signal Layer	Signal 1.0 oz	1.30
		3.0mil Core	3.00
L11	Plane Layer	Power/Ground 1.0 oz	1.30
		2.7mil Prepreg	2.70
L12	Signal Layer	Copper Foil 0.5 oz	1.90
			0.50

MEASUREMENT AND RESULT

MOISTURE EFFECT

Test coupons were pre-baked for 24 hours at 120°C and stabilized for 24 hours at room temperature (23˚C) and 55% RH. Delta L measurements were taken. The coupons were then placed into a chamber for two weeks at 85°C and 85% RH. Following the two week high temperature and high humidity exposure period the coupons were stabilized at room temperature for 1 hour at 23˚C and 50-55% RH. Delta L measurements were taken to measure the moisture effect.

Insertion loss results are shown in Figure 2. Solid lines represent insertion loss before exposure to moisture. Dotted lines represent insertion loss after exposure to moisture. The results conclude there was no significant insertion loss difference resulting from exposure to moisture. In this case ground layer 11 prevents moisture penetration.

Resin type also influences test results. PPE, hydrocarbon and PTFE systems have a symmetric chemical structure resulting in low moisture absorption properties compared with epoxy and phenolic systems. The symmetric structures of PPE and PTFE are shown in Figure 3.

Figure 2. MEASURMENT RESULTS BEFORE AND AFTER MOISTURE UPTAKE

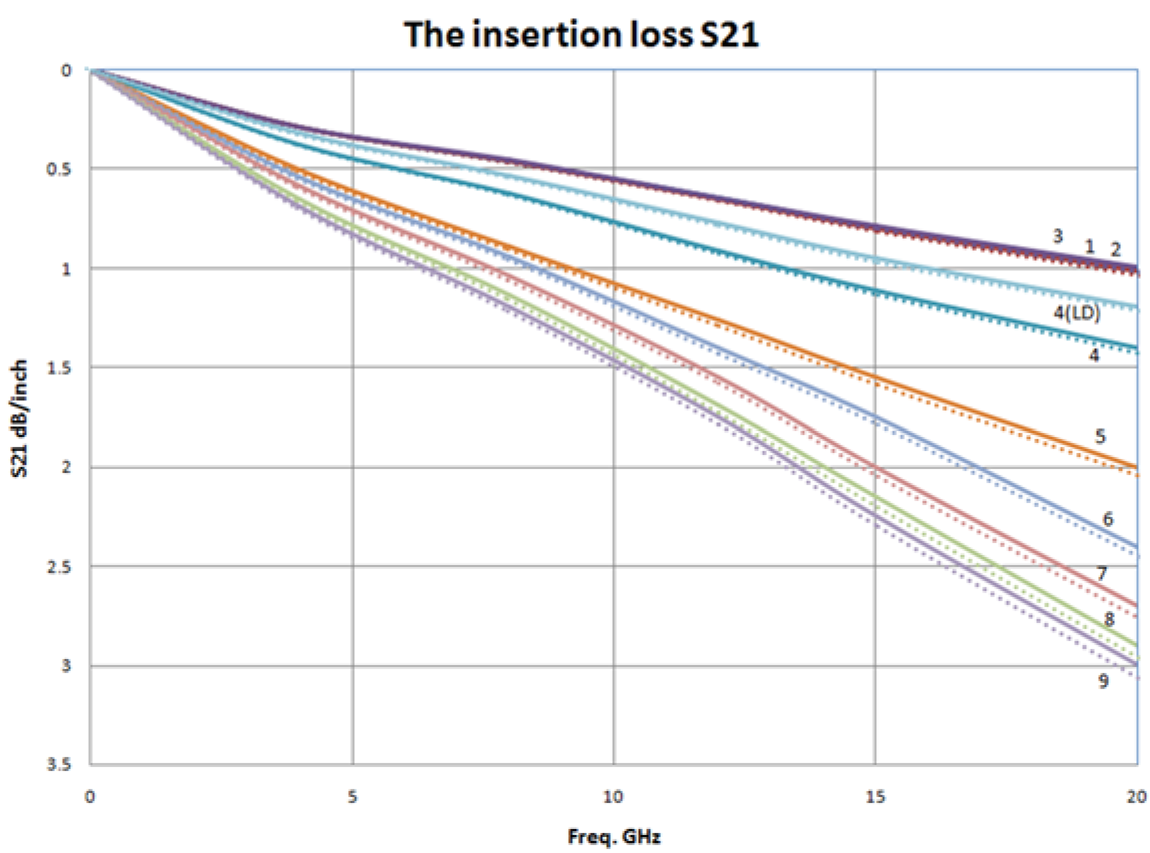
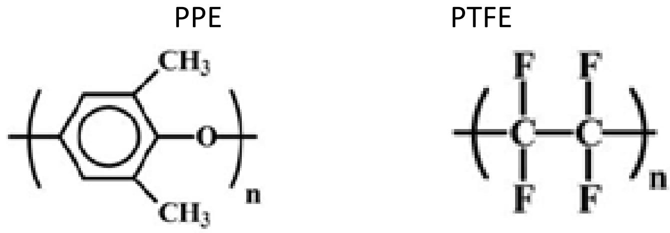


Figure 3. PPE & PTFE STRUCTURES



THE TEMPERATURE EFFECT

The temperature effect test setup is demonstrated in Figure 4. The temperature effect test results are shown in Figure 5. Two temperature exposure ranges, 20^{o}C to 60^{o}C and 20^{o}C to 80^{o}C were considered. The measurements were performed following 60 minute stable exposure at 60°C and 80°C. 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 materials are the most stable.

Temperature effect test results at 4GHz are plotted in Figure 4. Test results are listed in Table II at 4GHz, 8GHz and 12.89GHz.

The temperature effect is more significant at higher loss levels. On a percentage basis loss is greater at higher frequencies.

Figure 4. TEMPERATURE EFFECT Test Setup

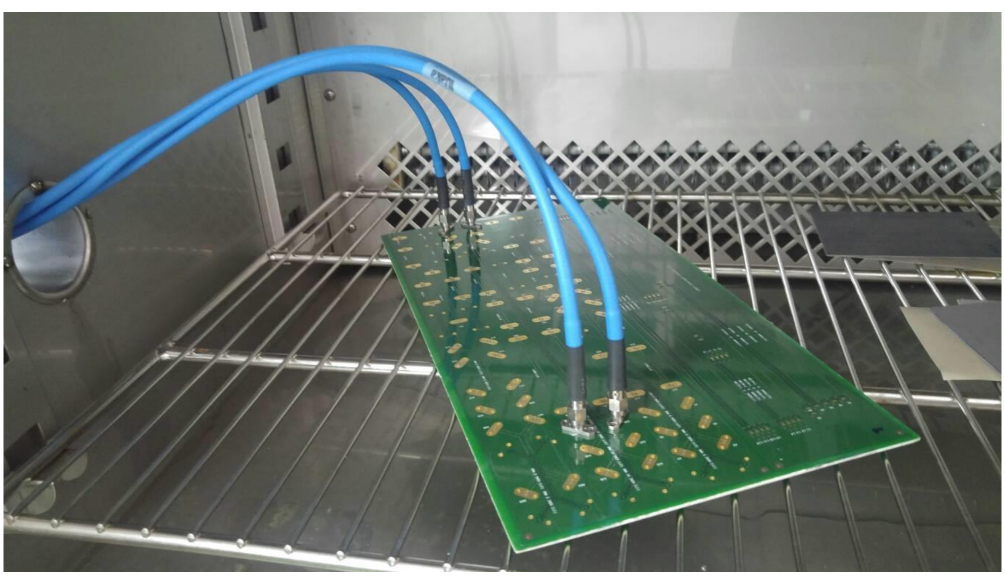


Figure 5. TEMPERATURE EFFECT at 4GHz

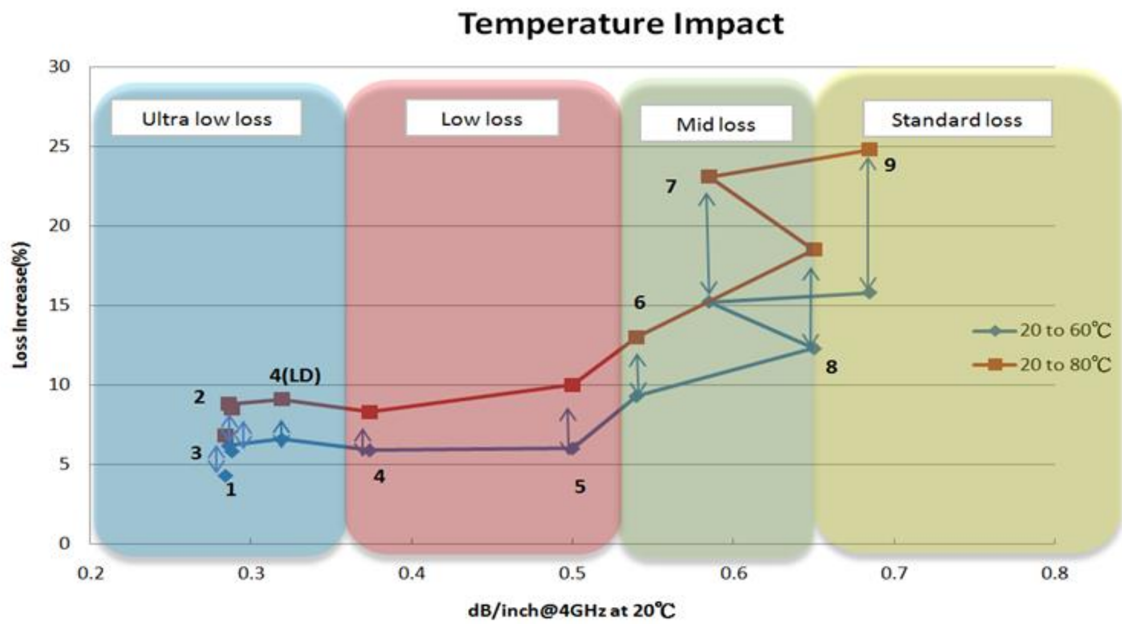


Table II TEMPERATURE EFFECT (FREQUENCY SPECIFIC)

Loss Class	Sample No.	Insertion Loss (4GHz) dB/inch @ 20°C	Incease in Loss (%)	
			20°C to 60°C	20°C to 80°C
Ultra Low Loss	1	0.286	6.2	8.8
	2	0.288	5.8	8.5
	3	0.284	4.3	6.8
	4 LD	0.319	6.6	9.1
Low Loss	4	0.374	5.9	8.3
	5	0.500	6.0	10.0
Mid Loss	6	0.540	9.3	13.0
	7	0.650	12.3	18.5
	8	0.585	15.2	23.1
Standard	9	0.685	15.8	24.8

Loss Class	Sample No.	Insertion Loss (8GHz) dB/inch @ 20°C	Incease in Loss (%)	
			20°C to 60°C	20°C to 80°C
Ultra Low Loss	1	0.449	6.4	9.0
	2	0.454	6.2	8.7
	3	0.452	5.3	7.1
	4 LD	0.529	6.8	9.3
Low Loss	4	0.621	5.3	7.7
	5	0.890	6.7	11.2
Mid Loss	6	0.940	9.9	14.6
	7	1.038	16.5	25.1
	8	1.130	14.2	21.2
Standard	9	1.190	17.2	26.8

Loss Class	Sample No.	Insertion Loss (12.89 GHz) dB/inch	Incease in Loss (%)	
		@ 20°C	20°C to 60°C	20°C to 80°C
Ultra Low Loss	1	0.632	7.4	10.4
	2	0.638	7.2	10.2
	3	0.637	5.8	8.9
	4 LD	0.772	7.8	10.8
Low Loss	4	0.909	6.4	9.1
	5	1.360	7.6	12.9
Mid Loss	6	1.400	11.7	17.4
	7	1.548	18.6	28.1
	8	1.690	15.7	23.5
Standard	9	1.748	18.1	28.3

CONCLUSION

The moisture effect on loss is minimized by ground planes acting as a barrier preventing moisture penetration. Temperature has an effect on loss which can be significant according to material resin type and frequency. Increases in loss correlate to loss class and frequency with lower loss materials being more stable.

REFERENCES

[1] J. Hsu, T. Su, K. Xiao, X. Ye, S. Huang, Y. Li, "Delta-L Methodology for Efficient PCB Trace Loss Characterization", *Microsystems Packaging Assembly and Circuits Technology Conference (IMPACT)*, 2014.