SIMULATION METHOD FOR EFFECTIVE THERMAL CONDUCTIVITY DETERMINATION OF COMPLEX BOARDS

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***Abstract**: Resistors, capacitors, transistors, and LEDs are components used in electronic systems, normally assembled to printed circuit boards – PCBs. Such components generate heat in operation which must be conducted away efficiently to frames where the board is fixed. The components operating temperatures depend on heat dissipation rate, mounting technology, component placement and finally effective thermal conductivity of the PCB. The temperature of some components may reach about 100º C while the PCB frame is kept at near-ambient constant temperature. The reliability of electronic components is directly related to operating temperature. Hence, a correct temperature prediction shall be provided by the thermal project of the board under the hottest operation conditions. The PCB effective thermal conductivity is a significant parameter which influences the component temperature and its determination for complex multi-layer PCBs is not a simple task. In space applications, the only way to spread and reject heat of electronic equipments is by thermal conduction once there is no air available to apply convection-based cooling systems such as heat sinks and fans. In this paper we present a simulation method used to determine the effective thermal conductivity of multi-layered boards. Such method uses a CAD based thermal model builder named SINDA/FLUINT Thermal Desktop and aims to determine the effective conductivity of a PCB by comparison between a detailed multi-layered anisotropic model and an equivalent homogeneous model. The method was applied for PCB-frame configurations typical for space applications. The simulation outcomes were compared to the values of effective conductivity obtained by analytical methods. Besides, a sensitivity analysis is performed on variations in component mounting technology and PCB layers placement. The results are discussed in a way of evaluation of applicability of existing methods and estimation of inherent uncertainty of PCB thermal effective conductivity determination.*

***Keywords:** Effective thermal conductivity, PCB*

1 Introduction

Excessive heat can damage electronic systems, since component parameter values usually vary with temperature and it is important not to exceed the designed temperature ranges. Above such temperatures, parts are no longer guaranteed to be within specification and perfect operation conditions. Thus thermal design can be considered a quite important aspect of a system's over design since components that generate a great amount of heat can reach excessive temperatures increasing the chances of failure. According to Carchia (1999), the most common methods to provide thermal control include: Heat sinks for components that give off a considerable amount of heat; Fans to improve airflow through enclosure; the use of a thermal conduction plane. Thermal conduction planes within printed circuits boards conduct heat away from generating components. In space applications, the only way to spread and reject heat of electronic equipments is by thermal conduction once there is no air available to apply the convection-based cooling systems mentioned above.

In this context, thermal modeling of heat conduction in multi-layered printed circuit boards is occasionally simplified by the use of effective thermal conductivity. Such parameter combines the influences of individual layer conductivities into a single value that can be applied as if the board had only one homogeneous layer where overall thickness and surface area are preserved. Some analytical methods have been proposed to calculate effective conductivity, where arithmetic mean, geometric mean and harmonic mean are among them. All of these methods are based on the cross-plane conductivity (series) and the in-plane conductivity (parallel) which are generally considered to be the lower and upper limits for the effective conductivity respectively. However, the published papers do not provide a clear definition how to calculate this value once the results are quite different between the lower and upper limits. This paper aims to contribute on how to evaluate the effective thermal conductivity of a typical multilayer PCB for space application by direct numerical simulation.

2 Simulation Method

The method used to estimate the effective thermal conductivity of complex multi-layered boards is based on numerical simulations which uses the CAD based thermal model builder SINDA/FLUINT Thermal Desktop. It consists of modeling a complex and a simplified model that represent the same PCB and afterwards comparing them. The complex model is a multi-layered board wherein each of the layers has the same conductivity value as in the real PCB. On the other hand, the simplified model is a single-layered board, which thickness is obtained by summing the various layer thicknesses of the complex model, with a unique conductivity value called effective conductivity, Fig 1. The same boundary conditions and heat loads are applied both to the complex and simplified models.

Initially, we run the simulation for the complex model where the component (heat source) will reach certain temperature at the steady state. After that, we run the simulation for the simplified model and change the board's conductivity until the component reaches the same temperature as in the complex model. Therefore, this conductivity can represent the effective conductivity of the complex model.

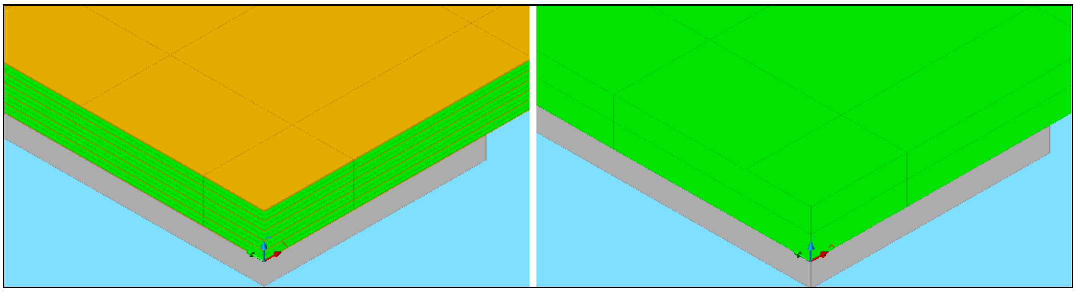

Figure 1. Complex multi-layer and simplified single-layer models.

3. PCB for Space Applications

The PCB sample used for the analysis was a 160 mm x 233.5 mm x 2 mm, consisted by 6 signal layers (conductive): top, GND, power, inner 1, inner 2 and bottom. Each layer has a certain covering percentage of copper (conductive traces) and a fiberglass reinforced epoxy (FR4) is used as a dielectric material between layers; photographs of the external surfaces are shown in Fig. 2.

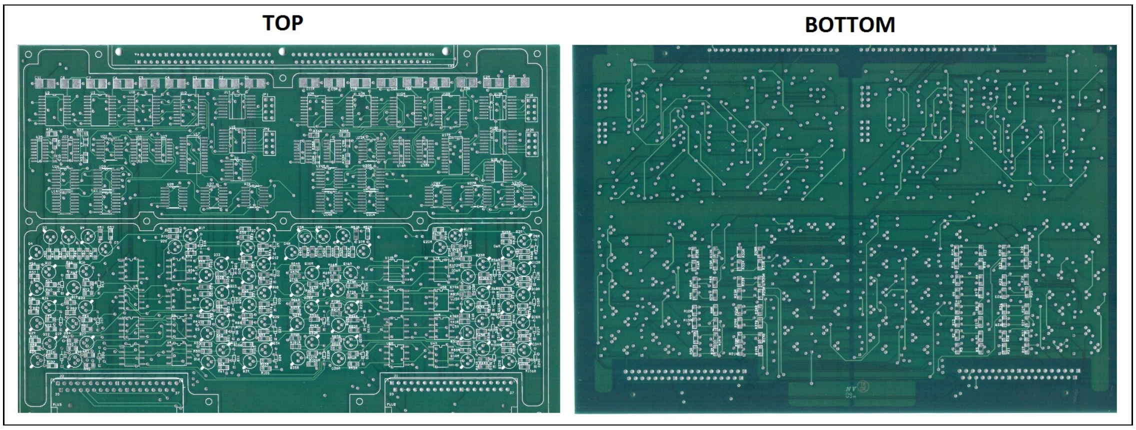

Figure 2. Multi-layered PCB for space applications (top/bottom photos).

From the board's project we can see the 6 signal layers in Fig. 3. We have estimated the copper coverage of each signal layer in order to apply a percentage factor over the copper conductivity in our model.

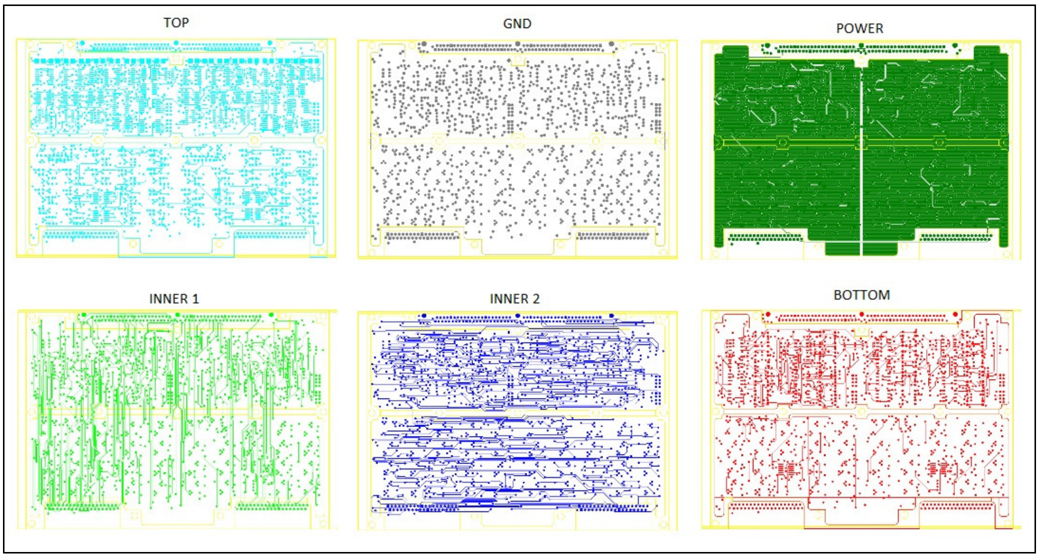

Figure 3. The 6 signal layers of the PCB.

Adopting the simulation method shown above, we created 2 equivalent models, a complex (11 layers) and a simplified one (single layer). The only boundary condition imposed to the model was a 10 mm wide frame kept at constant temperature of 20º C, which was placed at the bottom surface with heat transfer coefficient of 400 W/m^{2}K as contact condition. We tested several mesh configurations with gradual refining in order to get stable results that were achieved by setting 30 x 30 x 2 edge nodes for all board layers with 5000 W/m^{2}K for the contact between them. Tab. 1 shows the layer composition of the complex model, the signal layers with conductive lines were treated as a homogeneous layer with an equivalent conductivity equal to copper conductivity (400 W/mK) multiplied by the percentage of copper covering area, which was roughly estimated based on the PCB's project.

Table 1. Complex model composition.

LAYER	MATERIAL	THICKNESS (mm)	CONDUCTIVITY (W/mK)
1 – top	Copper (7%)	0.035	28
2 – dielectric	FR4	0.358	0.25
3 – GND	Copper (95%)	0.035	380
4 – dielectric	FR4	0.358	0.25
5 – power	Copper (2%)	0.035	8
6 – dielectric	FR4	0.358	0.25
7 – inner 1	Copper (6%)	0.035	24
8 – dielectric	FR4	0.358	0.25
9 – inner 2	Copper (8%)	0.035	32
10 – dielectric	FR4	0.358	0.25
11 – bottom	Copper (5%)	0.035	20

For the heat load, a 2 W dissipating component was created in 3 size configurations: 10 x 8 mm, 20 x 8 mm and 20x16 mm with 2500 W/m^{2}K for the contact with the top board surface. Such component was placed in 13 different positions as presented in Tab. 2. Two frames represented in the model as solid bars with fixed temperature are placed at left and right edges of the PCB.

Table 2. Component position coordinates with the PCB's lower left corner as the origin (0,0).

Position	x (m)	y (m)
1	0.0430	0.1180
2	0.1075	0.1180
3	0.1720	0.1180
4	0.0430	0.0790
5	0.1075	0.0790
6	0.1720	0.0790
7	0.0430	0.0400
8	0.1075	0.0400
9	0.1720	0.0400
10	0.0753	0.1010
11	0.1401	0.1010
12	0.0753	0.0620
13	0.1401	0.0620

4. Simulations Results

We run the simulation for the 13 positioning cases changing the component size three times, which generated the results for effective conductivity mean for each component position and its standard deviation, presented in Tab. 3.

Table 3. Effective conductivity mean and its standard deviation for each component placement.

Position	Mean (W/mK)	SD
1	7.482	0.211
2	8.087	0.151
3	7.452	0.210
4	7.550	0.378
5	8.066	0.288
6	7.497	0.342
7	7.530	0.350
8	8.107	0.270
9	7.489	0.329
10	7.868	0.219
11	7.998	0.154
12	7.862	0.222
13	7.995	0.155

This results in an overall mean and standard deviation of 7.768 W/mK and 0.340 respectively. In order to get aware of any tendencies of our data, we have placed the origin of the system at the board's center and plotted the effective conductivity mean against the component's horizontal position (x axis), thereby generating the chart presented in Fig. 4.

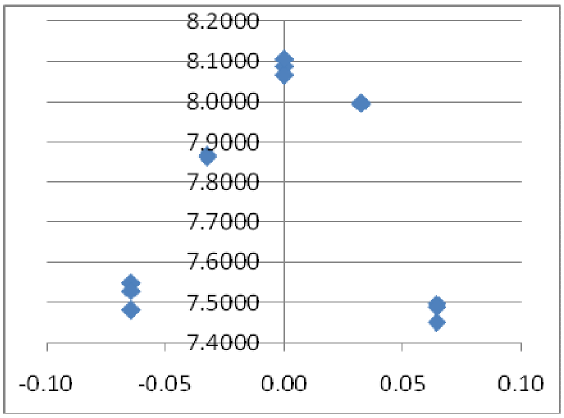

Figure 4. Effective conductivity mean against the horizontal position of the component

By visually analyzing the chart above, we can clearly see that the effective conductivity mean has a certain decreasing tendency as further away the component is placed from the center.

5. Conclusion

The PCB effective thermal conductivity was obtained by direct simulation used the CAD based thermal model tool SINDA/FLUINT Thermal Desktop. For the real 6-layer PCB the average value is 7.768 W/mK and 0.340 as standard deviation, that lies between the limits of the in-plane and arithmetic mean simplified analytical models.

A tendency was observed by plotting the results of each positioning case; the effective thermal conductivity tends to decrease as further away the component is placed from the center, which means that the estimated effective conductivity is minor as the component approaches the frame. That is probably happening because when the component is close the frame which is kept at 20º C, the conductivity is a less important parameter for the steady state component's temperature, and as described above, the simulation method is based on the component's temperature at the steady state.

For future work, more simulation cases will be needed to better understanding how the effective conductivity behaves along the board and to have more data, which would allow us to statistically analyze the effective conductivity on multi-layer boards with higher accuracy. The experimental validation of the present method is also under way.

Acknowledgments

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