http://dx.doi.org/10.5540/DINCON.2011.001.1.0161

DINCON 2011
10ª Conferência Brasileira de Dinâmica, Controle e Aplicações
28 de agosto a 1º de setembro de 2011

STATISTICAL ANALYSIS OF THERMAL CONDUCTIVITY DISTRIBUTION OVER ELECTRONIC BOARDS BASED ON SIMULATIONS

Rafael Lopes Costa [1], *Valeri Vlassov* [2], *Hélio Koiti Kuga* [3]

[1] CMC/INPE, São José dos Campos – SP, Brazil, rcosta.engmec@gmail.com
[2] DMC/INPE, São José dos Campos – SP, Brazil, vlassov@dem.inpe.br
[3] DMC/INPE, São José dos Campos – SP, Brazil, hkk@dem.inpe.br

Abstract: The paper presents a simulation method used to estimate the parameter called effective thermal conductivity of multi-layer PCBs. We have applied the method in a board characteristic for space applications afterwards performing a statistical analysis of the results in order to observe tendencies.

Keywords: Effective thermal conductivity, PCB, engineering applications.

1. INTRODUCTION

Excessive heat can damage electronic systems, since component parameter values usually vary with temperature and it is important not to exceed the manufacture's temperature range. Above such temperatures, parts are no longer guaranteed to behave within specification. Thus thermal design can be an important aspect of a system's overall design, [1]. Components generate heat in operation and can reach excessive temperatures. According to [2], 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; or 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-layer printed circuit boards is occasionally simplified by the use of effective 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, [3]. Several methods have been proposed for calculating effective conductivity, including the cross-plane conductivity (series) and the in-plane conductivity (parallel), which are generally considered to be the lower and upper limits for effective conductivity.

2. CALCULATION METHOD

In order to estimate the effective conductivity of multi-layer boards we present a method based on numerical simulations which uses the CAD based thermal model builder SINDA/FLUINT Thermal Desktop.

The method consists of creating a conjugate pair of a complex and a simplified model that represent the same PCB layout and afterwards comparing them. The complex model is a multi-layer board wherein each of the layers has the same conductivity value as in the real PCB. Each signal layer with conductive traces is treated as a homogeneous layer with an equivalent conductivity equal to the copper conductivity multiplied by the percentage of covering area with electric conductive lines. The covering percentage was estimated visually based on a CAD design of the PCB.

On the other hand, the simplified model is a single-layer board, which thickness is obtained by summing the various layer thicknesses of the complex model, with a unique conductivity value called effective conductivity. The same boundary conditions and heat loads are applied both to the complex and simplified models, Fig. 1.

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 several simulations for the simplified model modifying 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.

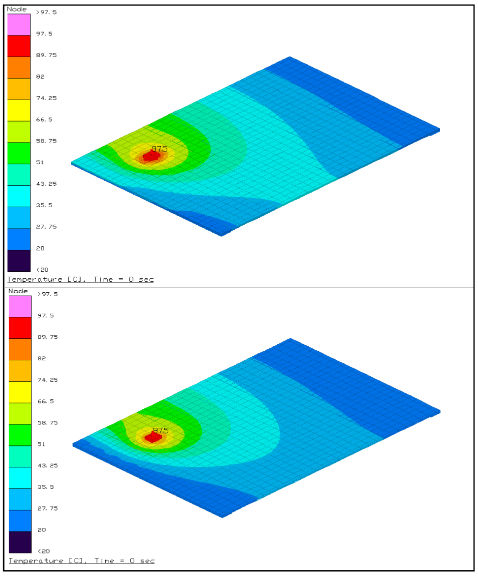

Figure 1. Complex and simplified models showing the simulation results.

3. PCB FOR SPACE APPLICATIONS AND ITS MODELING

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

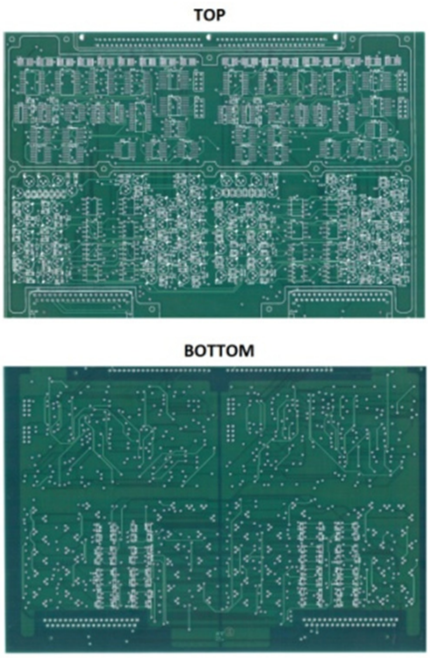

Figure 2. Multi-layered PCB for space applications (top/bottom photos).

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 by visual observation in order to apply a percentage factor over the copper conductivity in our model.

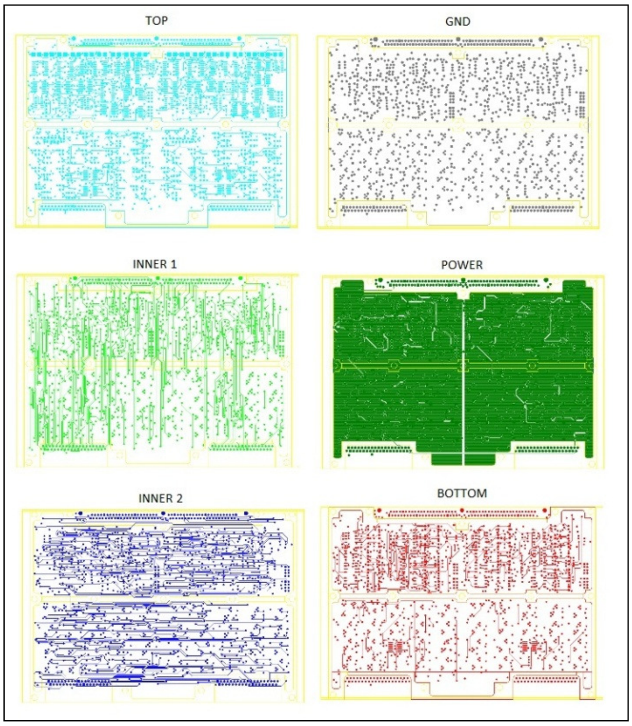

Figure 3. The 6 signal layers of the PCB.

As we had done previously, we created 2 equivalent models, a complex (11 layers) and a simplified (single layer) with no convection along the board simulating the absence of air in space. 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 400 W/m^2K as contact condition. We tested several mesh configurations 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^2K for the contact between them. Tab. 3 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 visually estimated based on the PCB's project.

Table 3. 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

DINCON 2011
10ª Conferência Brasileira de Dinâmica, Controle e Aplicações
28 de agosto a 1º de setembro de 2011

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^2K for the contact with the top board surface. Such component has been placed in 13 different locations; the positioning coordinates are presented at Tab. 2.

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. STATISTICAL ANALYSIS OF THE 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 at 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

In order to get aware of any tendencies in our data, and afterwards try to fit it into a certain type function, 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.

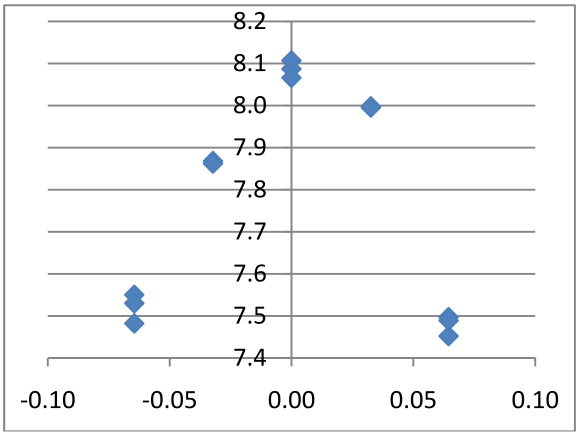

Figure 4. Effective conductivity mean against the horizontal position of the component.

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

The weighted least squares method was applied in order to fit the data into a function. Such method is used for finding the best-fitting curve to a given set of points by minimizing the sum of the squares of the offsets ("the residuals") of the points from the curve, [4]. The sum of the squares of the offsets is used instead of the offset absolute values because this allows the residuals to be treated as a continuous differentiable quantity.

Also, the standard deviations of Tab. 5 were used to weight the mean effective thermal conductivity of the 13 positions.

Initially we tried to fit our data into a quadratic function that would generate a parabola, but a substantial error was found preventing such function to be applied.

Then we tried do adjust the data into a cubic function, modeled as the Eq. 1, generating the coefficients and their errors (from the covariance matrix) in Tab. 4.

$$z = ax^3 + bx^2 + cx + d + ey \qquad (1)$$

Table 4. Coefficients and error extracted from the least squares resulting covariance matrix.

Coefficient	Standard Deviation
-248.3290	1.0758
-144.1046	0.0376
-0.6223	0.0040
8.0781	0.0001
-0.1443	0.0021

By substituting the coefficients above in Eq. 1 we have the Eq. 2 as follows.

$$z = -248.3290x^3 - 144.1046x^2 - 0.6223x + +8.0781 - 0.1443y \quad (2)$$

Fig. 5 shows the curve fitted to represent the mean effective thermal conductivity as function of horizontal position.

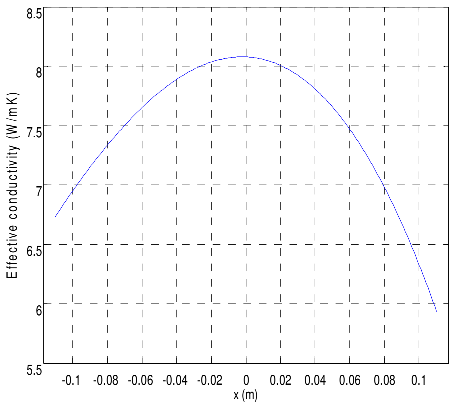

Figure 5. Fitted effective thermal conductivity mean against horizontal position.

5. CONCLUSION

We presented a simulation method used to determine the effective thermal conductivity of complex multi-layer boards. A printed circuit board typical for space applications was used as an example of the method applicability.

Based on the results presented above, we could clearly note that the effective thermal conductivity has a decreasing tendency as further the component is placed from the center of the board. The weighted least squares method was applied to our data in order to fit the data into a bi-dimensional cubic function.

Initially, because of the model's symmetry, it was expected to fit the data into a square function, but a great error was generated probably due to the small number of points and maybe some model inaccuracy. The cubic fit gave the desired results with accuracy.

The approach looks promising for simplifying the thermal analysis and design of electronics, in particular for space applications.

For future work, more simulation cases will be needed to better understanding how the effective thermal 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.

ACKNOWLEDGEMENTS

The authors would like to thank the financial support of CAPES as well as the Space Mechanics and Control Division – DMC of the National Institute for Space Research -INPE .

REFERENCES

[1]PUB Vlassov, V.V. Analytical Model of the Two-Dimensional Temperature Distribution over a Single Electronic Circuit Board. RETERM - Thermal Engineering (Engenharia Térmica), ISSN 1676-1790. No 3, 2003, pp. 32-37

[2]PUB Carchia, M., 1999. "Electronic/Electrical Reliability", Carnegie Mellon University, Pittsburgh, Pennsylvania, USA.

[3]PUB Culham, J. R., Teertstra, Yovanovich, M. M., "The Role of Spreading Resistence on Effective Conductivity in Laminated Substrates", University of Waterloo, 2000.

[4] Lancaster, P. and Salkauskas, K. Curve and Surface Fitting: An Introduction. London: Academic Press, 1986.