

# REPLACEMENT OF MULTILAYER PCB FOR EQUIVALENT COMPOSITE BOARD AT TEMPERATURE SIMULATION IN COMSOL ENVIRONMENT

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## Abstract

Very thin multi-layers of Cu and epoxy compound in PCB (printed circuit board) complicate creation of computational meshes in COMSOL simulation program. Number of degrees of freedom in simulated system increases – it significantly extends simulation computational time. We suggest substituting the PCB in axial and radial direction for one composite structure with equivalent physical parameters of multilayer PCB.

## 1 Principle of PCB simplification

PCB structure has dissimilar conditions for heat transfer in the board volume. We try to define thermal resistances in  $x$ ,  $y$ ,  $z$  axis directions in 3D space according to Fig. 1.

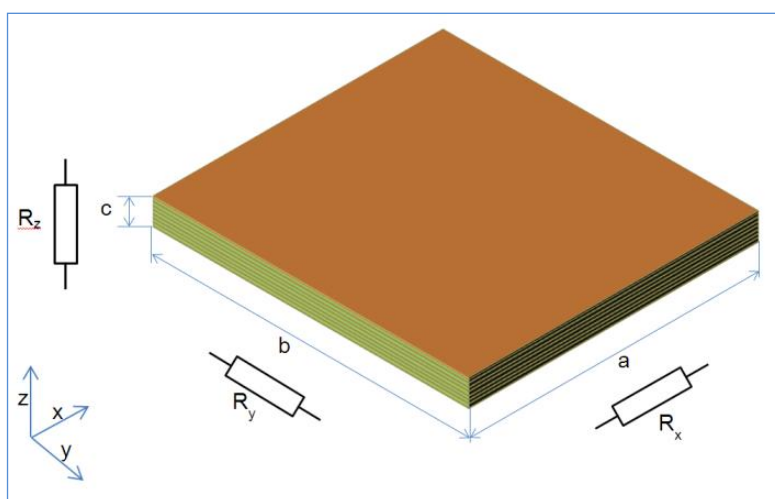


Figure 1: Multilayer PCB board

We can see on Figure 1 interleaved copper layers and epoxy compound layers. Thermal resistances of entire board in  $x$  and  $y$  directions differ from thermal resistance in  $z$  direction.

Cross thermal resistance in  $z$  axe direction (Figure 2) consists of separate layer thermal resistances connected in series.

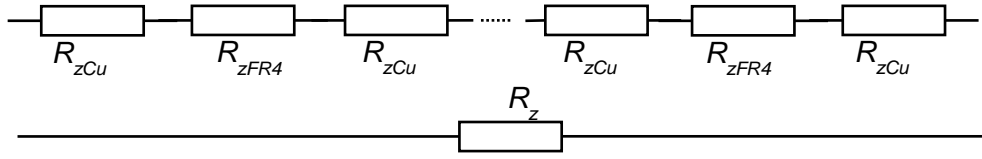


Figure 2. Thermal resistance of PCB in  $z$  direction.

According to Figure 2 is resistance of PCB structure in cross direction:

$$R_z = \sum_{k=1}^n R_{zCu}(n) + \sum_{k=1}^m R_{zFR4} \quad m = n * R_{zCu} + m * R_{zFR4}, \quad (1)$$

where:  $R_{zCu}$ ,  $R_{zFR4}$  are thermal resistances of copper or epoxy compound FR4 type,

$n$  is number of copper layers

$m$  is number of epoxy layers.

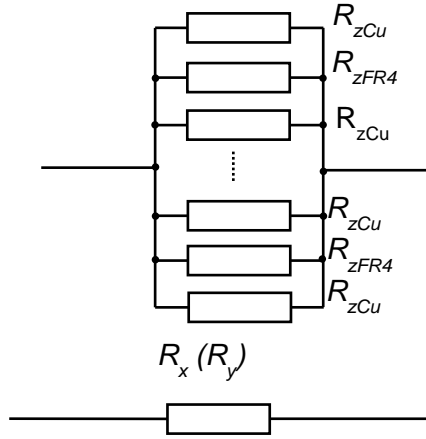


Figure 3. Thermal resistance of PCB in  $x, y$  direction

According to Figure 3 is conductivity of PCB structure in longitudinal direction:

$$\frac{1}{R_x} = \sum_{k=1}^n \frac{1}{R_{zCu} n} + \sum_{k=1}^m \frac{1}{R_{zFR4} m} = n * \frac{1}{R_{zCu}} + m * \frac{1}{R_{zFR4}} \quad (2a)$$

$$\frac{1}{R_y} = \sum_{k=1}^n \frac{1}{R_{zCu} n} + \sum_{k=1}^m \frac{1}{R_{zFR4} m} = n * \frac{1}{R_{zCu}} + m * \frac{1}{R_{zFR4}} \quad (2b)$$

Small layers of PCB (Figure 1) represent interconnected system of very thin blocks with the same surface and different thickness of copper or epoxy compound. Thermal resistance of block in 3D space for  $x, y, z$  directions is defined in equations:

$$R_x = \frac{\Delta x}{k_x * A_{yz}}, \quad (3)$$

$$R_y = \frac{\Delta y}{k_y * A_{xz}}, \quad (4)$$

$$R_z = \frac{\Delta z}{k_z * A_{xy}}, \quad (5)$$

where:  $\Delta x$  - thickness of block in x direction, and  $A_{yz}$  - area which thermal flow runs through in perpendicular direction,

$\Delta y$  - thickness of block in y direction, and  $A_{xz}$  - area which thermal flow runs through in perpendicular direction,

$\Delta z$  - thickness of block in z direction, and  $A_{xy}$  - area which thermal flow runs through in perpendicular direction,

$k_x, k_y, k_z$  - thermal conductivity of material in given direction.

We can get final formulas for thermal conductivity in crosswise and longitudinal direction from equations (1) to (5):

$$k_z = \frac{n \cdot w_{Cu} + m \cdot w_{FR4}}{\frac{n \cdot w_{Cu}}{k_{Cu}} + \frac{m \cdot w_{FR4}}{k_{FR4}}} = \frac{w}{\frac{n \cdot w_{Cu}}{k_{Cu}} + \frac{m \cdot w_{FR4}}{k_{FR4}}} \quad (6)$$

$$k_x = \frac{n \cdot k_{Cu} \cdot w_{Cu} + m \cdot k_{FR4} \cdot w_{FR4}}{n \cdot w_{Cu} + m \cdot w_{FR4}} = \frac{n \cdot k_{Cu} \cdot w_{Cu} + m \cdot k_{FR4} \cdot w_{FR4}}{w} \quad (7)$$

$$k_y = \frac{n \cdot k_{Cu} \cdot w_{Cu} + m \cdot k_{FR4} \cdot w_{FR4}}{n \cdot w_{Cu} + m \cdot w_{FR4}} = \frac{n \cdot k_{Cu} \cdot w_{Cu} + m \cdot k_{FR4} \cdot w_{FR4}}{w} \quad (8)$$

where:  $w_{Cu}$  - thickness of copper layer,  $w_{FR4}$  - thickness of epoxy layer,  $w$  - all over thickness of PCB,  $k_{Cu}$  - copper thermal conductivity,  $k_{FR4}$  - epoxy layers thermal conductivity.

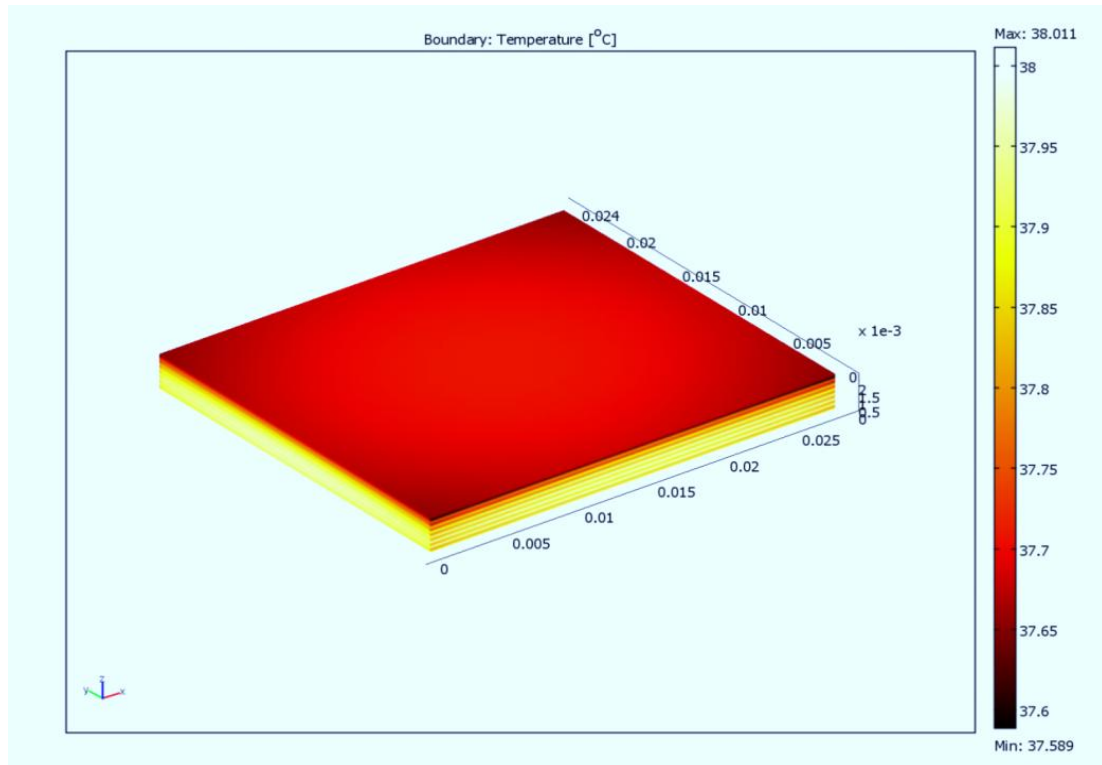


Figure 4. Surface temperature distribution on simulated model of PCB 8xCu+7xFR4

## 2 Temperature simulation of PCB board

Independent simulations in COMSOL environment with Thermal module were accomplished with two samples of PCB with the same dimensions 24,4 mm x 27,9 mm. The same value of power

dissipation 0.2W was applied in patterns. Border conditions for both of samples were the same too (external temperature 20 °C, natural laminar flow).

The first sample contained 8 copper layers with thickness  $w_{Cu}= 0,035$  mm and thermal conductivity  $k_{Cu}=400$  W/m\*K and 7 epoxy compound layers with thickness  $w_{FR4}=0,3$  mm and  $k_{FR4}=0,3$  W/m\*K.

The second sample contained one layer of composite material with thickness 2,38 mm and thermal conductivity as tensor with components calculated from equations (6, 7, 8):

$$k_x= 47,3235 \text{ W/m}^*\text{K},$$

$$k_y= 47,3235 \text{ W/m}^*\text{K},$$

$$k_z= 0,3399 \text{ W/m}^*\text{K}.$$

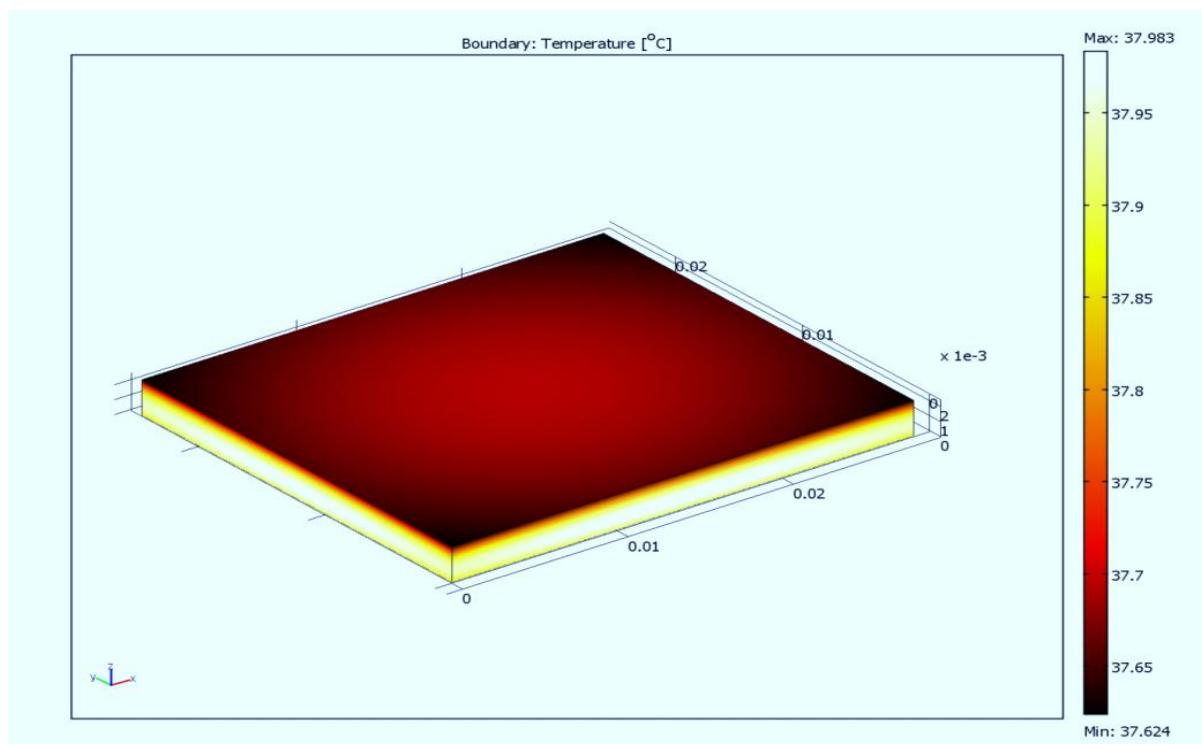


Figure 5. Surface temperature distribution on simulated composite model of PCB

### 3 Comparison of results at thermal simulation of multilayer PCB board to one layer composite board

There is graphic representation of temperature field on PCB board surface on figures 4 and 5. Figure 4 shows 3D graphic course of 8-layer PCB board temperature field. Figure 5 shows 3D graphic course of composite PCB board temperature field. We can see on mentioned diagrams that results of 3D simulations are almost identical.

Figure 6 compares internal temperatures of 8-layer PCB board and composite PCB board in board cross-section with axe in the middle of both PCB samples. None simulation temperature difference inside the PCB board overreached value 0,02 °C. Figure 7 shows percentage representation of relative temperature differences on axe z in monitored thickness 0 - 2,4 mm of PCB board.

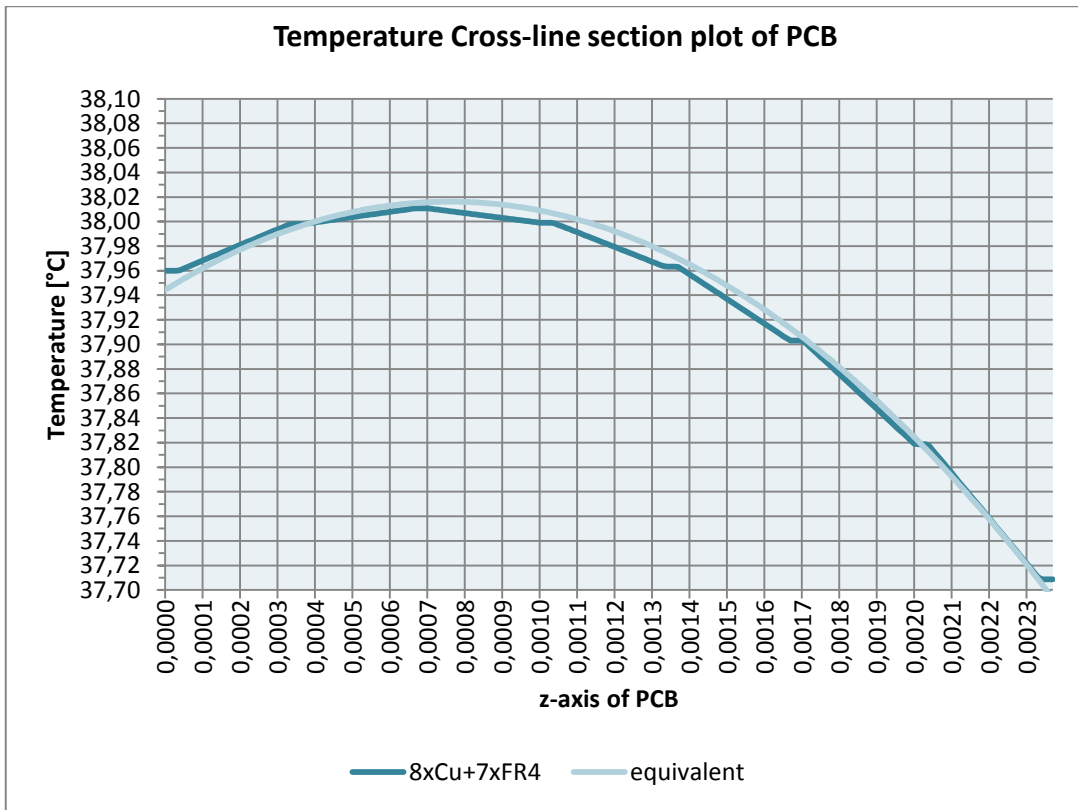


Figure 6. Comparison of internal temperatures in the middle of PCB board 8xCu+7xFR4 and in composite model

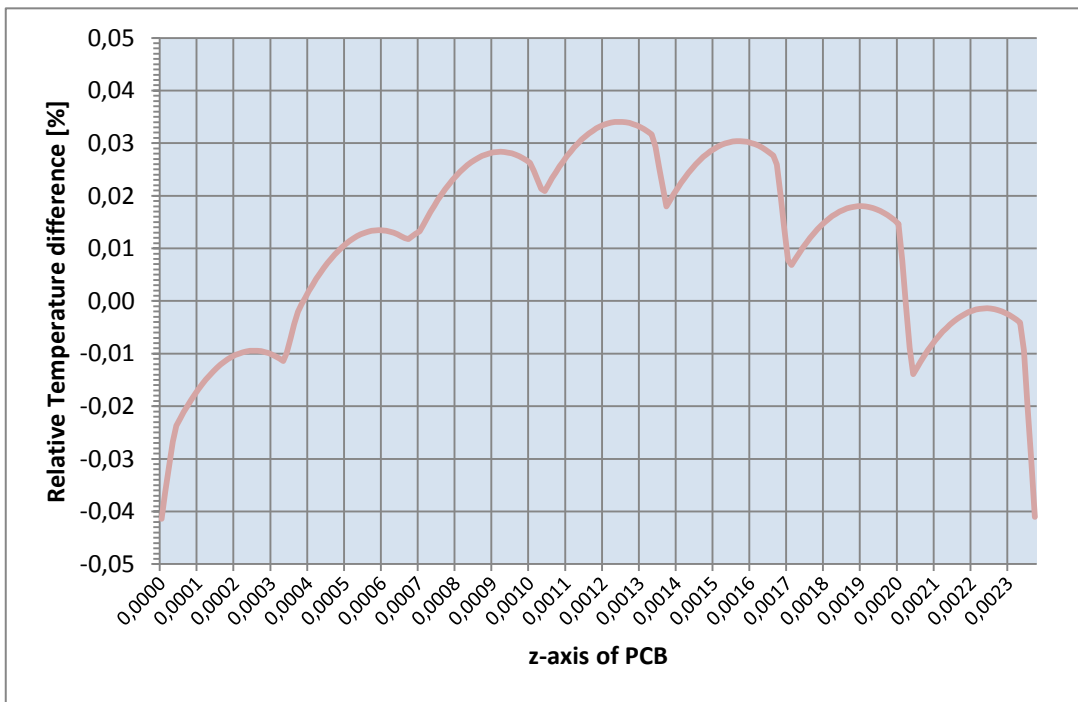


Figure 7. Relative temperature difference cross-line section plots of the 8xCu+7xFR4 and equivalent PCBs

## 4 Results

Contemporary construction of electronic power equipments utilizes as mechanical and electrical base a multilayer PCB board. Single semiconductor elements and integrated circuits are built-in the board. It is suitable to reduce number of thin and large planes by creation of geometric model of electronic equipment. This is case of multilayer PCB board. Authors used a composite physical model applicable for temperature simulation needs. The equivalent model unlike a multilayer geometry significantly decreases number of elements of computational mesh. Results of simulation confirm that temperature field in 8-layer PCB board and in composite PCB board differ very little. Results of simulation of PCB board samples for DC-DC converter with dimensions 24,4 mm x 27,9 mm show that relative temperature deviation is 0,04 % in the worst case.

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