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Algorithms for indirect investigation of heat distribution in electronic systems

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ABSTRACT

This paper deals with the development of methodology suited for design of computation algorithm which is able to determine power losses of electronic systems based on measured temperature distribution (thermo-vision measurements). For such purpose deterministic algorithms for power loss identification were developed using two different approaches. Both of them were verified by simulation experiments and relevant simulation models.

Applications of proposed methodologies were further used for more complex electronic systems – brick power supply module. First, thermo-vision measurements of selected system's operation were done in order to verify proposed estimation methodologies. The power loss determination estimated from designed methodologies was verified by the comparison of results from the thermo-vision measurements of operation and the experiments of thermal simulation.

Finally, the suitability of methodologies was tested in more complex systems such as smartphones. The investigation of accuracy of the designed methodology was performed similarly by the comparison of simulation and measurements.

1. Introduction

Looking towards development of modern electronic devices, it can be noticed that current tendencies are focused on continual improvement of system's efficiency, reliability and thermal stability. The main reason is the higher integration and minimization of electronic systems as they become more and more complex in the commercial area (cell-phones, tablets, PCs, white goods, etc.) as well as in the industrial (e.g. power supply units, drives and pumps). Along with these phenomena the greater emphasis has to be put on the thermal management of such devices. Taking account of complex electrical and electronic equipment and devices, it is very important to focus on proper design of thermal management during the post-prototype stage. Manufacturers of semiconductor devices target optimal thermal properties of their devices in the way of utilization of modern materials, technologies, or packaging processes. This is also due to the fact that each consumer's electronic device has to achieve international electronic standards from EMC, efficiency and thermal point of view. It can be said that all of the above mentioned criteria are mutually related to each other.

Nowadays the heat management of electronic systems comes into focus as there exit various computational fluid dynamics software systems as well as FEM based software systems which enable fast design of system's prototype with satisfactory results [1]–[5]. For such purposes a designer needs to have information regarding loss conditions of each component of the electrical system. The problem occurs in case of non-availability of such information and also when the experimental measurements of the system do not allow identifying the loss conditions. Design of exact thermal simulation model of electrical system in such situations acts as time consuming problem due to the fact, that the value of each power loss of each loss component has to be estimated. Due to these facts the development of new improved systems with better thermal behavior seems to be a really challenging issue.

In general there is a solution how to determine the value of power dissipation of the system's components and the results are satisfactory. The principle consists of the utilization of indirect computation algorithm which is able to determine the power losses of active components of an investigated system, based on the data gained by thermo-vision measurements of such system. Based on these facts there are some requirements which have to be met – thermal simulation model of investigated system and thermo-

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vision measurements during the system's operation [8]–[10].

In this paper the development procedure of simulation models and computational algorithms for indirect investigation of heat distribution in electrical and electronic systems is presented.

2. Deterministic algorithm for indirect investigation of power losses

The aim of proposed computation algorithm is to determine the power dissipation (power losses) of the active and passive components (semiconductor devices, integrated circuits, resistors, inductors, etc.) of the investigated electronic system for the purpose of thermal modeling.

The principle is based on the thermo-vision measurements of the investigated system, while the most important information is the surface temperature of individual active devices (the measurements are performed with open frame devices). Estimated power loss by deterministic algorithms is supposed to be used for development of accurate thermal models of complex electronic systems in which the information regarding the power losses of individual components is difficult to obtain in standard way. There is a reason for minimization of number of active components in order to optimize thermal simulation models [6] [7].

First, the proposed methodology is explained by the test simulation model (Fig. 1), which consists of Printed Circuit Board (PCB) and six active dissipative components (ICs, or passive devices). The geometry of the model is designed in COMSOL Multiphysics software, and all the necessary materials and physical properties together with boundary conditions are defined using utilization of predefined software libraries. Proposed methodology is based on identification of a resistance matrix of an investigated system.

Analysis is based on the fact that six devices are heated separately by power losses P_1 - P_6. This means that determination of resistance matrix is based on continuous powering of individual devices - first the 1st device is powered (P_1) and other devices 2nd – 6th are passive ($P_2 - P_6 = 0$ W), etc.

The aim of the procedure is the determination of temperature of each component in the way of modification of power losses while the value of estimated temperature should be equal to the temperature which is required (in reality which is measured within thermo-vision). Then the relationship of the investigated temperature is given by following formula:

$$\begin{Bmatrix} T_1 \\ \dots \\ T_n \end{Bmatrix} = \begin{Bmatrix} R_{ii} & \dots & R_{ij} \\ \dots & \dots & \dots \\ R_{ji} & & R_{jj} \end{Bmatrix} \times \begin{Bmatrix} P_1 \\ \dots \\ P_n \end{Bmatrix} \tag{2}$$

, where

R_{ij} - $i \neq j$, are thermal resistance values between reference points of components i and j.

R_{ii} - thermal resistance values between reference point of selected unity dissipative component and its surroundings.

2.1. Determination of R_{ij} values

The process of determination of the values of resistance matrix (R_{ij}, and R_{ii}) is based on previously mentioned "*unity power criterion*". The procedure for resistance matrix computation is as follows: First, $P_1 = 1$ W for the first device of the test model (Fig. 1) while other devices have their power losses equal to zero ($P_2 = P_3 = P_4 = P_5 = P_6 = 0$ W). Then this procedure is repeated for each device ($P_2 = 1$ W, P_1, $P_3 - P_6 = 0$ W /$P_3 = 1$ W, $P_1 - P_2 = 0$ W, $P_4 - P_6 = 0$ W, etc.). In this method the heat flow has to be understood as a current and the temperature as a voltage (3), (4). COMSOL simulation model (Fig. 1) is used for the determination of the resistance matrix based on previous description (Fig. 2).

For calculation of the each matrix resistance, next equations are used:

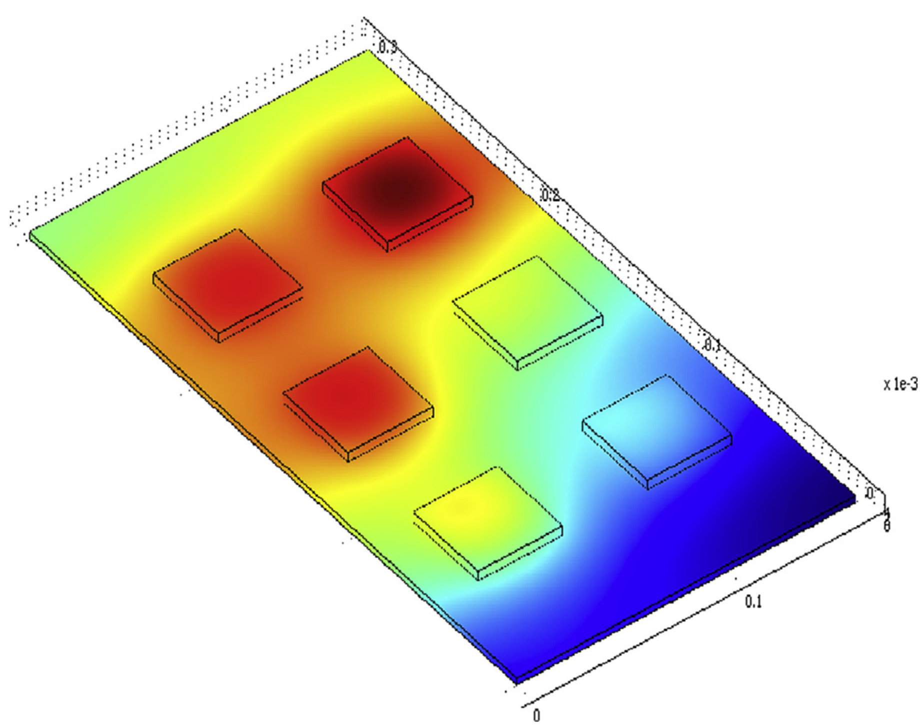

Fig. 1. Test simulation model of PCB with six dissipative devices (A – F).