Nonlinear modeling for thermal behavior on power integrated circuits

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Abstract. The growing pervasiveness of electronic devices, in many areas of everyday life, has led to an increasing demand for power electronic devices. The effective management of electric power, the high performances that the devices must have, together with their ever-increasing density, packed in very small areas, has made it imperative to examine in depth the heating of devices, the production of heat and its dissipation. In this contribution, an innovative approach to model nonlinear thermal phenomena occurring in integrated power device is presented, providing a low-cost solution in terms of computational complexity.

Introduction

The main concept is that the thermal dynamics of an electronic device is essentially a dynamic nonlinear spatiotemporal system characterized by interacting domains with different peculiarities, including material properties, heat loads and geometry. Essentially, two approaches to the problem can be considered: a Finite Element Methods (FEM), and a Lumped Parameters approach [1]. While FEMs are considered for simulating real systems with complex space-time dynamics, lumped parameters models capture the thermal response of a device as cascaded elementary RC networks. The main idea is to merge the peculiarities of FEM methods, which explicitly considers spatial extension of the device, with the lower order of lumped parameter models. In particular, the models of the phenomenon, which we will formulate, aim at representing the input-output relationship between the temperature retrieved in each area and the temperature of the 8-neighborhood formed by the proximal 8 areas at a distance of radius 1 as in Fig. 1(a) [2]. We considered a power electronics device made with SiC technology.

Results and discussion

The data provided by the solution of the finite elements model constitute the starting point for the implementation of the next step of our purpose, that is to use the same data to implement a process of identification of the phenomenon that allows the achievement of the same results, but with slightly reduced calculation and implementation efforts. As concerns the NARX model, it has been identified by using an artificial neural network, considering: two regressors for each input, with a three samples delay. The model is obtained by using 10 neurons with sigmoidal activation function. The one-step-ahead prediction related to a single point of the FE mesh is reported in Fig. 1(b). In the Harmmerstein-Wiener model, the input-output relationship of the system is decomposed into three interconnected elements: the dynamics of the system is represented by a linear transfer function, while the static nonlinearities of the system act on inputs and outputs. The nonlinearities were characterized by piecewise linear functions. The linear core of the model was identified with techniques of linear identification, using the least squares method, fixing two regressors for each input. The one-step-ahead prediction related to a single point of the FE mesh is reported in Fig. 1(c).

Comparing this result with what was obtained in the previous results, and highlighting the accuracy with which the model follows the temperature trend in a randomly assigned point of the FE mesh, the fundamental role that non-linearities play in defining the exact thermal behavior of the system, clearly emerges.

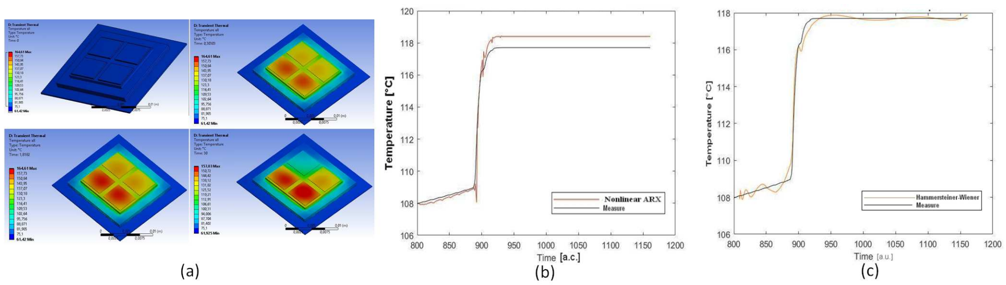

Figure 1: (a) Four different moments of the simulation; (b) One-step-ahead prediction of the temperature over a single point of the FE mesh for “Nonlinear ARX” (NARX) implemented by using neural networks; (c) One-step-ahead prediction of the temperature over a single point of the FE mesh for Hammerstein-Wiener Model” (H-WM).

References

[1] Carubelli, S. and Khatir, Z., 2003. Experimental validation of a thermal modelling method dedicated to multichip power modules in operating conditions. Microelectronics journal, 34(12), pp.1143-1151.

[2] Apicella, M.L., Buscarino, A., Corradino, C., Fortuna, L., Mazzitelli, G. and Xibilia, M.G., 2017. Temperature Model Identification of FTU Liquid Lithium Limiter. IEEE Transactions on Control Systems Technology, 26(3), pp.1132-1139.