Secondment Report Form

Secondee	Nistal González, Ismael
Host Organization	Id: IMST
	Name: IMST GmbH
Research Topic(s)	
	Thermal simulation of RF circuits for antenna front-ends

ACTIVITIES DURING THE SECONDMENT

I. INTRODUCTION

Nowadays, a crucial aspect in electronic designs is thermal analysis, which aims at predicting the working temperature of a device. This analysis can be performed using various software tools and Computational Fluid Dynamics (CFD) simulators. Yet, these are not always available for RF designers, and moreover the complexity of the system may require long simulation times. The model presented here can be easily implemented into existing electromagnetic simulation software with acceptable levels of simulation time. The thermal-electrical analogy was used in order to evaluate the heat distribution on the surface of an electronic device. The main mechanisms of heat transfer, namely conduction, convection and radiation, were integrated in the model. Empire XCcel™ [1] was used for the simulations. This is a versatile and powerful 3D-EM solver based on the FDTD method. The simulation results and the accuracy of the method were validated by measuring a set of PCBs using an infra-red (IR) camera.

II. THERMAL-ELECTRICAL ANALOGY

Due to the similarity between thermal and electrical conduction, it is possible to perform thermal analysis using an EM solver. Indeed, Poisson´s equation for electrical charge can be assimilated to the heat-equation in the steady state [2] by using the following transformations shown in TABLE I.

TABLE I. THERMAL-ELECTRICAL ANALOGY CONVERSION TABLE.

Electrical	Thermal
Voltage (V)	Temperature (K)
Current (A)	Power (W)
Electrical Conductivity ($\Omega^{-1}m^{-1}$)	Thermal Conductivity (W/(mK))
Electrical Resistance (Ω)	Thermal Resistance (K/W)

III. METHOD

Using the proposed analogy, the 3D-EM solver has to be initialized with the following requirements:

1) The electrical conductivity of the materials has to contain its specific thermal conductivity.
2) Special components such as coolers or chip packages are simulated as electrical resistances with the thermal resistance value provided by the manufacturer.
3) Thermal power sources are modeled using electrical current sources.
4) DC simulation is used to get the thermal solution in the steady state.

It is common practice to perform a simple thermal analysis once the thermal characteristics of the components to be used are known. For example, using the thermal conductivity of the materials, the junction-to-case thermal resistance of the chip (ability to dissipate heat from the surface of the die to the outside surface of the package), the heatsink-to-ambient thermal resistance if necessary (which includes convection and radiation as well), and neglecting natural convection and radiation elsewhere, it is possible to predict the temperature and even the heat distribution using the proposed solution. Actually, when the convective (and radiative) heat transfer coefficient h ($W/(m^2K)$) is known, it is also possible to take it into account over the structure, and simulate as a resistance in a determined area.

The problem arises when this information is not available. Moreover, it is also necessary to define in the EM solver how the air (or any other liquid/gas used for the cooling) dissipates the heat by convection and radiation.

The model proposed here is capable of predicting the temperature and heat distribution in a 3D structure under these unfavorable conditions. The main difficulty appears when calculating convection and radiation, because of their dependence on the surface temperature, which is in fact the unknown variable. A set of functions programmed in Python [3] allows executing the required simulations iteratively with Empire XCcel^{TM}.

With this method the temperature on the area exposed to the air is evaluated so that it is possible to calculate the convection and the radiation heat transfer coefficient in the steady state [4]. Since the temperature is not known in the beginning, two arbitrary initial coefficients are used. These values do not affect the final result. After the first iteration of the simulation, the temperature in the 3D structure is accessible, and the coefficients derived from it are used for the new iteration. The routine simulates the structure and calculates the coefficients until a convergence in the temperature of the structure is obtained. The main challenges were the calculation of the average temperature on the surface and the way to include these coefficients in the EM solver.

IV. COMPARISON BETWEEN SIMULATION AND MEASUREMENTS

As stated above, a set of PCBs was fabricated to compare simulation and measurement results. The proposed PCBs were made of RO4350B material, with Surface Mount Devices (SMD) resistors as heat sources. All PCBs include two main sources with 8 SMD resistors each. Both sources are connected through a copper line. 5 measurement points are defined between the two sources. An anti-glare-spray was used to cover the surface to compensate the differences in the emissivity of the materials used in the PCBs. As shown in Figure 1, Empire XCcel^{TM} delivers a good prediction of both the maximum reached temperature and the heat distribution. As additional information, the temperature of the different measurement points is also plotted in Figure 2.

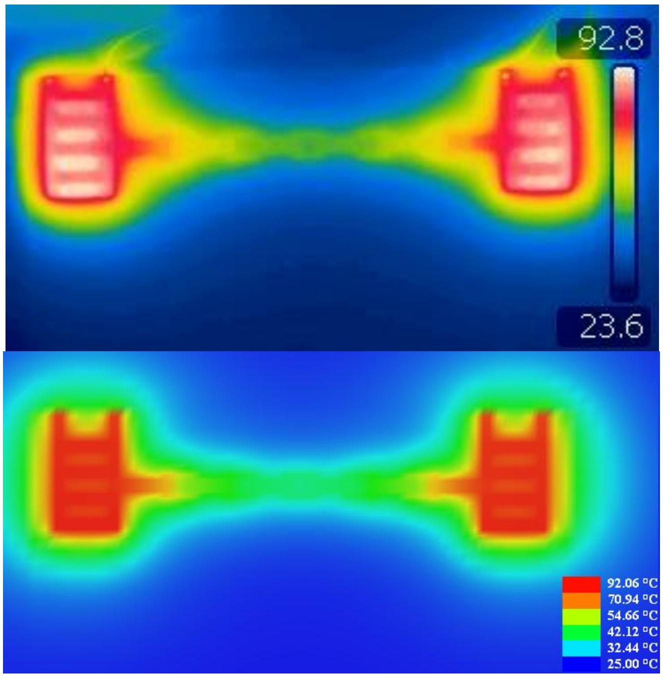

Figure 1. Heat distribution on the PCB. Measurement with an IR Camera (*top*). Simulation with Empire XCcel^{TM} (*bottom*).

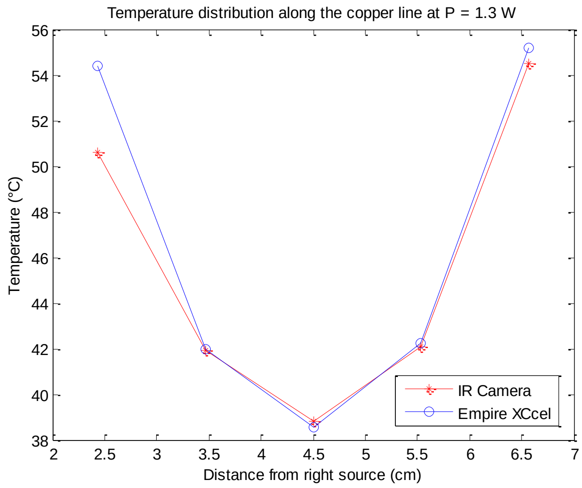

Figure 2. Temperature distribution in the measurement points.

REFERENCES

[1] EMPIRE XCcel Reference Manual, http://www.empire.de/.

[2] L. Jiang, S. Kolluri, B. J. Rubin, H. Smith, E. G. Colgan, M. R. Scheuermann, J. A. Wakil, A. Deutsch, and J. Gill, "Thermal Modeling of On-Chip Interconnects and 3D Packaging Using EM Tools," IEEE Electrical Performance of Electronic Packaging, pp. 279-282, Oct. 2008.

[3] Python documentation, http://python.org/doc/.

[4] J. H. Lienhard IV, and J. H. Lienhard V, A Heat Transfer Textbook, 4th ed. Massachussets: Phlogiston Press, 2011, pp. 399-457, 527-596.

[5] A. D. Kraus, and A. Bar-Cohen, Design and Analysis of Heat Sinks. New York: Wiley, 1995.

[6] Y. Shabany, "Radiation Heat Transfer from Plate-Fin Heat Sinks," IEEE Semiconductor Thermal Measurement and Management Symposium, pp. 132-136, Mar. 2008.

[7] P. Teertstra, M. M. Yovanovich, and J. R. Culham, "Analytical Forced Convection Modeling of Plate Fin Heat Sinks," IEEE Semiconductor Thermal Measurement and Management Symposium, pp. 34-41, Mar. 1999.

MAIN RESULTS OF THE STAY

Number of Publications: __1__

Number of Documents/ Reports: __0__

Number of Case Studies & Demonstrators: __6__

Other(s):
(1) Contribution to the adaptation of a FDTD simulator for thermal analysis
(2)____________________________________
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(3)____________________________________
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* Attach all relevant documentation that specifies your results

FORECAST ACTIVITIES

It is envisaged to test the methodology in more complex systems and validate the model for other environments, i.e. using heat-sink as the main cooling mechanism, including radiation and convection in its fins.

In order to improve CARE's secondment program, please fill this short questionnaire. Use the space at the end to expand your answers, if needed. Our aim is to improve the general experience for secondees in future.

Disagree ≺ ➤ Agree

GENERAL

My objectives were achieved.	**1** □	**2** □	**3** □	**4 x**
The research topics were relevant to my work.	**1** □	**2** □	**3** □	**4 x**
I benefited from being part of a wider research culture.	**1** □	**2** □	**3** □	**4 x**

HOST ORGANIZATION

I am satisfied with the quality and quantity of supervision I received.	**1** □	**2** □	**3** □	**4 x**
I had access to adequate resources to support my research.	**1** □	**2** □	**3** □	**4 x**

SECONDMENT PROGRAM

I would recommend this secondment programme to others.	**1** □	**2** □	**3** □	**4 x**
I believe the skills I have learned will help me to improve my job/research.	**1** □	**2** □	**3** □	**4 x**
I would apply to another programme similar to CARE.	**1** □	**2** □	**3** □	**4 x**
In general, how would you classify the CARE Secondment Programme?	**1** □	**2** □	**3** □	**4 x**

Other questions/comments to be potentially considered: ________________________________
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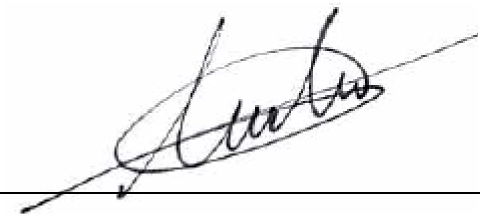
Candidate: Nistal González, Ismael **Date**: 2012/02/14



Signature ____