PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Ciro Scognamillo

Cycle: XXXV

Training and Research Activities Report

Year: First

Tutor: prof. Vincenzo d'Alessandro

Date: October 21st, 2020

1. Information:

- **PhD student: Ciro Scognamillo**
- **DR number: DR 993889**
- **Date of birth: 01/09/1995**
- **Master Science degree: Electronic Engineering**
- **University: Federico II**
- **Doctoral Cycle: XXXV°**
- **Scholarship type:** ***funded by prof. Rinaldi's family***
- **Tutor: prof. Vincenzo d'Alessandro**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Flexible two-echelon location-routing for supply networks	Seminar	1	0.2	08/11/19	Prof. Claudia Archetti	Y
A dynamic and probabilistic orienteering problem	Seminar	1	0.2	08/11/19	Prof. Claudia Archetti	Y
Lo spazio cibernetico come dominio bellico	Seminar	2	0.4	15/11/19	Dott. Gian Piero Siroli	Y
Matlab Foundamentals	Course	20	2	20/02/20–23/03/20	Prof. Agostino De Marco, Ing. Stefano Marrone, Ing. Francesco Orefice	Y
Scientific Programming and Visualization with Python	Course	20	2	27–28/02/20	Prof. Alessio Botta	Y
Computational Biology: Large scale data analysis to understand the molecular bases of human diseases	Seminar	1	0.2	09/04/2020	Prof. Michele Ceccarelli	Y
How to get published with the IEEE?	Seminar	2	0.4	20/04/20	Dr.ssa Eszter Lukacs	Y
Elettromagnetismo e salute	Seminar	1	0.2	09/04/2020	Prof. Rita Massa	N
Innovation management, entrepreneurship and intellectual property	Course	14	5	05/05/20–05/06/20	StartCup Campania	Y
Design and Implementation of Augmented Reality Software Systems	Course	20	4	05–25/06/20	Prof. Anna Rita Fasolino, Dr. Domenico Amalfitano, Dr. Domenico Irilli	Y
Access the eLearning library on IEEE Xplore	Seminar	1	0.2	04/05/2020	Eszter Lukacs	Y
Large Scale Training of Deep Neural Networks	Seminar	2.5	0.5	06/05/20	Giuseppe Fiameni, PhD	Y

Design e Nuove tecnologie: Possibili scenari per fronteggiare l'emergenza	Seminar	1	0.2	11/05/20	Amleto Picerno Ceraso	Y
La programmazione europea e la ricerca. Nuovi scenari della programmazione europea dopo il 2020. La gestione di un progetto di ricerca	Seminar	2	0.4	13/05/20	Ing. Filippo Ammirati	N
WindTre:Picus	Seminar	2	0.4	14/05/20	Ing. Marcello Savarese	N
SAS Analytics	Seminar	2	0.4	14/05/20	Dr. Cinzia Gianfiori	N
La rapidità della medicina e la velocità del cambiamento del nostro mondo organizzato da Università degli Studi di Napoli. Health 4.0.	Seminar	2	0.4	14/05/20	Paolo Netti	N
Realtà Virtuale e salute reale. Health 4.0. Dal bit alla mente: spazi virtuali per la salute	Seminar	2.5	0.5	15/05/20	Valentino Megale	N
Campi elettromagnetici pulsati: dal meccanismo d'azione alle applicazioni cliniche	Seminar	1.5	0.3	15/05/20	Dott.ssa Simona Salati	Y
Planning 5G under EMF constraints: challenges and opportunities.	Seminar	2	0.4	18/05/2020	Prof. Luca Chiaraviglio	N
SPS Webinar Series - SPACE (Signal Processing And Computational imagE formation)	Seminar	2	0.4	19/05/20	IEEE Signal Processing Society: Raja Giryes, Laura Waller, Michael Unser, Katie Bouman, Yoram Bresler, Orazio Gallo, Saiprasad Ravishankar	N
Strategie per creare un ponte tra la ricerca universitaria e le imprese	Seminar	1	0.2	19/05/20	Ateneo Webinar APEF	N
Virtual seminars on SENSING (PLASMONICA)	Seminar	4	0.8	20/05/20	Michele Marina Giordano, Chiara Novara, Riccardo Sapienza	N
Applicazioni mediche dei campi elettromagnetici basate sull'incremento di temperatura: ipertermia e ablazione	Seminar	2	0.4	22/05/2020	Prof. Marta Cavagnaro	Y
CVPL CV & ML online seminar. Bias from the wild	Seminar	2	0.4	26/05/2020	Prof. Nello Cristianini	N

Progettare per l'industria con la simulazione	Seminar	1	0.2	27/05/20	COMSOL online webinar	N
Malattie professionali da Campi Elettromagnetici tra Scienza e Giurisprudenza	Seminar	1	0.2	27/05/20	Dott. Alessandro Polichetti	N
Laboratorio virtuale gratuito con COMSOL Multiphysics®	Seminar	2	0.4	4/06/2020	COMSOL online webinar	Y
AC/DC Coil Modeling Lecture Series Session 4: Modeling 3D Coils	Seminar	1	0.2	5/06/2020	COMSOL online webinar	Y
CVPL CV & ML online seminar. Adversarial attacks on image classifiers	Seminar	2	0.4	10/06/2020	Prof. Andrea Cavallaro	N
Progettare batterie con la simulazione	Seminar	1	0.2	10/06/20	COMSOL online webinar	N
Noninvasive Mapping of Electrical Properties Using MRI	Seminar	1.5	0.3	11/06/20	Prof. Riccardo Lattanzi	Y
Exploring Autonimy in Robotic Flexible Endoscopy	Seminar	2	0.4	12/06/20	Prof. Pietro Valdastri	Y
Machine Learning	Course	18	3.6	06–17/07/20	Marco Aiello, Anna Corazza, Diego Gragnaniello, Francesco Isgrò, Roberto Prevete, Francesco Raimondi, Carlo Sansone	Y
Topics on Microelectronics	Course	17.5	5	08–10/09/20	Prof. Andrea Baschirotto, Prof. Piero Malcovati	Y
Valutazione dei livelli di esposizione e del rispetto dei limiti Antenne e 5G	Seminar	1.5	0.3	20/10/20	Prof. MD Migliore, Un Cassino e Lazio Meridionale	Y
Misure di segnali complessi nell''ambiente: Sistemi 5G	Seminar	1.5	0.3	20/10/20	Dr. D. Franci, Arpa Lazio	Y
Estrapolazioni su segnali 4G e 5G	Seminar	1.5	0.3	20/10/20	Dr. S. Adda, Arpa Piemonte, Dr. S. Pavoncelli Arpa Lazio	Y

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1 Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**0**	**0.8**	**8**	**0**	**8.8**
Bimonth 2	**0**	**0**	**10**	**0**	**10**
Bimonth 3	**4**	**0.8**	**7**	**0**	**11.8**
Bimonth 4	**9**	**8.6**	**5**	**0**	**22.4**
Bimonth 5	**3.6**	**0**	**6.4**	**0**	**10**
Bimonth 6	**5**	**1.2**	**4.5**	**0**	**10.7**
Total	**21.6**	**11.4**	**40.9**	**0**	**73.7**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3 Research activity:

My research interest focuses on electrothermal (ET) effects in electronic devices, circuits, and systems; these detrimental effects may reduce both long-term reliability and electrical performance and, in some cases, even break the devices. Thermal issues are critical because of

- the growing power density (i.e., steadily smaller devices and higher integration levels);
- the adoption of low thermally conductive materials such as oxides (e.g., silicon dioxide, SiO_2) or compound semiconductors (e.g., gallium arsenide, GaAs);
- the use of electronic devices, including photovoltaic (PV) panels, in harsh environments.

For these reasons, new technologies and circuits have to be accompanied by *thermal-aware* designs. The literature is populated by many contributions where the heat propagation and the electrothermal behavior of devices have been investigated. However, such approaches are extremely inefficient, prone-to-errors, and/or outdated and there is therefore plenty of scope for improvements and new ideas.

For the sake of clarity, I subdivided my first-year research activity into three subsections and related them to the corresponding scientific contributions:

1. - thermal and electrical investigation of state-of-the-art power modules, [1.j, 2.j];
2. - fault diagnosis in PV panels (*EMPHASIS*), [4.j];
3. - highly-efficient ET analysis of multicellular SiC MOSFETs, [3.j, 1.b].

1. Thermal and electrical investigation of state-of-the-art power modules

The increasing need for higher performance and reliability is the present-day challenge in the power electronics industry. Innovative packaging techniques are currently sought in order to provide better cooling solutions and to improve the reliability of electronic systems, even under harsh working conditions. Among the modern packaging strategies, multi-chip power modules (PMs) stand out thanks to their enhanced thermal and electrical behavior. A well-established PM technology is represented by a planar solution; here, power devices are soldered on a direct bonded copper (DBC) substrate and the interconnections between them are granted by wire bonds. Since the cooling system is typically mounted underneath the assembly, this technology is denoted as single-sided cooled (SSC). Although still widespread at commercial level, many studies highlighted the limitations of SSC PMs: (i) due to their parasitic inductive effects, wire bonds hinder the achievement of higher circuit operating frequencies; (ii) while a heavy and large baseplate ensures mechanical robustness to the PM assembly, it also precludes the adoption of these PMs in high portability applications.

For the above reasons, my research interests moved towards an alternative PM technology, which includes two DBCs assembled in a sandwich-like configuration with the power devices and their interconnections (vertical cylinders or spheres, referred to as *bumps*) embedded in between them. The resulting structure enjoys two cooling surfaces and is referred to as double-sided cooled (DSC). In [1.j], I contributed to carry out a fair comparison between SSC and DSC PMs in terms of their static and dynamic electrical behavior by means of finite-element method (FEM) simulations in the COMSOL Multiphysics software package. More specifically, the comparison was performed by varying the boundary conditions of the numerical problem in a wide range of practical interest. As a main outcome, the innovative DSC technology was found to be less convenient than the SSC counterpart unless very good boundary conditions (e.g., forced liquid coolers) are ensured.

For what concerns the merely electrical contribution [2.j], it consists in a combined experimental-FEM investigation of the electrical ruggedness in DSC PMs. Thanks to the collaboration with PRIMES Laboratories in Tarbes, France (where I spent a week as stated in the abroad period section), I contributed to manufacture several DSC PM samples with different spacing between the DBCs (that is dictated by the size of the bumps). The samples were then subjected to an incremental electrical stress and the voltages corresponding to partial discharge and dielectric breakdown were measured. Surprisingly, the reliability of DCS PMs turned out to reduce as the distance between the DBCs increased. Such reduction was quantified and related – thanks to electrostatic FEM simulations – to a *push-out effect* involving the shape of the potential lines.

2. Fault diagnosis in PV panels (*EMPHASIS*)

Smart operation and maintenance approaches are of paramount importance in improving the long-term reliability of PV modules. Infrared-based fault diagnosis emerges among them by virtue of its low costs (e.g., thanks to the use of drones) and computational efforts. In [4.j], I contributed to develop and test an *Efficient Method for PHotovoltaic Arrays Study through Infrared Scanning* (*EMPHASIS*). EMPHASIS represents an innovative analytical method for identifying malfunctioning events and failures in PV panels; in addition, it offers the capability to evaluate the electrical working conditions of the individual cells by virtue of a power balance equation embedded in the numerical tool.

To evaluate the accuracy of the proposed approach, several temperature maps were required. A typical way to obtain such maps is to exploit drones equipped with infrared cameras. However, the adoption of aerial thermal maps could have led to some limitations. First, it is not always possible to create *ad-hoc* faults (e.g., localized hotspots or shunted cells). Second, aerial IR scanning does not provide the actual cell-level powers, which – in the accuracy evaluation – were to be compared with the method predictions. For these reasons, I contributed to develop a numerical methodology aimed at obtaining extremely reliable FEM temperature maps to be fed to EMPHASIS. The methodology relies on the combination of (i) a SPICE-like macrocircuit – emulating the ET behavior of the PV panel – and (ii) an *in-house* routine that replicates the panel under investigation in the FEM environment.

As a main outcome, EMPHASIS was found to accurately localize both shunted cells and localized hotspots and the cell-level prediction error was evaluated in the range 9–16%.

3. Highly-efficient ET analysis of multicellular SiC MOSFETs

In [3.j, 1.b], I contributed to carry out highly-efficient ET analyses of SiC MOSFETs. The novelty of the methodology relies on the combined use of a model-order reduction (MOR) tool (FANTASTIC), developed by prof. Codecasa from Politecnico di Milano, and a SPICE macrocircuit replicating the transistor-level physics.

Commonly-adopted approaches are based (i) on the interaction between a circuit simulation program and a 3-D numerical thermal-only solver in a relaxation procedure, or (ii) on the extension of a finite-volume/-element software package to account for the electrical behavior of the transistor with simplified models. However, for the specific case of SiC power transistors, results can be trustworthy only by using device models that accurately describe the key physical parameters and their non-intuitive temperature dependences, which are rather different compared to the traditional Si counterparts. In addition, regardless of the technology, the pre-processing geometry/mesh construction within the environment of the thermal solver is onerous and troublesome. Lastly, these approaches are very resource-hungry and prone to convergence failures, especially if dynamic simulations under critical conditions have to be performed. In this activity, an innovative circuit-based ET simulation approach was developed for multicellular SiC power MOSFETs, with the ambition of optimizing the trade-off between computational efficiency and accuracy.

The effectiveness and efficiency of the proposed strategy have been verified on a 1200 V, 50 A multicellular 4H-SiC VDMOS. It has been shown that the simulation of short circuit and unclamped inductive switching tests requires only 300-400 s on a normal PC, despite the critical conditions and the very short time discretization, and that potentially dangerous temperature gradients/hogging can be easily identified.

4. Research products:

Journal contributions:

1.j - A. P. Catalano, **C. Scognamillo**, V. d’Alessandro, and A. Castellazzi, “Numerical analysis and analytical modeling of the thermal behavior of single- and double-sided cooled power modules,” *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 10, no. 9, pp. 1446–1453, Sep. 2020.

2.j - **C. Scognamillo**, A. P. Catalano, P. Lasserre, C. Duchesne, V. d'Alessandro, and A. Castellazzi, “Combined experimental-FEM investigation of electrical ruggedness in double-sided cooled power modules,” *Microelectronics Reliability*, 113742, 2020.

3.j - V. d’Alessandro, L. Codecasa, A. P. Catalano, and **C. Scognamillo**. “Circuit-Based Electrothermal Simulation of Multicellular SiC Power MOSFETs Using FANTASTIC,” *Energies*, vol. 13, no. 17, 4563.

4.j - A. P. Catalano, **C. Scognamillo**, P. Guerriero, S. Daliento, and V. d’Alessandro, “The use of EMPHASIS for the thermography-based fault detection in photovoltaic plants,” *Energies*, 2020. (*under review*).

Book chapters contributions:

1.b - A. P. Catalano, **C. Scognamillo**, V. d'Alessandro, L. Codecasa, "Optimum module design III: Electrothermal," in *SiC Power Module Design: Performance, robustness and reliability*, A. Castellazzi and A. Irace, IET, ch. 4. ISBN: 978-1-78561-907-6. *(in press).*

Conference contributions:

1.c - A. P. Catalano, O. Olanrewaju, **C. Scognamillo**, V. d'Alessandro, and A. Castellazzi, "Stress-induced vertical deformations in state-of-the-art power modules: an improved electro-thermo-mechanical approach," *Proc. IEEE International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, Jul. 2020.

2.c - A. P. Catalano, R. Trani, **C. Scognamillo**, V. d'Alessandro, and A. Castellazzi, "Optimization of thermal vias design in PCB-based power circuits," *Proc. IEEE International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, Jul. 2020.

3.c - **C. Scognamillo**, A. P. Catalano, R. Trani, V. d'Alessandro, and A. Castellazzi, "3-D FEM investigation on electrical ruggedness of double-sided cooling power modules," *Proc. IEEE International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, Jul. 2020.

4.c - **C. Scognamillo**, A. P. Catalano, A. Castellazzi, and V. d'Alessandro, "Numerical analysis of the thermal impact of ceramic materials in double-sided cooled power modules," *International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, Sep. 2020.

5.c - A. P. Catalano, **C. Scognamillo**, A. Castellazzi, and V. d'Alessandro, "Experimental validation of analytical models for through-PCB thermal vias," *International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, Sep. 2020.

5. Conferences and seminars attended

- *International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE)*, online conference, 6–28 Jul 2020. I presented two contributions: [2.c, 3.c].
- *International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, online conference, 14 Sep–9 Oct 2020. I presented two contributions: [4.c, 5.c].
- *European Symposium on Reliability of Electron Devices, Failure Physics and Analysis (ESREF)*, online conference, 4–8 Oct 2020. I presented one contribution: [2.j].

6. Activity abroad:

Research activity in PRIMES Laboratories (Tarbes, France) in the period 13th–17th of January.

7. Tutorship

Co-supervision of BSc student (Claudio Bovenzo) thesis on "*Development of a MATLAB script for the optimization of equivalent networks for SPICE electrothermal simulations of power modules*".