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

PhD Student: Ciro Scognamillo

Cycle: XXXV

Training and Research Activities Report

Academic year: 2020-21 - PhD Year: Second

Tutor: prof. Vincenzo d'Alessandro

Date: October 21, 2021

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PhD program in Information Technology and Electrical Engineering

PhD student: Ciro Scognamillo **Cycle: XXXV**

1. Information:

- **PhD student: Ciro Scognamillo**
- **PhD Cycle: XXXV**
- **DR number: DR 993889**
- **Date of birth: 01/09/1995**
- **Master Science degree: Electronics Engineering**
- **University: Federico II**
- **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]
SSM Scientific Colloquia:	Seminar	2	0.4	19/11/2020	Dr. Capozziello	N
SSM Scientific Colloquia:	Seminar	2	0.4	26/11/2020	Dr. Fusco	N
SSM Scientific Colloquia:	Seminar	2	0.4	03/12/2020	Dr. Bullo	N
SSM Scientific Colloquia:	Seminar	2	0.4	10/12/2020	Dr. Risaliti	N
Picariello Lectures Lesson IV: #andràtuttobene: Images, Texts, Emojis & Geodata in a Sentiment Analysis Pipeline	Seminar	1.5	0.2	25/11/2020	Prof. Serena Pelosi	Y
Picariello Lectures Lesson V: At the Nexus of Big Data, Machine Intelligence, and Human Cognition	Seminar	1.0	0.2	2/12/2020	Prof. George S. Djorgovski	Y
Picariello Lectures Lesson VI: Exploiting Deep Learning and Probabilistic Modeling for Behavior Analytics	Seminar	1.0	0.2	9/12/2020	Prof. Giuseppe Manco	Y
Picariello Lectures Lesson VII:	Seminar	2.0	0.4	16/12/2020	Marcello Savarese	Y

Data Driven Transformation in WINDTRE through Managers voice						
Picariello Lectures VIII: From Photometric Redshifts to Improved Weather Forecast an interdisciplinary view on machine learning	Seminar	1.0	0.2	13/1/2021	Prof. Kai Polsterer	Y
Picariello Lectures IX: Cybercrime and electronic evidence, The international legal framework for an effective criminal justice response	Seminar	1.0	0.2	20/1/2021	Matteo Lucchetti	Y
Picariello Lectures Lesson X: Artificial Intelligence for notary's sector - a case study	Seminar	1.0	0.2	21/1/2021	Salvatore Palange	Y
Picariello Lectures Lesson XI: The era of Industry 4.0: new frontiers in business model innovation	Seminar	1.0	0.2	3/2/2021	Marco Balzano	Y
Picariello Lectures Lesson XII: Machine Learning: causality lost in translation	Seminar	1.5	0.2	10/2/2021	Edwin A. Valentjin	Y
Picariello Lectures Lesson XIII: Approaches to Graph Machine Learning	Seminar	1.0	0.2	17/2/2021	Miroslav Cepek	Y
SSM Scientific Colloquia	Seminar	2	0.4	14/01/2021	Dr. Juergen Kurths	N
SSM Scientific Colloquia	Seminar	2	0.4	28/01/2021	Dr. Rosario Fazio	N
SSM Scientific Colloquia	Seminar	2	0.4	04/02/2021	Dr. Massimo Porfiri	N
SSM Scientific Colloquia	Seminar	1	0.2	18/02/2021	Dr. Francesco Solombrino	N
SSM Scientific Colloquia	Seminar	2	0.4	18/03/2021	Dr. Auricchio	N

SSM Scientific Colloquia	Seminar	2	0.4	25/03/2021	Dr. Longo	N
SSM Scientific Colloquia	Seminar	2	0.4	01/04/2021	Dr. Musolesi	N
Picariello Lectures Lesson XIV: Visual Interaction and Communication in Data Science	Seminar	2.0	0.4	3/3/2021	Marco Quartulli	Y
Picariello Lectures Lesson XV: Big Data and Computational Linguistics	Seminar	2.0	0.4	10/3/2021	Francesco Cotugno	Y
Picariello Lectures Lesson XVI: Sensoria Health	Seminar	1.0	0.2	17/3/2021	Stefano Rossotti	Y
Picariello Lectures Lesson XVII: The coming revolution of Data driven Discovery	Seminar	1.5	0.2	25/3/2021	Prof. Giuseppe Longo	Y
Picariello Lectures Lesson XVIII: DoveAndiamoDomani - Deep Tech	Seminar	1.5	0.2	28/4/2021	Francesco Matteucci	Y
Picariello Lectures Lesson XIX: Artificial Intelligence and 5G combined with holographic technology: a new perspective for remote health monitoring	Seminar	2.0	0.4	26/5/2021	Dr. Pietro Ferraro Dr. Pasquale Memmolo	Y
Picariello Lectures Lesson XX: Distributional Semantics Methods: How Linguistic features can improve the semantic representation	Seminar	2.0	0.4	23/6/2021	Alessandro Maisto Flora Amato	Y
MATLAB Associate Certification	Course	20	3.0	13/07/2021	Mathworks	Y
Real Time Embedded Systems	Course	10	2.5	13/05/2021 – 15/07/2021	Prof. Cilardo Prof. Cinque	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**	**2.6**	**6.8**	**0**	**9.4**
Bimonth 2	**0**	**2.6**	**5.0**	**0**	**7.6**
Bimonth 3	**0**	**2.6**	**7.0**	**0**	**9.6**
Bimonth 4	**0**	**0.8**	**7.2**	**0**	**8.0**
Bimonth 5	**5.5**	**0**	**8**	**0**	**13.5**
Bimonth 6	**0**	**0**	**10**	**0**	**10**
Total	**5.5** (+ 21.6 first year)	**8.6** (+ 11.1 first year)	**44.0** (+ 40.9 first year)	**0** (+ 0 first year)	**58.1** (+ 73.4 first year)
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

During my second year, I have been studying electrothermal (ET) effects in InGaP/GaAs HBTs and power modules; in addition, I focused on thermal and ET modeling of such devices, in order to build fast, efficient, and accurate SPICE-like circuits replicating their ET behavior. On the other hand, I contributed to develop and test EMPHASIS (*Efficient Method for PHotovoltaic Arrays Study through Infrared Scanning*), which is an analytical method devoted to the diagnosis and fault detection in PV panels.

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

1. - thermal investigation and ET modeling of InGaP/GaAs and SiGe HBTs, [1.j, 2.j];
2. - thermal investigation and ET modeling of power modules, [3.j, 1.c, 2.c];
3. - fault diagnosis in PV panels (*EMPHASIS*), [3.c];
4. - ballasting networks in RF power amplifiers.

1. Thermal investigation and ET modeling of InGaP/GaAs and SiGe HBTs

Gallium arsenide heterojunction bipolar transistors (HBTs) are the dominant technology for handset power amplifier; however, designing robust circuits with GaAs devices requires special care because of strong ET effects arising from low thermal conductivity of the substrate, lateral heat spreading counteracted by mesa isolation, and high operating currents. In this scenario, ET simulation tools are highly desired: unfortunately, the choice of the simulation approach is challenging. Full 3-D ET device simulations based on the finite-element method (FEM), e.g., with Atlas from Silvaco or Sentaurus from Synopsys, are onerous or even unviable when dealing with complex structures like practical transistor arrays.

To address this issue, SPICE-compatible ET models can be constructed: they rely on the thermal equivalent of the Ohm's law and on the full coupling between the electrical and thermal behaviors of

devices. In [1.j], I contributed to develop the ET physics-based and SPICE-compatible macrocircuit (i) by building an extremely-detailed 3-D structure of the HBTs produced by Qorvo Inc. and (ii) by tuning the Kirchhoff's transformation in order to take into account nonlinear thermal effects dictated by high temperatures.

For what concerns silicon germanium HBTs, this technology is currently used in a large variety of commercial and research applications in the mm- and even sub-mm-wave frequency spectrum, like automotive radars, high-bandwidth communication, material science, medical equipment, and optical transmission. Unfortunately, boosting the frequency performance of such transistors unavoidably leads to significant self-heating phenomena and very high thermal resistance values.

In [2.j], I contributed to investigate the *structure function* algorithm and its applicability to a SiGe:C HBT manufactured by Infineon Technologies AG within the framework of the DOTFIVE project. The structure function takes as an input the dynamic thermal response of the device and provides useful information about the layers and materials composing the assembly. In practice, it is mainly adopted to evaluate defects in the structure – e.g., voids in the insulator, delamination events. The algorithm's output is represented by a cumulative C_{TH} *vs.* cumulative R_{TH} relationship, which can be established by processing the Z_{TH} *vs.* time characteristic and analyzing the equivalent *Foster* and *Cauer* thermal networks derivable from it. At the end of the process, the heat flow through each interface can be examined, even in a markedly 3-D path.

2. Thermal investigation and ET modeling of power modules

Starting from the studies conducted during my first year, I contributed to develop a simulation-based procedure to evaluate the impact of design parameters on the performance of *any* power converter topology. More specifically, in [3.j, 1.c], a state-of-the-art power module embedding (i) a DC-DC boost converter and (ii) an inverter for photovoltaic applications was characterized and replicated in a numerical environment. In addition, an experimental campaign was preliminarily performed: it was aimed at characterizing the assembly parasitic components (i.e., series inductances and resistances, parallel capacitances). As a result, a parametric analysis was performed, which demonstrated the applicability of the tool to complex and nontrivial investigations. More specifically, the impact of the gate resistance and switching frequency was thoroughly examined by means of fast and efficient ET simulations; the efficiency of the converters was calculated and reported as figure of merit of the circuit performance.

In [2.c], the double-sided cooled PMs were investigated from the thermal point of view. I contributed to develop stationary thermal networks – that is, made up of resistances – which accurately describe the heat flow behavior, also accounting for 3-D mechanisms (i.e., shunt through vertical interconnections).

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

In the modern worldwide scenario of pollution and global warming, the photovoltaic (PV) technology has already assessed itself as a valid alternative to traditional energy sources, thus gaining the attention of governments, industries, and private citizens. Nowadays, the most important challenge in this field is to easily detect malfunctioning events in the panels embedded in both large- and small-scale PV plants. During my first year, I contributed to develop an approach denoted as EMPHASIS – which stands for *Efficient Method for the PHotovoltaic Arrays Study Through Infrared Scanning* – to aid the

cell-level diagnosis of PV panels. 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.

In [3.c], EMPHASIS was put to the test under uneven and nonuniform environmental conditions. As it happens during their lifetime, PV panels can suffer from uneven wind distribution, nonuniform ambient temperatures and/or irradiance; diagnostics method need to be reliable even in such cases. In order to prove EMPHASIS accuracy, an uneven heat transfer coefficient *h* distribution – emulating the harsh environmental condition – was applied on the panel front surface. Then, the method was applied and the estimated cell-level power distribution was compared with the reference one, which was preliminarily obtained by resorting to the *simulated experiments* methodology.

4. Ballasting networks in RF power amplifiers

An open topic is represented by ballasting networks in RF power amplifiers. Such networks are adopted to push ET instabilities – e.g., collapse of current gain – at higher voltages and currents, thus enlarging the safe operating area of devices. An industry standard consists in resorting to 400 Ω base ballasting resistors, as they provide a good trade-off between static and dynamic performances; more specifically, the former (latter) are enhanced (deteriorated) by the insertion of the base resistor.

The goal of this activity is to mitigate the drawback on the dynamic performance introduced by the ballasting network; the use of materials characterized by a resistivity with a positive temperature coefficient (i.e., the resistance of which increase with the temperature) may pave the way to more stable and efficient power amplifiers. This idea has been confirmed in simulations and I look forward to test it in a real-case scenario.

4. Research products

Journal contributions:

1.j - V. d'Alessandro, A. P. Catalano, **C. Scognamillo**, L. Codecasa, and P. J. Zampardi, "Analysis of electrothermal effects in devices and arrays in InGaP/GaAs HBT technology," *Electronics*, vol. 10, no. 6, 757, 2021.

2.j - L. Codecasa, V. d'Alessandro, A. P. Catalano, **C. Scognamillo**, D. D'Amore, and K. Aufinger, "Accurate and efficient algorithm for computing structure functions from the spatial distribution of thermal properties in electronic devices," *IEEE Transactions on Electron Devices*. (*in press*)

3.j - **C. Scognamillo**, A. P. Catalano, M. Riccio, V. d'Alessandro, L. Codecasa, A. Borghese, A. Castellazzi, G. Breglio, and A. Irace, "Compact modeling of a 3.3 kV SiC MOSFET power module for detailed circuit-level electrothermal simulations including parasitics," *Energies,* vol. 14, no. 15, 4683, 2021.

Conference contributions:

1.c - **C. Scognamillo**, A. P. Catalano, A. Borghese, M. Riccio, V. d'Alessandro, G. Breglio, A. Irace, R. N. Tripathi, A. Castellazzi, and L. Codecasa, "Electrothermal modeling, simulation, and electromagnetic characterization of a 3.3 kV SiC MOSFET power module," *Proc. International Symposium on Power Semiconductor Devices and ICs (ISPSD)*, Jun. 2021.

2.c - A. P. Catalano, **C. Scognamillo**, A. Castellazzi, L. Codecasa, and V. d'Alessandro, "Study of the thermal behavior of double-sided cooled power modules," *Proc. IEEE International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, 2021.

3.c - **C. Scognamillo**, A. P. Catalano, P. Guerriero, S. Daliento, A. Castellazzi, L. Codecasa, and V. d'Alessandro, "PV fault detection through IR thermography: using EMPHASIS under uneven environmental conditions," *Proc. IEEE International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, 2021.

5. Conferences and seminars attended

- *International Symposium on Power Semiconductor Devices and ICs (ISPSD)*, online conference, Jun. 2021. I presented one contribution: [1.c].
- *International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, online conference, Sep–Oct 2021. I presented one contribution: [3.c].

6. Periods abroad and/or in international research institutions

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7. Tutorship

- Co-supervision of BSc student (Gabriele Felaco) thesis on "*A MATLAB implementation of thermography-based approaches for the efficient and non-invasive fault detection of PV plants*".
- *50-hour tutorship assistance to 1st year courses (Fisica I, Fisica II) given to proff. Valore and Montemurro.*

8. Plan for year three

During my third year, I will be spending six (6) months at the Université de Bordeaux (FR) since October 15th. Prof. Thomas Zimmer and Dr. Sebastien Fregonese will be my scientific supervisors at the Laboratoire de l'Intégration du Matériau au Système, where I will focus on the experimental RF characterization of SiGe HBTs.

I aim at enriching the skills developed during the first two years with laboratory experience. More specifically, I will be working on state-of-the-art HBTs manufactured by ST Microelectronics and IHP; measurements up to 40 GHz will be performed through the combination of a probe station and a vector network analyzer. As figures of merit, the S-parameters (at low and high frequency), the DC characteristics and thermal impedances of devices will be extracted and analyzed.

A draft structure of my thesis follows; it will be subdivided into 2 sections, namely, power electronics and RF applications, while the methodologies and modeling techniques will be in common between the two areas.

- Introduction: electrothermal effects in electronic devices and circuits; innovative technologies offering enhanced electrical ratings at the cost of worse thermal behavior; need for fast, efficient, and accurate electrothermal simulation tools.

- Methodology: *in-house* routine devoted to automatically build and discretize complex 3-D domains; construction of SPICE-compatible compact models; extension of Szekely's structure function to markedly 3-D heatflows.
- Results and discussion
  - Power modules: comparison between single-sided and double-sided cooled technologies; electrothermal modeling of double-sided cooled power modules; electrothermal simulations of converters and inverters embedded in multi-chip SiC power modules; combined experimental-FEM investigation of the *push-out* effect in double-sided cooled power modules.
  - RF applications: electrothermal modeling of InGaP/GaAs HBTs; applicability of structure function algorithms to state-of-the-art SiGe HBTs; innovative ballasting networks enlarging the safe operating area of InGaP/GaAs HBTs.