



NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

## **New techniques for analysis, design, and control of chaotic dynamics**

### **Ph.D. candidate**

Amarnath VENKATACHALAM

### **Cycle**

XXXIX

### **Tutors**

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Prof. Arturo Buscarino

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# 1. Description of the research program

In many complex systems, the onset of chaotic dynamics can be associated with improved performance or enhanced and robust functionality. For this reason, developing methods for the analysis, design, and control of chaotic dynamics is of utmost importance. The research aims at the analysis of chaotic dynamics in electronic circuits made of single units with innovative topologies as well as configurations of coupled circuits where emergent patterns may arise. The research will also aim at the definition of new control techniques for these complex systems, including not only pairwise interactions but also interactions in groups of more than two units. Such interactions have been in fact proved to be crucial in many natural and artificial systems and engineering them (for instance in multi-agent systems such as teams of robots) paves the way to new self-organized functionalities and novel solutions for complex network services.

In more detail, in the first year two activities are planned. The first concerns the experimental investigation of the patterns that can arise in a network of up to ten Stuart-Landau electronic circuits. The board is available at the University of Catania, and has been designed in collaboration with prof. Ludovico Minati, that will also supervise this activity. The second activity concerns the analysis of a chaotic circuit, designed by prof. Frasca and prof. Minati, and based on a BJT. The aim is to derive a mathematical model, that will capture the main features of the circuit. This will allow to unveil the mechanisms generating chaos in the circuit.

In the second year, the focus will be on two-body and multi-body interactions in coupled circuits and multi-agent systems. In particular, the activity will start with the design of elementary interaction functions, that may couple three units. This step will be carried out both using numerical methods and experimental investigations of elementary coupling electronic devices. From this analysis, we expect to gain understanding of how these interactions can be exploited for designing new control laws for multi-agent systems. For this reason, the research plans to investigate first two-body interactions in multi-agent systems and then, in the third year, to fully focus on three-body or higher-order interactions in such systems.

## 2. Schedule of the research activities

### First academic year (planned)

	Description	Period	Activity abroad
Experimental investigation of patterns in coupled Stuart-Landau electronic circuits	Nonlinear systems, such as coupled Stuart-Landau circuits, often exhibit complex patterns and behaviors. Our research plans to experimentally investigate a system made by up to 10 nonlinear Stuart-Landau circuits, already available in the laboratory at the University of Catania, to detect new complex patterns and unveil the role of directionality in the onset of such patterns	November 2023 – June 2024	NO
Analysis of the double-scroll chaotic circuit based of BJT	This research activity likely involves analyzing and understanding the dynamics of specific chaotic circuits, such as the double-scroll chaotic circuit based on BJT. Our research plans to derive an approximated mathematical model capturing the main mechanisms for the onset of chaos in such circuit.	February 2024 - October 2024	NO

### Second academic year (planned)

	Description	Period	Activity abroad
Theoretical and experimental investigation of three-body interactions in chaotic circuits	Three-body interactions in chaotic systems can lead to even more complex dynamics. Our research can explore the mathematical underpinnings of such interactions, contributing to a deeper understanding of chaotic behavior. This will be the basis to build upon to develop control techniques to manage or exploit these interactions.	November 2024 – october 2025	YES  (6 months abroad, 6 months Catania)
New control techniques for MAS based on two-body interactions	Nonlinear control is essential for various applications, including multi-agent systems. We can design a controller that take advantage of the chaotic behavior for coordinated or adaptive behavior in multi-agent systems.	May 2025 – October 2025	NO

### Third academic year (planned)

	Description	Period	Activity abroad
New control techniques for MAS based on multi-body interaction.	Extending our research to multi-body interactions in nonlinear systems can provide a unique perspective on controlling and coordinating multiple agents. We can explore methods that harness the complex dynamics for improved control, synchronization, or information exchange in multi-agent systems.	November 2025 – october 2026	YES  (3 months abroad, 9 months Catania)

### 3. Training and research activities plan

#### First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Intelligent Control Systems	Jan-Feb 2024	Yes	2
	Human autonomous systems interaction	Mar-Apr 2024	Yes	1
B. Master's degree courses	Complex adaptive systems	Nov 2023 – Jan 2024	Yes	6
	Dynamic systems, Chaos and Complexity	March-June 2024	Yes	6
C. Soft skill courses				
D. Participation to seminars	Climbing the ladder: from nonlinear control to robot locomotion	13/05/2024 to 17/05/2024	No	3
	Introduction to Nonlinear Systems & Control	03/06/2024 to 07/06/2024	No	3
E. Participation to international congresses or workshops	The plan is to attend 1 conference at the end of the first year (4 days)	End of first year	No	4
F. Presentation of research products at international congresses or workshops	Presentation at the conference to be attended at the end of the year		No	2
<b>TOTAL OF ECTS FOR TRAINING ACTIVITIES</b>				<b>27</b>
G. Individual research activity	Research activity on the topics detailed above			30
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of at least one manuscript for a conference or a journal			3
<b>TOTAL OF ECTS FOR RESEARCH ACTIVITIES</b>				<b>33</b>
<b>TOTAL OF ECTS</b>				<b>60</b>

#### Second academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Participation to SIDRA PhD School		No	3
B. Master's degree courses	Nonlinear control systems	Mar 2025-June 2025	Yes	6

C. Soft skill courses	PoliBa soft skill		No	3
D. Participation to seminars	At least two other courses will be selected on the basis of the didactic offer that will be present for a.y. 2024/25		No	3
E. Participation to international congresses or workshops	The plan is to attend at least a conference in the second year	Second year	No	4
F. Presentation of research products at international congresses or workshops	The plan is to present at least one contribution at an international conference	Second year	No	2
<b>TOTAL OF ECTS FOR TRAINING ACTIVITIES</b>				<b>21</b>
G. Individual research activity	Research activity on the topics detailed above			33
H. Supervision of students	One or two master students doing thesis on subjects related to the detailed PhD research activities will be supervised			1
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of at least one manuscript for a conference or a journal			5
<b>TOTAL OF ECTS FOR RESEARCH ACTIVITIES</b>				<b>39</b>
<b>TOTAL OF ECTS</b>				<b>60</b>

### Third academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses				
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars				
E. Participation to international congresses or workshops	The plan is to attend at least a conference in the third year			4
F. Presentation of research products at international congresses or workshops	The plan is to present at least one contribution at an international conference			2
<b>TOTAL OF ECTS FOR TRAINING ACTIVITIES</b>				<b>6</b>
G. Individual research activity	Research activity on the topics detailed above			48

H. Supervision of students	One or two master students working on topics related to the PhD research activities will be supervised			1
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of at least one manuscript for a conference or a journal			5
<b>TOTAL OF ECTS FOR RESEARCH ACTIVITIES</b>				54
<b>TOTAL OF ECTS</b>				<b>60</b>

#### 4. List of the publications written by the candidate in the triennium

Not applicable at the first year.

Ph.D. student name

Amarnath Venkatachalam.



Tutor 1 name and title.

Mattia Frasca, Prof.



Tutor 2 name and title

Ludovico Minati, Prof.

Co-tutor 1 name and title

Arturo Buscarino, Prof.

Co-tutor 1 name and title

Lucia Valentina Gambuzza, Prof.

