جامعة عبد المالك السعدي
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Université Abdelmalek Essaadi

**Pole for Doctoral Studies**
**Center for Doctoral Studies Sciences, Technologies, and Medical Sciences**

# ANNOUNCEMENT OF DOCTORAL THESIS DEFENSE

Centre des Etudes Doctorales Sciences et Techniques et Sciences Médicales

**M. BELAID Hassan**

**Will present their research work with the aim of earning a Doctorate**

**Doctoral program: Sciences de l'Ingénieur**
**Discipline: Physics**
**Specialty: Photonic and Optics**

**On 03/12/2025 at 11H00 at the Meetings Hall of the National School of Applied Sciences of Tetouan, UAE**
**Under the Theme**

**Analytical and Numerical Study of Epsilon Negative (ENG) and Near-ZeroRefractive Index (NZI) BasedMetamaterials for Advanced Wireless Communication Systems**

**Front of the jury composed of :**

| First Name & Last Name | Establishment | Designation |
|---|---|---|
| Pr. MEDOURI Abdellatif | ENSA of Tetouan, UAE | President |
| Pr. ARIOUA Mounir | ENSA of Kenitra, UIT | Reviewer |
| Pr. KHOULJI Samira | ENSA of Tetouan, UAE | Reviewer |
| Pr. MAHBOUB Oussama | ENSA of Tetouan, UAE | Reviewer |
| Pr. HADDI Ali | ENSA of Tetouan, UAE | Examiner |
| Pr. NASRI Khalid | ENSA of Tetouan, UAE | Examiner |
| Pr. HAJAJI Anas | ENSA of Tetouan, UAE | Supervisor |

***Host Research Structure:*** Advanced Science and Technology Team (STA), Industrial and Civil Science and Technology Laboratory (STIC), ENSATé.

# Abstract


Electromagnetic devices have become irreplaceable in our daily lives and are the foundation of the modern technological infrastructure that our contemporary society fundamentally relies on. From smart detection systems and Internet of Things to nano-photonics and medical imaging technologies like MRI scanners, electromagnetic based devices are ubiquitous and underpin nearly every aspect of 21st-century technology, yet their performance remains constrained by the limitations of their constituent conventional materials.

Current configurations based on natural media suffer from high energy dissipation, narrow operational bandwidths, and weak nonlinear responses. Furthermore, these materials lack the ability to reduce the high ohmic losses of the electromagnetic spectrum associated with the media properties and require highly complex and expensive physical fabrication processes. More critically, those limitations are the results of the intrinsic atomic compositions of media, which is difficult to control or manipulate. This forces engineers to adopt complex designs with large electrical lengths in order to compensate for material deficiencies.

Consequently, the resulting devices often become bulky, inefficient, or limited to specific frequency ranges. Such fundamental constraints emphasizes an urgent need for alternative approaches that can transcend the limitations imposed by natural material properties.

For this aim, a new class of materials termed "metamaterial" is introduced. The recent progress of experiments on light-matter interaction phenomena now allows us to consider the design of a new generation of devices based on controlling the electromagnetic parameters of materials. In fact, metamaterials circumvent these barriers by replacing chemistry with structure, with affordable and easy implementation that can upgrade the overall electromagnetic performance of existing devices. Having said that, optical metamaterials have rapidly transitioned from a niche interest to mainstream scientific priority across multiple disciplines, especially in the past decade. Metamaterials represent one kind of synthesized composite structures that exhibit controllable and unique optical characteristics within a desired frequency range, which help achieve new and exotic electromagnetic wave interactions not attainable with regular materials. They are usually made of metallic resonant inclusions embedded in dielectric matrices with dimensions much smaller than the operational wavelength.

This dissertation is devoted to investigate the fundamental theories, working principles, computational approaches, design methodologies and optimization strategies of electromagnetic resonant metamaterials that mainly possess negative electric permittivity along with Near-Zero-Index behavior, and its applicability in improving modern advanced wireless technologies and devices operating at the microwave regime.

This PhD report presents the following key points. It begins with a precise definition of metamaterials and their historical context, followed by a detailed exploration of the underlying physical mechanisms that enable negative behavior through Maxwell's equations. The impact of material composition, geometry, and frequency scaling on the metamaterial's electromagnetic properties is thoroughly examined. A core contribution of this PhD thesis in the current efforts of Research & Development in the field of metamaterials, is the design of novel ENG (epsilon-negative) metamaterial unit cells, developed using advanced computational techniques, including the Finite Element Method (FEM), Finite Integration Technique (FIT), and the Robust Transmission-Reflection (RTR) Method for extracting the optical characteristics.

Circle enclosed square and Nested hexagonal shapes are proposed as alternatives to standard resonator architecture, and are intended to boost the functionalities of wireless antennas. FIT based electromagnetic software CST Microwave Studio was used to carry out the design, simulation, characterization and parametric optimization of the suggested ENG resonant structures. To compensate for the lack of experimental aspect of our research, FEM based numerical EM tools such as COMSOL MultiPhysics and HFSS were employed to cross-verify the simulation outputs and validate the metamaterials design, while MATLAB was used to retrieve the optical properties exploiting the S-parameters data generated from CST simulations outcomes.

The numerical results not only indicated a good improvement in the performance of the LPDA antenna when the meta-atoms were aligned as an array cover and employed above the antenna, but also achieved particularly high gain and broadband response with very low losses compared to the regular LPDA antenna at frequency band where ENG and NZI responses are observed, thereby validating the goal of this thesis. The dissertation concludes with a discussion about future metamaterial research directions, with particular emphasis on their potential integration into next-generation smart electromagnetic systems and advanced wireless communication technologies.

**Keywords** : *ADS, COMSOL MultiPhysics, CST Microwave Studio, Epsilon Negative Materials (ENG), Effective Medium Ratio (EMR), Gain Enhancement, HFSS, Metamaterial, LPDA Multiband Antenna, Near-Zero-Refractive Index Materials (NZI), Split Ring Resonator, Radar and Satellite wireless communication Systems.*