

## 6-month Master's internship (Stage de fin d'études) Complex-Valued Neural Networks for Inverse Scattering Problems

### Keywords:

Inverse problem; Wave diffraction; Deep learning; Physics-assisted neural networks; Complex-valued neural networks; Phase equivariance; Computational imaging

### Context:

The framework of this internship project lies in the field of microwave imaging, which has attracted significant interest due to its potential as a practical and efficient technique for medical systems, material characterization, remote sensing, and non-destructive testing, among others. The main objective of microwave imaging is to retrieve the distribution of dielectric properties within a region of interest. It is well known that the inverse scattering problem constitutes the fundamental formulation for microwave imaging methods. Although this problem has been extensively studied from a theoretical perspective, new methods are continuously being developed to address emerging applications.

The use of deep learning is one such recent avenue and has demonstrated strong effectiveness [1]. However, in inverse scattering problems, the governing physical equations cannot be neglected [2]. Preliminary works proposed in [3,4] show the effectiveness of combining physical equations (here, Maxwell's equations), traditional iterative methods, and learning-based approaches to improve both the efficiency and speed of inversion methods, within a framework hereafter referred to as CSINet. Nevertheless, much remains to be explored, in particular the use of complex-valued neural networks (CVNNs) [5], which extend traditional real-valued neural networks by allowing neurons and their parameters to take complex values. This is especially relevant for problems in which wave phenomena are naturally represented in the complex domain. CVNNs can directly model amplitude and phase information, thereby improving accuracy in wave-based problems while enhancing generalization capabilities in electromagnetic and acoustic inverse problems.

### Internship Objectives:

In electromagnetic inverse problems, the incident field, scattered field, and the contrast of the object to be reconstructed are all complex-valued quantities, whose phase carries rich physical information. The objective of this project is to explore the application of CVNNs to this type of problem and to compare them with conventional real-valued neural networks. In a second phase, the internship will also aim to propose methodological improvements, such as exploiting phase invariance and designing layers whose responses vary in a predictable manner when the input is multiplied by  $e^{j\phi}$ , in order to reduce training data requirements and improve model robustness.

### Internship Plan:

- Theoretical Study:
  - Understand the differences between real-valued and complex-valued neural networks (activation functions, backpropagation rules, convergence properties).
  - Explore existing complex-valued architectures ([5], [6], etc.).
  - Understand the architecture and principles of CSINet: the combination of Maxwell's equations, classical iterative schemes, and learning modules.
- Practical Implementation:
  - Start from CSINet and replace real-valued blocks with their complex-valued counterparts.
  - Rely on PyTorch extensions for complex numbers to implement these modules.
  - Define complex or mixed complex-valued loss functions.
  - Apply these models to complex-valued datasets for microwave imaging.
- Evaluation and Comparison:
  - Compare the performance of CVNNs with that of real-valued networks.
  - Analyze the impact of complex representations on accuracy, robustness, and generalization.

- **Scientific Contribution:**

- Propose methodological improvements (e.g., new complex activation functions, adapted optimization methods, handling of phase invariance).
- Write a technical report summarizing the results, potentially leading to a peer-reviewed publication.

**Potential PhD Continuation:**

The PhD framework (subject to securing funding through various doctoral funding calls) will focus on inverse problems in imaging based on learning approaches, with an emphasis on physics-assisted learning, and with potential applications in multi-physics medical imaging.

**Candidate profile:**

1. Master's student (M2) or final-year engineering student in signal/image processing, applied physics, applied mathematics, machine learning, and/or related fields.
2. Proficiency in Python and MATLAB is required; familiarity with deep learning frameworks (PyTorch or TensorFlow) is desirable.
3. Experience with inverse reconstruction algorithms would be an asset.
4. A strong interest in the interactions between AI and physics is expected.

**Practical information:**

**Duration and dates:** 6 months in 2026

**Remuneration:** Approx. 600 € per month

**Location:** Université Paris-Saclay, CentraleSupélec, Laboratoire de Génie Électrique et Électronique de Paris, 91192, Gif-sur-Yvette, France.

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