Model-based deep learning for efficient electromagnetic modelling of high-dimensional frequency selective surfaces

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1 Objectives

The main objective of the internship is to create a neural-network-based electromagnetic (EM) model of an frequency selective surface (FSS) capable of predicting its frequency response (S-parameters) from the FSS geometry and angle of incidence (AoI) of the EM wave over the surface, while avoiding heavy full-wave simulations. Physical insight will be incorporated into the structure of the proposed neural network by the use of equivalent circuits as an intermediate step in the prediction process. As a consequence, the developed method is *model-based*.

A second objective of this project is to verify and clearly demonstrate the advantage of using this model-based strategy using physical insight. To do so, another neural network will be developed, which will make predictions of the S-parameters based directly on the geometric parameters of the FSS without using any equivalent circuit. An exhaustive comparison of the performances attained by both approaches will be carried out.

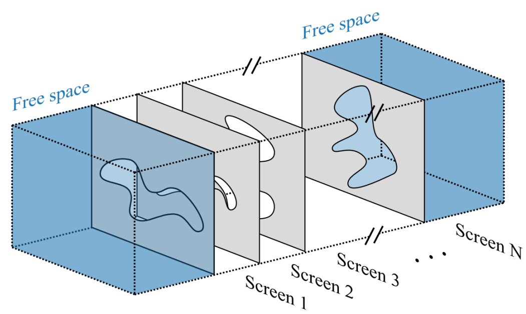

Figure 1: Example of FSS with many DoFs

2 Novelty

Model-based deep learning (DL) has been introduced recently as a trade-off between signal processing and machine learning [1] and led to promising results in various fields of signal processing for the physical layer [2–6]. On the other hand, classical machine learning methods have been applied to the design of radio-frequency (RF) structures for some time [7–11]. However, these papers do not take advantage of the underlying physics to build of model-based learning methods, and therefore still require heavy full-wave simulations. This project will be therefore the first time that model-based learning is applied to the characterization of RF devices.

3 Organization

It is envisioned to divide the intership in four stages (durations are indicative):

1. Familiarization with the problem (3 weeks)
   - The student will begin to work with the already existing code with the objective of getting a deep understanding of its functioning, the generation of the train and test datasets and the choice of the configuration parameters.
2. Verification of the advantage of model-based solutions (8 weeks)
   - The student will develop a neural network that makes predictions about the S-parameters without putting any physical insight into the model. He/she will run tests to compare the performance of this approach with the one that makes use of physical insight.
3. Integration of the angle of incidence (AoI) as an input parameter (8 weeks)

- The student will expand the model with physical insight to take into account the AoI of the waves over the FSS.

4. Close up (5 weeks)

   - The student will participate in the elaboration of a manuscript with the obtained results and he/she will also document and package all the developed code.

Regarding the mentoring of the student, Luc Le Magoarou will be in charge of providing the support regarding the neural network theory aspects, while Lucas Polo-López and María García-Vigueras will provide guidance regarding the EM modelling aspects. Moreover, all the three participants are well experienced in software developing and they will be able to help the student with any problems that may arise regarding this subject.

4 Potential outcomes

Reducing the computational burden of EM simulations with many degrees of freedom is a subject of great interest for many research fields involving electromagnetics. In fact, this DL-assisted EM modelling is one of the objectives of the future EM modelling platform that will be developed within the QOSC platform of IETR. The results of this project could be leveraged well beyond the scope of FSS, to be integrated in the platform.

In terms of dissemination, a paper submission at the end of the internship is envisioned.

5 Logistics

The internship will be hosted in the SIGNAL and SURFWAVE teams of the IETR (on the campus of INSA Rennes), for a duration of six months starting between January and March of 2024. Students in their final year (M2/PFE) with a background/interest in electromagnetics, signal processing, machine learning and applied mathematics are encouraged to apply by sending an email to luc.le-magoarou@insa-rennes.fr.

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