ScuDo
Scuola di Dottorato – Doctoral School
WHAT YOU ARE, TAKES YOU FAR

XXXVII Cycle

New paradigms in modelling of impedance and meta-surfaces for radiation and scattering for next generation industrial application

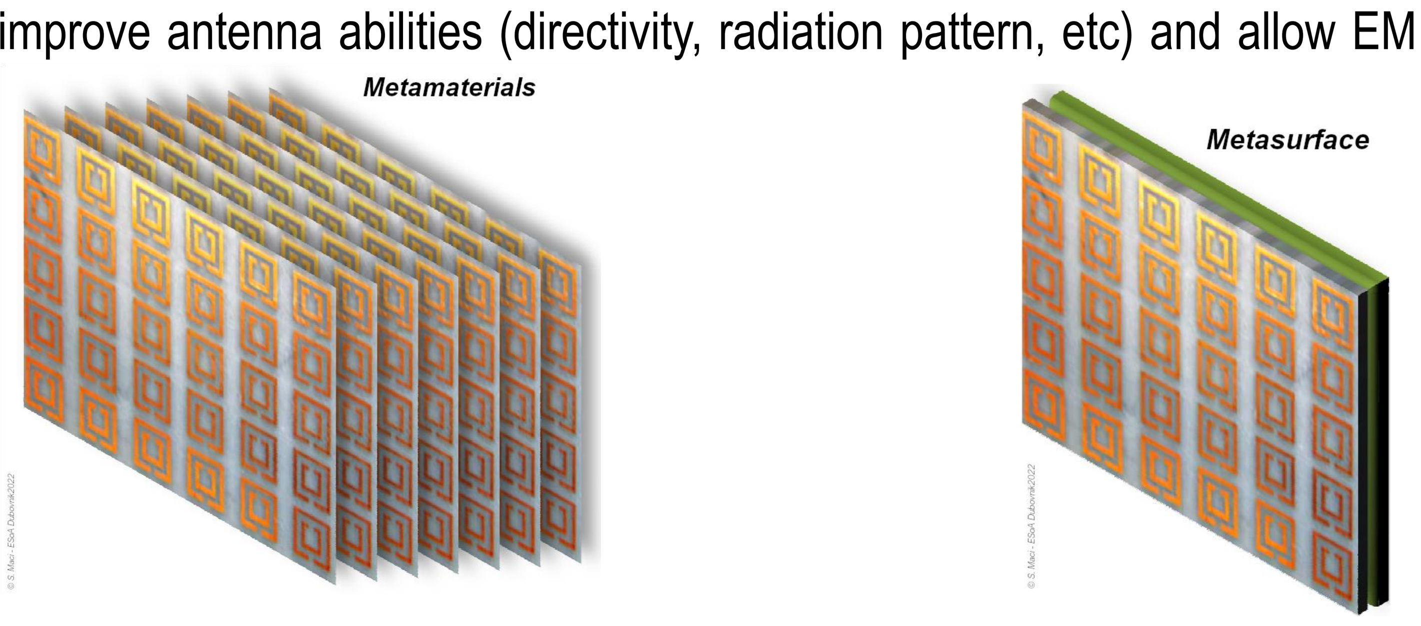
Margaux Bruliard

Supervisor: Prof. Giuseppe Vecchi

Research context and motivation

- **Metasurfaces** are thin layers of metamaterials element or unit-cell, i.e. thin layers of materials with unusual properties such as:
    - Reflection/refraction of plane waves
    - Dispersion properties of surfaces

  that can improve antenna abilities (directivity, radiation pattern, etc) and allow EM "smart skins"



- To simplify complex antenna models, **Impedance Boundary Conditions (IBC)** are used to approximate the penetration of the electromagnetic field on a short distance outside the boundary of a medium. For this reason, they **are commonly used in inverse problems,** i.e. antenna or reflecting surface design based on the radiation or scattering fields desired

- IBCs are applied in multiple configurations models such as thin dielectric sheets, perfect conductors with thin dielectric coatings, etc. For all these reasons, IBCs are very effective tools and a kernel of industrial simulators in computational electromagnetics.

Addressed research questions/problems

We consider the boundary-value problem for Maxwell equations in frequency domain (time-harmonic), and its numerical solution via Surface Integral Equation formulation and discretization via a Boundary-Element method usually called **the Method of Moments** (MoM) It involves two types of integral operators

$$\boldsymbol{L(X)(r) = -j\,\omega\mu\,\hat{n}\times\int_S G(r,r')\cdot[\,I+\frac{1}{k^2}\nabla\nabla\cdot]X(r')dr'}$$

$$\boldsymbol{K(X)(r) = \hat{n}\times\int_S \nabla G(r,r')\times X(r')dr'}$$

- The IBC are used to described a structure with sub-wavelength patterning at a larger scale, i.e in a homogenized way, in terms of a boundary condition (BC) between E an H (tangent) fields. The standard IBC is of the kind is

$$\boldsymbol{\hat{n}\times E = \overline{\overline{Z_s}}\cdot\hat{n}\times(\hat{n}\times H)}$$

- Maxwell equations with this additional BC can be conveniently solved via a surface integral equation formulation resulting in the so called **Electric Field Integral Equations (EFIE) with IBC (EFIE-IBC)**

$$\boldsymbol{L(J_s) + K\left(\overline{\overline{Z_s}}\cdot(\hat{n}\times J_s)\right) = -\,\hat{n}\times E^{inc}}$$

- While very effective and employed, this formulation still suffers from **stability issues** for some types of the surface impedance of importance in recent metasurface applications, and a few other application problems.

Can we define a mathematical Integral Equation – IBC formulation to model all relevant structures effectively and accurately?

Submitted and published works

Acknowledgments

This Ph.D. and the research associated have received funding from the European Union's Horizon 2020 research and Innovation program under the Marie Skłodowska-Curie grant agreement No 955476 and take part in the Computationally Empowered Electromagnetic Industrial Talents (COMPETE) project

COMPETE
MARIE CURIE ACTIONS

Novel contributions

The overall research is poised to address the following innovations

1. **A full stable IE-IBC formulation describing a metasurface that will:**
    - Induce a well-posed and well-conditioned MoM matrix problem
    - Incorporate the framework featuring this new formulation in a cooperative framework with other Fellows of the EU H2020 MSCA COMPETE project

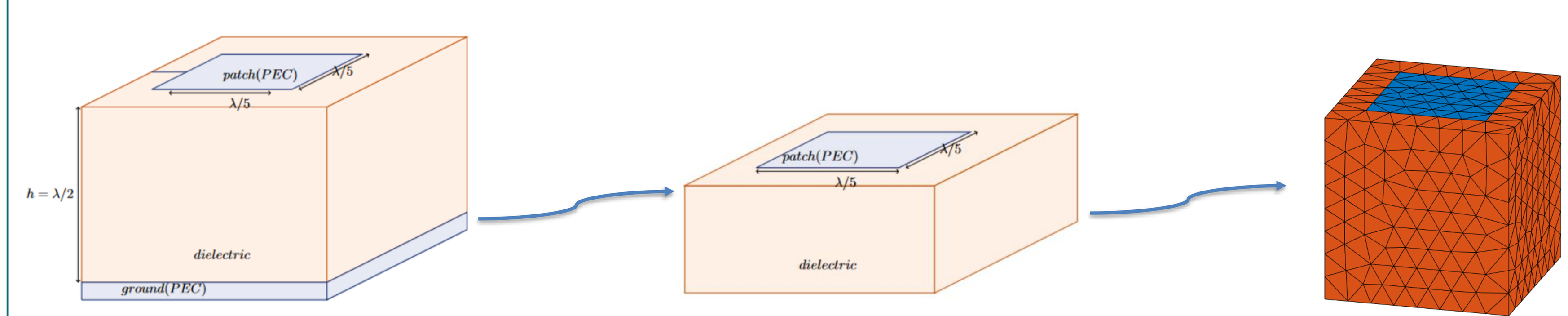
2. **Effective description of unit cells and host (platform) geometry:**

Adopted methodologies

- In order to arrive at a new formulation it is necessary to analyze in depth the mathematical properties and practical issues involved in the two involved operators L and K

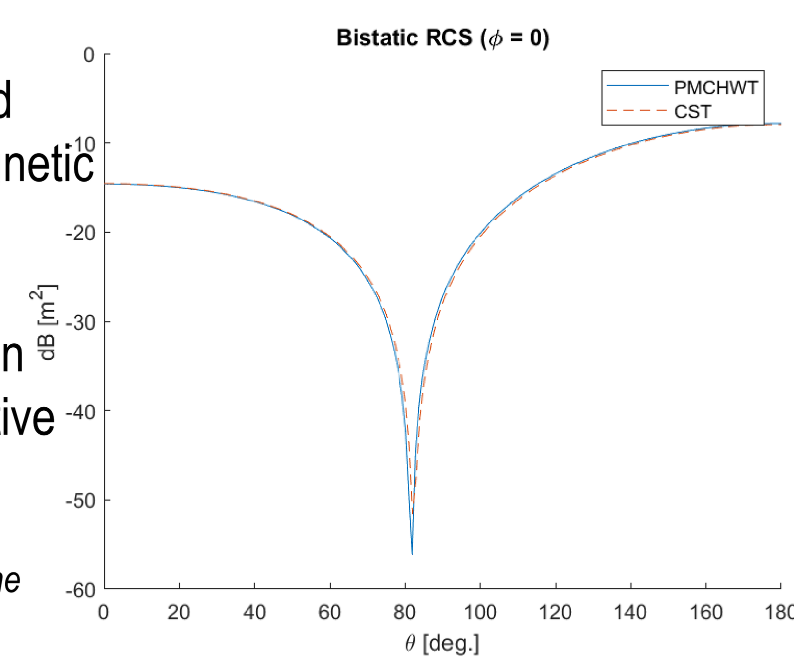
- This first part of the research has involved this study and implementation of the two operators witout IBC , which is a necessary part of the overall objective

- **Integral Equations formulations and MoM matrix build-up**
    - Building MOM code with Galerkin discretization method for elementary (im)penetrable bodies
    - Analysis of a reduced microstrip patch antenna unit-cell:



Sketch of a microstrip patch antenna *Reduced model* *Associated Mesh*

- **The Radar-Cross-Section (RCS)** computed here, represents the signature of an electromagnetic object in a far field.
- In this specific case, it is the bistatic RCS of a microstrip patch antenna of length side 0.2λ on a dielectric layer of square length 0.5λ and relative permittivity $\epsilon_{2r} = 2.2$



- *CST Studio© commercial software has been used to verify the results provided by the code developed during this Ph.D.*

Future work

- Far-Field scattering computation of a full array antenna, and analysis of model stability with and without IBC.
- Stable IE-IBC model for multi-uniaxial penetrable layers.
- Formulation of a stable IBC model for curvilinear objects: application to an aircraft radome

List of attended classes

- 01DPJRV – Lens antennas: Fundamentals and present applications (7/12/2021, 10 hours)
- 01DOBRV – Mathematical-physical theory of electromagnetism (06/06/2022, 15 hours)
- 01SFVRV – Metamaterials: Theory and Multiphysics applications (01/04/2022, 20 hours)
- 01UIZRV – Microwave Sensing and imaging for innovative applications in health and food industry (22/03/2022, 20 hours)
- European School of Antennas – Metasurfaces for Antennas (13/05/2022, 30 hours)
- European School of Antennas – Antenna Synthesis (09/09/2022, 30 hours)
- 02LWHRV – Communication (31/03/2022, 5 hours)
- 01RISRV – Public Speaking (28/02/2022, 5 hours)
- 01SYBRV – Research Integrity (21/12/2021, 5 hours)
- 02RHORV – The new Internet Society: entering the black-blox of digital innovations (08/06/2022, 6 hours)
- 01UNXRV – Thinking out of the box (01/12/2021, 1 hour)
- Nature Masterclasses : Training for researchers & scientists (24/04/2022, 12 hours)