ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE,TAKES YOU FAR

XXXII Cycle

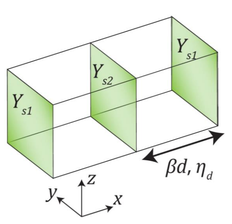
Advanced Computational Electromagnetics for Metasurfaces

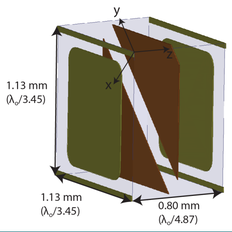
Vernì Francesco

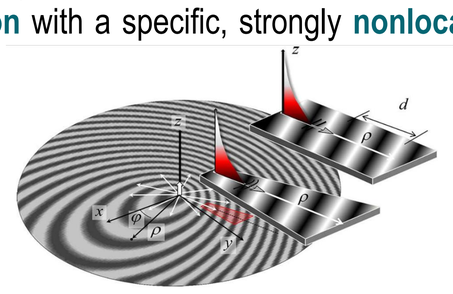
Supervisor: Prof. Vecchi Giuseppe

Research context and motivation

- **Metasurfaces** are thin metamaterial layers characterized by unusual **reflection/refraction properties** of plane waves and/or **dispersion properties** of surface/guided waves. Metasurfaces at microwave, mm-wave and optical frequencies have shown broad applicability of the work (e.g. **Antennas, Lenses, Polarizers**)
- Metasurfaces are composed of a **dense periodic** texture of **small elements** (in terms of wavelength) printed on a **dielectric slab**.
- For Metasurfaces, instead of PEC boundary condition, the exact b.c. can be approximated by the Leontovich b.c., which is also known as **Impedance Boundary Condition** (IBC). The IBC is a homogenization type of approximation for (electrically) **thin structures**.
- The IBC can also be applied to model thin dielectric sheets, perfect conductors with thin dielectric coatings, corrugated surfaces, rough surfaces, and other configurations. Because of this, the IBC approximation has been **widely used in industry**.
- Metasurfaces allow also realization of **perfect refraction and reflection** of incident plane waves into arbitrary directions. Indeed, **ideal refraction** is possible only if the metasurface is **bianisotropic** (weak spatial dispersion), and ideal reflection without polarization transformation requires **spatial dispersion** with a specific, strongly **nonlocal response to the fields**.

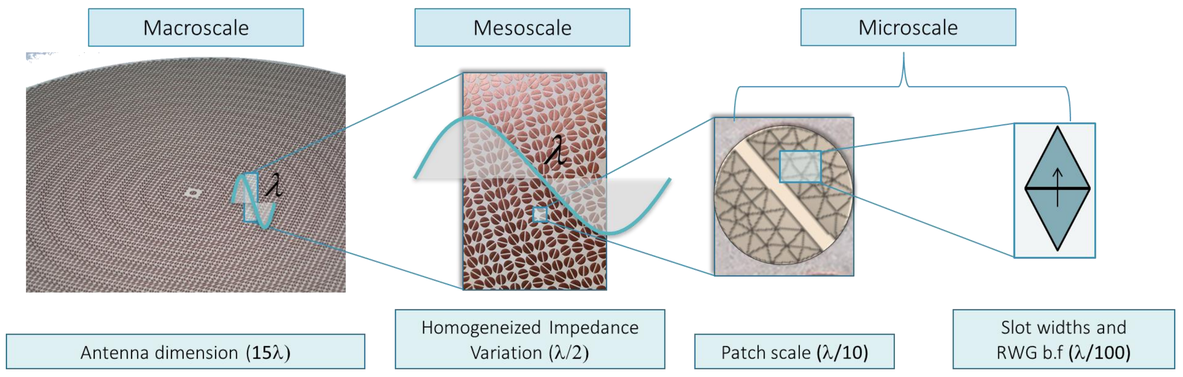






Addressed research problems

METASURFACE ANTENNA: ANALYSIS AND DESIGN



MULTISCALE PROBLEM

List of external research activities

Design via IE-MoM of Cascaded Planar Modulated Metasurfaces for Wavefront and Polarization control [Granted from **Blanceflor Foundation**]

- A. Grbic, University of Michigan (UoM), Department of Electrical Engineering and Computer Science (EECS), Ann Arbor, MI, USA.

MeTaSurface Sterable Antenna (MTSSA) Polarizer Design

- Istituto Superiore Mario Boella (ISMB), Advanced Computing and Electromagnetics (ACE), Torino.
- Universita' degli Studi di Siena (UNISI) & Wave Up s.r.l. (WU), Siena..

Submitted and published works

- F. Vernì, M. Righero, G. Vecchi, *"Analysis of Large Complex Metasurfaces Antennas With the Fast-Synthetic Approach",* 12th European Conference on Antennas and Propagation (EUCAP), London, 2018
- F. Vernì, M. Righero, G. Vecchi, *"Entire-Domain Spectral Basis Functions for the Efficient Design of Metasurface Antennas of Circular Shape*", IEEE International AP-S and USNC-URSI Radio Science Meeting, Boston, 2018
- F. Vernì, A. Grbic, G. Vecchi, *"Numerical Simulation of Cascaded Planar Metasurfaces Exhibiting Bianisotropic Properties"*, IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Boston, 2018
- E. Martini, S.C. Pavone, M. Albani, V. Martorelli, G. Giordanengo, V. Sozio, A. Ferraro, R. Beccherelli, F. Caminita, M.A. Francavilla, F. Vernì, M. Bandinelli, G. Toso, G. Vecchi, S. Maci, "*Study of reconfigurable leaky wave antennas based on liquid crystals for continuous beam scanning with a single control*", 39th ESA Antenna Workshop on Multibeam and Reconfigurable Antennas for Space Applications, 2-4 October 2018, ESA-ESTEC, The Netherlands.
- F. Vernì, M. Righero, G. Vecchi, *"Efficient Pattern Computation for Metasurface Antenna Design Scheme using Div-Conforming Annular-Ring Entire-Domain Basis Functions", Progress on Methods of Multiscale Modeling and Optimization, International ACES Symposium, Nanjing, China, August 2019*
- F. Vernì, M. Righero, G. Vecchi, *"On the Use of Entire-Domain Basis Functions and Fast-Factorizations for the Design of Modulated Metasurface*", IEEE Transactions on Antennas and Propagation, September 2019 (accepted)

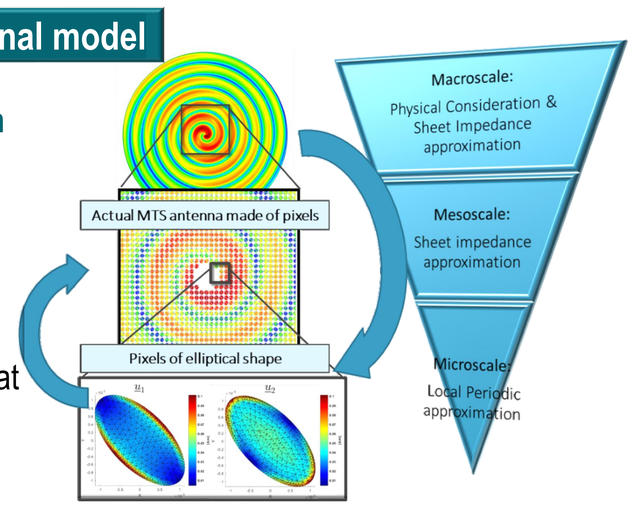
Novel contributions

- Use of Circular and Annular **div-conforming Entire Basis Functions (EBF)** suited for IBC-Electric Field Integral Equation (EFIE) and **Planar Modulated Metasurface**: **compression** of MoM system towards the minimum number of unknowns.
- **Spectral truncation** of the solution, based on spectral content of impedance profile.
- **Regularization**, improving **conditioning** properties of matrix system in **iterative solution**
- **Reduced computational costs** of a factor 100 in **optimization** problems related to the field distribution, which therefore must be known for **several impedance profiles**.
- Use of **Synthetic Function eXpansion (SFX)** for fast (via fft-based layered media) full-wave analysis of actual Metasurface made of pixels of arbitrary shapes.
- **Efficient computation** and **storage** of radiation pattern matrix and impedance profiles using EBF.

Adopted methodologies

Approximate "full-wave" computational model

- Use of **sheet impedance approximation** for macroscale and mesoscale.
- Complete **full-wave simulation** (down to pixel element level) used typically only in final, *"virtual prototyping phase".*
- Local use of **periodic solver** (single-cell) for implementing (design) the impedance at microscale.

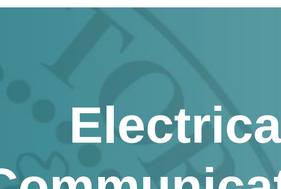


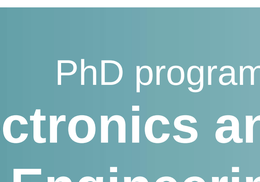
Numerical Optimization for Homogenized Impedance Synthesis

- IBC-EFIE solution via **div-conforming Entire Domain Basis Functions**
- Cost function determined using **Radiation Pattern Masks.**
- Optimization Algorithm: **Pattern Search and Particle Swarm**
- Efficient **Pattern and Tensor Impedance computation and storage via EBF.**

Future work

- Metasurfaces with electric, **magnetic and electro-magnetic/magneto-electric** responses have been recently presented for free space, wave-guiding, and antenna applications.
- Full-wave fast-solver for the design of metasurfaces with **bianisotropic** responses with a special emphasis on modulated metasurfaces, i.e. aperiodic cell arrangements. **Abrupt phase changes**, **extreme polarization control**, and even **amplitude control** are possible with these metasurfaces.
- Design of metasurfaces consisted of cascaded patterned sheets separated by **electrically-thin dielectric spacers**.





List of attended classes

- 01ROCRQ – Tensor Decomposition: Algebra, Geometry and Computational Aspect (January 2017, 20h)
- 01RONKG – Python in the Lab (February 2017, 20h)
- European School of Antennas course – Leaky Waves and Periodic Structures for Antenna Applications (April 2017, 30h)
- 01MMRRV – Advanced computational electromagnetics for antenna analysis and design (May 2017, 20h)
- European School of Antennas course – Advanced computational electromagnetics (Sept 2018, 30h)
- 01SWQRV - Responsible research and innovation, the impact on social challenges (15h)
- 01SYBRV - Research integrity (15h)
- Fall PhD School 2018 on Extreme Electromagnetic Matter Interactions - EXEMI 2018 (14h)
- EMERALD Core Transferable Skills Week
- 01SZERK – Time Management (2h)
- 01SZTRP - Computational complexity and approximation (30h)
- 01UGERO – Materials by Design – How structures meets functions (July 2019, 12h)
- 01TBDRT - Multiscale mathematical modeling in engineering, biology and medicine (February 2019, 25h)

POLITECNICO DI TORINO

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