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XXXVII Cycle

Metasurface Antennas: From Basic to Application

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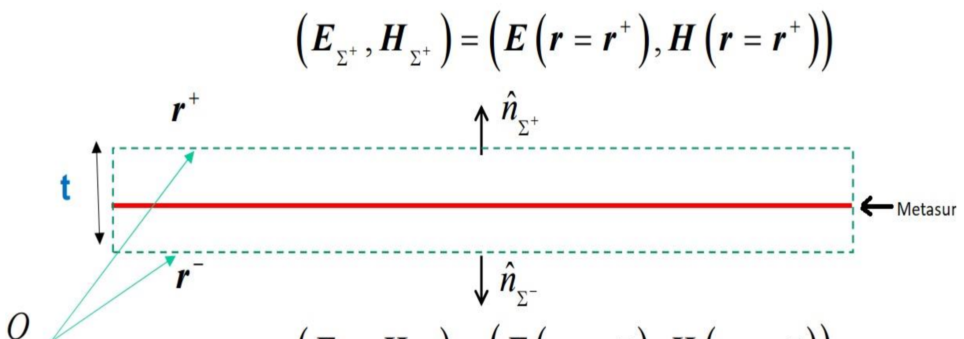
Research context and motivation

- Metamaterials are materials that are structured at a subwavelength scale to exhibit desired effective material parameters that can be those not found in nature.
- **Metasurfaces** are two-dimensional equivalents of volumetric metamaterials. As a result, they occupy less space, may exhibit lower losses, and are often simpler to fabricate than volumetric metamaterials.
- They consist of scatterers or apertures, arranged along a surface, that exhibit unusual reflection, transmission, or dispersion properties.
- Metasurfaces are distinct from classical periodic primarily because the **lattice spacing** is much smaller than a **wavelength**.
- One of the most popular applications of metasurfaces is to create **low profile**, **high gain antennas**. Typically, the surface impedance variation along the device is designed to yield a desired far field pattern.
- Metasurfaces (with some assumptions) can be described with a **surface impedance boundary condition** (**IBC**).
- **Impedance Boundary Condition** for an infinitely thin surface [1]:

$$(E_{\Sigma^+}, H_{\Sigma^+}) = (E(r=r^+), H(r=r^+))$$



$$(E_{\Sigma^-}, H_{\Sigma^-}) = (E(r=r^-), H(r=r^-))$$

$$\hat{n}_{\Sigma^-} \times H_{\Sigma^-} = -\hat{n} \times H_{\Sigma^-}$$

$$\hat{n}_{\Sigma^-} \times E_{\Sigma^-} = -\hat{n} \times E_{\Sigma^-}$$

- **Transparent IBC** Model or two-sided, relies on the tangential components of the average electric field and magnetic field jump[1]

$$\hat{\mathbf{n}} \times \mathbf{E}_{av} = \hat{\mathbf{n}} \times \left[\underline{\underline{Z}}_s \cdot (\hat{\mathbf{n}} \times (\mathbf{H}_{\Sigma^+} - \mathbf{H}_{\Sigma^-}))\right]$$

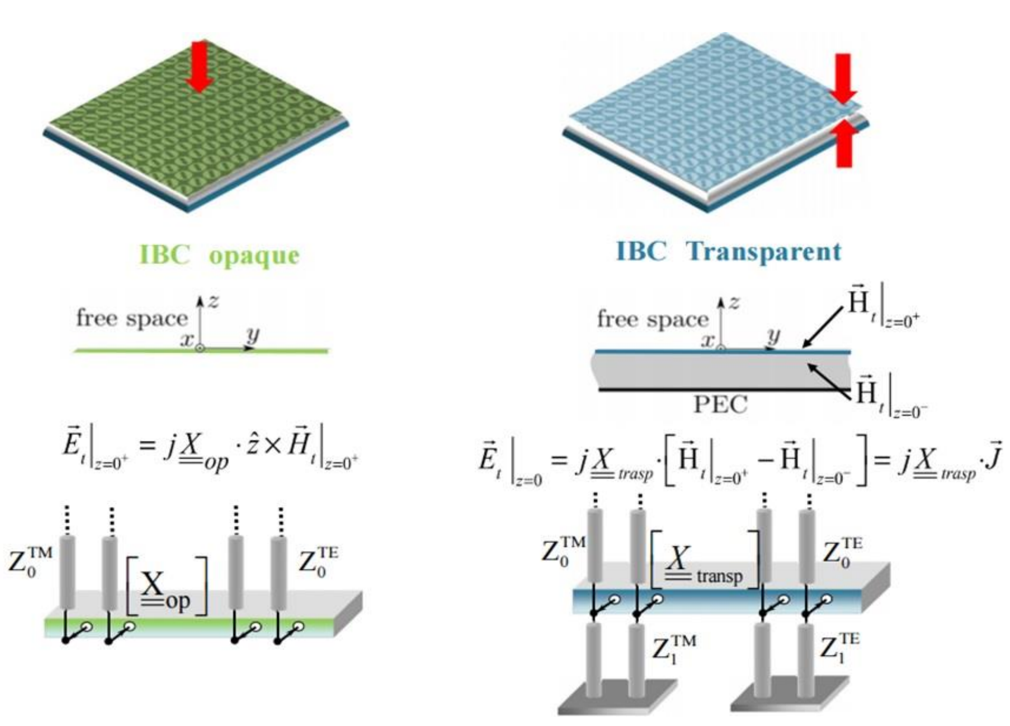
$$\underline{E}_{avg} = \tfrac{1}{2}(\underline{E}_{\Sigma^+} + \underline{E}_{\Sigma^-}) \quad \underline{J}_{eq} = \hat{n} \times (\underline{H}_{\Sigma^+} - \underline{H}_{\Sigma^-}) \quad \underline{M}_{eq} = (\hat{n} \times \underline{E})_{avg} \quad \underline{M}_{eq} = \hat{n} \times (\underline{\underline{Z}} \cdot \underline{J}_{eq})$$

- **Opaque IBC** Model or one-sided relies on the tangential components of the electric and magnetic fields on one side of the surface[1].

$$-\hat{n} \times \hat{n} \times \underline{E}_{\Sigma^+} = \underline{\underline{Z}}_s \cdot (\hat{n} \times \underline{H}_{\Sigma^+})$$

or

$$\hat{n} \times \underline{E}_{\Sigma^+} = \hat{n} \times \left[\underline{\underline{Z}}_s \cdot (\hat{n} \times \underline{H}_{\Sigma^+})\right]$$



- [1] Francavilla, M. & Martini, Enrica & Maci, S. & Vecchi, G.. (2015). On the Numerical Simulation of Metasurfaces With Impedance Boundary Condition Integral Equations. Antennas and Propagation, IEEE Transactions on. 63. 2153-2161. 10.1109/TAP.2015.2407372.

Addressed research questions/problems

- The key problem is the design of a low profile and high gain metasurface antenna.
- It is made of sub-wavelength conducting circular patches on a grounded substrate.
- The problem can be described "macroscopically" through **Transparent-IBC**
- The design is divided in two phases:

  a) Design of the surface Impedance with a commercial software
  Geometry and Properties:

Frequency	Relative permittivity	Relative permeability	Substrate thickness	Unit cell length
32 GHz	3	1	0.762 mm	2 mm

  b) Synthesis it with a EIFE-IBC code

- Pros and coins:

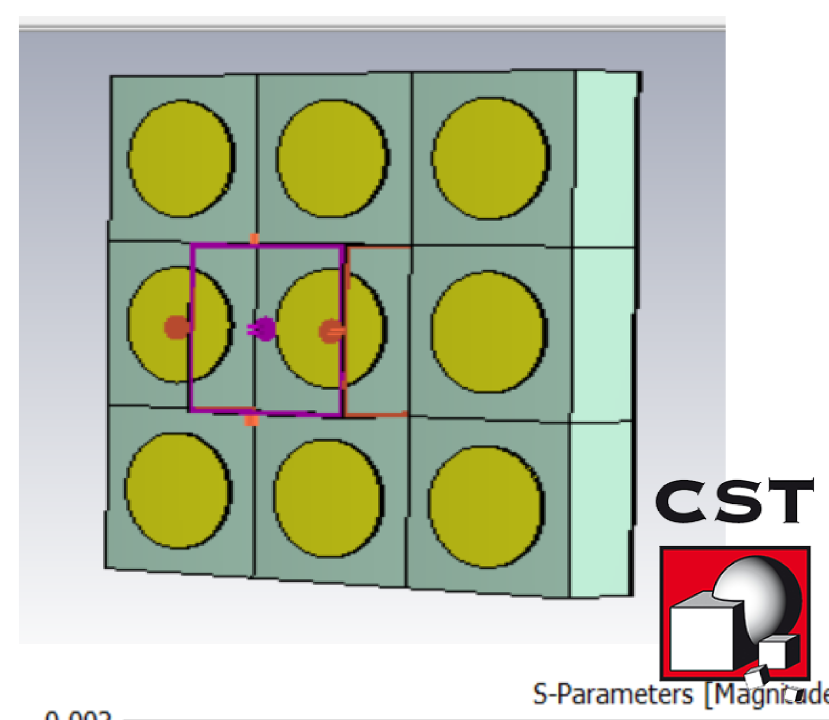
✓Computationally efficient (avoid dense meshes to discretize small elements)
✓Suitable for large antennas
✓Easier to achieve reconfigurability
✗Requires a non-linear process, theoretically and computationally challenging

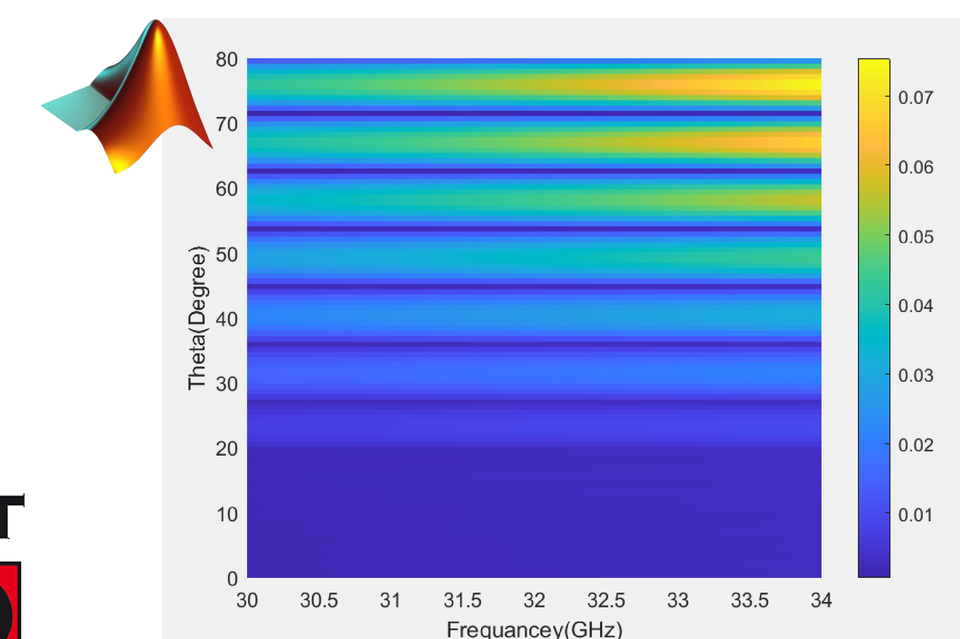
Novel contributions

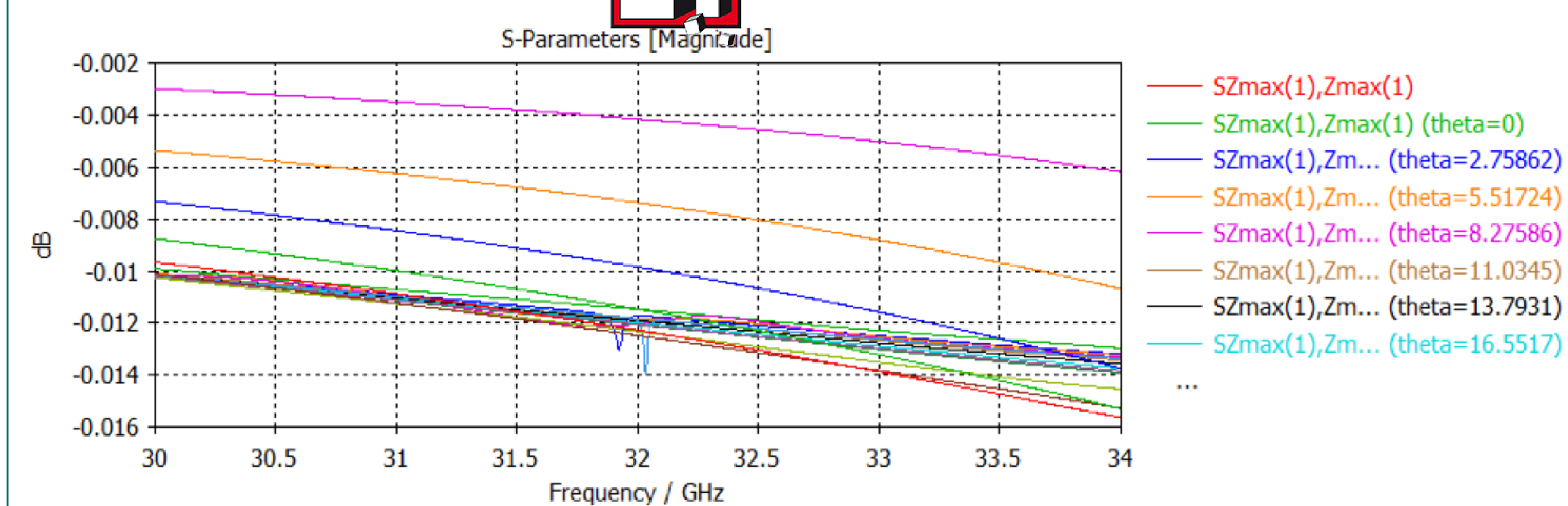
- For a general understanding of the problem, it is needed to first adopt a commercial software to simulate and see what is the deficiency of it to be improved
- In order to arrive to a complate full-wave computation of EFIE-IBC it is needed to first discritize the Integral equation using a Boundary-Element method usually called the Method of Moments (MoM) compute EIFIE-MoM.

Adopted methodologies

- Simulation using CST and Coding with Matlab
- Observing S-parameters of the general Metasurface consisting of circular patches in different observation angle using CST
- Generation absorption function of the surface using Matlab

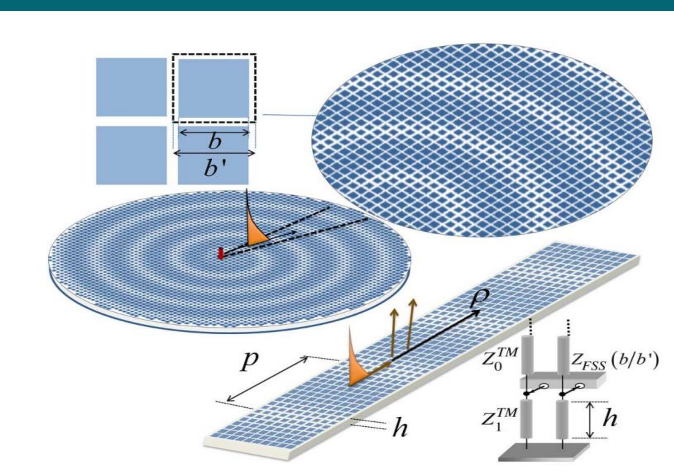






Future work

- Improve the properties of the designed unit cell
- Gradualy modulating the priodicity
- Optimization of the final system



List of attended classes

- 01TUFRV – All you need to know about research data management and open access publishing (12/4/2022, 3 CFU)
- 01SCSIU – Machine learning for pattern recognition (22/7/2022, 4 CFU)
- 01DOBRV – Mathematical-physical theory of electromagnetism (11/7/2022, 3 CFU)
- 01SFVRV – Metamaterials: Theory and Multiphysics applications (8/4/2022, 4 CFU)
- 01UIZRV – Microwave sensing and imaging for innovative applications in health and food industry (22/3/2022, 4 CFU)
- 01RGBRV – Optimization methods for engineering problems (7/6/2022, 6 CFU)
- 01QRPRV – Satellite Navigation signal exploitation for atmospheric and environmental monitoring (30/6/2022, 3 CFU)
- 01DOCRV – The Hitchhiker's Guide to the Academic Galaxy (16/6/2022, 4 CFU)
- 01SYBRV – Research Integrity (14/9/2022, 1 CFU)
- ESoA course 2022 – Advanced Computational EM (23/9/2022, 3 CFU)

Submitted and published works

- N/A

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering