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XXXVI Cycle

Low-Profile Beam-Scanning Antennas

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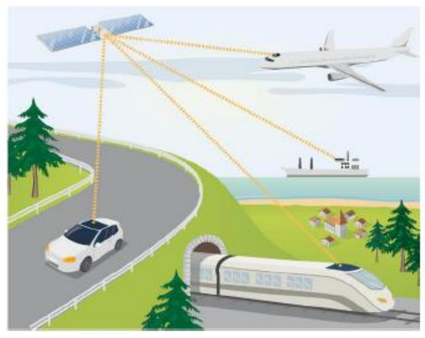
Research context and motivation

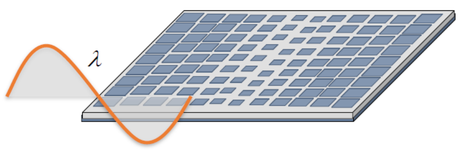
- Beam-scanning antennas have the capability of changing the direction of the main radiating beam following externally applied inputs.
- This feature is needed in all those applications that require communications between moving objects (Satcom On The Move systems, 5G, automotive radar technology,…).
- Current state-of-the-art solutions make use of electronically reconfigurable phased arrays or require the mechanical roto-tilting of the antenna. However, both approaches have drawbacks: phased arrays, although flat, are expensive and require complex feeding networks (high losses), while mechanical steering is speed-limited and requires bulky external components.



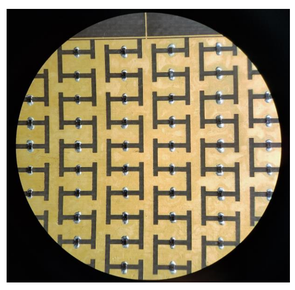
- There is a need for flat, cheap, electronically-reconfigurable antennas.

Addressed research questions/problems

- The key problem is the design and implementation of a flat, electronically-reconfigurable antenna exploiting the radiation phenomena arising in metasurfaces.
- A metasurface is a surface with sub-wavelength texture ("unit cells"). Its wave response is described in terms of a continuous surface impedance.
- Proper spatial modulation of such impedance (periodic patterning) generates wave radiation, with the beam direction depending on the phase velocity of the underlying guided wave.

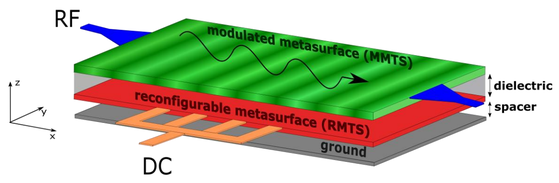


- Metasurfaces allow the realization of very thin structures in which the power distribution network and the radiating section coexist (leaky-wave paradigm).
- The idea is to realize a fixed-frequency beam scanning antenna that can be reconfigured by electronically tuning the surface impedance of (part of) the structure thanks to voltage-controlled varactor diodes.



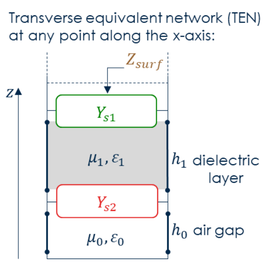
Adopted methodologies

Synergic combination of approximate analytical models and simulations



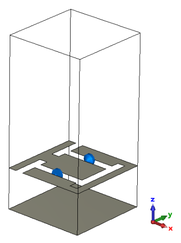
Approximate analytical model:
Transverse Resonance Technique (TRT)

- Based on the transmission equivalent network (TEN) of the antenna stack-up
- Each layer (i.e. metasurface) is represented by its sheet admittance



Commercial solver simulations

- The constitutive unit cells are studied assuming local periodicity
- Sheet admittances are retrieved from scattering simulations in a periodic environment



Design process

Choice of the unit cells' layouts and dielectric layer

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Parametric computation of the sheet admittances as functions of geometric features and/or varactor diodes' biasing state

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Use of the TRT to study the impedance profile of the antenna and the presence of guided modes

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Determination of the modulation pattern of the upper metasurface in order to obtain the desired main beam direction

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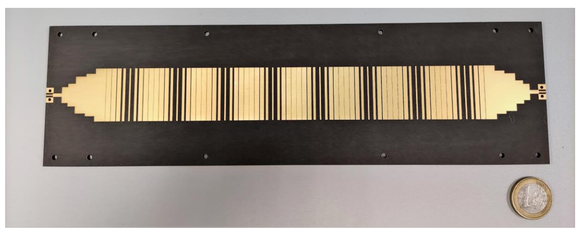
Testing of the designed solution through full-wave simulations of the complete structure

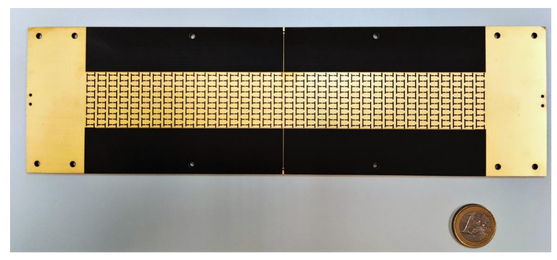
Novel contributions

Design of a multilayered structure with two (metasurface) impedance planes



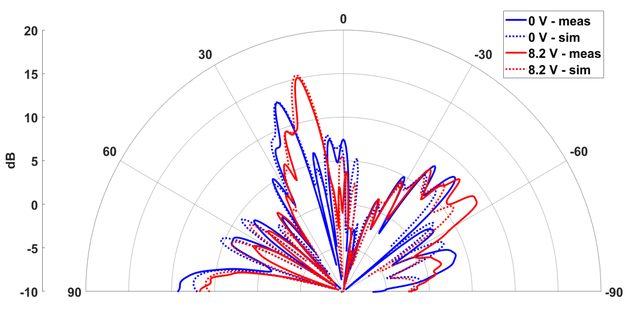
The upper modulated metasurface is responsible for radiation.

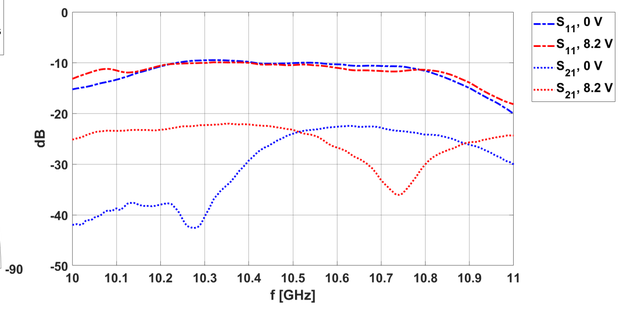
The lower reconfigurable metasurface, loaded with varactor diodes, ensures beam scanning.



Principle of operation: the lower metasurface acts as an electronically-controlled, variable-impedance plane; changing the value of such impedance affects the phase velocity of the traveling wave and, therefore, the radiation angle.

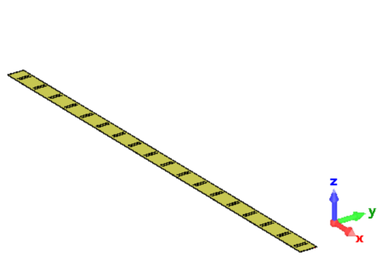
Measurements of a first prototype prove that beam scanning can be achieved with the proposed architecture (7° steering range at 10.65 GHz, total thickness less than $\lambda_0/6$).

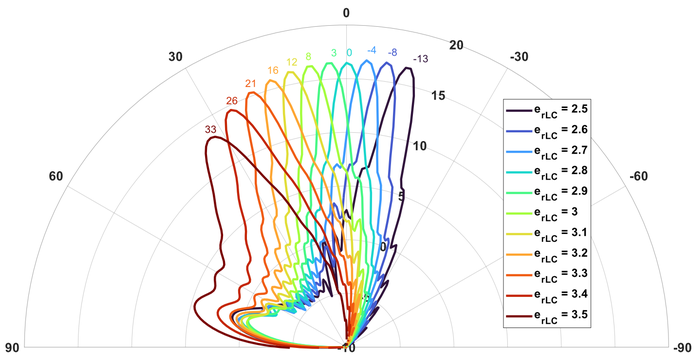




Future work

- Improvement of the scanning range of the proposed architecture
  - ➢ Design of more efficient unit cell's layouts in terms of sensitivity to varactor diodes' biasing state
  - ➢ Use of atypical modulation schemes for the upper metasurface that may reduce the sidelobes in the radiation pattern and possibly increase the scanning range
- Design of other beam-scanning architectures that rely on the tunability of Liquid Crystals (LCs) (currently in progress)
  - ➢ Large steering range
  - ➢ Very low profile
  - ➢ Possibility of 2D scan exploiting an array of antennas





Issues to fix:

- ➢ How to deal with the high material losses of LCs in the microwave range
- ➢ Design of an innovative structure to effectively bias the Liquid Crystals

Submitted and published works

- L. Teodorani, F. Vernì, G. Giordanengo, R. Gaffoglio, G. Franco, and G. Vecchi, "*Beam Scanning Leaky-Wave Antenna with a Reconfigurable Impedance Plane*", 16th European Conference on Antennas and Propagation (EuCAP), Madrid, 2022
- L. Teodorani, F. Vernì, G. Giordanengo, R. Gaffoglio, G. Franco, and G. Vecchi, "*Fixed-Frequency Beam-Scanning Antenna with a Reconfigurable Metasurface*", IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Denver, 2022
- L. Teodorani, F. Vernì, G. Giordanengo, R. Gaffoglio, and G. Vecchi, "*Low-Profile Dual-Metasurface Beam-Scanning Antenna*" (submitted)

List of attended classes

- 01MMRRV – Tecniche numeriche avanzate per l'analisi ed il progetto di antenne (9/6/2021, 20h)
- 01DPJRV – Lens antennas: Fundamentals and present applications. (didattica di eccellenza) (7/12/2021, 10h)
- 01QTEIU – Data mining concepts and algorithms (3/2/2022, 20h)
- ESoA – Leaky Waves and Periodic Structures for Antenna Applications (30/4/2021, 30h)
- ESoA – Advanced Mathematics for Antenna Analysis (21/5/2021, 26h)
- ESoA – Compressive Sensing in Electromagnetics (29/10/2021, 24h)
- ESoA – Metasurfaces for Antennas (13/5/2022, 30h)
- ESoA – Antenna Synthesis (9/9/2022, 30h)

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering