Analysis and Design of Reconfigurable Intelligent Surfaces

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PhD:

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- **MSc Degree:** Telecommunications and digital media engineering, Università degli Studi di Napoli Federico II;

- **PhD start Date**: 01/01/2023;

- **Scholarship Type:** PNRR Partenariato Esteso PE14, RESearch and innovation on future Telecommunications systems and networks (RESTART);

- **Research group:** Applied electromagnetics;

- **Research Laboratory:** Laboratorio di microonde ed onde millimetriche. Camera anecoica elettromagnetica.

Collaborations:

- Università degli Studi di Firenze, Dipartimento di Ingegneria dell'Informazione;

- Politecnico di Torino, Dipartimento di Elettronica e Telecomunicazioni;

- Consiglio Nazionale delle Ricerche, Istituto per il Rilevamento Elettromagnetico dell'Ambiente.

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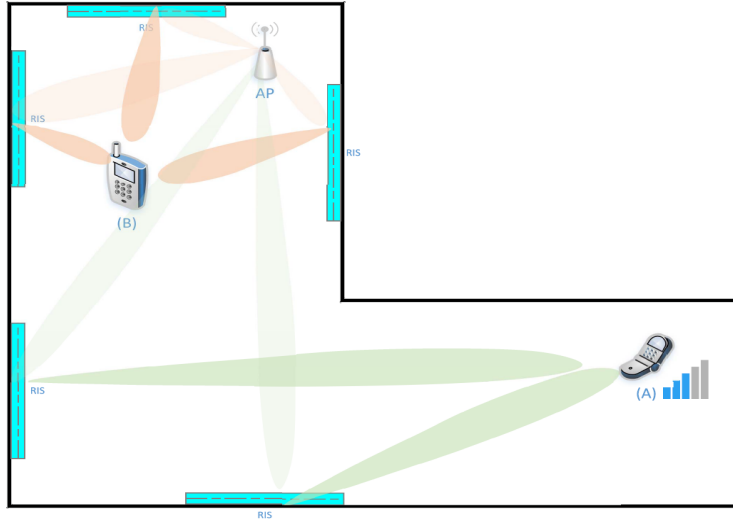
The performance of wireless channels are difficult to manage in terms of SNR (signal to noise ratio), received power, latency, reliability, high data-rate and coverage.

These goals are difficult to be achieved with traditional communication system, because of:

- use of the mm-scale wavelength;

- huge number of APs (access points) and BS' (base stations).

Reconfigurable intelligent surfaces (RIS') have evolved reflecting properties that can be achieved with:

1. Reflecting surfaces made of elements that have dimensions and spacings of approximately half a wavelength;

2. Reflecting surfaces made of sub-wavelength elements that can realize macro-elements.

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Summary of study activities
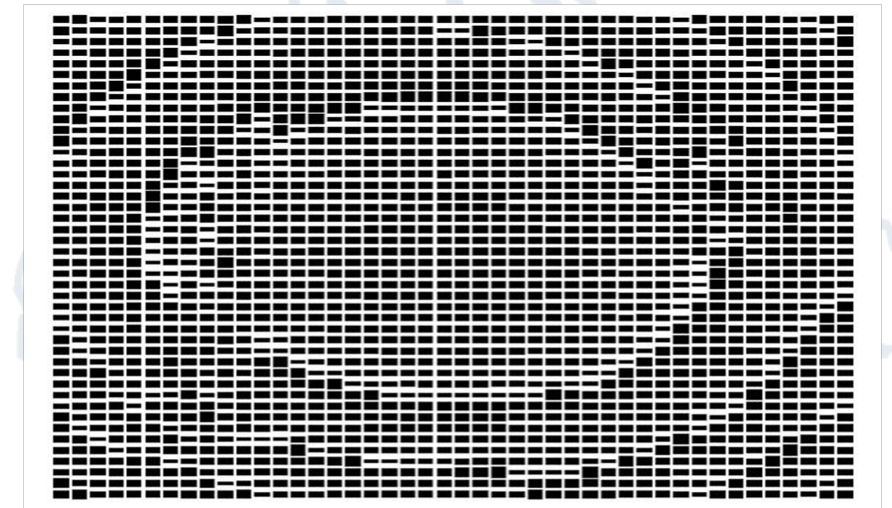
Ad hoc PhD courses	MSc Courses
How to boost your PhD	Misure a microonde e onde millimetriche
Academic entrepreneurship	

Seminars:
- How to Publish Under the CARE-CRUI Open Access Agreement with IEEE;
- Machine Learning-Enabled Optimization and Synthesis of Metasurface Antenna;
- Challenges in Antenna Measurements for Space and Defense Application;
- Ricerca e formazione nella società della transizione digitale;
- Space-Time Modulated Metasurfaces for Reconfigurable Intelligent Surface Enabled 5G/6G Communications;
- 3D-printing of hybrid structures from Meta-Atoms to dielectrics, metamaterials and antennas.
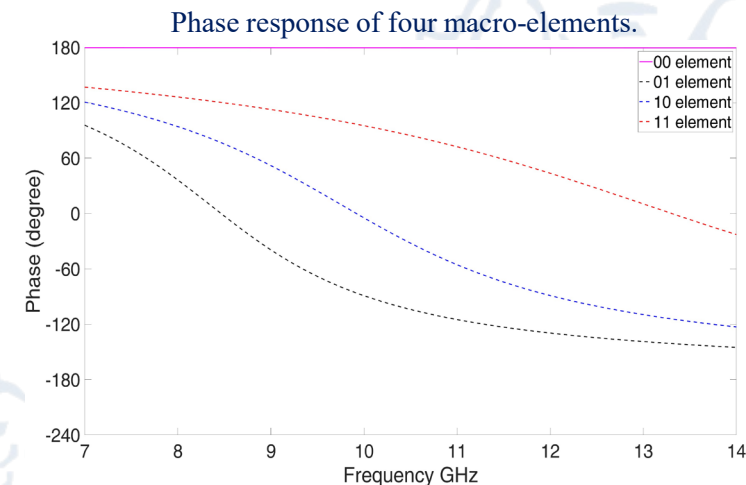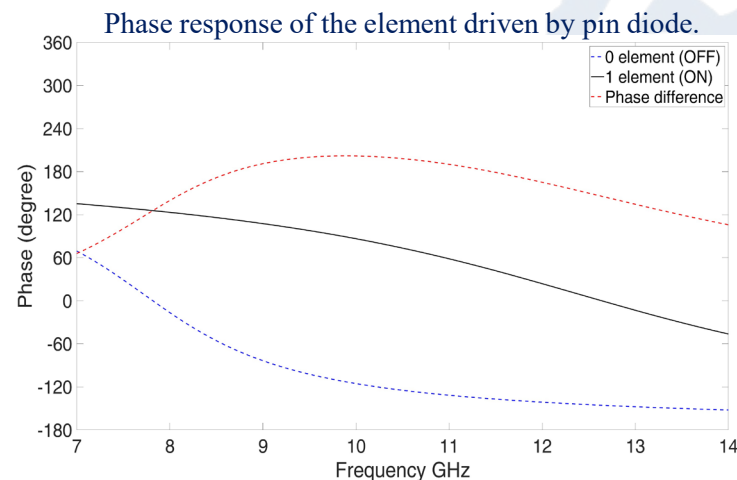
Conferences:
- *Participation as a volunteer at the 17th European Conference on Antennas and Propagation (EUCAP), in Florence (Italy), 26/03/2023-31/03/2023.*

- *Participation as speaker at the 24th International Conference on Applied Electromagnetics and Communications (ICECOM), in Dubrovnik (Croatia), 27/09/2023-29/09/2023.*

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Characterization of the element of a reflecting surface.

An analysis of the possibly state-of-the-art elements has been carried out.

Some promising approaches have been identified and replicated by setting up a simulation environment with commercial software (Ansys HFSS):

➢ the reflecting behavior of already existing elements and macro-elements has been simulated to evaluate the scattering response in amplitude and phase;

➢ the obtained results can be exploited in the synthesis process of a RIS to realize new structures with improved properties.

Phase response of the element driven by pin diode.

Phase response of four macro-elements.

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Synthesis procedure to design a RIS.

In a first step, reflecting surfaces made of elements that have dimensions and spacings of approximately half a wavelength have been considered.
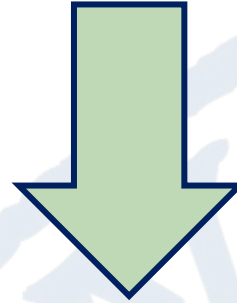
Subsequently, it will be possible to move on to the characterization of reflecting surfaces made of sub-wavelength elements.

The preliminary results have been obtained in collaboration with Università di Firenze and Politecnico di Torino.

Politecnico di Torino

UNIVERSITÀ DEGLI STUDI FIRENZE

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A multi-stage synthesis procedure developed for the case of reflectarray antennas has been updated:

- at the earlier stages, a simplified model is exploited to reduce the computational complexity;
- subsequently, more refined models are introduced to increase the accuracy, but with an increased computational complexity.

The trapping into false solutions and the computational burden are mitigated.

Scalar Phase Only model (array factor)

$$F_{co}(u,v) = \sum_{n=1}^{N} e^{-j(k_{xinc}x_n + k_{yinc}y_n + k_{zinc}z_n)} e^{j\psi_n} e^{j\beta(ux_n + vy_n + wz_n)}$$

Initially, the unknown phases have been expanded by few Zernike polynomials.

Then they have been represented by means of impulsive functions to effectively exploit the degrees of freedom of the reflecting structure.

Accurate model

$$\begin{pmatrix} F_{co} \\ F_{cr} \end{pmatrix}(u,v) = Q(u,v) \sum_{n=1}^{N} \underline{E}_{fn} S_n(u,v) e^{j\beta(ux_n + vy_n + wz_n)}$$

$S_n(u,v)$ is the scattering matrix.

$$\underline{E}_{fn} = \underline{E}_0 e^{-j(k_{xinc}x_n + k_{yinc}y_n + k_{zinc}z_n)}$$

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A reflecting surface made of 62x33 elements, spaced by d = 5.45 mm at an operating frequency of 27 GHz, has been designed. A power pattern synthesis has been considered with design specifications given by the use of masks.

The image of the directivity is shown (the dashed red lines indicate the main cuts) and zoomed into the region of interest:

U-cut, v = -0.0167 m^{-1}

BW 3 dB

$\Delta\theta = 6.5°$

V-cut, u = -0.5 m^{-1}

$\Delta\theta = 11°$
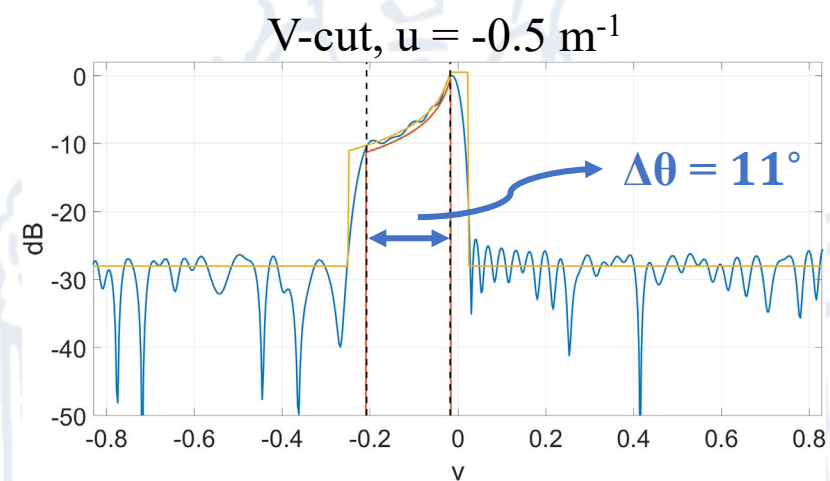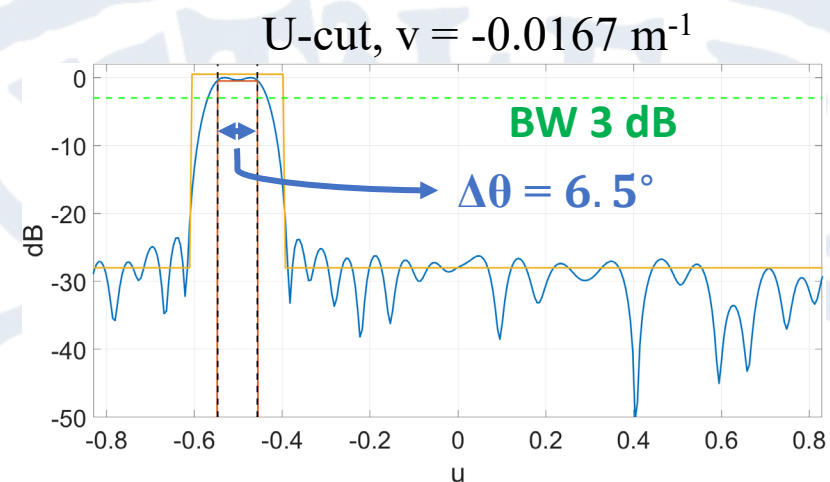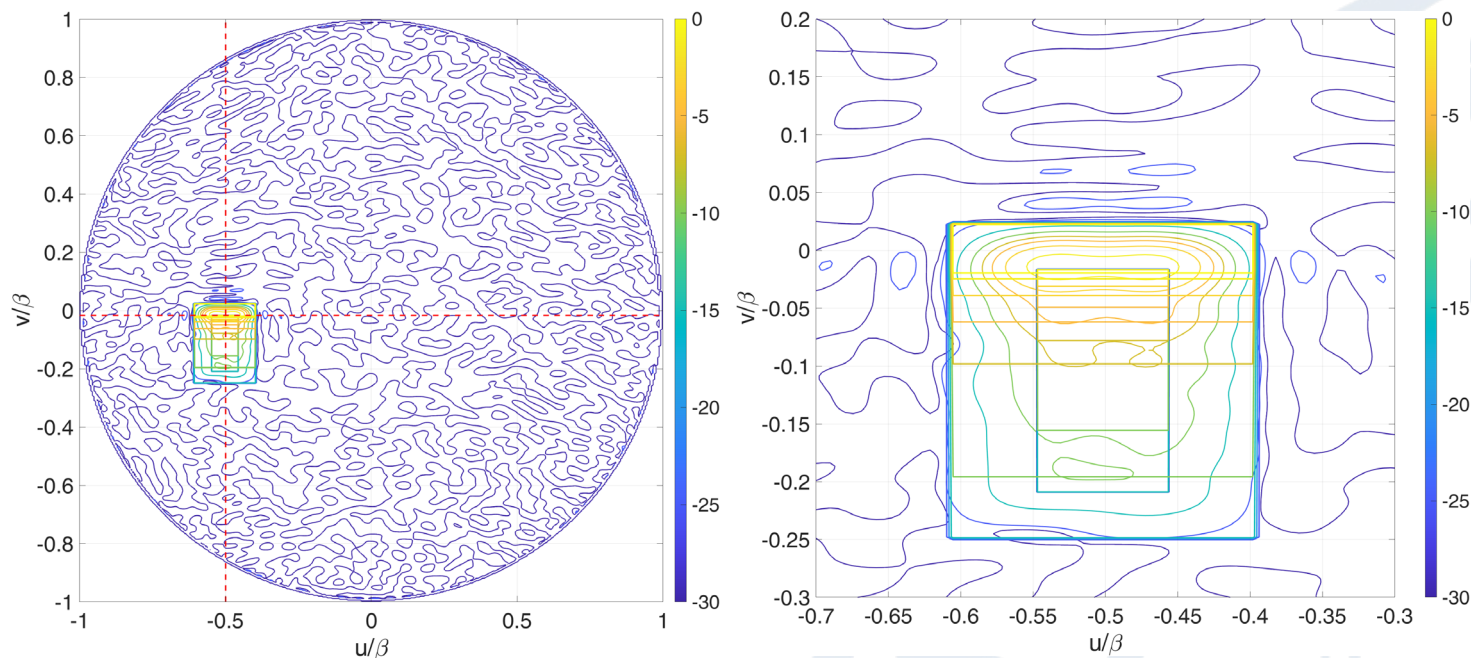
SLL	D max	D min	D mean	BW 3 dB in u
-22.05 dB	28.79 dB	16.62 dB	21.47 dB	9°

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Journal Paper:

Title: Resolution-Enhanced Electromagnetic Inverse Source: a Deep Learning Approach,

Authors: A. Capozzoli, I. Catapano, C. Curcio, G. D'Ambrosio, G. Esposito, G. Gennarelli, A. Liseno, G. Ludeno, F. Soldovieri,

Status: published,

Journal name: IEEE Antennas and Wireless Propagation Letters.

Conference Paper:

Title: A Deep Learning Approach to Electromagnetic Inverse Source,

Authors: A. Capozzoli, I. Catapano, C. Curcio, G. D'Ambrosio, G. Esposito, G. Gennarelli, A. Liseno, G. Ludeno, F. Soldovieri,

Status: published,

Conference name: 24th International Conference on Applied Electromagnetics and Communications (ICECOM), in Dubrovnik (Croatia), 27/09/2023-29/09/2023.

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Next Year

Research activities next year:

Implementation of an accurate dual polarization synthesis.

Realization of reflective surfaces made of sub-wavelength elements.

Next year's credits:

Courses:
- TOMOGRAFIA E IMAGING: PRINCIPI, ALGORITMI E METODI NUMERICI (9 CFU),
- REAL AND FUNCTIONAL ANALYSIS (9 CFU),
- IPERTERMIA E MEZZI DI CONTRASTO PER APPLICAZIONI BIOMEDICHE E RADIOFREQUENZA (9 CFU).

Doctoral school:
- ESoA Courses, 'Metasurface for antennas', 20-24 May 2024, Siena (Italy), with coordinators Prof. S. Maci and Prof. Z. Sipus.

Seminars:
- Simposio tecnico-scientifico "UNA NUOVA SFIDA: LO SVILUPPO DELLA CAPACITÀ IPERSONICA" Accademia Aeronautica Pozzuoli 9-10 Nov. 2023 (2,2 CFU).

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