



UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

itee^{PhD}
information technology
electrical engineering



Analysis and Design of Reconfigurable Intelligent Surfaces

Tutor:

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PhD:

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Cycle: XXXVIII

Year: 2023-2024 (Second)

Background

- **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 di Firenze, Dipartimento di Ingegneria dell'Informazione;
- Politecnico di Torino, Dipartimento di Elettronica e Telecomunicazioni;



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Summary of study activities

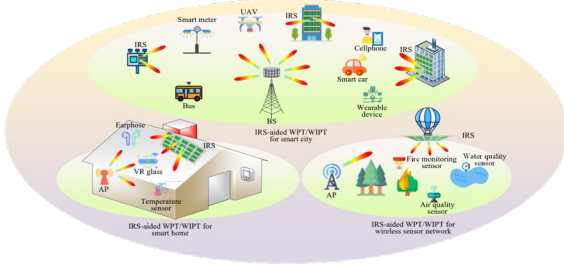
Courses:

- MSc course, “ Ipertermia e Mezzi di Contrasto per Applicazioni Biomediche a Radiofrequenza”, Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Elettrica e delle Tecnologie dell’Informazione.
- MSc course, “ Real and Functional Analysis”, Università degli Studi di Napoli Federico II, Dipartimento di Matematica e Applicazioni "Renato Caccioppoli".
- Doctoral School, “Metasurfaces for Antennas”, European School of Antennas and Propagation (ESoA) given at the University of Siena.

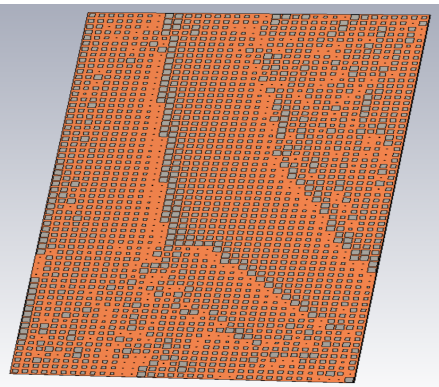
Seminars:

- Antenna Measurement Challenges and Opportunities – the Next Ten Years;
- Antenna Diagnostics - Identifying and Understanding Antenna Diseases;
- IA e 5G: Tecnologie Abilitanti per la Manutenzione Predittiva;
- 5G & Digital Transformation: A View from an Unconventional Perspective;
- Regolazione in Tema di Intelligenza Artificiale alla Luce dell’ AI Act ;
- Generative AI for Software Engineering: Strategies, Impacts, and Practical Applications.

Research activity



In recent years, in the context of wireless communication channels, reflecting surfaces (RS') have been suggested to establish alternative communication paths when transmitters and receivers are not in line-of-sight.



In the literature, for array based reflecting surfaces, two main approaches have been investigated:

1. the first one on elements that have dimensions and spacings of approximately half a wavelength;
2. the second one on sub-wavelength elements that can realize macro-elements.

This year, my research activity has regarded the first approach.

For the future, sub-wavelength elements will be taken into consideration.

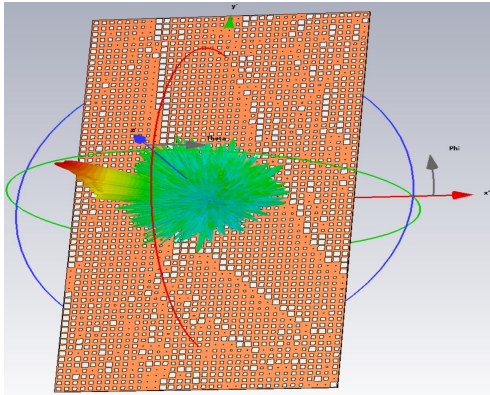
Until now, in the literature, synthesis techniques based on simplified electromagnetic models have been exploited to just achieve control of the beam's pointing direction.



More sophisticated design techniques, based on accurate models, are needed to reach advanced performance in terms of:

- side lobe level (SLL);
- beam shaping;
- beam steering and reconfigurability.

Research activity: objective and methodology



To design a large structure and to predict successfully its scattered field, the synthesis procedure must rely on an accurate scattering model.



However, an optimization algorithm that employs an accurate model presents a computational burden due to the large number of unknowns involved.

Design procedures to reduce computational burden and to keep at the same time high performance are needed.

Phase-Only synthesis – Stage A: Zernike



Phase-Only synthesis – Stage B: Impulse



Accurate synthesis



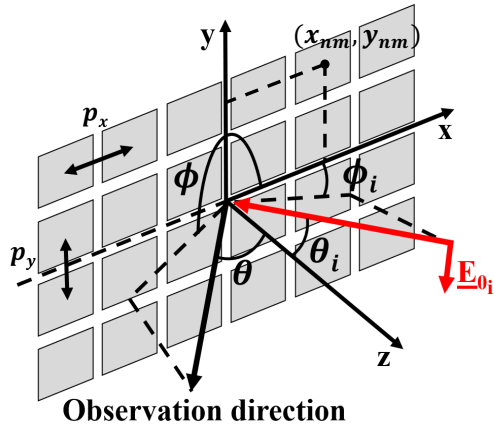
Antenna Layout

The proposed solution adopts a multi-step approach to balance accuracy and computational efficiency:

- at the first stages, a Phase-Only model with few unknowns is considered to reduce the computational complexity;
- subsequently, more refined models are introduced to increase the accuracy, but with further burden on computation.

Research activity: objective and methodology

The Phase-Only synthesis is often adopted at the initial stages of the procedure to design a reflecting surface. The advantage of a Phase-Only model is that the elements of the reflecting surface are treated as simple phase shifters.



The scattering matrix of the element is now considered.

Advanced Phase-Only model:

Flat RS, $z_{nm} = 0$

$$\underline{F}(u, v) = \underline{Q}(u, v) \underline{S}_0(u, v) \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \underline{E}_{fnm} e^{j\psi_{nm}} e^{j\beta(ux_{nm} + vy_{nm} + wz_{nm})}$$

unknown control phase

The radiated pattern is the product of the “element factor” and the “array factor”. In this way, an FFT can be exploited in the optimization algorithm.

The PO model is capable to control only the co-polar component of the radiated field pattern.

In the future conforming surfaces, with $z_{nm} \neq 0$, that fit the installation site will be considered

A locally impinging plane wave on the element (n, m) is assumed with angles of incidence (θ_i, ϕ_i) embedded in the direction cosines:

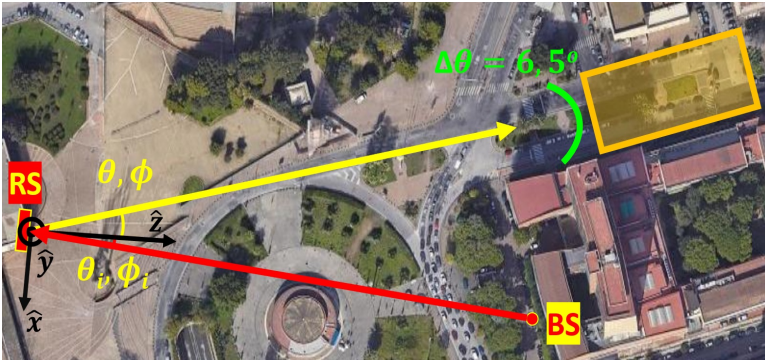
$$\underline{E}_{fmn} = \underline{E}_{0i} e^{-j(k_{xi}x_{nm} + k_{yi}y_{nm} + k_{zi}z_{nm})}$$

Flat RS, $z_{nm} = 0$

The proposed synthesis method can also be adapted to different types of primary sources.

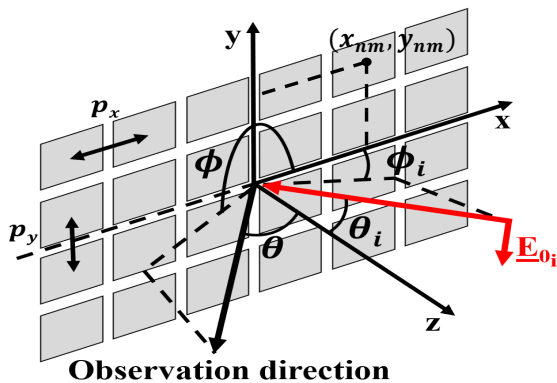
Urban scenario application

The design specifications have been enforced to improve the coverage in the urban scenario, as in the figure. Particularly, the region highlighted in orange.



A reflecting surface can be exploited to improve the street coverage:

- a flat-top beam is useful to cover the entire width of the street;
- a cosecant beam compensates the different distances of the reflecting surface to all the points along the street.



A reflecting surface operating at a frequency $f_0 = 27 \text{ GHz}$ is considered, in particular:

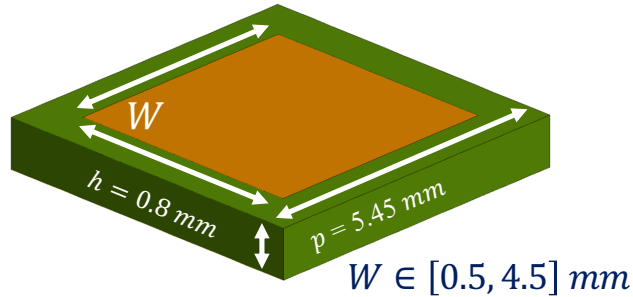
- $N = 35$ and $M = 64$ elements are arranged along x-axis and y-axis, respectively;
- the spacing between the elements is $p_x = p_y = 5.45 \text{ mm}$;
- $(\theta_i, \phi_i) = (20^\circ, 0^\circ)$ are the angles of incidence of the impinging plane wave.

The synthesized beam, tilted in the xz plane, pointing to the $(\theta, \phi) = (30^\circ, 180^\circ)$ direction:

- is flat-top in the horizontal plane (u -cut);
- has a cosecant shape in the vertical plane (v -cut).

Unit-cell

The choice of radiating elements plays a significant role in terms of radiation characteristics, bandwidth, and polarization control.



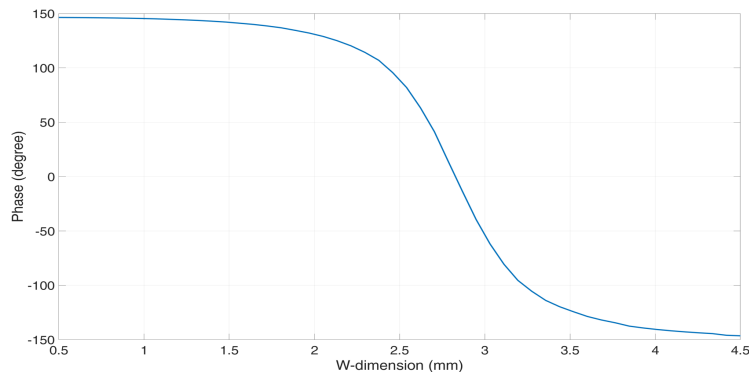
The considered substrate is a DiClad527 with permittivity $\epsilon_r = 2.55$ and loss tangent $\tan\delta = 0.0022$.

Elements with a half-wavelength dimension have been considered.

In particular, a square unit-cell with a square metal patch has been selected to:

- be low-cost;
- be easy to manufacture, without a multi-layer structure;
- operate in dual polarization.

S-curve of the reflection coefficient at 27 GHz

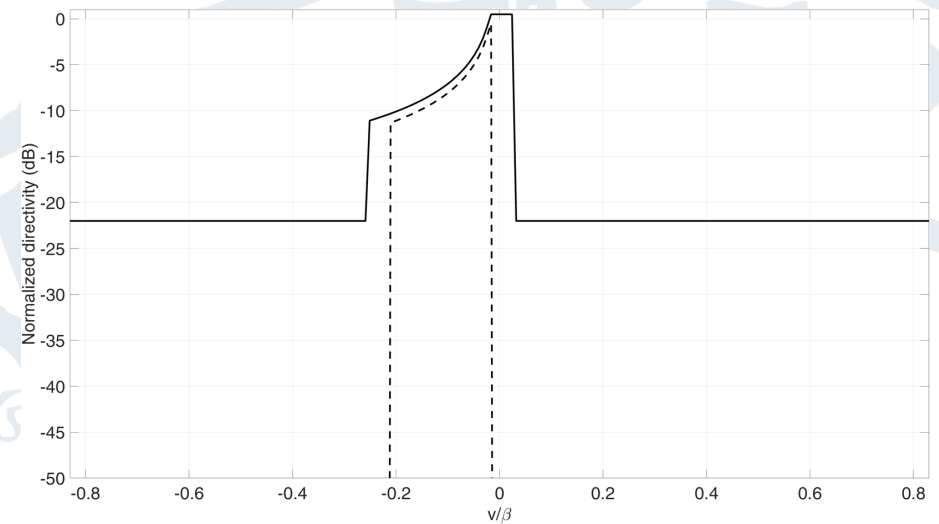
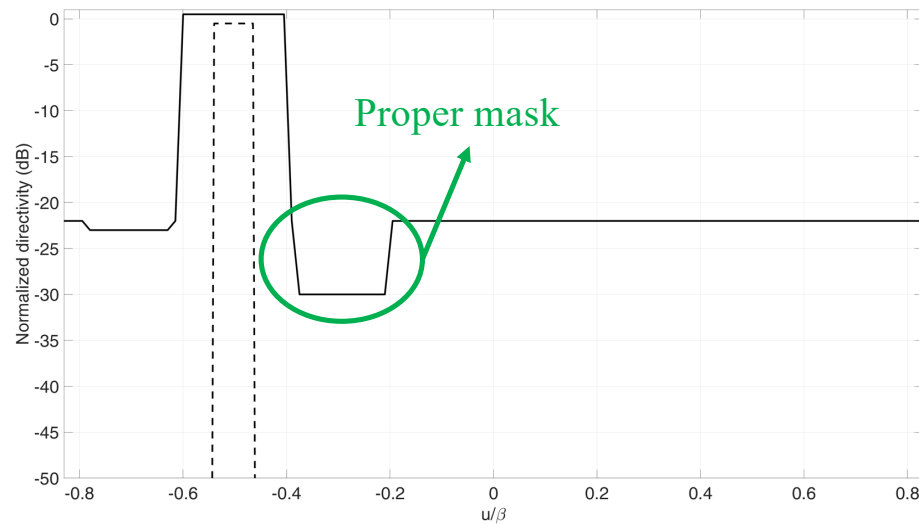


The characteristics of the element have to ensure a proper control of the scattered field.

The phase shifts obtained by PO synthesis have been used to size the elements of the reflecting surface according to the S curve in figure.

Mask functions

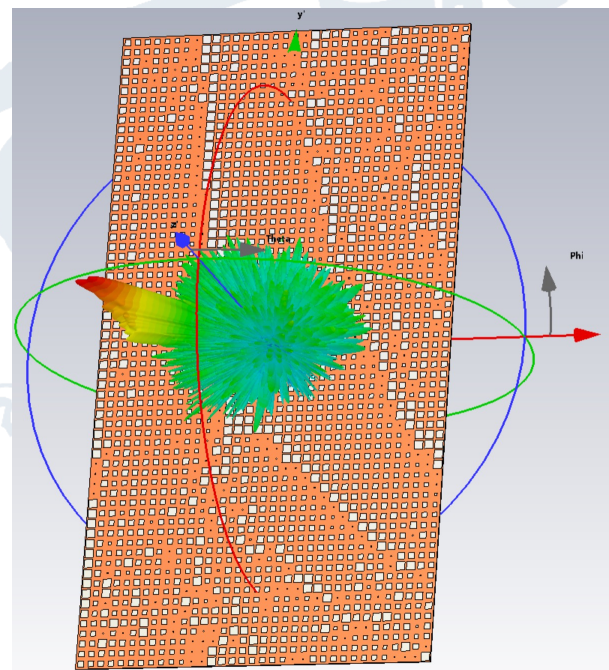
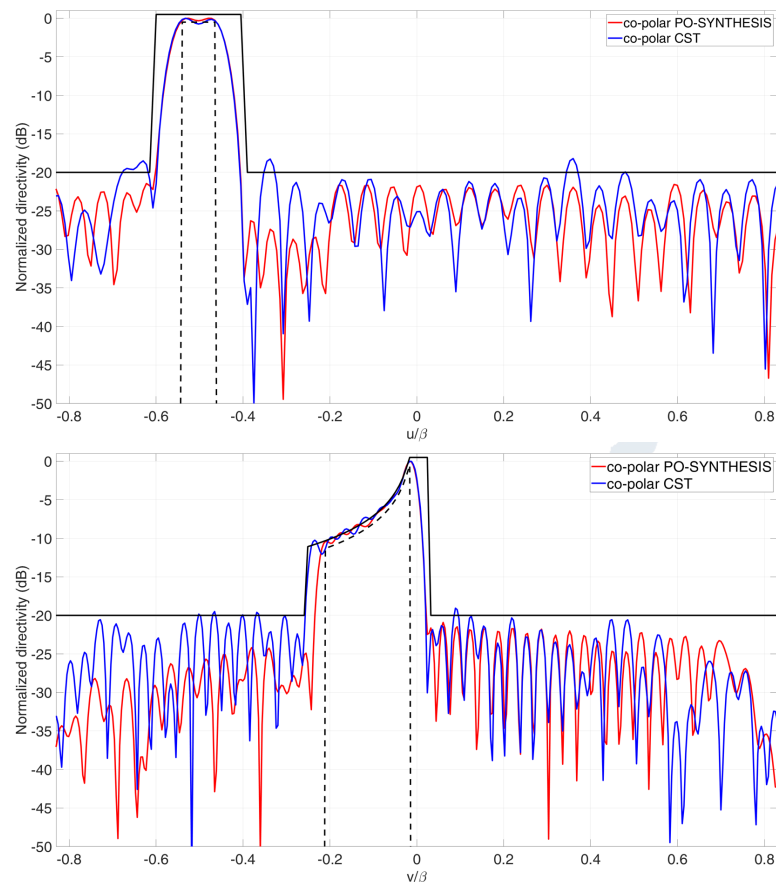
A power pattern synthesis has been considered with design specifications in terms of mask functions.



The mask functions have been appropriately chosen during the synthesis process, to adequately address the problem of the contribution of specular reflection.

Results

The synthesized far-field pattern (red lines) fulfils the design specifications in terms of SLL and beam shaping.



The good results (blue lines) are kept when they are evaluated by a commercial electromagnetic full-wave software.

Research activity: products

Conference Paper:

Title: Phase-Only Synthesis of a Reflecting Surface for Enhancing Coverages in Urban Scenarios,

Authors: S. Ayaz, M. Beccaria, A. Capozzoli, C. Curcio, G. D'Ambrosio, A. Freni, A. Liseno, P. Pirinoli,

Status: accepted,

Conference name: 19th European Conference on Antennas and Propagation (EuCAP), Stockholm, Sweden,



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Next Year

Research activities third year:

The development and implementation of a synthesis strategy based on an accurate model

Further work will be carried out on subwavelength elements and electronically controlled components.

Next year's credits as seminars:

- Doctoral School on antenna synthesis, European School of Antennas and Propagation (ESoA) at Università degli Studi di Napoli

Activity abroad:

- In the context of the collaboration among the Università degli Studi di Napoli, the Università di Firenze and the Politecnico di Torino, the potential choice for a possible period abroad is currently being defined.