UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

itee PhD information technology electrical engineering

DIETI UNINA

Characterization of Reconfigurable Intelligent Surfaces

Tutor:
Prof. Amedeo Capozzoli

Co-Tutor:
Prof. Ana Arboleya Arboleya
Prof. Claudio Curcio
Prof. Angelo Liseno
Prof. Manuel Sierra Castañer

PhD Student:
Eros Ciccarelli

Cycle: XXXIX

Year: 2024-2025 (Second)

Background

- **MSc Degree:** Electronic Engineering, Università degli Studi di Napoli Federico II;
- **PhD start Date**: 01/11/2023;
- **Scholarship Type:** PNRR Partenariato Esteso PE14, RESearch and innovation on future Telecommunications systems and networks, to make Italy more smART (RESTART);
- **Research group:** Applied electromagnetics;
- **Research Laboratory:** Laboratorio Numerico di Elettromagnetismo. Laboratorio di Microonde ed Onde Millimetriche. Camera Anecoica Elettromagnetica. Laboratorio di Antenne.

Collaborations:

- Universidad Politécnica de Madrid (UPM), Escuela Técnica Superior de Ingenieros de Telecomunicación;
- Universidad Rey Juan Carlos (URJC), Escuela de Ingenieria de Fuenlabrada.

UNIVERSIDAD POLITÉCNICA DE MADRID

Universidad Rey Juan Carlos

Summary of Study Activities

Courses:

- Ad-hoc PhD course, "Antenna Synthesis", European School of Antennas and Propagation (ESoA) at Anacapri, Napoli, Italy;
- MSc course, "Analisi Funzionale", Università degli Studi di Napoli Federico II, Dipartimento di Matematica e Applicazioni "Renato Caccioppoli".
- Ad-hoc PhD course, "Cooperative and Non-Cooperative Localization Systems", Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione.

Seminars:

- Robot Autonomy among Decision-Making Agents;
- Multibeam Antennas;
- Safety of Highly Automated Driving Systems:
- Multi-Neighborhood Search for Combinatorial Optimization;
- How complex is to schedule the Italian Serie A? Problems and methods in sports timetabling;
- PhD Survival Strategies;
- Superconducting Radio Frequency Cavities for Quantum Computing and Communication;
- Trusted Execution Environments for QPUs;
- RESTART Plenary Dissemination Workshop;
- Near-Field Meta-Steering: a Low-Profile Method for Complete Steering of the Beam of Any Fixed-Beam Antenna;
- Argumentation-Based Reasoning Frameworks for Public Interest Communication in Healthcare;
- Estimations of Unimodular Signal Waveform and Uncertain Receive Signal Steering Vector for Robust Optimal Receive Beamforming Design;
- Optimization in Transportation and Logistics;
- Local Explainability in Machine Learning: A collective framework;
- Radar Cross-Section Estimation and Measurements;
- Guardians or Threats? AI at the Frontlines of Cybersecurity.
- AI Powered User Interface Design.

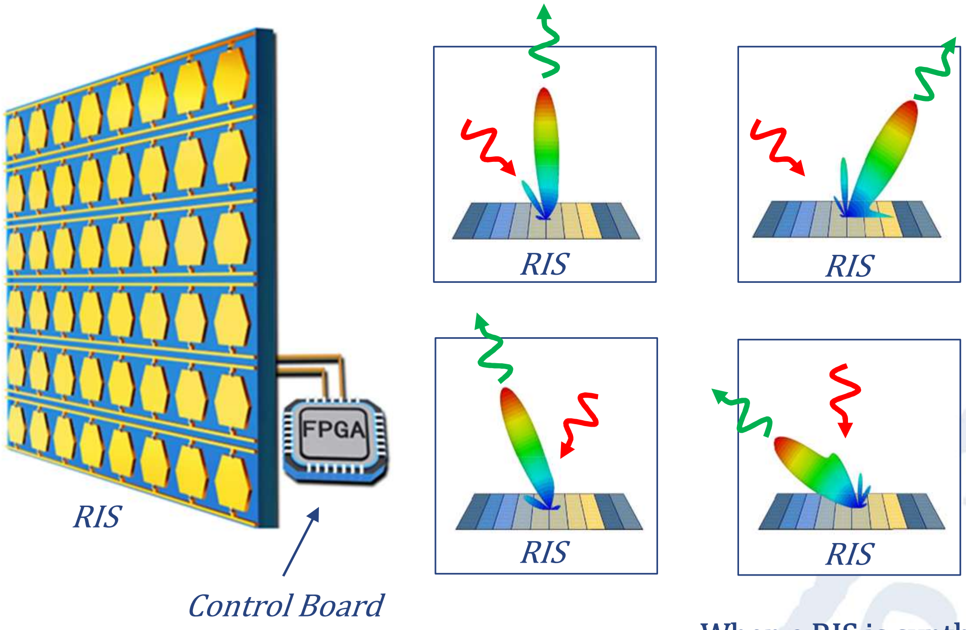
Conferences:

- *Participation as speaker at the 46th Annual Meeting and Symposium of the Antenna Measurement Techniques Association (AMTA), in Cincinnati (Ohio, US), 27/10/2024 – 01/11/2024.*

Period Abroad, 06/09/2024 – 30/12/2024:

- *Collaboration with the Universidad Politècnica de Madrid, under the supervision of Prof. Manuel Sierra Castañer, and the with the Universidad de Rey Juan Carlos about advanced measurement systems and techniques.*

Research Field - Characterization of Reconfigurable Intelligent Surfaces



Reconfigurable Intelligent Surfaces (RIS') are intelligent scattering surfaces able to change their electrical characteristics autonomously to scatter the impinging field of interest in the direction desired for indoor or urban applications. Reflecting properties can be achieved with reflective elements whose dimensions are comparable to the wavelength or sub-wavelength organized in macro-elements.

RIS' are provided with a control board allowing the reconfiguration of the antenna to change the characteristics of the scattered field according to the needs of the working scenario.

When a RIS is synthetized two methods are needed:

Fast Characterization

A method for the radiating characterization of a RIS in the fastest possible way.

Smart Illumination

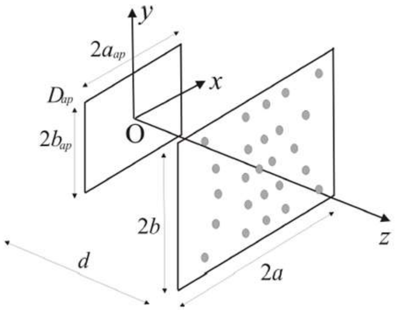
A method to assess the control board behavior when the RIS is excited by proper signals with predefined spatial-temporal pattern.

Research Activity – Fast Characterization

The radiating characterization of a RIS could be **time consuming** and imply avoidable **recurrent costs**, furthermore, considering each of its possible configurations. Two advanced techniques are interesting for a **Fast Characterization**, based on: Singular Value Optimization (SVO) or Probe-Arrays (PA's).

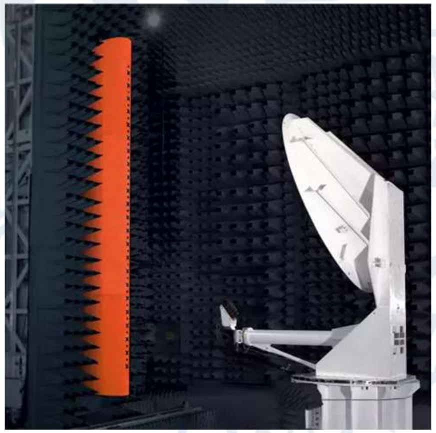
Smart Sampling: SVO approach

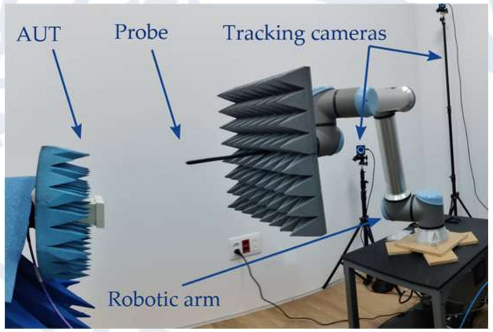
SVO-based approaches exploit mild a priori information on the AUT and on the measurement setup and optimize the number and the positions of the acquisition points, minimizing the scanning path length and provide accurate prevision of the **Antenna Under Test (AUT) Far-Field Pattern (FFP)**. *Proficient research activities come from our research group in Federico II.*



Advanced technologies: PA's

PA's-based techniques sample the field on multiple points for each acquisition position of the probe system. *PA's are available at the UPM.*



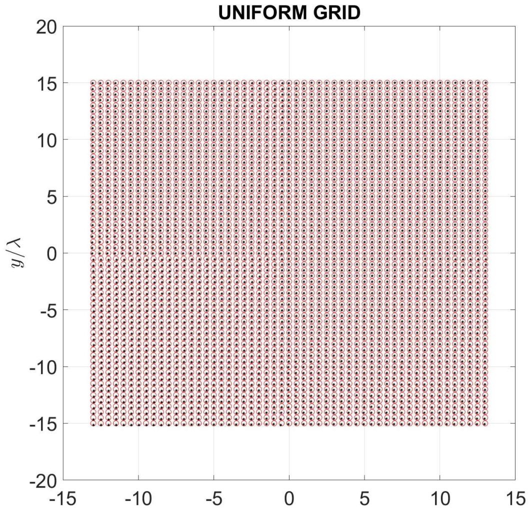


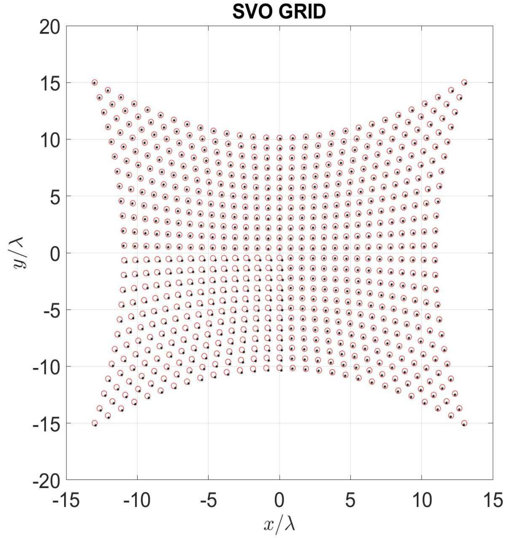
In the framework of the *collaboration with the UPM and URJC*, we have developed an **SVO approach based on PA's with a robotic arm.**

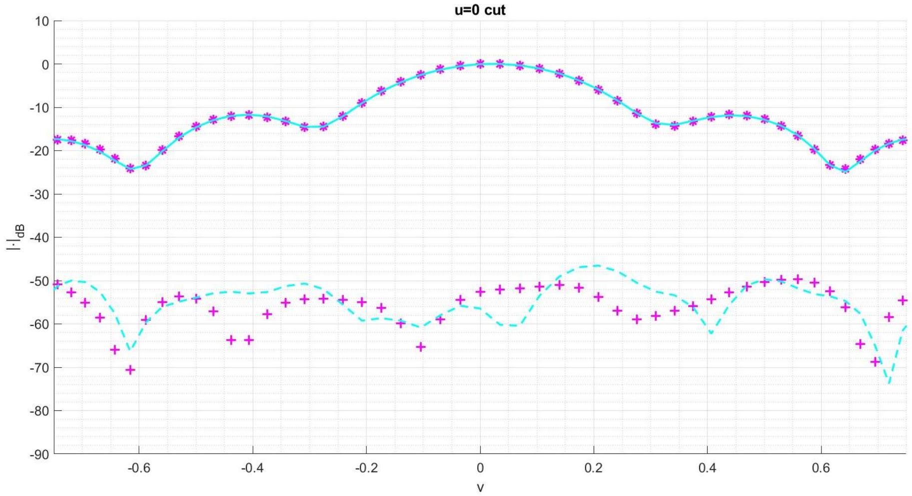
First preliminary measurements with a single-probe SVO to assess the use of the robotic-arm measurement system available at the URJC for physically large scanning area have been accomplished, as well as **numerical assessments** of the method have been carried out for **2x2** and **4x4 PA's.**

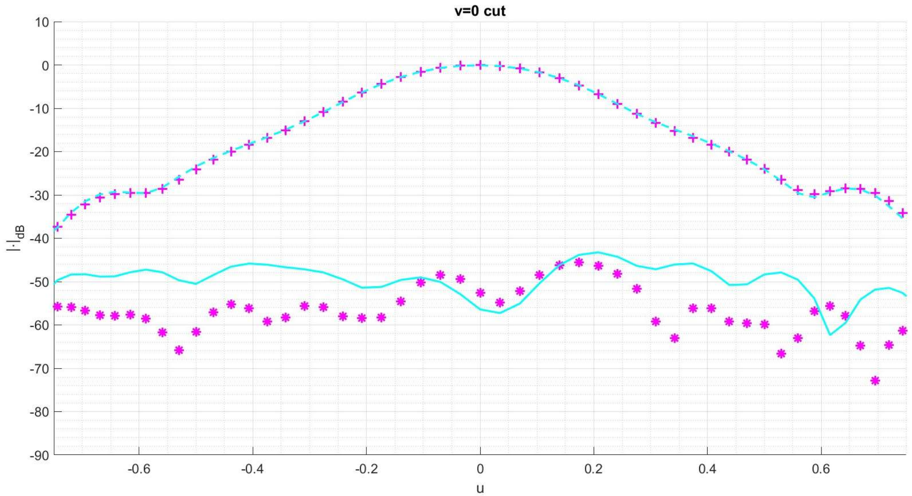
Research Activity – Fast Characterization

Results: Preliminary Experimental Assessment









Keys in figures:

*	E_ϑ retrieved with $\lambda/2$ grid
—	E_ϑ retrieved with SVO grid
+	E_φ retrieved with $\lambda/2$ grid
- -	E_φ retrieved with SVO grid
o	Nominal grid
o	Actual grid

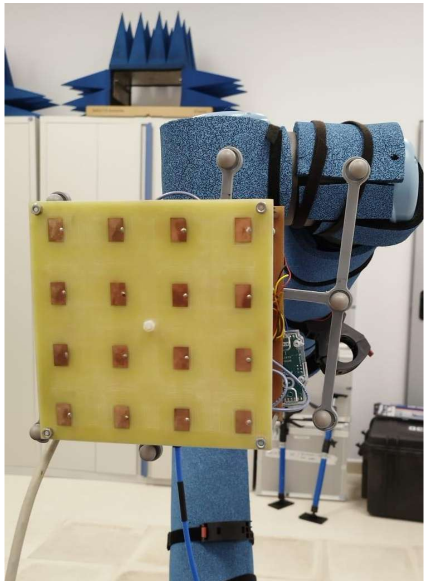
- AUT: Standard Gain Horn ASY-SGH-82;
- Probe: Open Ended Waveguide MVG OEW-820;
- Frequency: 7.5 GHz ($\lambda = 4$ cm);
- Aperture size ($x'y'$): $9.15\lambda \times 7.44\lambda$;
- Measurement plane distance: 5λ;
- Measurement plane size (xy): $26\lambda \times 30\lambda$;

The actual probe positions have been considered for both the approaches.

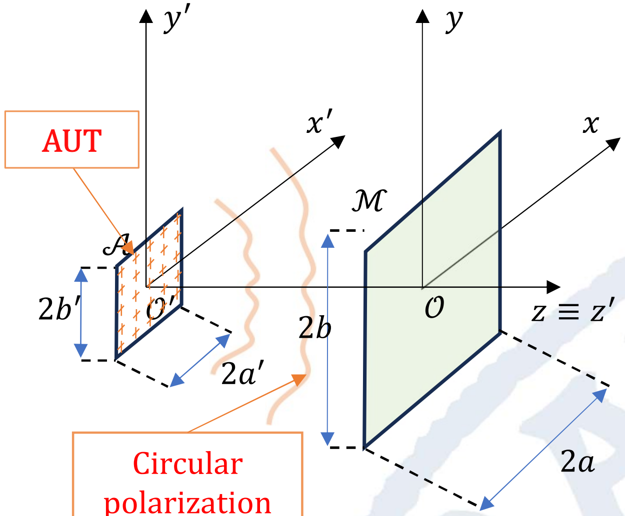
Comparison between different sampling techniques

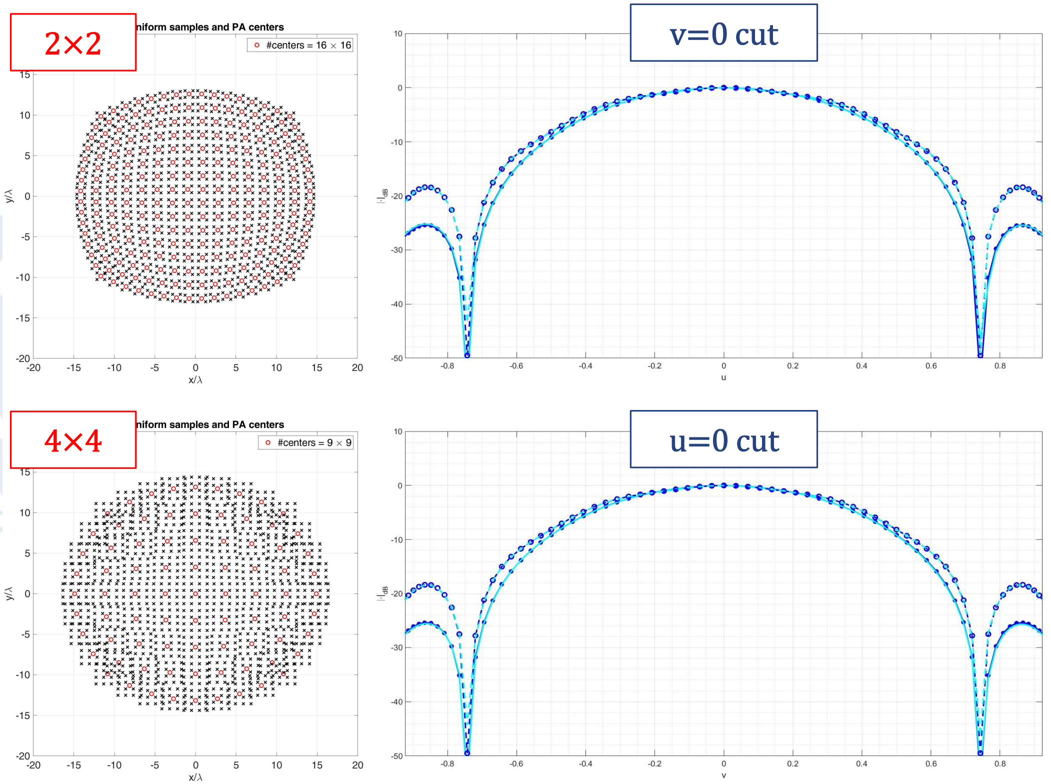
Technique	#sampling points
$\lambda/2$	53×61=3233
SVO 1×1	29×24=696

Research Activity – Fast Characterization



Results: Numerical Analyses, a case of interest





Additive Gaussian noise with an SNR of 40 dB has been assumed on the numerical data.

- AUT: 5x5 elements planar-array of identical crossed elementary dipoles;
- Probe: 2x2/4x4 array of patches;
- Frequency: 7.5 GHz ($\lambda = 4$ cm);
- Aperture size ($x'y'$): 6λ×6λ;
- Measurement plane distance: 5λ;
- Measurement plane size (xy): 30λ×30λ;

Comparison between different sampling techniques

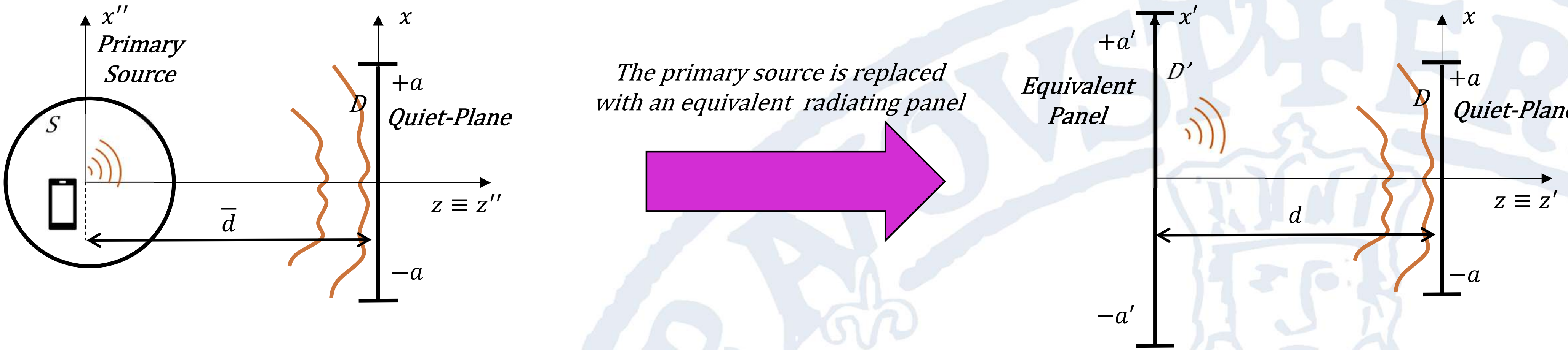
Technique	#sampling points
λ/2	61×61=3721
SVO 1×1	30×30=900
SVO 2×2	16×16=256
SVO 4×4	9×9=81

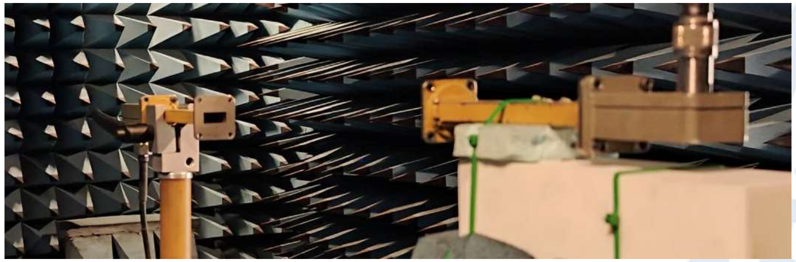
Keys in figures:

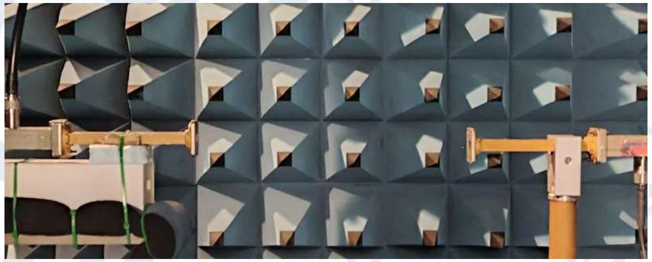
-•-	FEKO E_ϑ	- -	E_φ from SVO grid
—	E_ϑ from SVO grid	o	Array Center
-o-	FEKO E_φ	x	Probe Position

Research Activity – Smart Illumination

The generation of realistic signals, with proper spatial profile and time codification and accounting for eventually scattering from obstacles in the scenario, is indispensable to evaluate the performances of a RIS. The problem consists in the **synthesis of an equivalent source** (a panel herein) capable to reproduce the field generated by **any source/scatterer** confined in a region of the space, say S.





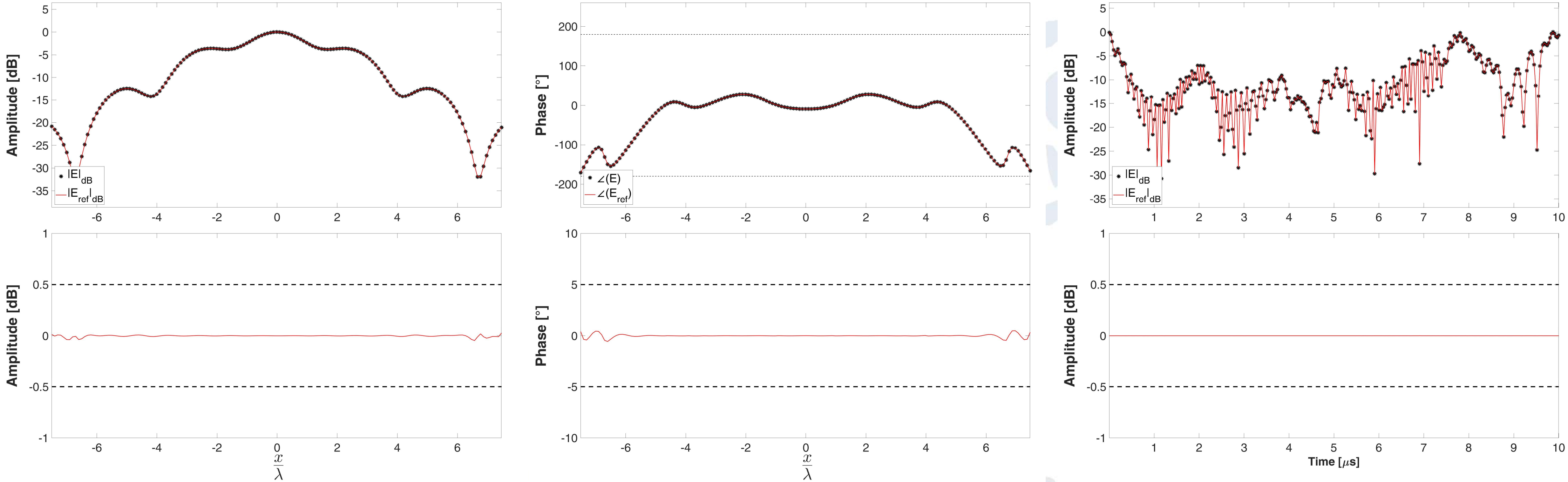


The experimental campaign has been carried out in the anechoic chamber available in the Laboratorio di Microonde ed Onde Millimetriche at DIETI.

A solution for the problem has been already proposed and assessed for a two-dimensional geometry. Here, an **experimental validation** is presented.

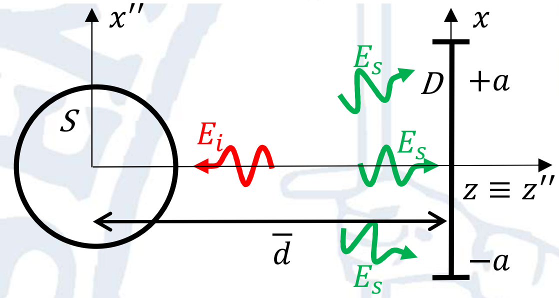
Experimental Results:

We considered a **canonical cylindrical scatterer** illuminated by a **chirped plane wave** traveling in the direction of the negative z-axis whose **bandwidth is** B.



Typical accepted tolerance on the maximum errors:
±0.5 dB
±5.0 °

Worst maximum errors vs frequency:
±0.047 dB
±0.560 °



Keys in figures:
* Synthetized Field
— Target Field

T [μs]	B [MHz]	$\bar{f}$ [GHz]
10	15.55	10

Next Year

Research activities third year:

- Further experimental tests for the SVO-based characterization of antennas using probe-arrays;
- Antenna characterization from Cylindrical Near-Field measurements exploiting Vector Prolate Spheroidal Wave Functions to represent the field of interest.

Next year's credits:

- MSc course: “Tomografia ed Imaging: Principi, Algoritmi e Metodi Numerici”, Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Elettrica e delle Tecnologie dell’Informazione.