National Lab RaSS Radar and Surveillance Systems

In supremae dignitatis 1343
Università di Pisa

cnit consorzio nazionale interuniversitario per le telecomunicazioni

Low Reflecting, Ultra Thin, Conformal Frequency Selective Metamaterials for Radar Camouflage and Cloaking

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Microwave and Radiation Lab
Università di Pisa www.mrlab.it

CNIT - Laboratorio Nazionale RaSS
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La segnatura radar ed elettrottica delle moderne unità navali:
valenza, metodi per il controllo e sviluppi tecnologici
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C.I.S.A.M.

Outline

- ❑ Introduction
- ❑ Research on metamaterials at UNIPI/CNIT
- ❑ Application to antennas and absorbers
- ❑ Practical aspects and implementation
- ❑ Conclusion and future developments

Introduction

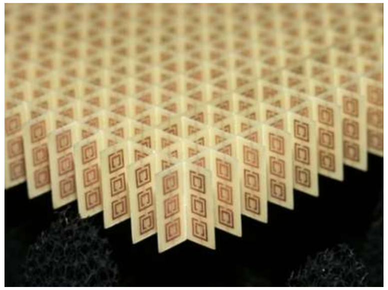
- Synergic collaboration between University of Pisa and CNIT (National Inter-University Consortium for Telecommunications)
- Microwave and Radiation Lab has more than 20 years of experience in EM problems including antenna design and optimization, metamaterials, numerical codes, electromagnetic compatibility, biomedical applications.
- Dynamic and stimulating environment for theoretical studies, applied research, prototyping and performance assessment with more than 20 members.

Introduction

- Penn State University (PA, USA)
- Ohio State University (OH, USA)
- Massachusetts Institute of Technology (MA, USA)
- University of Pennsylvania (PA, USA)
- University of Oxford (UK)
- University of Granada (Spain)
- University of Oviedo (Spain)
- European Space Agency (ESA)
- TNO (Holland)
- German Aerospace Center DLR (Germany)
- Helsinki University of Technology (Finland)
- NATO
- National Tsing Hua University (Taiwan)

Research on metamaterials

Metamaterials, Metasurfaces and Frequency Selective Surfaces

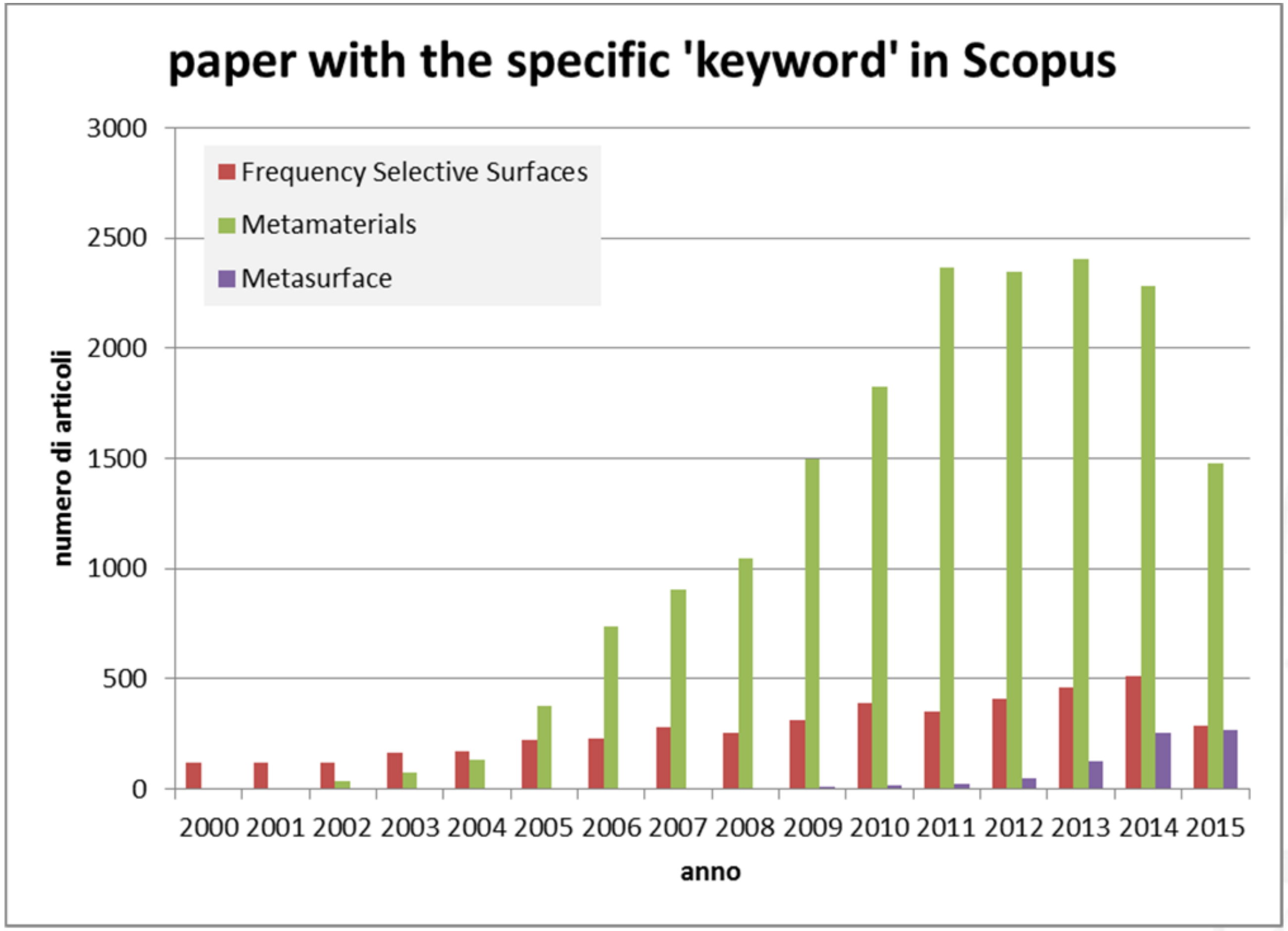


Metamaterials are 3D synthetic materials engineered to achieve unique properties not normally found in nature. Metallic inclusions are several time smaller than operating wavelength.

Metasurfaces constitute a class of thin metamaterials (2D), which are used from microwave to optical frequencies for several applications. Metasurfaces are typically Frequency Selective Surfaces with a subwalength periodicity and non resonant behavior.

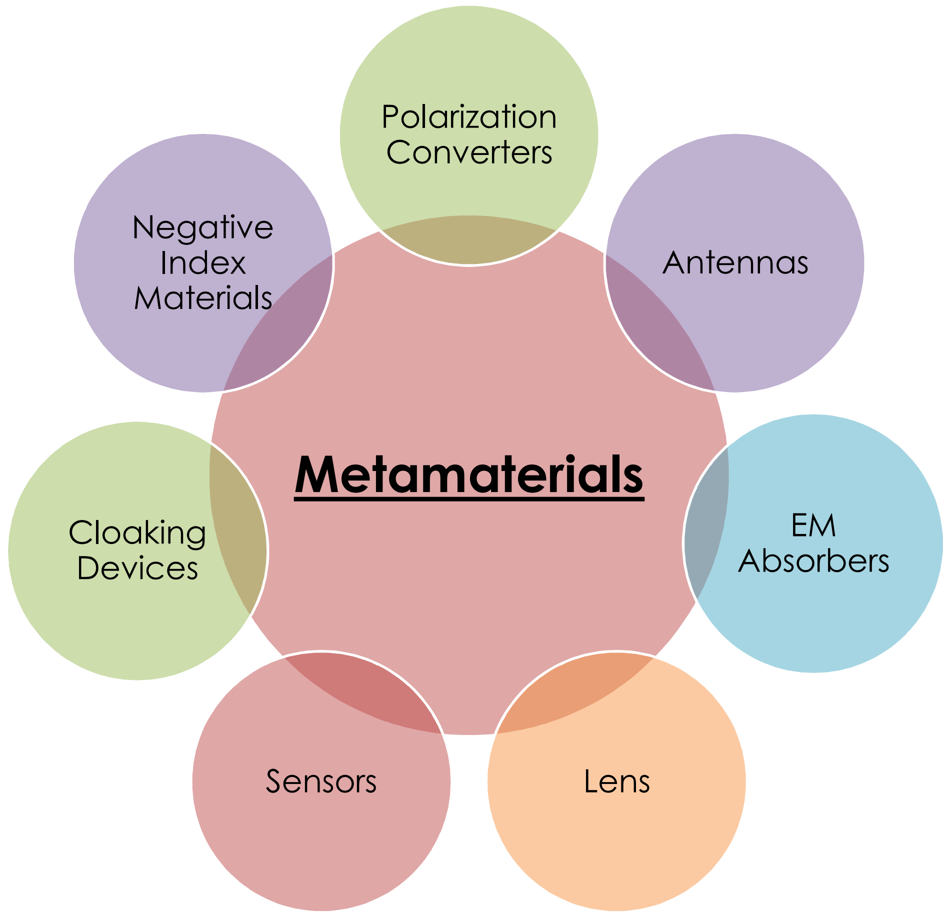
Holloway, Christopher L., et al. "An overview of the theory and applications of metasurfaces: The two-dimensional equivalents of metamaterials." *Antennas and Propagation Magazine, IEEE* 54.2 (2012): 10-35.

Research on metamaterials



The keywords Metasurface and Frequency Selective Surface are being replacing the keyword Metamaterial

Research on metamaterials



The keywords Metasurface and Frequency Selective Surface are being replacing the keyword Metamaterial

Research on FSSs and Metamaterials at Unipi/CNIT

People presently working on FSS:
- Simone Genovesi
- Filippo Costa
- Michele Borgese
- Francesco Scarano
- Davide Bianchi
- Francesco Alessio Dicandia
- Giuliano Manara
- Agostino Monorchio

1999: GA based FSS (Penn state collaboration)

2005: Single layer AMC, produced by Sciperio Inc. USA

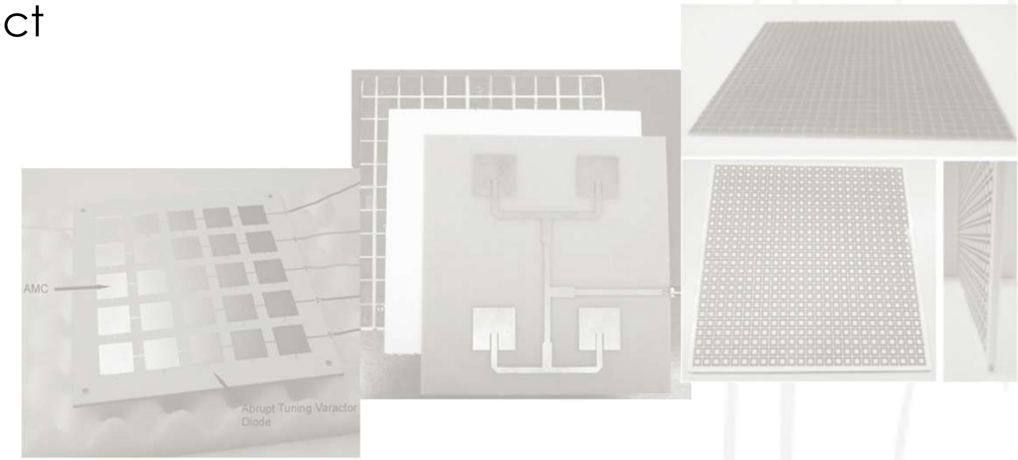
2006: M.A.R.T.A. project

Since 2007: FSS absorbers (highly cited papers)

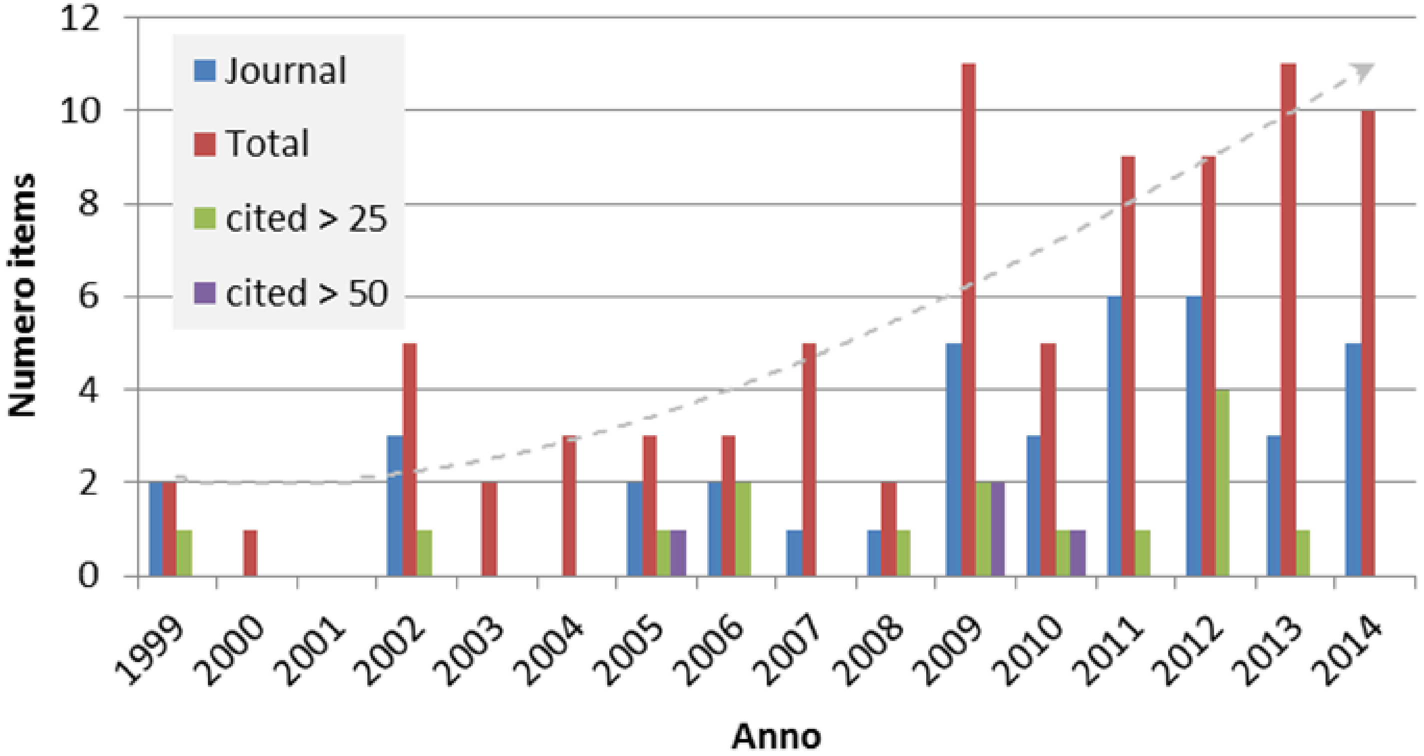
2011: SHIRED project

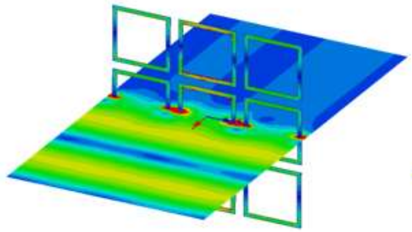
Since 2012: Integrated Low-RCS antennas with FSS

2014: L.O.R.E.N. project

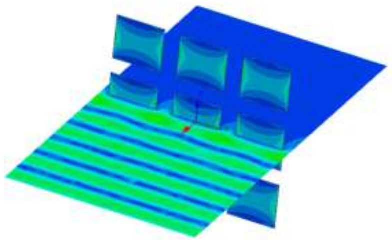


Articoli su FSS del gruppo di ricerca (indicizzati Scopus)

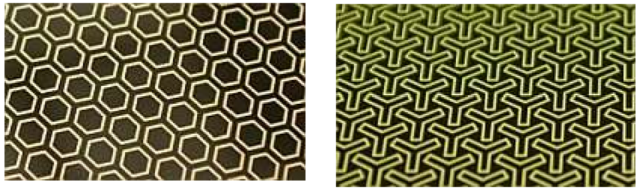




Ring @10 GHz



Patch @29 GHz



Approximate analysis

Equivalent circuit analysis

Accurate analysis

Efficient analysis

IEM-MoM

Slow analysis

FEM (Finite Element Method), FDTD (Finite Difference Time Domain)

Wavelength at which the grating lobes occur:

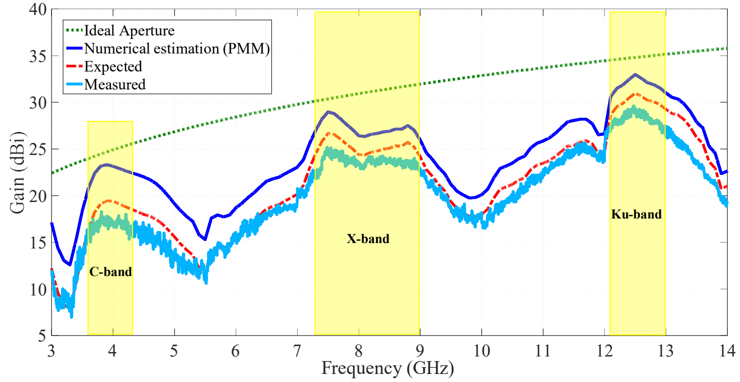
$$\lambda_g^{\varepsilon_r} = D\left(\sqrt{\varepsilon_r} + \sin(\vartheta)\right)$$

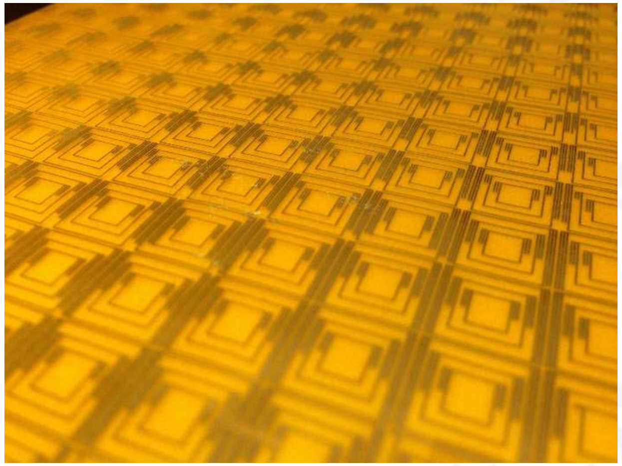
Quasistatic region $D \ll \lambda_g$	Resonance region $D < \lambda_g$	Grating lobes/Trapped dielectric modes region $D > \lambda_g$
TL model (averaged theory)		
TL model (retrieving approach)	TL model (retrieving approach)	
Multi-mode (retrieving approach)	Multi-mode (retrieving approach)	Multi-mode (retrieving approach)

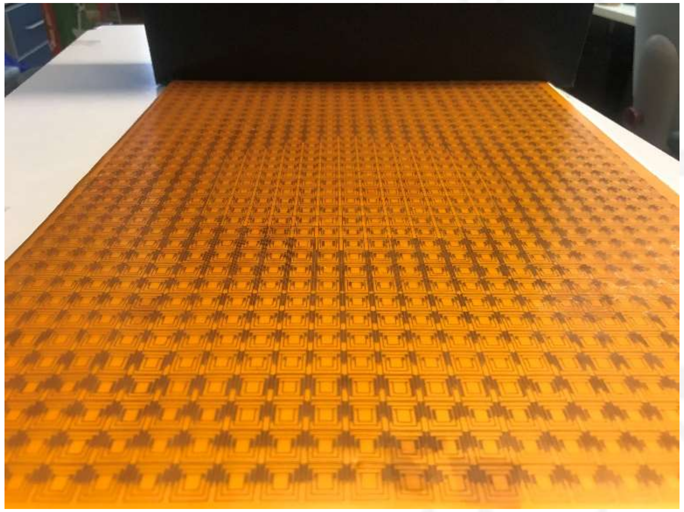
In the analysis of periodic structures, three different fundamental regions can be individuated

Application to antennas and absorbers

Multiband Reflectarray

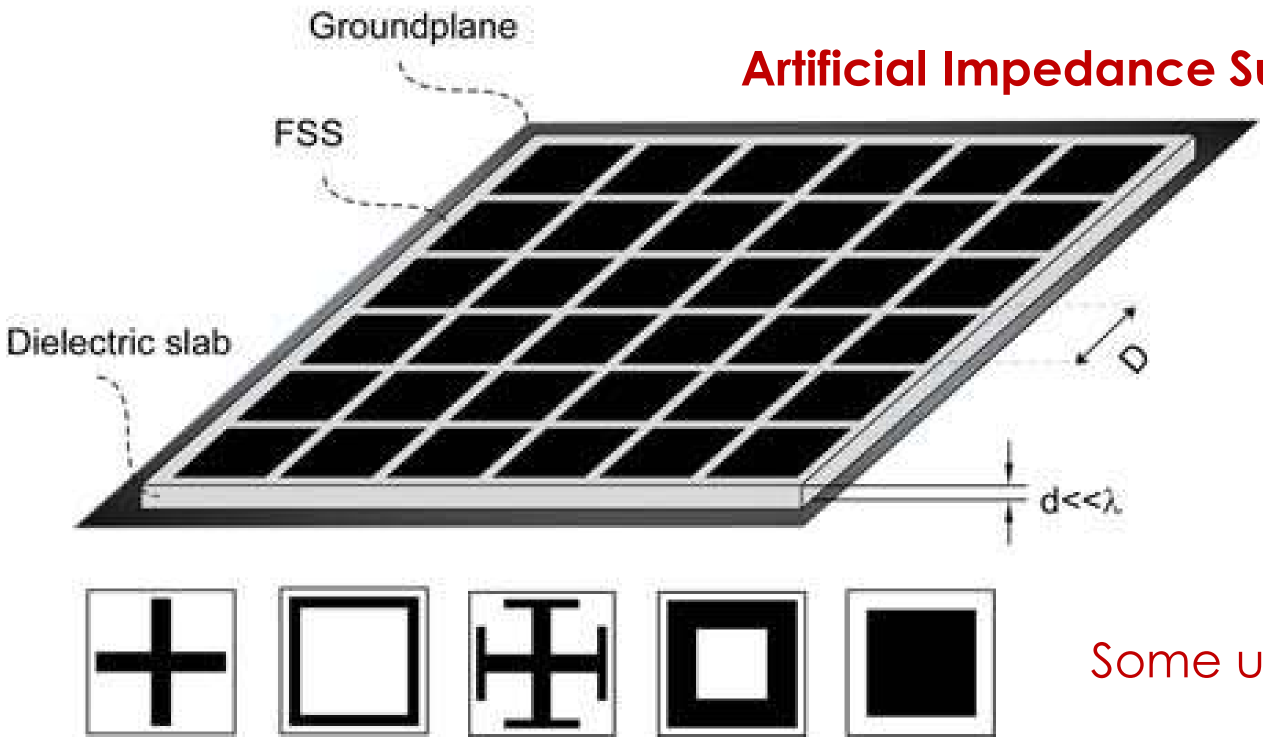






Application to antennas and absorbers

Artificial Impedance Surfaces

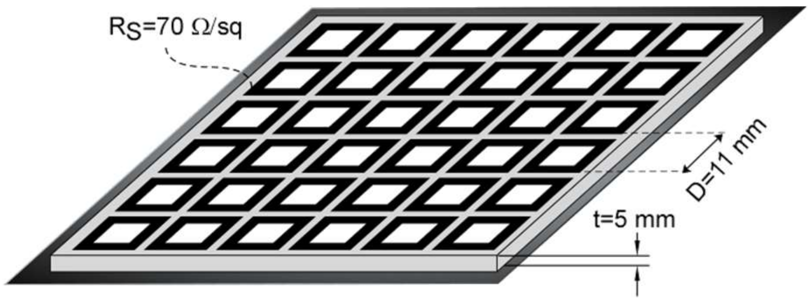


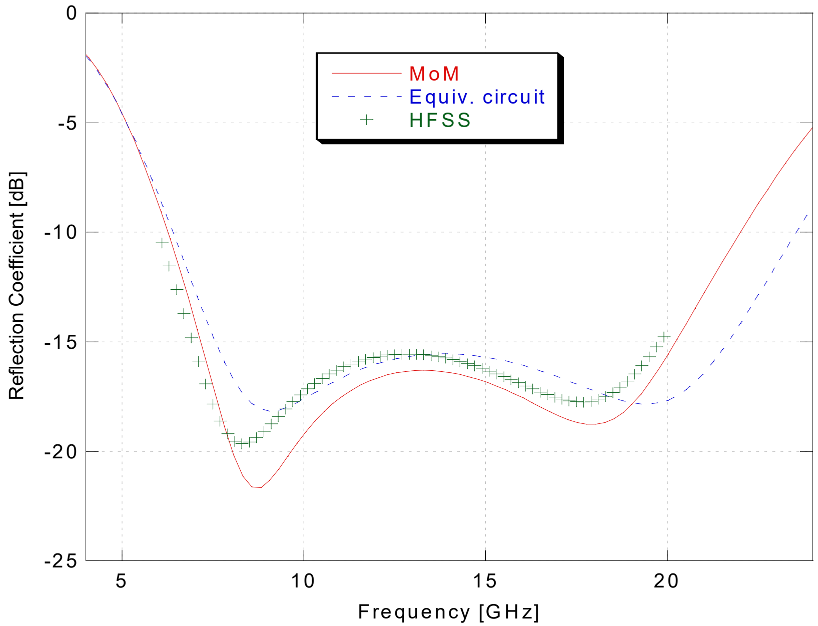
Some unit cell types

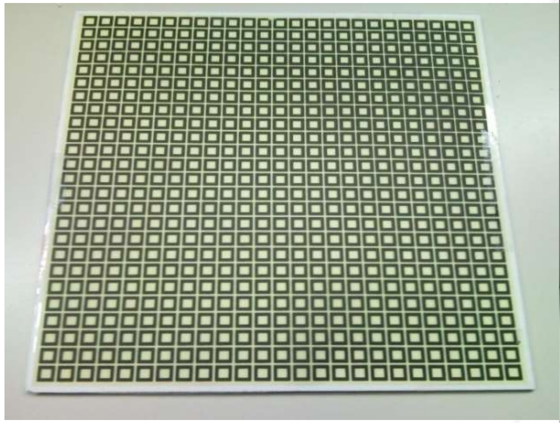
It consists of a periodic frequency selective surface (FSS) on the top of a grounded dielectric slab

Losses can be in the FSS or in the substrate

Wideband absorbers with resistive FSS







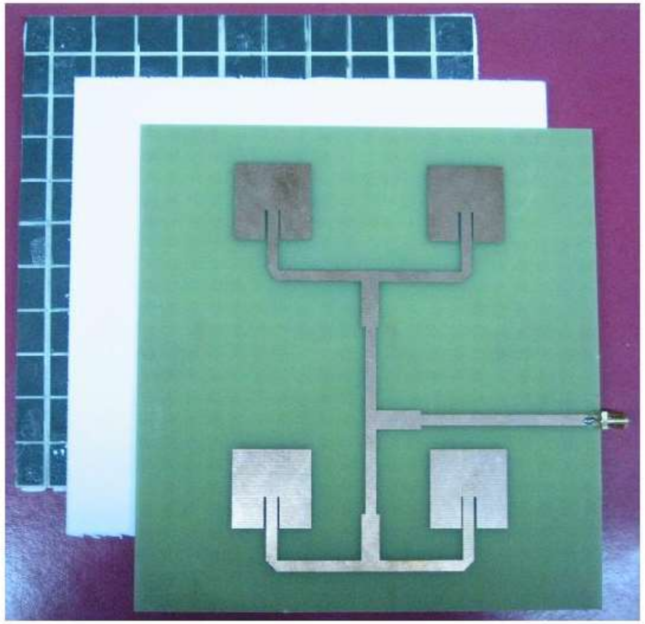
$$\left|\int_0^\infty \ln\left|R(\lambda)\right| d\lambda\right| \le 2\pi^2 \sum_i \mu_{r,i} d_i$$

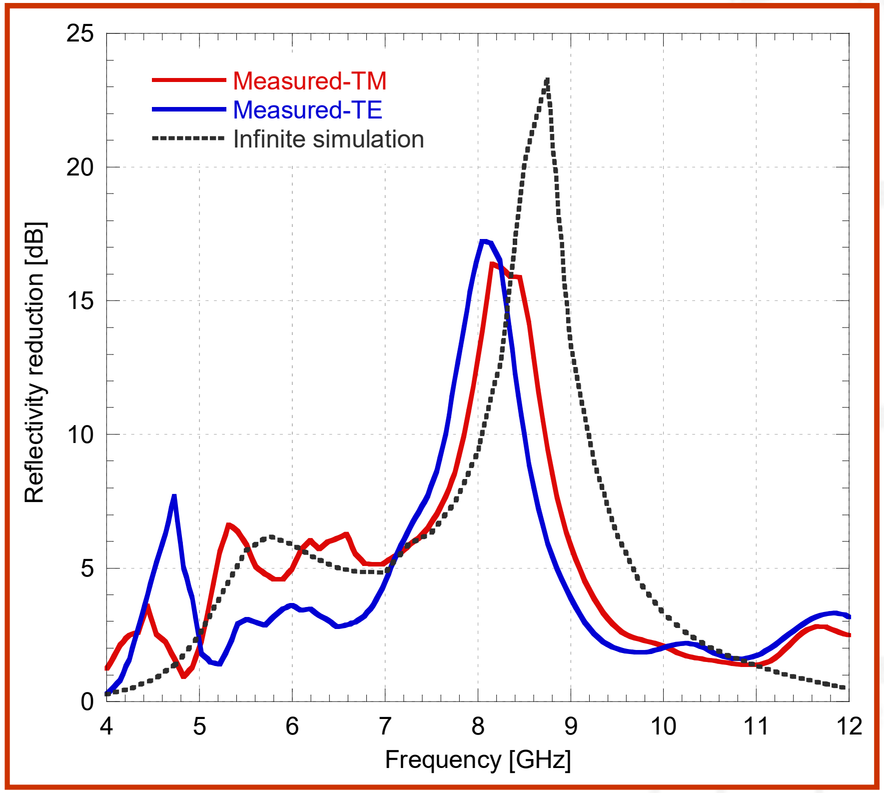
Total thickness: 5 mm

Physical limit: 4.5 mm

F. Costa, A. Monorchio, G. Manara, "Analysis and Design of Ultra Thin Electromagnetic Absorbers Comprising Resistively Loaded High Impedance Surfaces" IEEE Transaction on Antennas and Propagation vol. 58, no. 5, pp. 1551-1558, 2010.

Application to antennas and absorbers

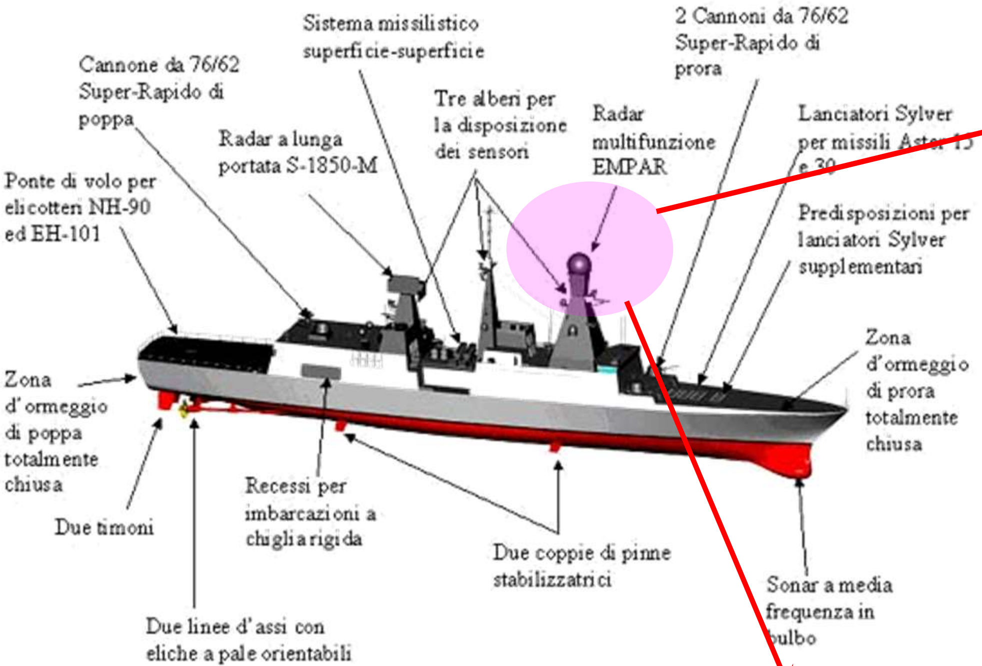


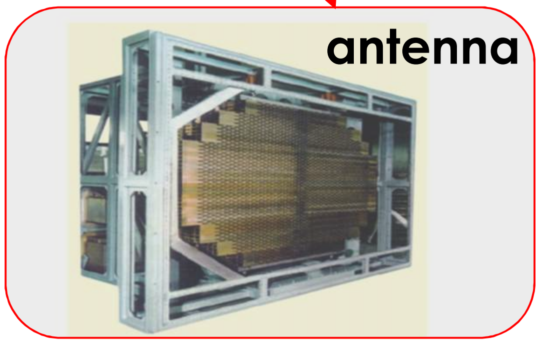


- Reduction of the RCS achieved in a wider bandwidth than the previous hybrid FSS ground plane case.

F. Costa, S. Genovesi, and A. Monorchio, "A Frequency Selective Absorbing Ground Plane for Low-RCS Microstrip Antenna Arrays", Progress In Electromagnetics Research, Vol. 126, 317-332, 2012.

Application to antennas and absorbers



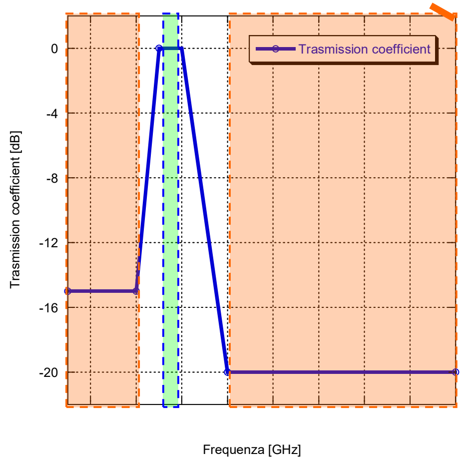


Application to antennas and absorbers

- **Only transmitted pass through radome without attenuation**

- **All other radar signals are reflected in a specular direction.**

- **<u>Fictitious RCS reduction</u>**

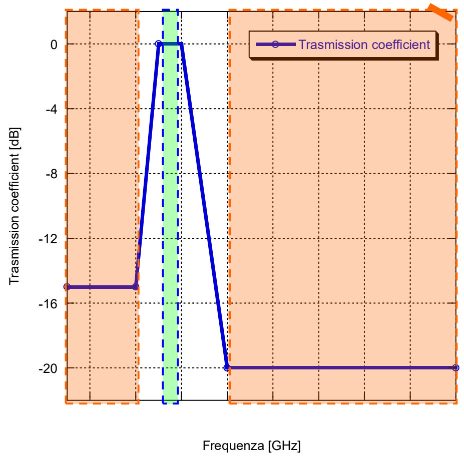


Application to antennas and absorbers

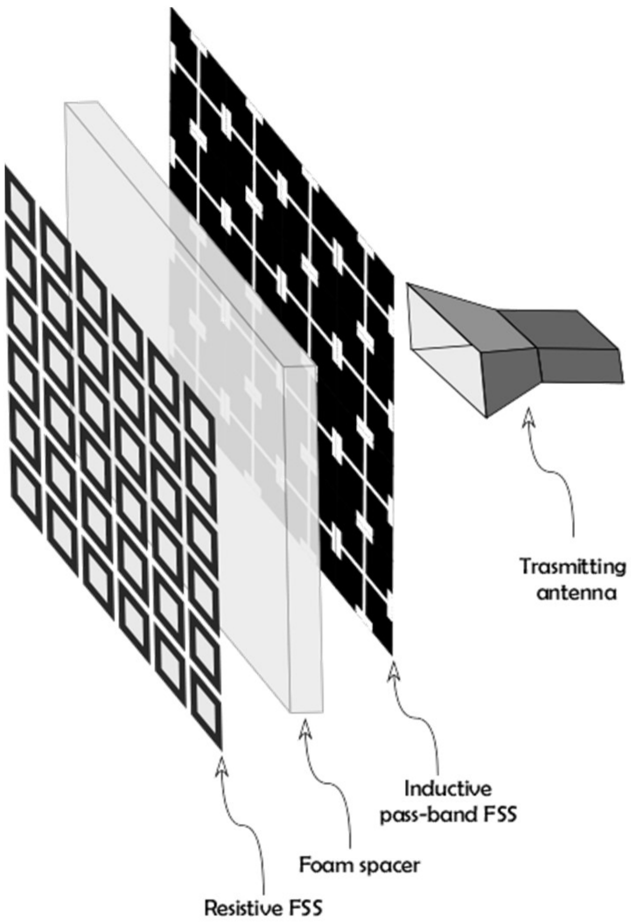
- Transmitted signals pass through radome

- All other radar signals are absoberd!!.

- <u>REAL RCS reduction</u>

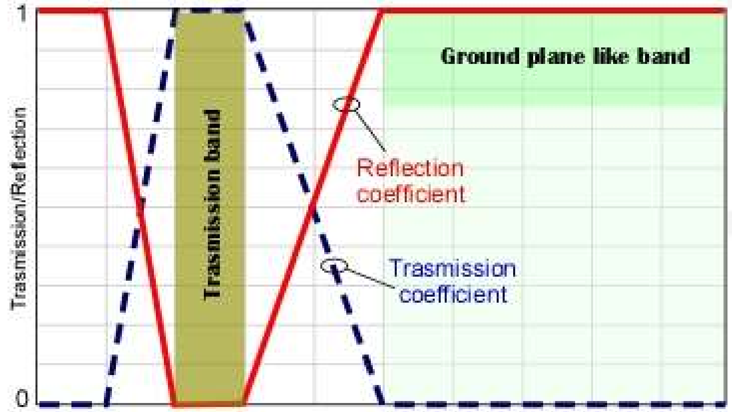


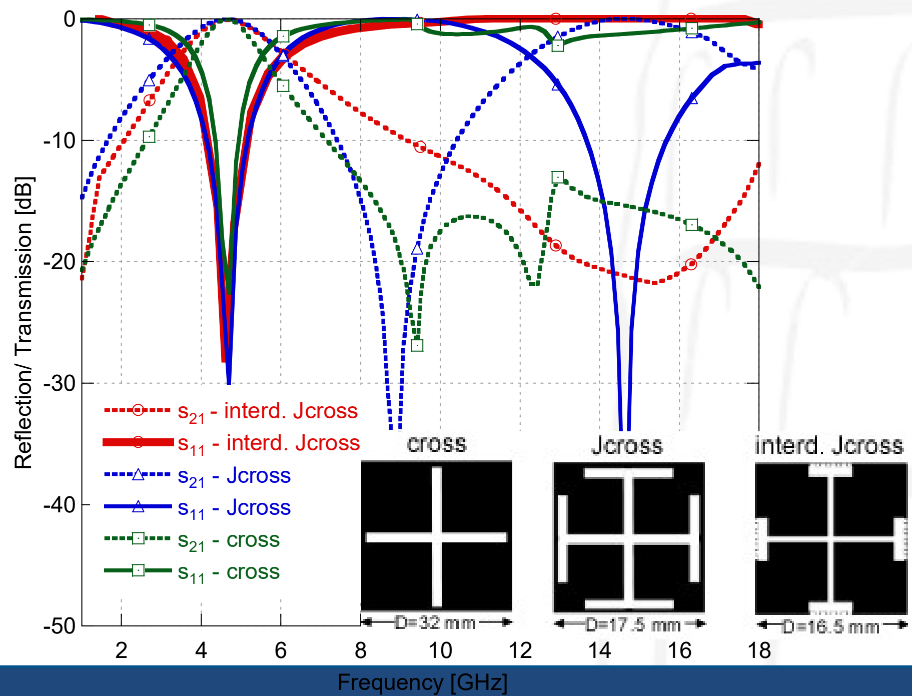
Application to antennas and absorbers



TARGET

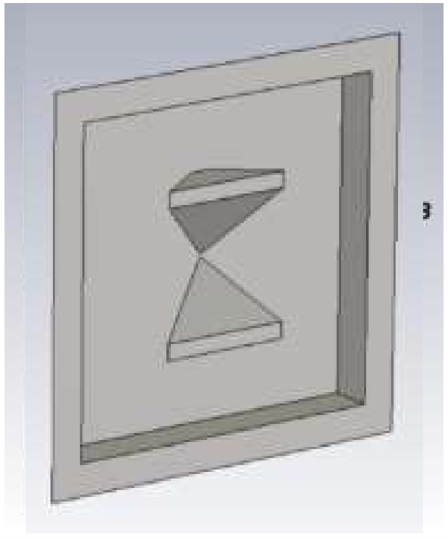
REAL DESIGN

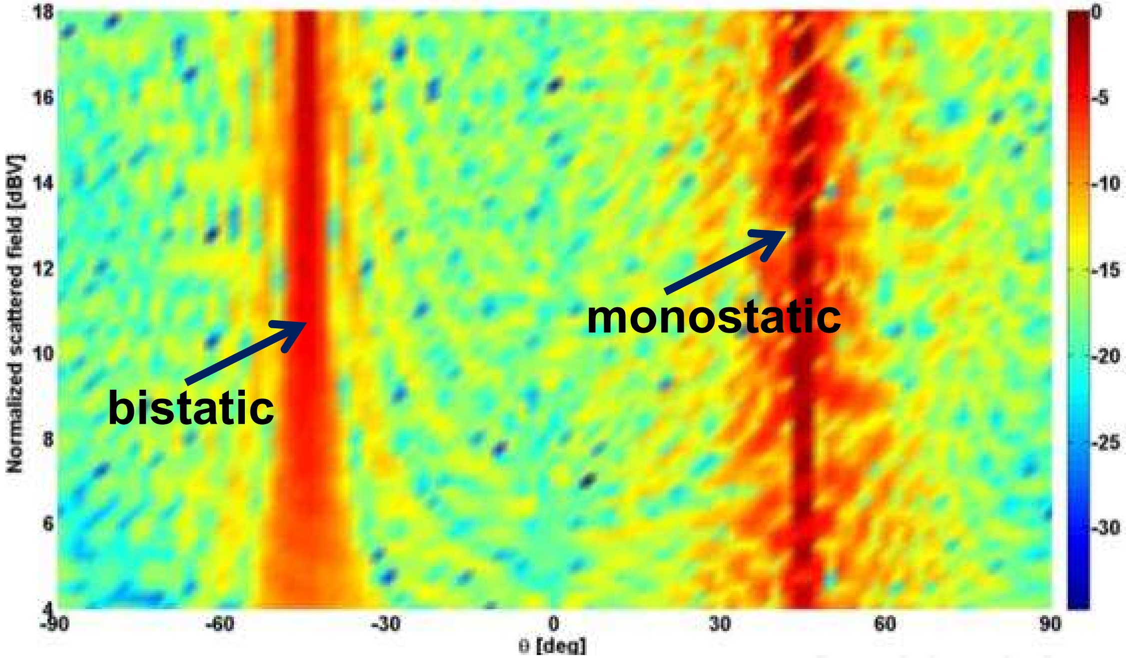


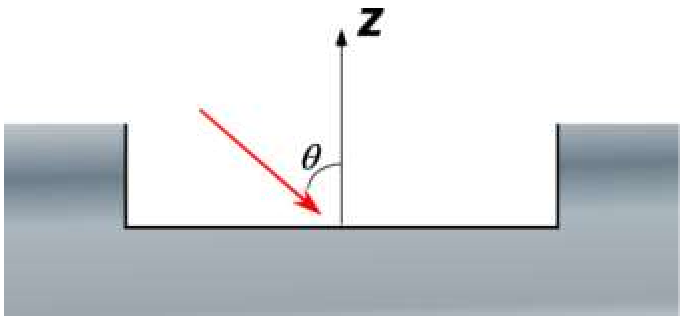


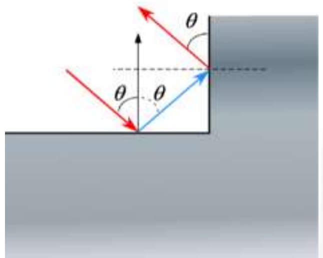
Application to antennas and absorbers

Effect of the cavity





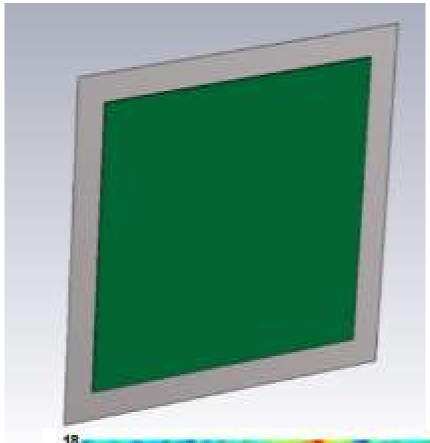




RCS reduction of UHF antennas within cavities

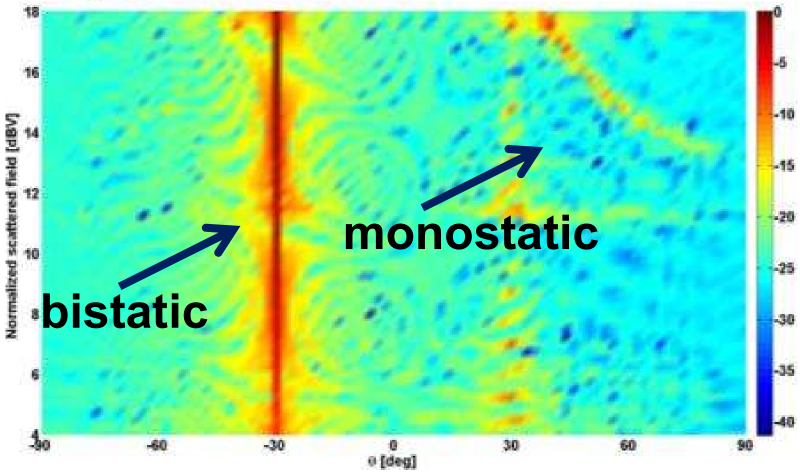
Antenna in cavity
+
Radome FSS

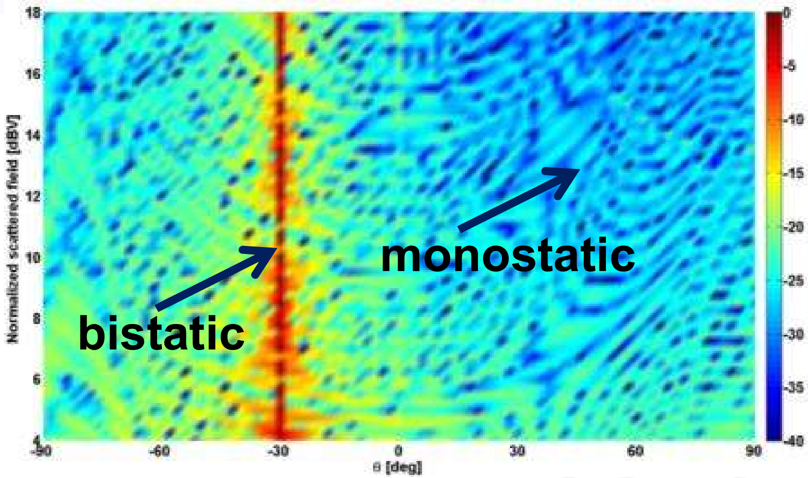
(obl. Inc. Θ=30°)



Antenna in cavity
+
Radome FSS
+
absorber

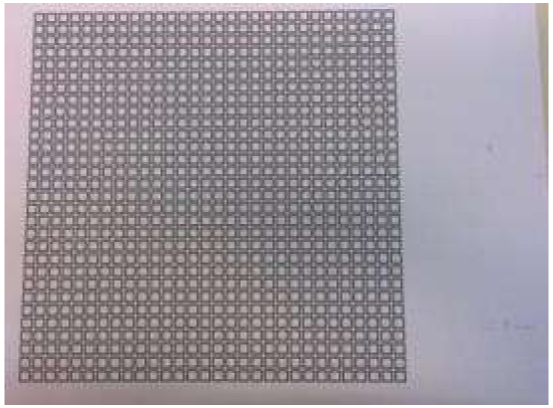
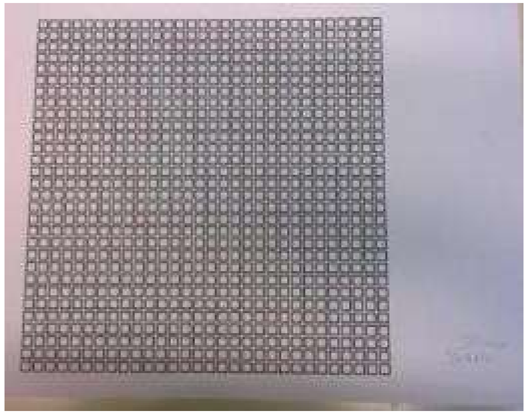
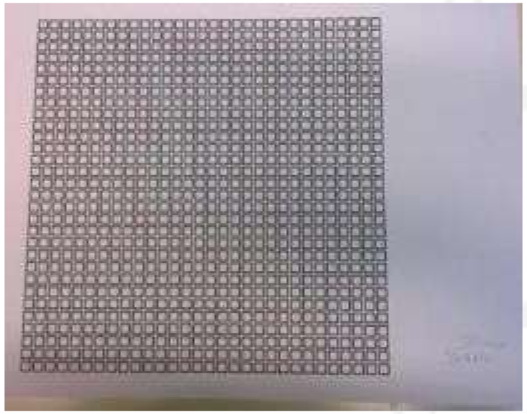
(obl. inc. Θ=30°)



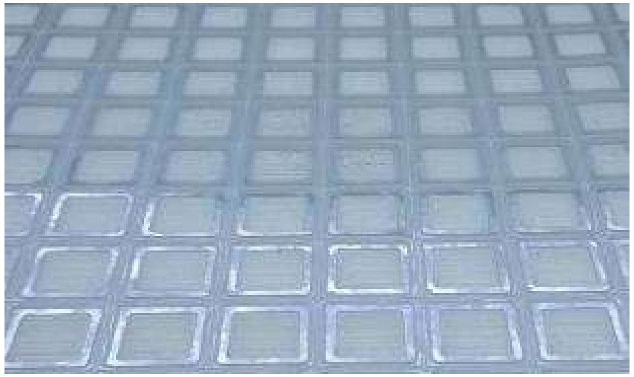


Practical aspects and implementation

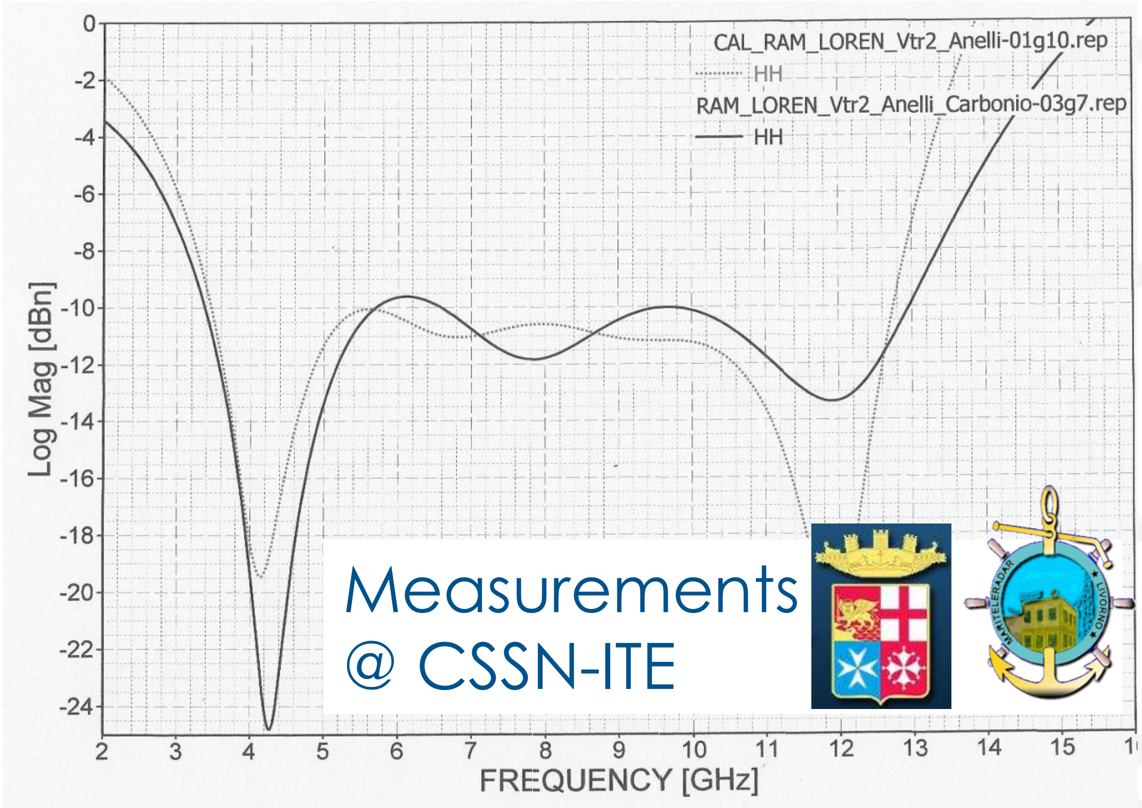
Silk printing technology

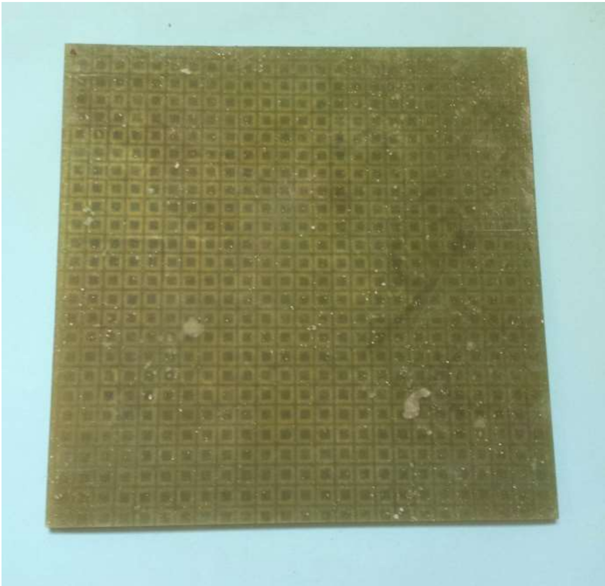




Resistive FSS loaded with silver nanoinks



Structural fiberglass absorbers





Implementation on large surfaces

Conclusion and future developments

- **Solid theoretical background on Frequency Selective Surfaces at the basis of metamaterials and metasurfaces development;**
- **Tailoring of state-of-the art absorbers properties and integration in radomes and antennas;**
- **Continuous efforts for realization and implementation on large surfaces and for structural materials.**

- ❑ **Minimally invasive absorbers for small footprint and high absorption performance (currently ongoing in LOREN project);**
- ❑ **Absorbers loaded with nanoparticle for further performance enhancement.**