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XXXIV Cycle

# Synthesis of High-Gain Flat Thin Antennas


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## Research context and motivation


- **Low-profile (flat) directive antennas** are needed whenever the thickness is relevant (e.g. cars, aircrafts,...). Their field of application includes satellite communications (SOTM) and point-to-point wireless links.
- **Planar arrays** are usually employed, with inherent drawbacks due to losses in the feed network. Therefore, focus has been put on planar structures able to integrate the feeding and radiating part.
- **Automatic design tools** are indispensable for the exploration of new, unintuitive geometries with higher efficiencies.
- Simulation involves a challenging **computational load**, due to the large electrical size and geometric detail of the involved structures.

## Addressed research questions/problems

- The key problem is the design of flat high-gain (low-loss) antennas based on **textured surfaces** with a **single source point.**
- This problem is addressed here in two different ways:

### 1 – Direct Texture Design

Optimization carried out directly on the physical geometry of the antenna, via global optimization (Genetic Algorithm).

Need of a full wave simulation at each optimization step; has been accelerated with specialized in-house simulation code.

- ✔ All the details are accounted for in the simulation, so once the optimization is done, the geometry is ready for manufacturing
- ✘ Computationally intensive, due to multiple full wave simulations
- ✘ Limited to small to medium size antennas (1÷3 λ)
- ✘ Hard to achieve reconfigurability

### 2 – Synthesis through equivalent surface impedance

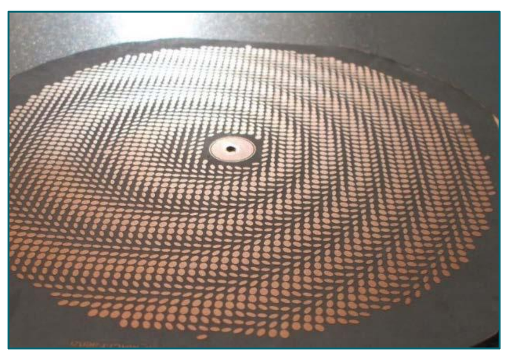
The surface texturing is made of sub-wavelength conducting patches or dielectric/metal relieves. It can be described "macroscopically" via the ratio between tangent electric and magnetic fields, called **surface impedance boundary condition (IBC):**

$$\boxed{\boldsymbol{E}_{\tan} = \overline{\overline{\boldsymbol{Z}}}_s \cdot (\hat{\mathbf{n}} \times \boldsymbol{H})}$$

The design is divided in two phases:

a) Design of the surface impedance
b) Realization of the texture that yields the desired IBC shape.

Phase b) is then realized via local periodic approximation of "unit cell" with small (subwavelength) size.



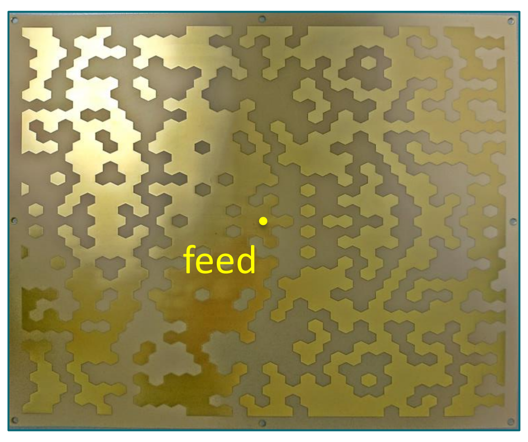
- ✔ Computationally efficient (avoid dense meshes to discretize small elements)
- ✔ Suitable for large antennas (~10λ)
- ✔ Easier to achieve reconfigurability
- ✘ Requires a non-linear process, theoretically and computationally challenging
- ✘ Need to synthesize all individual unit cells after optimization

## List of attended classes

- 01MMRRV – Tecniche numeriche avanzate per l'analisi ed il progetto di antenne (14/3/2019, 20 hours)
- 01SFURV – Programmazione scientifica avanzata in Matlab (27/06/2019, 28 hours)
- 01QRQRV – Compressed sensing: theory and applications (28/8/2019, 20 hours)
- Fall PhD School 2018 on Extreme Electromagnetic Matter Interactions - EXEMI 2018 (19/11/2018, 14 hours)
- European School of Antennas - Compressive Sensing in Electromagnetics (22/3/2019, 30 hours)
- EMERALD Core Transferable Skills Week (15/02/2019, 20 hours)

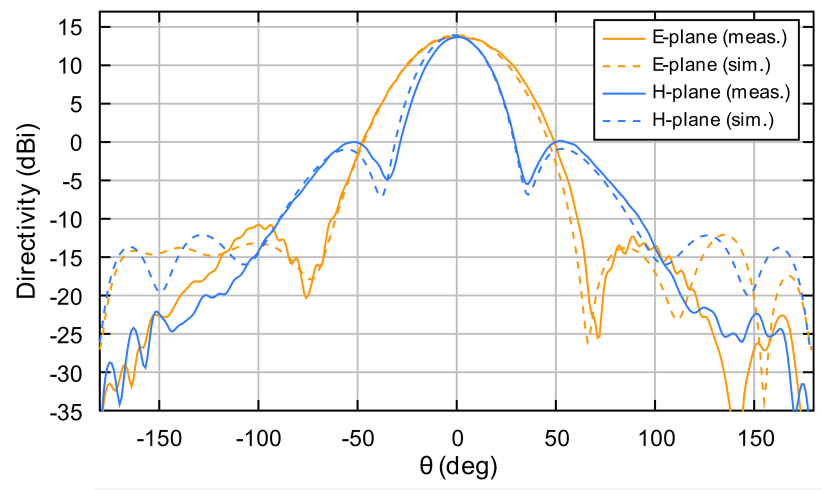
## Novel contributions

### 1 – Direct Texture Design

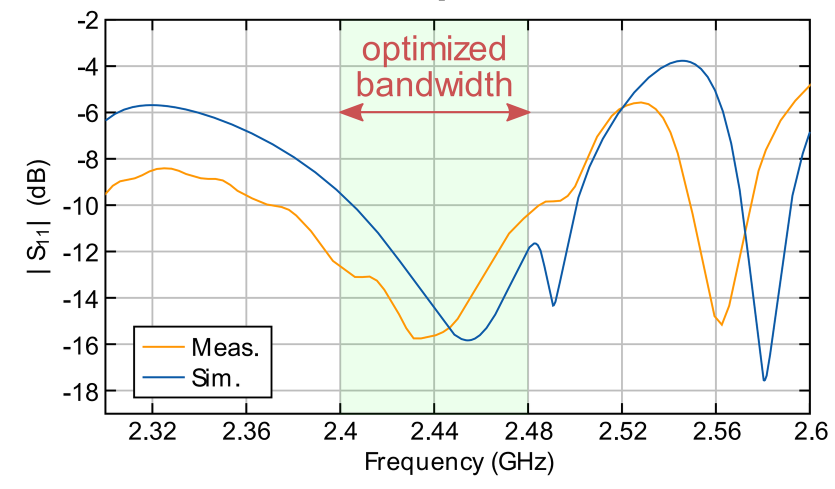



- First demonstration of a **low-profile, low-cost** antenna with **high aperture efficiency**
- Working frequency **2.44 GHz** (ISM band)
- **Broadside** directive radiation
- Size 2λ x 2λ = 24 x 24 cm$^2$
- Fabricated with commercial printed circuit techniques → **low-cost manufacturing**

Measured Far Field




Measured Input refl. coeff.




- Directivity = 13.7 dBi
- $|S_{11}|$ = -15.6 dB
- Aperture efficiency = 57.8% (e.g. paraboloid ≈ 60% but not flat)

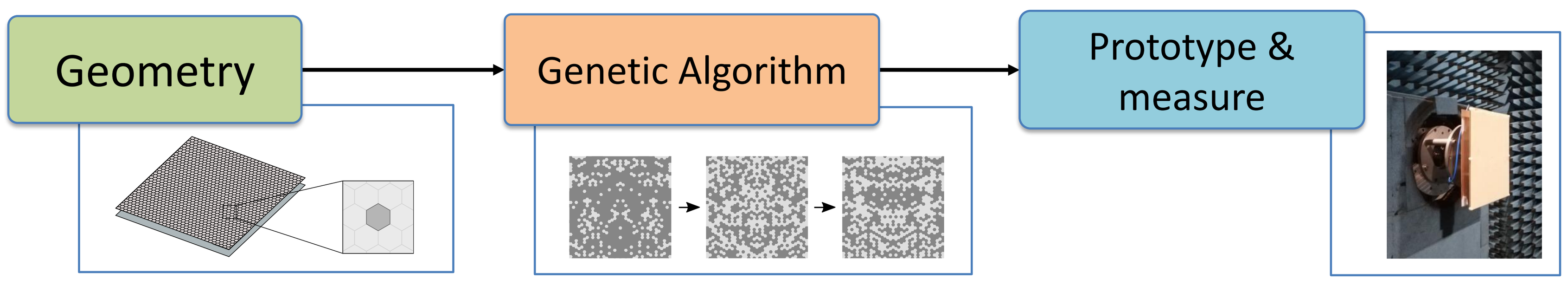
### 2 – Synthesis through equivalent surface impedance (work in progress)

- **Power synthesis:** from inequalities ("masks") on the objective radiated field amplitude → **non-linear inverse** problem

## Adopted methodologies

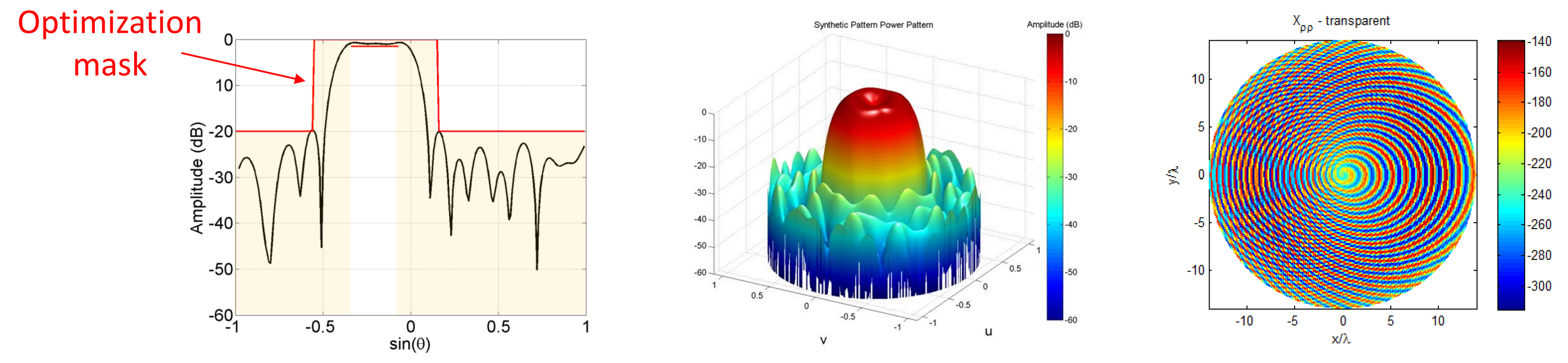
### 1 – Direct Texture Design

- Simulation based on the **Electric Field Integral Equation**
- **Binary global optimization** method (Genetic Algorithm)




### 2 – Synthesis through equivalent surface impedance (work in progress)

- **Iterative design process** based on constraints on physical and practical realizability
- Algorithm inspired by **Alternating Adaptive Projection** algorithm [*Quijano & Vecchi, IEEE TAP, 2009*]
- **Constrained convex optimization** at each step to obtain local impedance




## Future work

- Emphasis on full synthesis through equivalent surface impedance (more promising from application point of view).
- Reformulation of optimization constraints to better represent physical properties.
- Casting non-linear optimization as a sequence of convex optimization problems (more efficient to solve) to obtain impedance profile.

## Submitted and published works


- M. Zucchi, G. Giordanengo, M. Righero, J. L. Araque Quijano and G. Vecchi, "*Checkerboard-like low profile antenna optimization*", International Conference on Electromagnetics in Advanced Applications (ICEAA), Cartagena des Indias (Colombia), 10-14 Sept. 2018, pp. 535-537
- M. Zucchi, G. Giordanengo, M. Righero, J. L. Araque Quijano and G. Vecchi, "*Optimization of a Flat Directive antenna for 2.4 GHz band using Genetic Algorithm*", 13th European Conference on Antennas and Propagation (EUCAP), Cracovia, 2019, pp. 3176-3178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