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Two-Dimensional Antenna Beamsteering Using Metamaterial Transmitarray

João Reis[1,2], Zaid Al-Daher[1], Nigel Copner[1], Rafael Caldeirinha[1,2] and Telmo Fernandes[1,2]
[1]Faculty of Computing, Science and Engineering, University of South Wales, United Kingdom
[2]Instituto de Telecomunicações (DL-IT), ESTG, Polytechnic Institute of Leiria, Leiria, Portugal
Email: joao.reis@southwales.ac.uk

Abstract: A novel 2D-beamsteering technique employing a metamaterial transmitarray is presented. The proposed transmitarray, when coupled to a conventional horn antenna, allows its original radiation pattern to be steered in both elevation and azimuth planes. A fixed 25º steering in θ and ϕ (spherical coordinates) was achieved through electromagnetic simulations and validated against experimental results, obtained from a prototype comprised of 5 x 5 unit-cells at 5.35 GHz, carried out inside an anechoic chamber.

Keywords: Beamsteering, metamaterials, transmitarray, unit-cell.

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1. Transmitarray Operation Mode

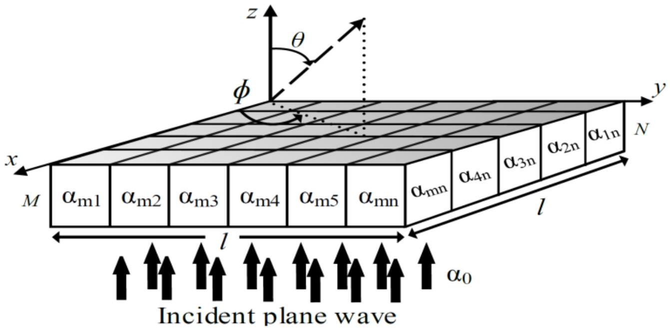


Figure 1: Proposed model for 2D beamsteering analysis.

$$\begin{cases} \psi_x = -\frac{2\pi}{\lambda}.p.sin(\theta).cos(\phi) \\ \psi_y = -\frac{2\pi}{\lambda}.p.sin(\theta).sin(\phi) \end{cases}, (1)$$

- When a planar incident electromagnetic wave propagates through the transmitarray, it experiences a different phase shifting, proportional to the elements transmission phase α_{mn} as illustrated in Fig. 1.

- Due to the gradient phase distribution along both direction of the array, the re-transmitted wave direction (θ, ϕ) can be calculated using Eq. (1), where ψ_x and ψ_y are the progressive phase along the X and Y axis, respectively, and p is the periodicity of array elements.

- By changing the phase α_{mn} of each array element in an progressive way, the original incident wave can be steered towards the desired output direction, relative to the normal of the structure.

2. Transmitarray Design, Simulation and Prototyping

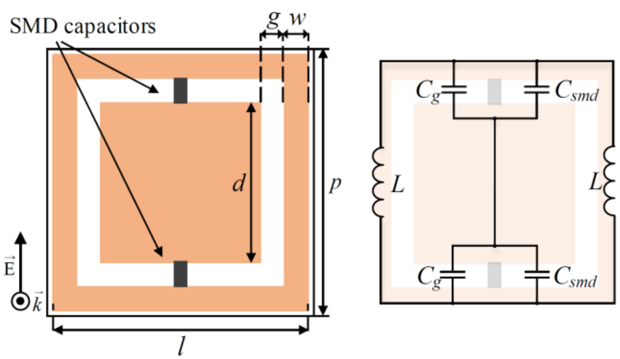


Figure 2: Square slot unit-cell and equivalent circuit.

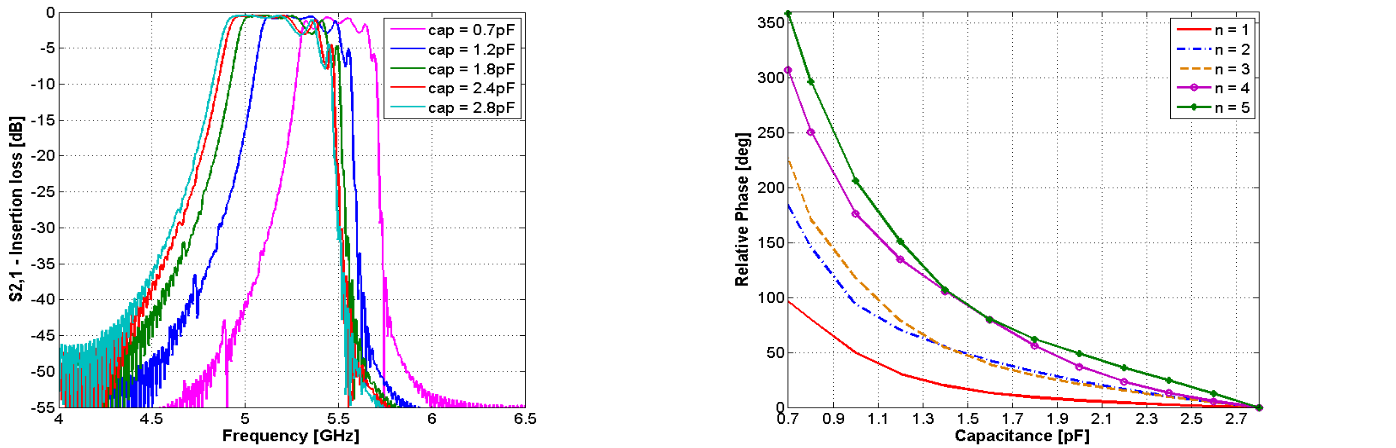
Dimensions: *p = 33 mm*, *l = 32.8 mm*, *d= 24 mm*, *g = 1.5 mm and w = 3 mm*, using Nelco NX9250 substrate with thickness *t = 1.5 mm*, ε_r = *2.50*, *tanδ = 0.0017* .

The square slot unit-cell, of Fig. 2, is proposed to reach phase (α_{mn}) control in each individual element of the array, and it counts with the following characteristics:

- *Spatial filtering:* EM wave passes through the structure with low insertion losses, Fig.3a;
- Band-pass filtering characteristic is shifted from *5* to *5.45 GHz* when capacitance is modified from *2.8* to *0.7 pF*;
- Extended phase range, up to 360º (Fig.3b), is achieved by stacking 5 layers of unit-cells at a distance of $\lambda/16$, separated by an air gap to increase the bandwidth and phase range;
- Steering output range up to θ = 25º and ϕ = 25º equivalent to Az = 22º and El = 10º in *Azimuth over Elevation* coordinate system, when mounted **as a 5 x 5 array.**

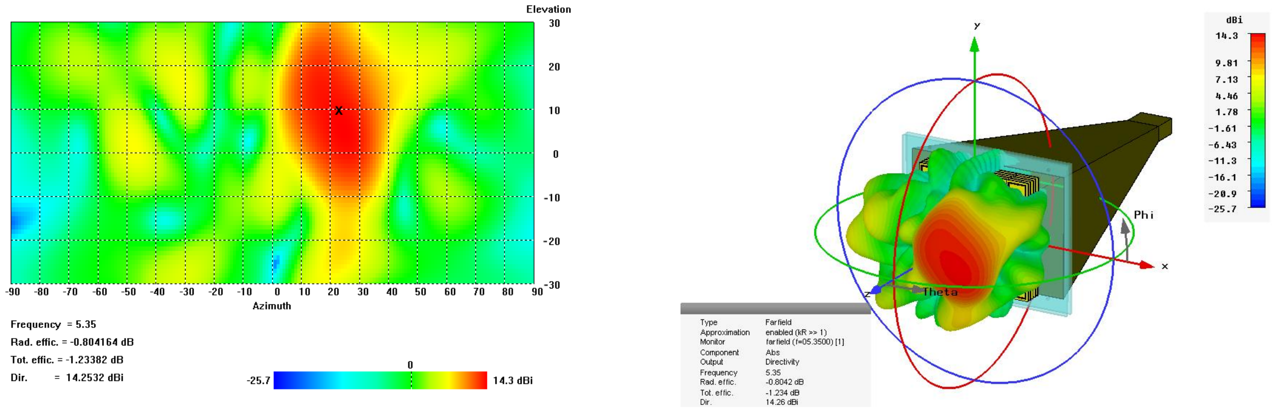
Two-Dimensional Antenna Beamsteering Using MM Transmitarray

2. Transmitarray Design, Simulation and Prototyping (cont.)



(a) (b)

Figure 3: Simulated (a) $S_{2,1}$ insertion loss (dB) and (b) Relative phase at 5.35GHz.



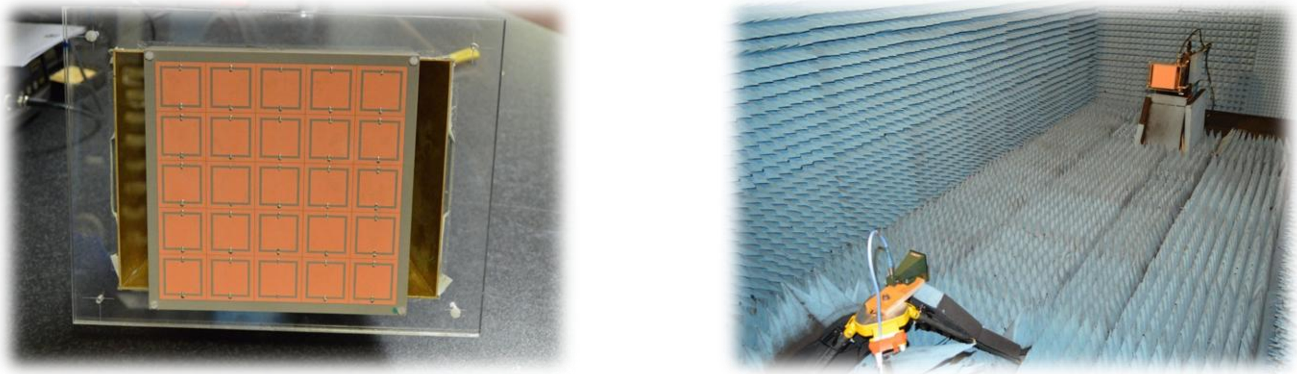
(a) (b)

Figure 4: Simulated (a) 2D far-field plot and (b) 3D radiation pattern for Az = 22º and El = 10º (θ = 25º, ϕ = 25º), using the transmitarray in front of a realistic model of a 20*dBi* horn antenna.

3. Experimental Results

To assess the prototype performance, both 2D far-field plot and 3D radiation pattern are compared with a reference horn antenna. The antenna with the transmitarray, has the following specifications:

- A maximum directivity of *11.4 dBi* at Az = 20º and El = 8º (θ = 22.5º , ϕ = 21.5º);
- HPBW of 18º in azimuth and 21º in elevation;
- Main lobe to side lobe level around 7dB.



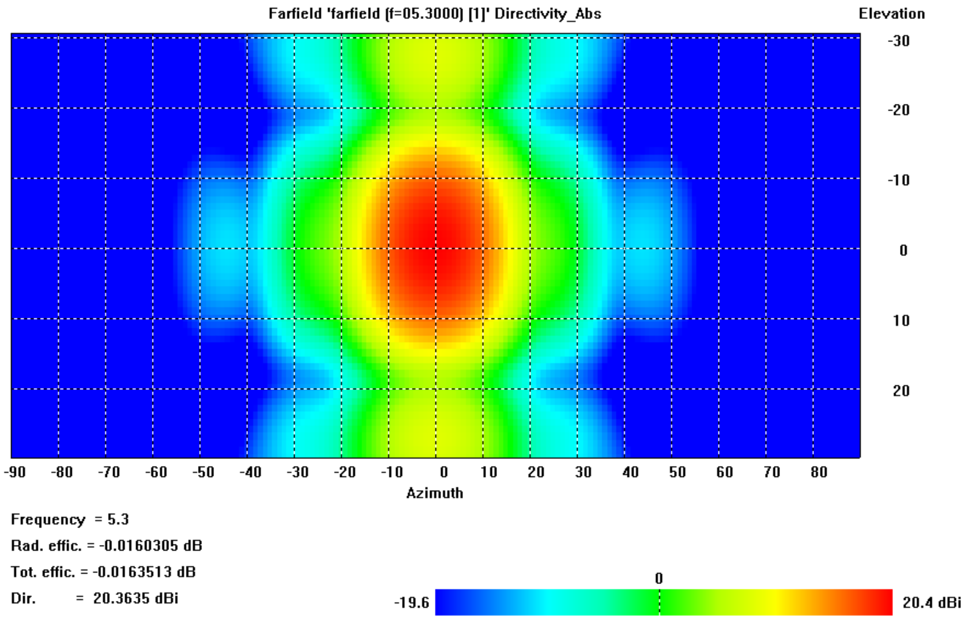
(a) (b)

Figure 5: (a) Transmitarray prototype and (b) illustration of the setup inside the anechoic chamber for the 3D radiation pattern measurement.

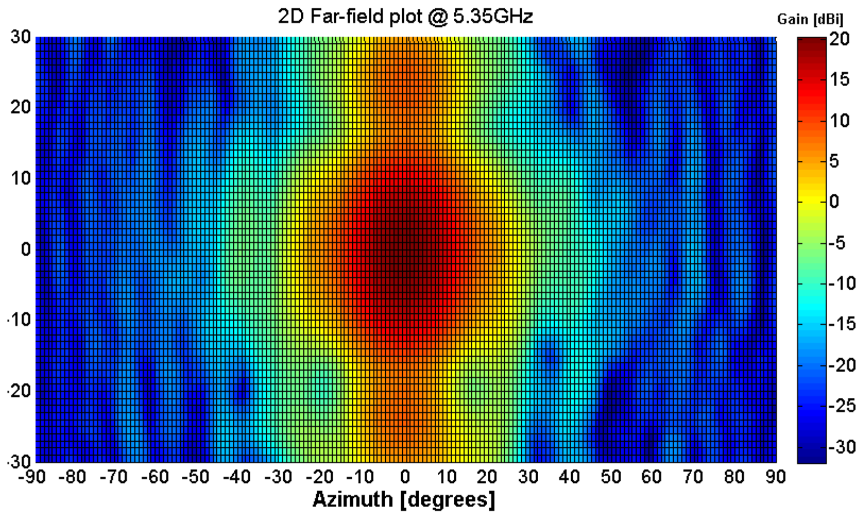
3.1 Reference Radiation Pattern @5.35GHz

Antenna only (no MM strucutre)

Simulated Result



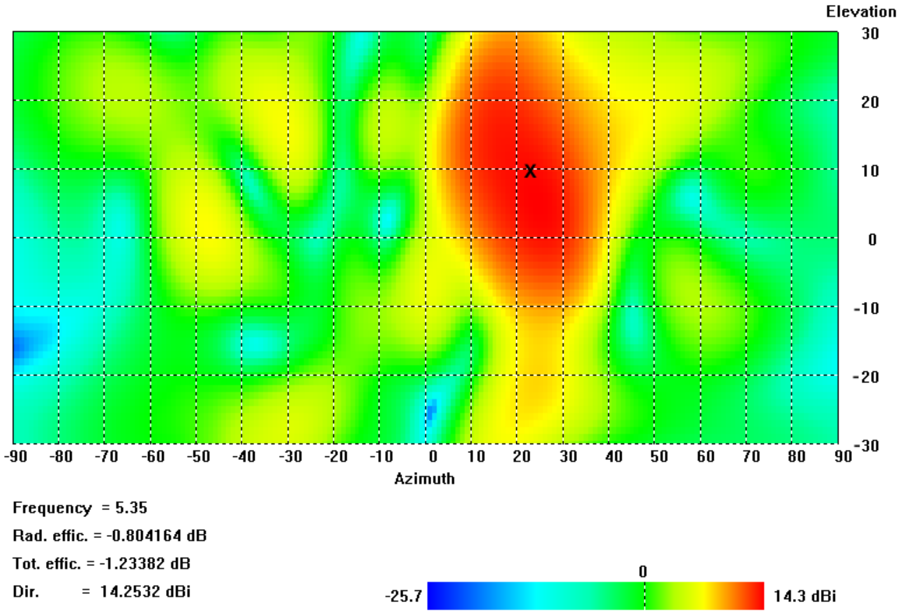
Measurement Result



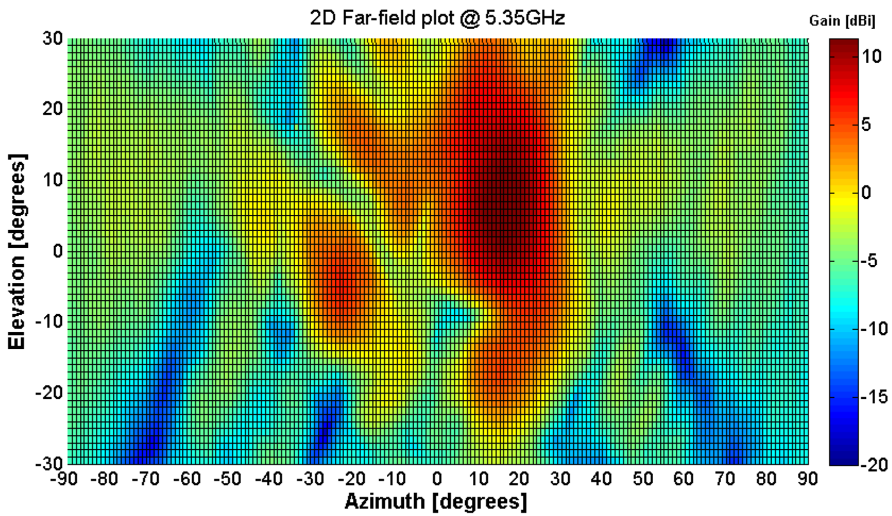
3.2 Desired Output Angle @ 5.35GHz

θ = 25º and ϕ = 25º >> Az = 22º and El = 10º

Simulated Results



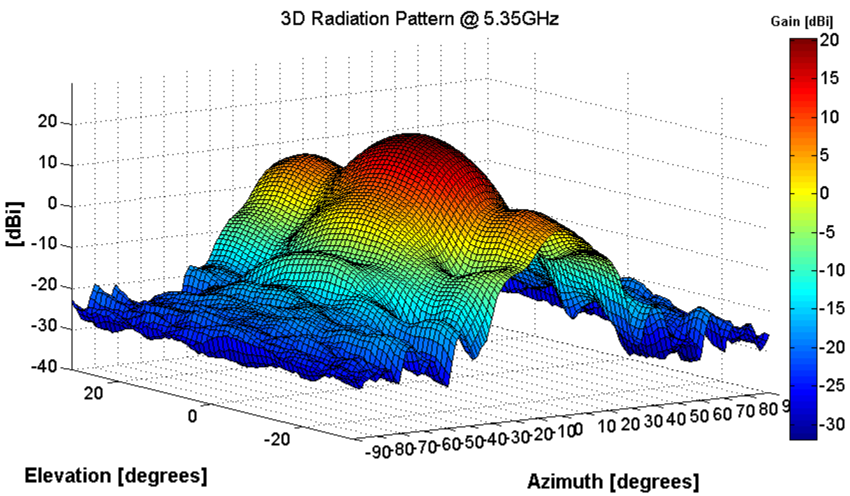
Measurement Results



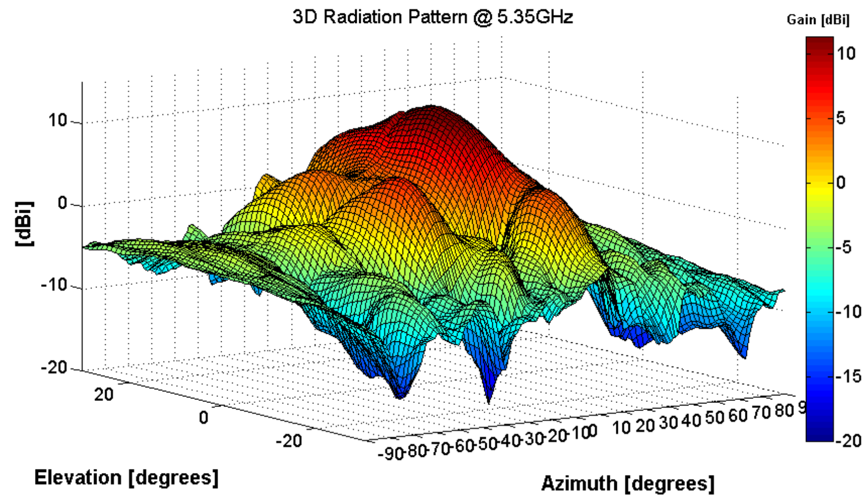
3.3 Desired Output Angle @ 5.35GHz

$\theta = 25^o$ and $\phi = 25^o$ >> $Az = 22^o$ and $El = 10^o$

Measured
Antenna only (original)



Measured
Antenna w/ structure



Conclusions

A new approach to the analysis of a metamaterial based transmitarray with 2D-beamsteering capability is proposed and validated by means of EM simulations and measurements. It was successfully demonstrated that the radiation pattern of a horn antenna can be shifted towards θ = 25º and ϕ = 25º (Az = 22º and El = 10º), when the transmitarray is coupled to the aperture of the antenna.