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Design and 3D printer realization of ultra-flat dielectric lens antennas for millimetre wave focusing systems.

Scientific Report on the Research Activity within the framework of the ESF program entitled "New Frontiers in Millimetre/Sub-Millimetre Waves Integrated Dielectric Focusing Systems"

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1 Introduction

Millimeter waves, because of their propagation characteristics, are being used in an increasing variety of applications, such as communication systems, radar and remote sensing, imaging and radio astronomy.

Artificial impedance surfaces have been demonstrated to be able to produce pencil beams with a medium-high gain [1] at millimetre wave frequencies. Basically, the artificial surface produces a leaky wave (LW) radiation by means of the interaction between an exciting surface wave (SW) and a modulated surface impedance pattern realized on an impenetrable dielectric slab. We will refer to such artificial surface as metasurface. Metasurfaces offer the possibility to completely control the radiated field properties by means of the excitation spectrum and surface impedance pattern. This latter is usually created by using a grounded dielectric slab periodically loaded. For example, the load on the dielectric surface can be formed by a dense arrangement of small metal patches on it. In a simpler way, a periodic corrugation on the slab thickness can be taken into account [2]. If the dielectric used is a plastic material used for rapid prototyping machines, the devices will result in a low cost solution.

From the theoretical point of view, such devices are based on a modulation of the surface reactance similarly to the canonical problem solved in [3]. There, a planar SW front is propagating on a plane possessing a sinusoidal modulation of the surface reactance. The problem is mono dimensional and solved rigorously to find the propagation characteristics of the SW in the modulated medium. Here we assume that the same conclusions can be applied to the two-dimensional case. In such problem, a cylindrical SW front interacts with a reactive plane having a modulation in both the radial and angular variables. One can describe the local interaction between an elemental angular wave-front of cylindrical SW and the corresponding elemental angular sector of the surface, by means of a 1D problem of a sinusoidal reactance excited by a planar SW (Figure 1).

The aperture field, resulting from the interaction between the SW and the modulated surface reactance, can be controlled both in amplitude and phase by properly acting on the modulation parameters. Typically, such modulation has a sinusoidal profile characterized by an average impedance value and a modulation index. By controlling such modulation index and the average impedance, the radiative performances of the dielectric lens can be improved, resulting in an improvement of the antenna efficiency and tapering control, thus leading to devices that can be effectively employed in focusing systems. In order to develop devices that are suitable for commercial applications, the use of new 3D printing technologies appears to be a promising solution. The 3D printer follows the input layout to lay down successive layers of liquid, powder, paper or sheet material to build the model from a series of cross sections. These layers, which correspond to the virtual cross sections from the CAD model, are joined or automatically fused to create the final shape. The primary advantage of this technique is its ability to create almost any shape or geometric feature with the use of cheap plastic materials without strong constraints on the EM properties of the material. Moreover, the plastic material used in the 3D printing process can be doped with powders to tune the dielectric constant to further increase the design degrees of freedom.

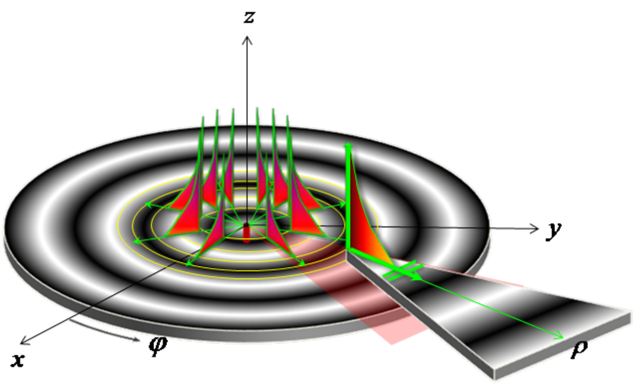

Figure 1: Cylindrical surface wave excitation on a modulated surface reactance. The interaction between SW and surface impedance is described by means of the local canonical problem of a planar SW impinging on a one-dimensional modulated surface reactance.

1.1 Purpose of the visit

The research groups both at the University of Siena and at Loughborough University have a long experience in analysis and design of periodic structures and in particular in metasurface-based antennas. In addition to this, the laboratories at the Electronic, Electrical and Systems Engineering School at Loughborough University are equipped with state of the art 3D printers, which allow the realization of prototypes with sufficient accuracy at millimetre wave frequencies. On the basis of the complementary skills of the two groups, the research project developed during the 5 month period that wwere be spent by Federico Puggelli at the Loughborough University was devoted to the design and 3D printer realization of an ultra-flat dielectric lens antenna.

2 Description of the work carried out during the visit

Following the theory outlined in [2], a dielectric leake wave spiral antenna was designed, to operate at the frequency of 15 GHz.
The antenna has a radius of 6 λ (12 cm), and its profile is described by the following equation

$$h = h_m \left[1 + m_s \cos\left(\beta_{sw}\rho - \phi\right)\right] \tag{1}$$

in which

$$\beta_{sw} = 363\,[\text{rad/m}] \qquad m_s = 0.47 \qquad h_m = 0.0026\,[m] \tag{2}$$

The dielectrid used in the 3D printing process has a relative permittivity of 2.73. The final product can be seen in Figure (2). According to the results of the simulations performed on a commercial software, the antenna is expected to have a directivity of 22 dB, resulting in a tapering efficiency of about 12 %.

Figure 2: Printed realization of the designed antenna.

3 Description of the main results obtained

In this section we provide the results of the measurements performed in the anechoic chamber at Loughborough University, and compared the collected data with the output of the simulations. As previously said, the measurements were run at an operating frequency of 15 GHz. The antenna under test (AUT) far field distance is 5.60 m. The distance between the probe and the AUT in the aforementioned anechoic chamber is 9.35 m. The measured directivity is 21.85 dBi (the simulated Directivity is 21.4 dBi). The measured gain is 20.037 dBi (the simulated realized gain is 19.66 dBi). The measured efficiency is 66% (the simulated efficiency is 67%). Figures (3)–(6) collect the results of the measurements and the simulations over four difference angles (rolls) ϕ (namely $\phi = 0$, $\phi = 45$, $\phi = 90$, $\phi = 135$), in terms of directive gain. The figures show that there is a perfect agreement between the measured antenna and the simulated one.

4 Future collaboration with host institution

Following the five month visit under the research grant provided by ESF "Newfocus", the two research groups at Loughborough University and at the University of Siena, respectively, will continue their collaboration, in order to improve the tapering efficiency of the Leaky Wave spiral antenna thus far designed. In this optic, Dr. Puggelli will extend his stay at Loughborough University until the end of September.

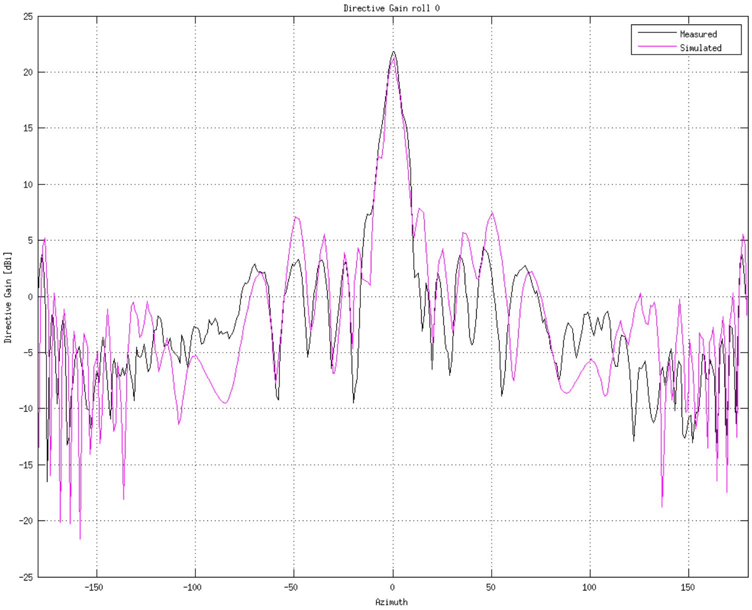

Figure 3: Directive Gain $\phi = 0$

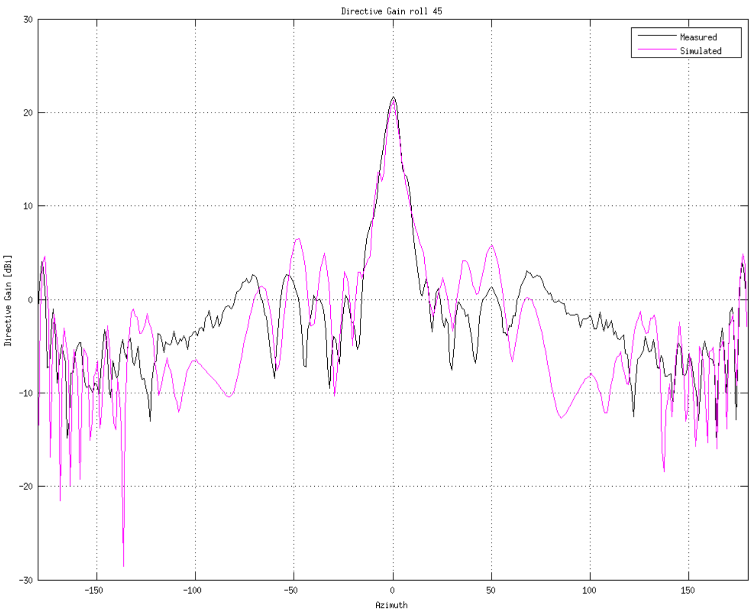

Figure 4: Directive Gain roll $\phi = 45$

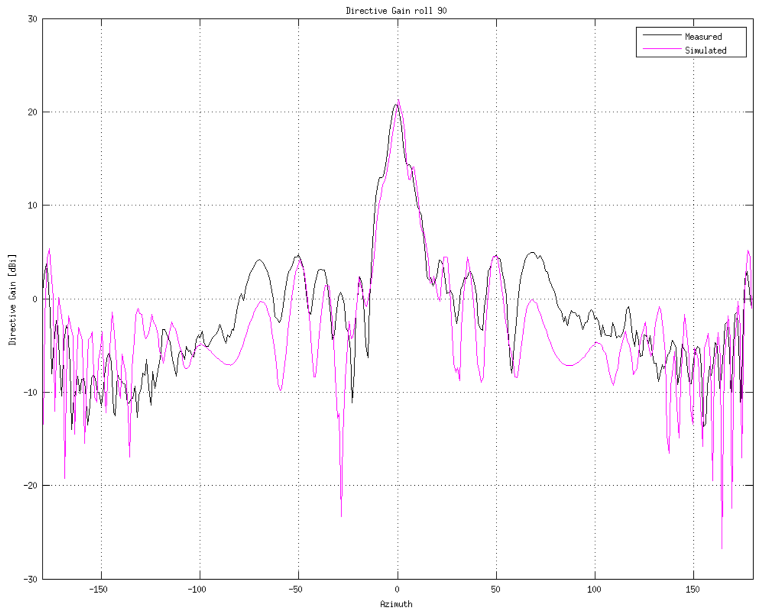

Figure 5: Directive Gain roll $\phi = 90$

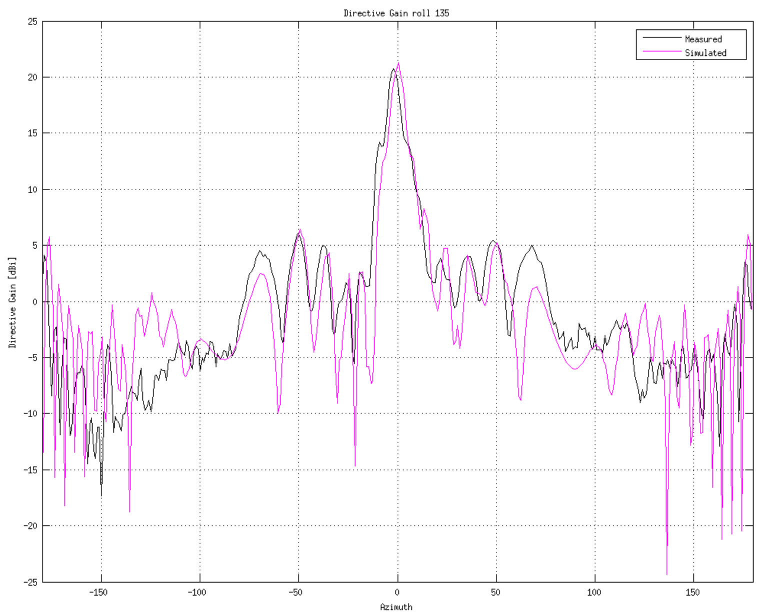

Figure 6: Directive Gain roll $\phi = 135$

5 Future publications

The two research groups are jointly preparing a journal paper, to be submitted to IEEE transactions on Antennas and Propagation, on the research topic developed under this ESF Newfocus research grant.

6 Other comments

The interaction between the two groups, in the frame of the Newfocus network of excellence support, by joining the expertise of the two partners, has surely given an important boost for the development of the proposed research project.

7 References

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