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(Article begins on next page)

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Beam Scanning Leaky-Wave Antenna with a Reconfigurable Impedance Plane

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Abstract—An electronically-reconfigurable leaky-wave antenna based on metasurfaces is designed and implemented. This innovative antenna consists of a multilayered structure with two (metasurface) impedance planes. The beam scanning at fixed frequency is achieved by electronically tuning the surface impedance of the lower plane using voltage-controlled varactor diodes. The rationale of this solution is that a variation in the impedance profile of the antenna in the direction transversal to propagation affects the phase velocity of the leaky wave and therefore the beam direction.

Index Terms—Leaky-wave antenna, metasurface, reconfigurability.

I. INTRODUCTION

In recent years, beam scanning antennas have been at the center of increasing interest because the ability to steer the beam direction at fixed frequency is needed in a wide range of modern applications such as satellite communication, IoT, 5G and automotive radar [1], [2].

Current state of the art solutions make use of electronically-reconfigurable phased arrays or require the mechanical rotation of the antenna itself. Both approaches have drawbacks: phased arrays, although flat, are expensive and intrinsically beset with high losses, while mechanical steering is speed-limited and requires bulky external components [3].

The antenna presented in this paper represents an alternative solution in terms of cost, power losses and form factor. It consists of a multilayered structure with two metasurface-based impedance planes, as shown in Fig. 1. Metasurfaces are two-dimensional sub-wavelength textures whose wave response is
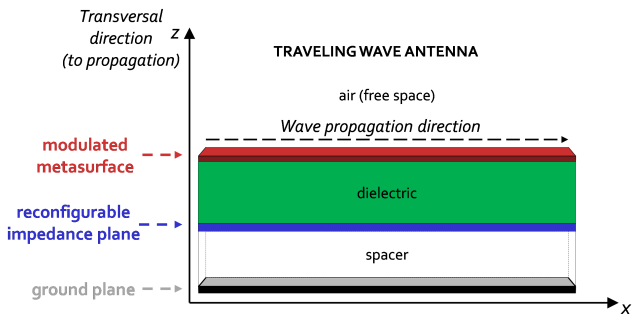

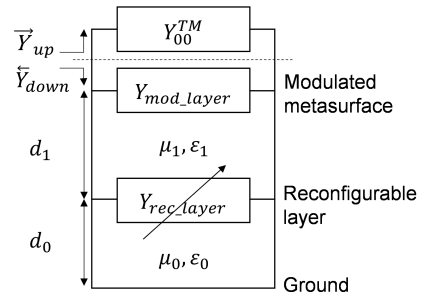Fig. 1. Multilayered structure of the antenna.

Fig. 2. Transmission line equivalent model of the antenna.

described in terms of a continuous surface impedance. In the designed antenna, an upper modulated metasurface ensures leaky-wave radiation [4], [5], while a lower, spatially-constant metasurface with reconfigurable impedance is responsible for beam scanning. Full-wave simulations of a detailed model of this structure demonstrate that beam steering is attainable with an architecture of this kind.

II. METHODOLOGY OVERVIEW

The main goal of the design process for this antenna is the determination and physical implementation of the reconfigurable plane's impedance values that are needed to obtain a certain beam scanning; these values must be attainable with proper biasing of the varactor diodes placed in this lower layer. To this aim, an approximate model is used in which the antenna is modeled as a transmission line in the transversal direction to wave propagation and each layer is represented by its sheet admittance (Fig. 2). This simplified approach has its rationale since the impedance profile of the structure affects the propagation constant of the leaky wave and therefore the beam direction. The link between these quantities is represented by the Transverse Resonance Equation (TRE) [6]:

$$\overleftarrow{Y}_{down} + \overrightarrow{Y}_{up} = 0 \qquad (1)$$

Solving the TRE gives the phase constant of the traveling wave and consequently the radiation angle.

The design process consists in reversing the transverse resonance equation and can be broken down in the following steps:

- A proper texture of the upper modulated metasurface is chosen (e.g. an array of strips separated by gaps of different width) and its sheet admittance (Y_{mod_layer}) is computed with simple normal-incidence scattering simulations of the unit cell [7].
- A commercial dielectric substrate (permittivity ε_1, thickness d_1) is selected. The width d_0 of the air gap is arbitrarily set.
- A parametric analysis of (1) by varying Y_{rec_layer} is performed to retrieve the sheet admittance values of the reconfigurable plane for which the TRE admits solutions (guided modes). These values must also be effective in changing the propagation constant of the sustained modes in such a way that an appreciable beam steering is approximately ensured.
- A proper geometry of the reconfigurable impedance plane's constitutive unit cell is studied; this layout must implement the needed values of Y_{rec_layer} by varying biasing voltage of the varactor diodes placed on it. If such a geometry cannot be found, the starting values of ε_1, d_1, d_0 are adjusted and the design process is repeated.
- Once the layouts of all layers are set, the complete antenna is simulated and a more accurate beam scanning is evaluated.

III. ANTENNA GEOMETRY AND SIMULATIONS

Following the design strategy presented in Section II, the layouts of the modulated metasurface and lower reconfigurable impedance plane are derived (Figs. 3 and 4); the modulated metasurface was implemented as in [5], while the unit cell of the reconfigurable plane was inspired by the one shown in Fig. 6(a) in [8]. This antenna is designed to work at 10.65 GHz; the varactor diodes inserted in the reconfigurable layer are all biased simultaneously via two buses, resulting in a very simple feeding network.

The detailed model of the antenna is then simulated with full-wave software [9]. The field pattern at 10.65 GHz in the plane $\varphi = 0°$ is represented in Fig. 5. Varying the biasing state of the varactors, an overall beam steering of 9° is found; although small, this result demonstrates that beam scanning is attainable with the proposed architecture. To verify the performance of this structure, a prototype fabrication is under way (partly shown in Fig. 6).
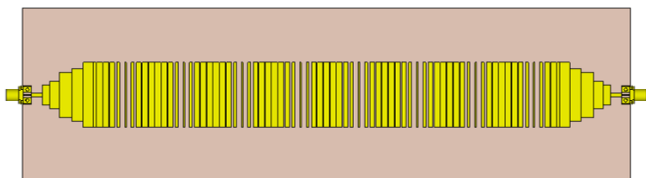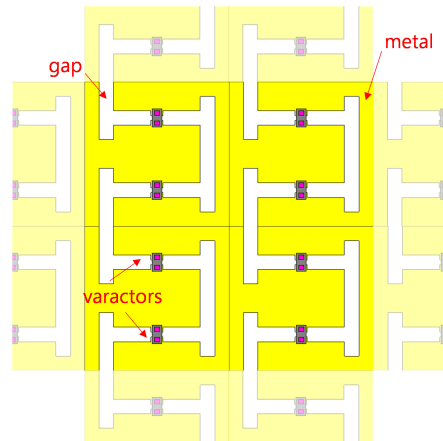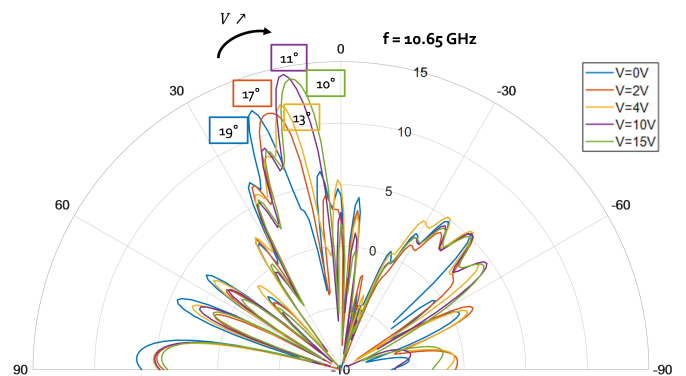
Fig. 4. Texture of the reconfigurable layer.

Fig. 5. Far-field at 10.65 GHz, with realized gain expressed in dB. The beam steers from 19° to 10° with increasing biasing voltage.

IV. CONCLUSION

In this paper, a novel architecture for a beam scanning, leaky-wave antenna is presented that consists in a multilayered structure with two metasurface-based impedance planes. Reconfigurability is achieved by electronically tuning the impedance of the lower plane using voltage-controlled varactor diodes; this affects the propagation constant of the leaky wave and ultimately the beam direction.

The main advantages of this solution with respect to other currently exploited architectures are the design simplicity, the absence of complex feeding networks and the small volume.

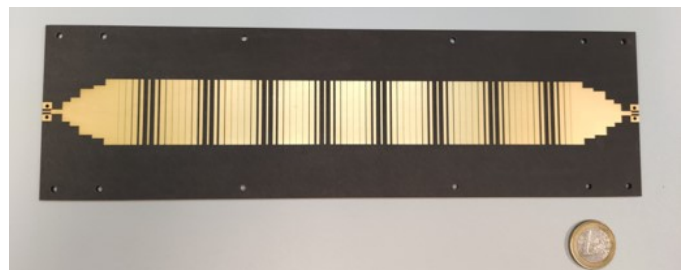Fig. 3. Top view of the designed antenna.

Fig. 6. Top view of the prototype.

To test the real performance of this antenna, a prototype fabrication is in progress and measurement results will be presented during the Conference.

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