Fixed-frequency beam-scanning antenna with a reconfigurable metasurface

Fixed-Frequency Beam-Scanning Antenna with a Reconfigurable Metasurface

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***Abstract*—A novel fixed-frequency beam-scanning antenna based on a reconfigurable metasurface is designed and fabricated. This architecture implements a sinusoidally-modulated reactance surface with voltage-controlled average reactance; this is achieved by printing a modulated metallic cladding on a dielectric substrate and substituting the standard ground plane with a tunable metasurface loaded with varactor diodes. Varying the varactors' bias voltage on the lower plane affects the overall average reactance of the structure and allows to control the radiation angle. Experimental measurements confirm the validity of this innovative beam-steering technique.**

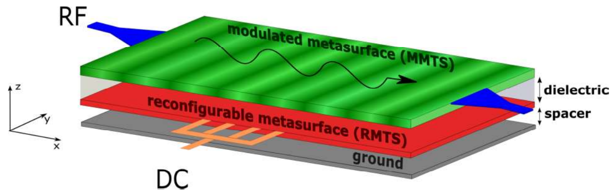


Fig. 1: Schematic structure of the proposed antenna.

I. Introduction

Fixed-frequency beam-scanning antennas are fundamental in many modern applications such as satellite communication, IoT, 5G and automotive radar [1], [2]. Small form factor and low cost are also sought-after features.
Current state-of-the-art solutions are represented by electronically-reconfigurable phased arrays, which are quite expensive and intrinsically beset with high losses.
In this paper, a novel fixed-frequency beam scanning leaky-wave antenna (LWA) based on a sinusoidally-modulated reactance surface (SMRS) is presented. SMRSs allow to independently control the radiation angle and the attenuation constant of the leaky wave [3] and are typically realized by printing a metallic cladding on a grounded dielectric substrate [4]. In the proposed solution, beam steering is obtained by substituting the ground plane with a tunable-impedance metasurface: changing the bias voltage of the varactor diodes placed in the metasurface's texture modifies the overall dispersion behavior of the structure and thus the propagation constant (and the radiation angle) of the traveling wave.
The designed antenna is extremely low-profile and requires a single bias voltage for all the active elements. While the steering range obtained with this prototype is small, the high efficiency and low cost make this architecture a promising solution in the field of reconfigurable antennas.

II. Theory

The schematic structure of the proposed antenna is shown in Fig. 1. The antenna is composed by two metasurface-based impedance planes printed on opposite sides of a dielectric layer: the upper metasurface is spatially modulated along the direction of wave propagation, while the lower metasurface consists of identical unit cells loaded with varactor diodes. A bare ground plane is placed at the bottom, separated from the reconfigurable metasurface by an air gap.
In the general case, a SMRS can be used to generate leaky-wave radiation of the $\mathrm{n} = -1$ harmonic of the traveling wave [3], [4]; assuming a TM mode propagation, the radiation angle θ_{-1} is linked to the average surface reactance $X_{\mathrm{s_{ave}}}$ by the approximate expression [4]:

$$\theta_{-1} = \arcsin\left(\sqrt{1+\left(\frac{X_{\mathrm{s_{ave}}}}{\eta_0}\right)^2} - \frac{2\pi}{k_0 p}\right) \tag{1}$$

where η_0, k_0 are the free space impedance and wavenumber and p is the modulation period.
If we approximate the considered multilayer structure with an equivalent impenetrable reactance surface that takes into account the effects of both metasurfaces, the average reactance $X_{\mathrm{s_{ave}}}$ of such modulated surface depends not only on the modulation pattern of the upper layer but also on the impedance of the reconfigurable plane. Therefore, according to (1), the radiation angle θ_{-1} can be steered electronically by changing the varactors' bias voltage while maintaining a fixed layout of the top layer.
In the antenna proposed in this paper, the upper modulated impedance plane is implemented via an array of metal strips separated by gaps of varying width, as it was done in [4], while the layout of the reconfigurable metasurface's unit cell is inspired by [5]. Fig. 2 shows the mapping between the overall surface reactance of the structure and the gap width between adjacent metal strips, for two different values of the varactors' bias voltage. From this graph it is clear that a fixed modulated pattern of the metal strips in the upper plane can correspond to a different average surface reactance (and, consequently, a different radiation angle) depending on the biasing state of the

varactors placed in the lower metasurface, thus allowing for electronically-controlled beam steering.

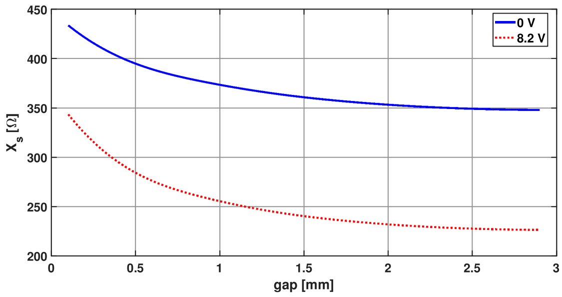
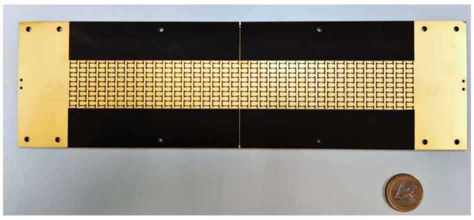


Fig. 2: Surface reactance vs. the gap width between adjacent strips in the upper plane, for different bias voltages of the varactors in the lower metasurface.



(a)

(b)

Fig. 3: Fabricated antenna prototype. (a) View of the reconfigurable metasurface on the back of the dielectric substrate. (b) Measurement setup in the anechoic chamber.

III. Results and Discussion

The fabricated prototype is pictured in Fig. 3. The radiating part of the antenna is 216 mm-long; adding the tapered sections to match a 50 Ohm coaxial cable (see Fig. 3b), the total length is about 281 mm. The reconfigurable plane, shown in Fig. 3a, contains 360 varactors that are biased simultaneously with one common voltage. The two metasurfaces are separated by a layer of Rogers RT5880 ($\varepsilon_r = 2.2, \tan\delta = 0.0009$) 3.175 mm-thick. The overall thickness of the structure is less than $\lambda_0/6$ at the working frequency of 10.6 GHz, resulting in a very small form factor.

Measured far-field patterns at 10.6 GHz for two varactors' bias voltages are plotted in Fig. 4; a beam steering of 7.5° is obtained when the voltage goes from 0 V to 8.2 V, thus proving

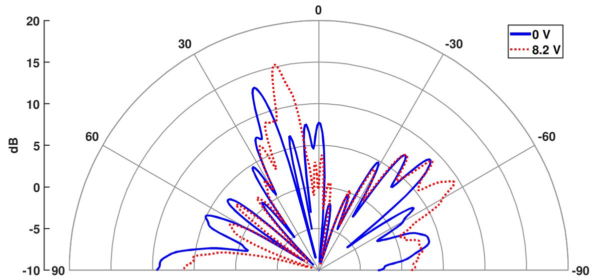


Fig. 4: Measured radiation pattern at 10.6 GHz for two values of the varactors' bias voltage; the beam steers from 19.5° (0 V) to 12° (8.2 V).

the beam-scanning capability of the proposed architecture. S_{11} is equal to -10 dB and S_{21} remains below -20 dB for every varactors' bias voltage. The gain spans from 10.8 dB to 12.8 dB, while the radiation efficiency is around 60%.

Although the angular scanning range achieved with this first prototype is limited, the small form factor, low cost, high efficiency and simple bias network make the proposed architecture an interesting solution for all those applications where fixed-frequency beam scanning and low encumbrance are equally important.

Acknowledgement

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