# Design of Compact Beam-Steering Active Slot Antennas with a Metasurface Reflector

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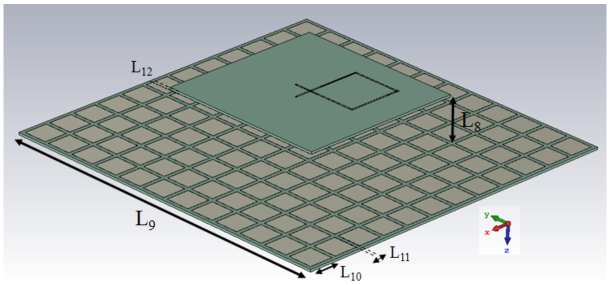
***Abstract*—A wideband and miniaturized reconfigurable antenna operating from 3.5 GHz to 5.5 GHz is proposed. This antenna has a simple structure and uses one tapered cross-shaped radiation slot with four parasitic slots and eight PIN diodes. Four diodes are used to control four reflector slots to steer the radiation pattern and the other diodes are used to switch the feeding path to modify the polarization of the radiated beam. The metasurface acts as a reflector and reduces the back lobe, while keeping the profile of the antenna small. Simulation results are presented. The main lobe has minimum gain of 7 dBi and can be steered along 5 positions $0^\circ$, $\pm 17^\circ$ in two perpendicular elevation planes.**

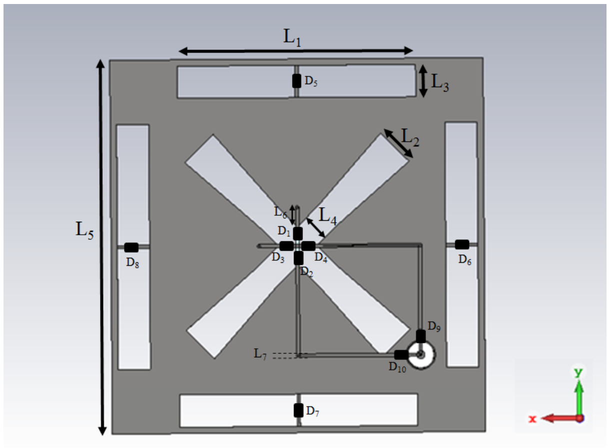
## I. INTRODUCTION

Reconfigurable antennas are well known and useful in many applications such as satellite communications, radar and wireless systems. Most reconfigurable antennas are designed using a Rotman lenses [1], Luneburg lenses [2], active phased arrays [3] or metasurfaces [4]. Antenna designs that include metasurfaces for different purposes have recently attracted a lot of interest because they are less bulky compared to phased arrays or Rotman and Luneburg lenses, especially at lower frequencies. As an aside, we note that metasurfaces also represent an increasingly popular solution for several optical applications, for example to realize flat lenses and nano-antenna structures [5], [6], [7]. Several recent papers have proposed to design antennas containing metasurfaces that provide and/or control the excitation. However, the individual radiating/scattering elements composing a metasurface are typically narrowband due to their resonant nature. This problem may be partially circumvented by considering frequency-reconfigurable metasurface designs.

Some authors also proposed using PIN diodes to control the direction of the antenna radiation, as in the Yagi-Uda design considered in Ref. [8]. Within this context, in this work, we propose a wideband antenna design in which a metasurface is part of the radiating structure, and diodes control the elements that are responsible for determining the beam direction. The antenna size is minimized thanks to the presence of the metasurface substrate, and a tapered cross-shaped antenna is used to increase the bandwidth.



(a)



(b)

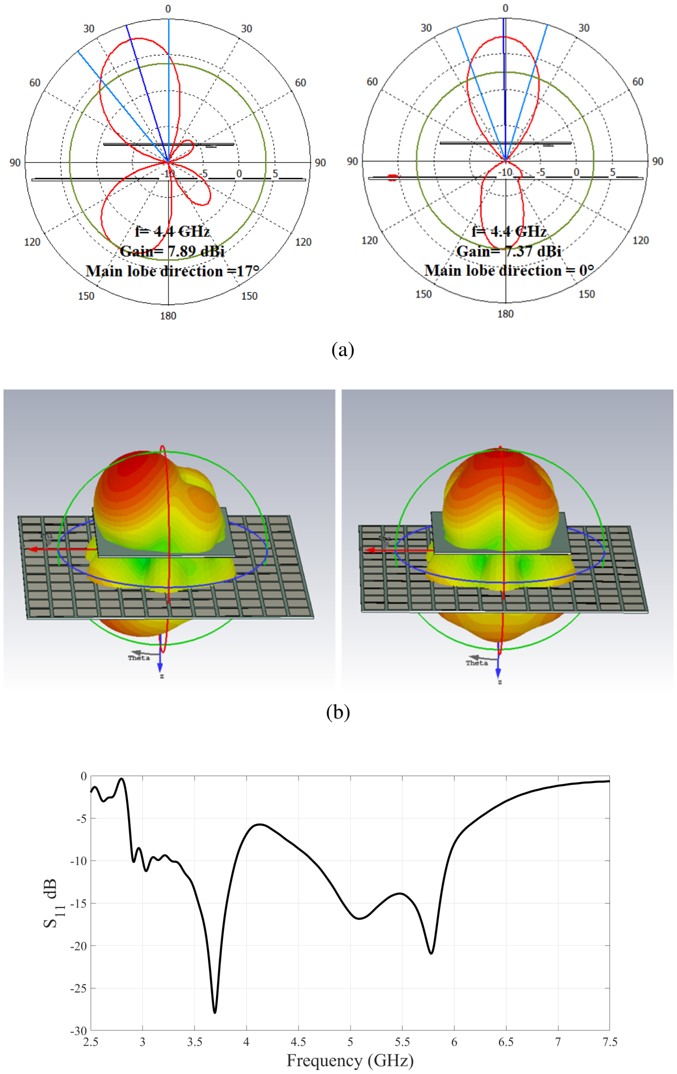
Fig. 1: Geometry of the proposed antenna. (a) Side view of the entire structure, (b) top view of the tapered cross-slot antenna. The dimensions are given in Table I.

## II. ANTENNA DESIGN

The structure of the proposed antenna consists of two elements: a tapered cross-slot antenna on a 0.76 mm Rogers FR4-4003 substrate with $\epsilon_r = 4.2$; and a capacitive metasurface on

TABLE I: Dimensions of the antenna (mm)

| Parameter | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ |
|---|---|---|---|---|---|---|
| **Dimension** | 38 | 6.2 | 5 | 4.2 | 58 | 2.9 |
| **Parameter** | $L_7$ | $L_8$ | $L_9$ | $L_{10}$ | $L_{11}$ | $L_{12}$ |
| **Dimension** | 0.5 | 15 | 120 | 8.5 | 1.4 | 0.76 |



(a)

(b)

(c)

Fig. 2: (a,b) Simulated radiation patterns in the y-z plane at 4.4 GHz. (c) Simulated $S_{11}$.

the same substrate. The structure is designed at the center frequency of 5.2 GHz. The metasurface consists of periodical unit cell patches placed at the distance $L_8 = 15$ mm to minimize the backward radiation lobe using a low-profile structure. The cross-shaped main slot is one wavelength long and is tapered; in this way, obtaining higher bandwidth is easier compared to a $\lambda/2$ slot, which has higher quality factor [9]. Cross slots occupy less real estate and can be fed to obtain two orthogonal polarizations using two orthogonal microstrip stubs, as shown in Fig. 1.

The input slot impedance is adjusted by changing the feed via points so that the return loss can be minimized. There are two paths to feed the antenna to obtain two orthogonal polarizations: for the first path diodes $D_3$, $D_4$ and $D_9$ should be ON and diodes $D_1$, $D_2$ and $D_{10}$ should be OFF while for the second path the state of the diodes is reversed. The PIN diodes are BAR50-02, SC-79 from Infineon Technologies with a physical dimensions of $1.2\ \mathrm{mm} \times 0.8\ \mathrm{mm} \times 0.55\ \mathrm{mm}$ and have 0.95 V forward voltage bias.

The cross-shaped antenna is surrounded by four slots acting as reflectors (the lengths of the slots exceed $\lambda_g/2$ so that their input impedances will be inductive according to the theory of a two-element dipole array [9]). The reflective slots are used to rotate the beam. Diodes $D_5$ and $D_7$ rotate the main beam in the y-z plane and diodes $D_6$ and $D_8$ rotate the main beam in the x-z plane. For example, when diode $D_5$ is ON and diode $D_7$ is OFF, the pattern rotates toward the negative y-axis. Thus, we can rotate the beam toward four different positions by appropriately switching the PIN diodes.

## III. SIMULATION RESULTS

The proposed antenna was simulated using CST Microwave Studio and optimized using its particle swarm algorithm. It has overall dimensions of $120\ \mathrm{mm} \times 120\ \mathrm{mm} \times 15\ \mathrm{mm}$. The final dimensions are listed in Table I. The radiation patterns when all the slot diodes are OFF and when one of them is ON are compared in Fig. 2b. As shown in Fig. 2a, the main beam rotates about 17°. The simulated $S_{11}$ is also shown in Fig. 2c. Further reduction of the back radiation lobe, and further miniaturization of the antenna profile could be obtained considering more advanced metasurface designs.

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