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Metal-Only Reflectarray Generating Two Independent Beams with Orthogonal Linear Polarizations

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Abstract—This paper presents a Metal-Only reflectarray antenna generating two independent beams with orthogonal linear polarizations. Such reflectarray is based on a dual polarized cell that allows to control the reflection phase of incident waves independently in both polarizations. The simulated gains of the two beams at 25 GHz are 30.77 dBi and 30.14 dBi respectively.

I. INTRODUCTION

Reflectarray antennas (RAs) can be seen as a combination of planar arrays and parabolic reflectors with the advantages of high gain, low profile, low cost and easy manufacturing. For some applications, RAs are required to generate multiple independent beams. In [1], a single layer dual-polarized 1-bit cell is used to design an independently controllable dual-beam reflectarray antenna. So far, several structures [2-4] have been designed with the ability to independently control the reflection phases of different polarizations. All these solutions are based on the use of dielectric substrates, which may bring certain limitations (such as the losses, and other undesired phenomena when working in harsh environments).

This contribution proposes a Metal-Only reflectarray antenna (MORA) allowing to generate two pencil beams with orthogonal polarizations. To the best knowledge of these authors, such an antenna has not yet been proposed in the open literature. The paper is organized as follows. Section II presents the MORA unit-cells, and Section III explains the design process and shows its performance based on full-wave simulations. Finally, conclusions are drawn in Section IV.

II. METAL ONLY REFLECTARRAY UNIT-CELL

A. Description of metal-only unit-Cells

Recently, a 3D Phoenix Cell (PC) was proposed by some of the authors and it was fabricated using Selective Laser Melting technology [5]. It consists of two concentric square metallic waveguides and a square metallic block at the center. Inspired by the 3D PC, a novel metal-only cell is used here to design two beams MORA. As shown in Fig.1, the difference between the initial 3D PC and the metal-only cell considered here is that four walls are added to split the two waveguides into two parts. This modification allows the proposed cell to independently control the incident waves with orthogonal linear polarizations. In addition, the cross-section of the cell is fixed, and the reflection

phase is controlled by tuning independently the heights of both waveguides (h_{in} and h_{ex}) as it will be explained next.

The cross-section of the cell is first designed so that the inner or outer waveguides are both propagative at the considered operating frequency, $f_0 = 25$ GHz. The outer waveguide supports a vertically polarized mode (along x) while the inner one supports a horizontally polarized one (along y). Note that the cutoff frequency of the inner waveguide is reduced below f_0 thanks to the square metallic block (L_p), which size is optimized to make propagation possible. Then, the reflection phase at f_0 for both modes is controlled by adjusting only the heights of the waveguides: h_{in} controls the phase of y polarization while h_{ex} deals with x one. In order to eliminate the coupling between both waveguides and to control the reflection phase independently in both polarizations, four walls are added to the cell (they are highlighted in red in Fig. 1). These four walls impose that the modes in the inner and outer waveguides are orthogonally polarized. Thus, the coupling between both waveguides can be minimized as much as possible by selecting appropriate wall thicknesses (w_1 , w_2). As a result, the proposed metal-only cell has two degrees of freedom to control the reflection phase independently and it can be used to design a MORA providing two independent beams with orthogonal polarizations.

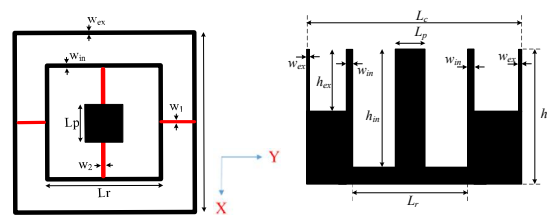


Figure 1. The proposed unit-cell : (left) top and (right) side views.

B. Performance of unit-cell

Before the design of the dual-beam MORA, the performance of the proposed metal-only cell is verified using simulations with HFSS[®]. A conductivity of 1.33×10^6 S/m is used to represent the real metal material. Typical Floquet boundary conditions are employed for this simulation to mimic an infinite array of identical elements. The detailed parameters of the cell are tabulated in Table I. Figure 2 shows the simulated reflection phase of the metal-only cell at normal incidence and at 25GHz. Note that the electric field direction is parallel to the y -axis for

Fig.2 (left) and to the x-axis for Fig.2 (right). As it can be seen, the complete 360° phase range can be achieved by increasing the height of the inner waveguide up to 15mm, and up to 9mm for the external one. Furthermore, the coupling between both waveguides is negligible: the maximum phase difference is 4° when varying h_{ex} for $h_{in}=7.5\text{mm}$. This demonstrates that h_{in} and h_{ex} can almost independently control the reflection phase in both polarizations. The reflection phases at different incident angles are shown in Fig.3. The parameters h_{ex} and h_{in} are set to 5mm (Fig.3(left)) and 8mm (Fig.3(right)), respectively. A maximum phase difference of 20° is obtained when varying the incident angle (theta, phi) for $h_{ex}=3.5\text{mm}$, which is completely acceptable for the design of a RA. Finally, a medium incident angle (15°, 90°) is adopted to simulate the database used to design an array. Figure 4 shows the reflection phase and loss at the incident angle (15°, 90°). It can be seen that the loss of the inner waveguide is significantly higher than that of the outer waveguide, which may deteriorate the gain.

TABLE I. DETAILED PARAMETERS OF METAL-ONLY CELL

Parameter	L_c	L_r	L_p	h_{in}	h_{ex}	w_{in}	w_{ex}	w_1	w_2
Value (mm)	6	4.7	3	0-15	0-9	0.3	0.2	1.6	0.4

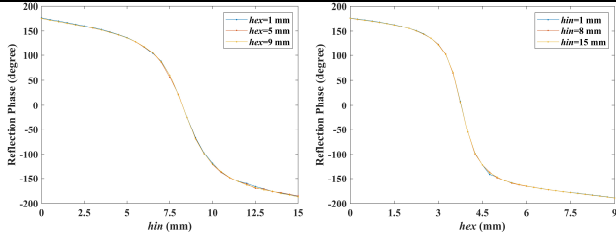


Figure 2. Phase response of the cell at 25GHz at normal incidence: inner waveguide (left); outer waveguide (right)

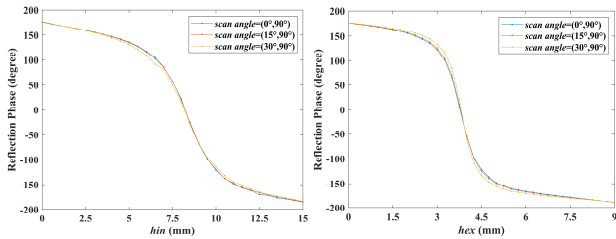


Figure 3. Phase response of the cell at 25GHz and at different incident angles: inner waveguide (TM polarization) (left); outer waveguide (TE polarization) (right)

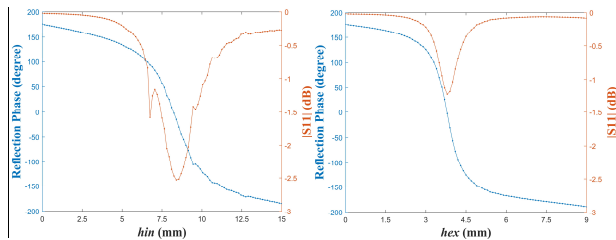


Figure 4. Phase response and loss of the cell at 25GHz at (15°, 90°) incident angle: inner waveguide (TM polarization) (left); outer waveguide (TE polarization) (right)

III. TWO BEAM REFLECTARRAY DESIGN

In this section, a dual-beam MORA is designed using the database in Fig.4. The radiating aperture is $15\lambda_0 \times 15\lambda_0$ while the inter-element spacing is $0.5\lambda_0$. The RA is illuminated by a

linearly-polarized horn antenna with an offset angle of (15°, 90°) with respect to the normal of the panel. The fd ratio is 1. The directions of the beams are (15°, 225°) and (15°, 315°) respectively. The h_{in} and h_{ex} heights of each cell are selected one by one to meet the required phase distributions for both beams (h_{in} for beam (15°, 225°) and h_{ex} for (15°, 315°)). The designed MORA is simulated in HFSS® together with its illuminating horn antenna. Figure 5 shows the simulated normalized radiation patterns at f_0 for a x- and y-polarized incident waves respectively. The horn antenna is rotated by 90° around the direction of propagation to change the polarization of the incident wave. It can be seen that the side lobe level and cross polarization level for both beams is below -29dB and -37dB respectively. The simulated gains are 30.14 dBi and 30.77 dBi respectively. The gain difference is mainly due to the loss of inner waveguide shown in Fig.4.

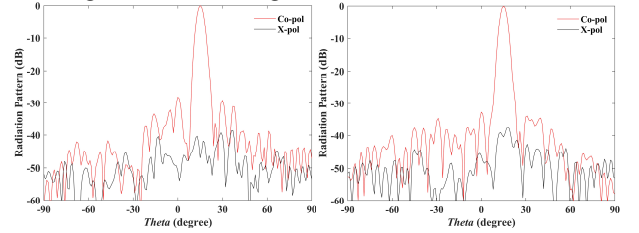


Figure 5. The simulated normalized radiation pattern: the beam controlled by inner waveguide (phi=225°) (left); the beam controlled by outer waveguide (phi=315°) (right)

IV. CONCLUSION

In this work, a novel metal-only cell is proposed and analyzed. The proposed cell has the ability to independently control the reflection phase of incident waves with orthogonal linear polarizations. A two beams MORA is designed using the proposed cell. The simulated gains of two pencil beams are 30.14dBi and 30.77 dBi respectively.

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