2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/USNC-URSI) | 978-1-6654-9658-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/AP-S/USNC-URSI47032.2022.9886020

A Broadband Reflectarray with Independently Controlled Dual-Beams

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***Abstract*—A broadband 1-bit independently dual-polarized dual-beam reflectarray antenna (RA) based on a magneto-electric dipole (MED) unit cell is proposed. This unit cell employs four stubs, which can be short-circuited (SC) or open-circuited (OC) to independently control two orthogonal linearly polarized beams. The proposed unit cell exhibits a very wide reflection phase bandwidth from 31.5 to 54 GHz (54.1 %). The radiation characteristics of the RA are obtained analytically, using the aperture field approach. The proposed reflectarray achieves a 1.5dB gain bandwidth of 35 % from 32 to 45.5 GHz.**

I. Introduction

There is an intensive ongoing research effort to design wideband, independently dual-polarized, and beam steerable cost-effective reflectarray antennas (RAs) for multi-user MIMO (MU-MIMO) applications [1]. So far, a passive broadband dual-polarized RA with independently controllable 1-bit dual-beam was presented in [2]. However, this design suffers from a limited 1.5dB gain bandwidth of 22 %. Hence, the need to use broadband radiating elements that can achieve stable radiating properties over a wideband operating bandwidth is of great interest. A detailed state of the art shows that magneto-electric dipole (MED) antennas proposed in [3] are promising solutions with excellent radiation characteristics and wide impedance bandwidth [4],[5]. The operation of MEDs is based on the Huygens source's concept, which was demonstrated in [6], using spherical wave expansion analysis.

II. Dual-Polarized 1-Bit MED Unit Cell

A. Unit Cell Design

The proposed unit cell is presented in Fig. 1. The two crossed electric dipoles are made from four horizontal square metal plates printed on a ground-backed dielectric substrate. Each horizontal plate is connected to the ground plane using six vertical metallic vias. The magnetic dipoles (slots) are made by each adjacent vertically oriented vias and the ground. This arrangement forms two crossed MEDs, producing a dipole at $\phi = 0°$ and $\phi = 90°$. The square plates are connected with: (a) two horizontally-oriented stubs, which are used to steer the horizontally-polarized (H-pol) incident beams by switching between a short-circuit (SC), and an open-circuit (OC) state, and (b) two vertically-oriented stubs, which are used to steer the vertically-polarized (V-pol) incident beams by exploiting the same switching mechanism.

The unit cell dimensions are optimized to achieve a relative reflection phase of 180° between the SC and OC states of the stubs for both polarizations in a wide bandwidth. A Taconic TLY substrate with a relative permittivity $\varepsilon_r = 2.2$ and a thickness h = 1.016 mm is used. The geometry of our optimized unit cell is shown in Fig. 1.

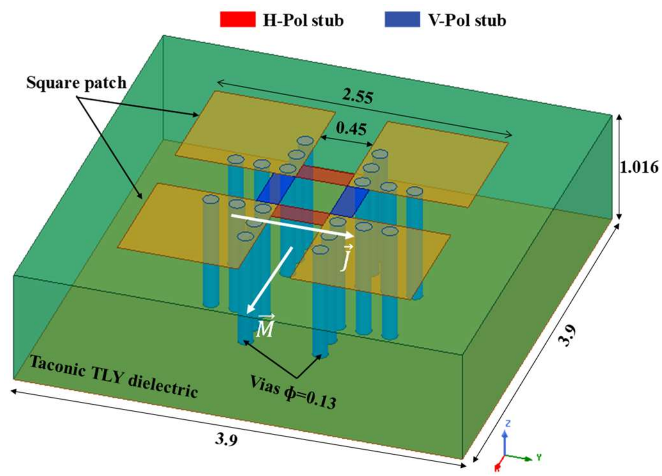

Figure 1. 1-bit dual-polarized crossed MED unit cell (dimensions in mm).

B. Principle of Operation

The simulated performance of our unit cell based on the infinite periodic array approximation is obtained using ANSYS HFSS, and it is shown in Fig. 2. When the reflection phase is 0°, the unit cell operates as a magnetic dipole (loop); hence, we will refer to this state as magnetic resonance. When the reflection phase is 180°, the unit cell operates as an electric dipole, and this state is referred to as an electric resonance. The unit cell is simulated under an H-pol incident wave. Therefore, its reflection characteristics should be controlled only by the horizontally-oriented stubs (colored red in Fig. 1) and not the vertically-oriented ones (colored blue in Fig. 1). This is confirmed in Fig. 2, and as a result, the proposed reflectarray unit cell exhibits the ability to steer two orthogonal linearly polarized beams independently. Furthermore, an electric along with a magnetic resonance are aligned around 31 GHz as well as 43 GHz at both operating states. The first electric resonance corresponds to a folded electric dipole formed by the patches, vias, and ground (H-pol stubs at OC state), while the first magnetic resonance corresponds to a magnetic dipole (loop) formed by the patches, stub, dielectric substrate (displacement current), and ground (H-pol stubs at SC state). The second electric resonance corresponds to an electric dipole formed by the patches and stub (H-pol stubs at SC state), and the second magnetic resonance corresponds to an open-ended magnetic dipole (loop) formed by the vias and the ground (H-pol stubs at OC state). Therefore, each aligned set consisting of an electric and a magnetic resonance results in an electric current $\vec{J}$ and a magnetic current $\vec{M}$, as shown in Fig. 1. The results in Fig. 2 show that our proposed unit cell exhibits multi-resonant properties and very wide bandwidth for which the relative phase between the two states is equal to $180° \pm 20°$. The relative phase bandwidth achieved by our unit cell is 54.1 %, from 31.5 to 54 GHz.

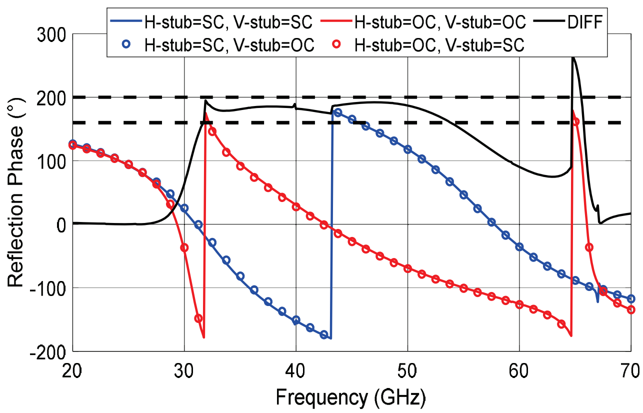

Figure 2. Reflection phases for an H-pol incident wave.

III. Reflectarray Radiation Analysis

A reflectarray antenna, based on the proposed unit cell, is designed with the following characteristics. It has a square aperture of 10λ×10λ, and it is fed by a horn feed, placed at the broadside direction with an F/D ratio close to one. The radiation characteristics of the RA are computed using an analytical model, which we developed based on the aperture field approach. This model uses the full-wave simulations of the unit cells and assumes an analytical pattern of $\cos^{qf}(\theta)$, where qf varies linearly between 3.4 and 30.4 from 26 to 56 GHz.

Fig. 3 shows the analytically calculated broadside gain of our reflectarray for the following cases: (a) with an ideal unit cell with relative phase between the SC-OC stub states of 180°, a reflection magnitude equal to 0 dB, and no cross-polarization, and (b) with our proposed unit cell that is described by our simulation analysis. It is seen that the RA with the ideal unit cell has approximately a 42 % 1.5dB gain bandwidth, whereas the RA with our proposed unit cell has a 35 % 1.5dB gain bandwidth. The bandwidth that we achieved with our unit cell is very broad. This result is attributed to the multi-resonant nature of our unit cell, which is shown in Fig. 2. Notably, the RA with our unit cell achieves a slightly smaller bandwidth than the RA with the ideal unit cell. This is attributed to the fact that the performance of our proposed unit cell deviates from the ideal operation in terms of phase and magnitude.

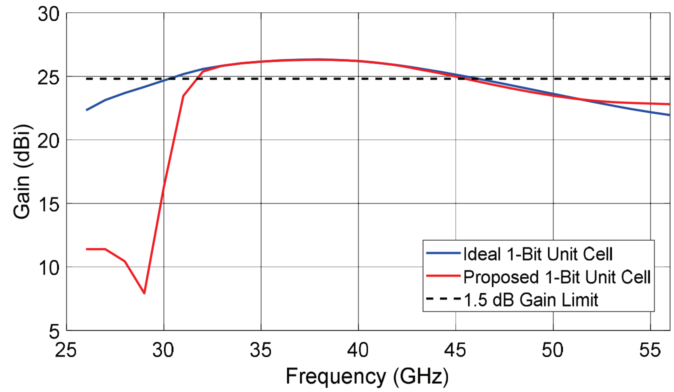

Figure 3. Broadside gain versus frequency.

IV. Conclusion

In this paper, a broadband 1-bit reflectarray antenna, which can independently steer two beams with orthogonal polarizations, is presented. This reflectarray is based on a MED unit cell, and it is well-suited for MU-MIMO applications. Specifically, the unit cell exhibits a very wide reflection phase bandwidth (54.1 %), and multi-resonant behavior. The corresponding reflectarray has good radiation characteristics in a very wide bandwidth as well (1.5dB gain bandwidth equal to 35 %). This 1-bit design can be implemented as an active RA by replacing the stubs with RF diodes.

Acknowledgment

This work was supported by the National Science Foundation under grant ECCS 2127762.

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