Simultaneous Beam-Steering and Polarization Conversion Using a Varactor-Integrated Metasurface

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***Abstract*—We propose a varactor-integrated metasurface on printed circuit board (PCB) which is capable of beam steering and polarization conversion simultaneously at 2.45 GHz with 90 MHz 3 dB bandwidth. By applying proper biasing voltage on the varactors, different phases are added to the orthogonal components of the incident linear-polarized field to achieve linear (LP) to circular (CP) or cross-linear (CLP) polarization conversion and up to 45° beam steering. This design is a good candidate for wireless communication systems to reduce the effect of pattern nulls and polarization mismatch.**

***Index Terms*—metasurface, beam steering, polarization conversion**

I. Introduction

Modern electronics are designed to be compact and the built-in antennas are usually linearly-polarized. Thus the transmission efficiency decreases when a pattern null or a polarization mismatch occurs. Recent research has proposed varator-integrated surfaces to steer the main reflected lobe by varying the applied voltage on the varators, which further changes the reflection phase of each unit cell [1], [2]. To address the polarization mismatch, conventional surfaces adopt asymmetrical geometry to induce different electrical responses for the orthogonal electric field components [3]–[6]. The drawback of these all-passive designs is that for a single frequency, it can only convert from linear to cross-linear or linear to circular polarization.

Here, we propose a varactor-based metasurface which performs beam steering and polarization conversion at the same time.

II. Unit Cell Design

Since any linear polarization can be decomposed into two orthogonal linear components, we designed a two-layer unit cell (neglecting the biasing layer) which can add different phases to the orthogonal components using varactors as shown in Fig.1 (a) and (b). On the top surface, four pentagons are connected to a grouned center patch by four varactors, which are modeled as capacitors $C_{1,2}$ in the simulations for simplicity. The varactors are biased through the ungrounded vias beneath the pentagons, and the center patch is directly connected to the bottom ground layer as the reference.

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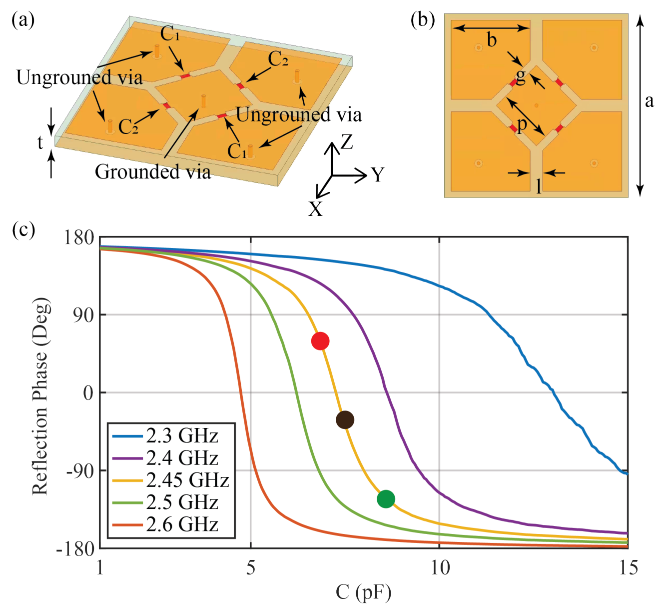

Fig. 1. Unit cell design. (a) and (b): Illustration and dimensions of the unit cell. $a = 29$ mm, $b = 12.5$ mm, $g = 1.2$ mm, $l = 2$ mm, $p = 9$ mm, $t = 1.575$ mm. The substrate is Rogers Duroid 5880. (c) Simulated reflection phase of a unit cell with periodic boundaries under normal incidence at different frequencies. Red dot: reflection phase 65°, $C = 6.8$ pF. Black dot: reflection phase -25°, $C = 7.4$ pF. Green dot: reflection phase -115°, $C = 8.5$ pF.

To study the reflection phase of the proposed design, the unit cell is simulated under normal incidence using periodic boundaries with $C_1 = C_2 = C$ in Ansys HFSS, and the reflection phases at different frequencies are illustrated in Fig.1 (c). It is observed that the reflection phase can take nearly any value between -180° to 180° from 2.4 to 2.6 GHz. Thus, polarization conversion and beam steering can be achieved simultaneously using this design by properly adjusting the biasing voltage of the varactors on every unit cell. Take 2.45 GHz as an example, when C_1 and C_2 are assigned by the capacitance of the red and black dots in Fig.1 (c), respectively, an X or Y polarization converts into CP since the reflection phase differs by 90° for the two orthogonal components. Similarly, if C_1 and C_2 takes the values of the red and green dots, respectively, an X or Y polarization converts into CLP because there is a $180°$ difference between the orthogonal components. Beam steering requires a phase difference between neighboring units. Assume the objective is to convert an X or Y polarization to CP, while the phase difference between adjacent units is $90°$ for steering. If C_1 and C_2 in the first unit are assigned with the red and black dots, then those of the second unit should be assigned by the black and green dots. Polarization conversion is realized by the phase difference brought by C_1 and C_2 within a unit cell, and beam steering is achieved by another overall phase introduced by C_1 and C_2 in the neighboring units.

III. Simulation Results

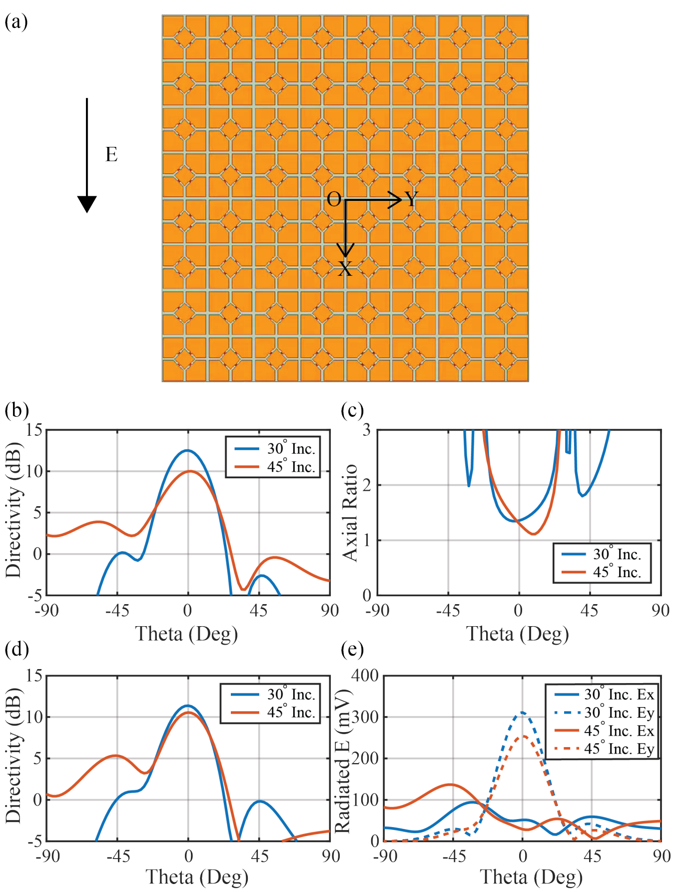

Fig. 2. Simulted results for an 8 by 8-unit surface. (a) Illustration of the surface. The propagation direction for $30°$ and $45°$ incidence is $(0, -\frac{1}{2}, -\frac{\sqrt{3}}{2})$ and $(0, -\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2})$, respectively. The incident field is X-polarized. (b) Directivity in the YOZ plane for different incident angle. (c) Axial ratio in the YOZ plane for different incident angle. (d) Directivity in the YOZ plane for different incident angle. (e) Radiated E in the YOZ plane for different incident angle.

To prove the concept, the unit cell is extended into an 8 by 8-unit surface as shown in Fig.2 (a). For simplicity, the following simulations are performed in 1D so that each column of the surface is assigned with the same $C_{1,2}$. We demonstrate its capability of simultaneous polarization conversion and beam steering with an X-polarized field under different incidence angles to study the axial ratio for LP-CP conversion or the radiated electric field components for LP-CLP conversion as shown in Fig.2 (b)-(e). Fig.2 (b) demonstrates the capability of the surface to steer the main lobe by $45°$ while the axial ratio of the main beam is below 1.5, proving that LP is converted to CP. (d) and (e) present an example of LP to CLP conversion under different incidence angles. As illustrated in Fig.2 (e), the X component is almost entirely converted into a Y component. The bandwidth of the proposed structure is shown in Fig.3 under different incidence angles for LP to CLP or CP conversion, respectively. Over 90 MHz 3 dB bandwidth is observed for all scenarios.

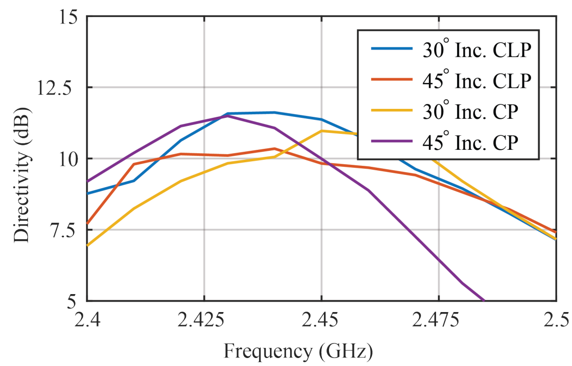

Fig. 3. Bandwidth study of the proposed surface under different incidence angle for LP to CLP or CP conversion.

IV. Conclusion

In this paper, we demonstrate the capability of simultaneous beam steering and polarization conversion of the proposed PCB-based varactor-integrated metasurface, which can be potentially used to improve the communication efficiency for wireless systems.

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