A dual circularly polarized metasurface-based antenna for synthetic aperture radars

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***Abstract*—This paper presents a dual circularly polarized metasurface-based antenna for synthetic aperture radars with a simulated high isolation of -30.6 dB and a simulated gain of 9.3 dB, within the bandwidth of 6.6%. This single element antenna achieves high isolation by using the ground with unbalanced # shaped-slot. A radiation metasurface with 4 × 4 periodic corner-truncated metallic plates changes the antenna from linear polarization (LP) to circular polarization (CP). A simple feeding network, consisting of two orthogonal ports is used in the design to excite RHCP or LHCP mode in the proposed antenna. So it is possible to employ only one antenna rather than two (RHCP and LHCP) when using the proposed structure.**

***Index Terms*—Dual circularly polarization, high isolation, antenna, aperture-coupled feed, metasurface, synthetic aperture radars.**

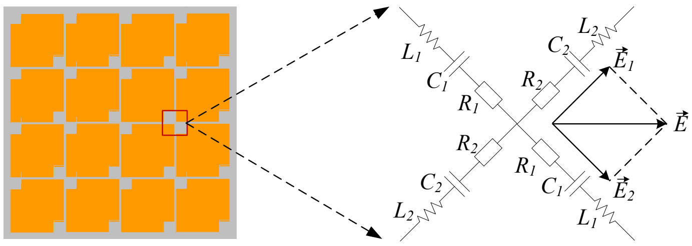
I. Introduction

Nowadays, synthetic aperture radars (SAR) are widely used for high-resolution spaceborne and airborne applications for monitoring the weather, climate change, earth resource mapping and civilian remote sensing. The antenna in a SAR system under consideration is required to have broadband and dual polarizations with high polarization purity [1]. Dual circularly polarized (DCP) patch antennas with broadband and high port-to-port isolation have been extensively used in many wireless systems, such as satellite communication and synthetic aperture radar. Much research on enhancing the performances in these fields of dual circularly polarized patch antennas has been introduced. Based on the feeding networks, these antennas can be divided into different types including aperture-coupled feed [2-3], coupled feed [4], or the hybrid feed of aperture and probe [5]. Aperture-coupled technique is the most commonly used technique in developing dual-polarized patch antennas. The presented antenna by Chakrabarti [6] consists of two spatially orthogonal ports corresponding to two apertures coupled to a patch whose two corners have been truncated for CP operation. The main disadvantage of this structure is the large dimension (the height was more than $0.1\lambda_0$) and narrow impedance bandwidth. Shen et al. [7] proposed a DCP antenna which consists of corner-truncated sequentially fed patch array. Low inter-port isolation and different resonant frequencies for left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP) are the limitations of the structure in [7]. In order to improve bandwidth, an air gap layer is usually added between the radiated patch and the ground plane [8]. However, the thickness of the antenna increases when using this technique. A dual-feed dual-polarized microstrip antenna with low cross polarization and high isolation is introduced in [9]. An aperture-coupled feed, which is comprised of a compact resonant annular-ring slot and a T-shaped microstrip feed line and a pair of meandering strips with a 180 phase differences are designed to excite a dual orthogonal linearly-polarized mode from a single radiating patch. However, the antenna has narrow impedance bandwidth. Ka Ming Mak et al. proposed a low cross-polarization, high isolation and dual polarized patch antenna which is designed by using two wideband feeding mechanisms for the two input ports in [10]. Large dimension and complicate structure are limitations of this antenna. Shared-aperture dual-band dual-polarized antenna is introduced for SAR applications in [11]. Two different sizes of patches were integrated in one aperture to obtain dual-band operation. The main advantages of these shared-aperture antennas are high gain and high port to port isolation. However, a feed network with multiple layers is required so these antenna have complex structure and high fabrication cost.

This paper presents a low-profile dual circularly polarized metasurface-based antenna for synthetic aperture radars. The antenna consists of a radiation metasurface, a ground plane and a feeding network. The metasurface with 4 × 4 periodic corner-truncated metallic plates is to not only achieve the high gain, but also provide the circularly polarization. The RHCP and LHCP mode of the proposed antenna are created by using a feeding network which consists of two orthogonal ports. A #-shaped coupled feeding structure is designed to realize wideband impedance matching and high isolation. For the low-profile structure of proposed antenna, the ground plane and a feeding network are printed on the top and bottom sides of a thin Roger 4003, respectively. The antenna features are demonstrated by the commercially available electromagnetic simulation software of the ANSYS electronics desktop. The proposed dual circularly polarized metasurface-based antenna has good performances of broad impedance bandwidth and high isolation.

II. ANTENNA DESIGN METHODOLOGY

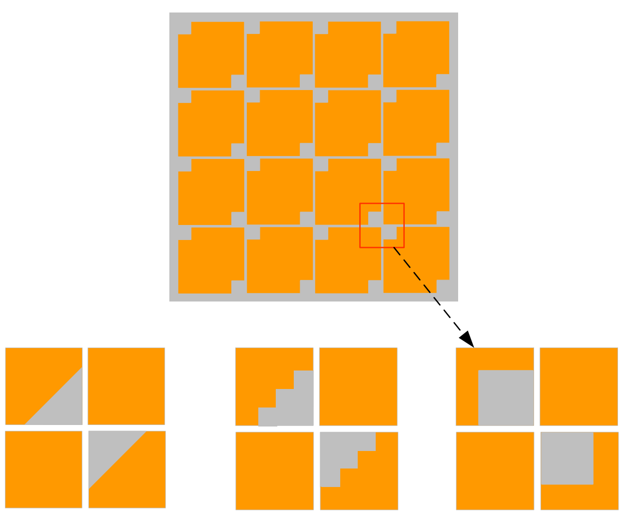
The desiged antenna consists of a radiation metasurface, a ground plane and a feeding network. The radiation metasurface and ground plane are printed on the top and bottom sides of the first substrate. The feeding network is printed on the bottom side of the second substrate.



(a) (b)

Fig. 1. The spatial equivalent circuit of the metal microstrip structure on the metasurface.

The original antenna is a slot antenna which is linear polarization along the Y-axis. When the metasurface is placed on the original slot antenna, the $\overrightarrow{E}$ field will be broken down into orthogonal components $\overrightarrow{E}_1$, $\overrightarrow{E}_2$ and the antenna is changed from linear polarization (LP) to circular polarization (CP) [12]. Fig.1 shows the spatial equivalent circuit of the metal microstrip structure when the antenna is excited and viewed from Port 1. Where, R_1, R_2 is the resistance, L_1, L_2 is the inductance of the equivalent circuit and C_1, C_2 is the distributed capacitance produced by the gap between two opposite unit cells. The equivalent inductance will be increased



(a) (b) (c)

Fig. 2. Unit cell with: (a) triangle corners truncated, (b) serrated corners truncated, (c) square corners truncated.

and the equivalent capacitance will be reduced when the sizes of the truncated corners are increased. The corners of unit cells are truncated such as the impedance Z_1, Z_2 are equal in magnitude but with a 90 degree phase difference, then $\overrightarrow{E}_1$, $\overrightarrow{E}_2$ are equal in magnitude but with a 90 degree phase difference. Hence, the antenna will be right handed circular polarization (RHCP). As shown in Fig.1, when the antenna is excited by the second port which is perpendicular to the first port, the unit cell is symmetrical with the X-axis and the antenna is changed to left handed circular polarization (LHCP) [13].

The design evolution of the metasurface structure is illustrated in Fig.2; i.e., the initial configuration is a plate with triangle corner truncated, the second design is a plate with serrated corner truncated, and the final one is the structure with square corners truncated. The metasurface is designed so that the antenna is dual circularly polarized while achieving a high port to port isolation. The simulated input port isolation of proposed antenna with the different corners truncated is presented in the Fig.3. As shown in Fig.3, the structure with square corners truncated has the best result compared to the other two antennas.

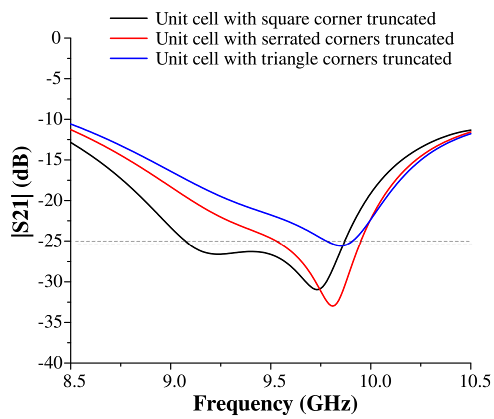


Fig. 3. Simulated input port isolation of proposed antenna with the different corners truncated.

Similar to the metasurface, the design evolution of the ground structure is illustrated in Fig.4, the initial configuration is ground with cross-slot, the second design is a ground with #-shaped slot, and the final one is the proposed structure with unbalanced #-shaped slot. The addition of the slots on the ground changes the current distribution on the metasurface. The port to port isolation of the antenna is enhanced by the unequal slots in the ground of proposed structure. All configurations were characterized via the ANSYS electronics desktop with the same conditions of Roger substrate. Fig.5 illustrates the simulated input port isolation of proposed antenna with the different grounds.

The data in Fig.5 shows that the isolation of the antenna with unbalanced # shaped-slot in the ground is better than that of the antenna with cross shaped-slot and # shaped-slot in the ground. It is over 22 dB over the frequency band from 9.0 GHz to 10.2 GHz.

III. ANTENNA GEOMETRY

Fig.6 depicts the geometry of the proposed antenna, which consists of a radiation metasurface, a ground plane and a feeding network. The radiation metasurface and ground plane are printed on the top and bottom sides of a Roger 5880

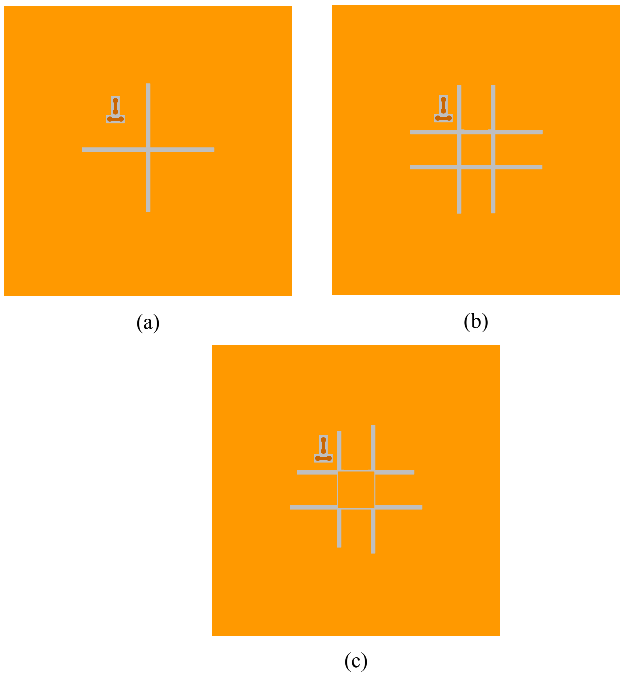


Fig. 4. Ground of proposed antenna with: (a) Cross-slot, (b) # shaped-slot, (c) Unbalanced #-shaped slot.

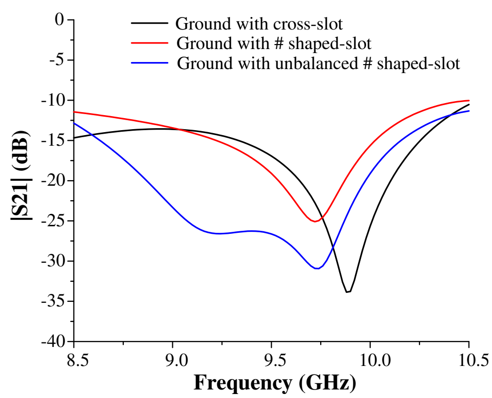


Fig. 5. Simulated input port isolation of proposed antenna with the different grounds.

substrate with dielectric constant of 2.2, loss tangent of 0.0009, and a thickness of 1.575 mm. The feeding network is printed on the bottom side of a Roger 4003 substrate with dielectric constant of 3.55, loss tangent of 0.0027, and a thickness of 0.508 mm. The radiation metasurface consists of 4×4 periodic corner-truncated metallic plates with periodic of L and gap of g between two adjacent plates. Excited by the 50-ohm feeding line, the metasurface is coupled by the slots etched on the ground plane, which generates a dual circularly polarized antenna. The geometry of the ground plane is shown in the Fig. 1c. The polarization conversion metasurface realizes the 90 degrees polarization conversion reflection for the incident wave. Referring to Fig. 6, the optimized design parameters of the antenna element are as follows: $Wgnd = 32mm$, $L = 7mm$, $g = 0.3mm$, $b = 1.6mm$, $d1 = 1.15mm$,

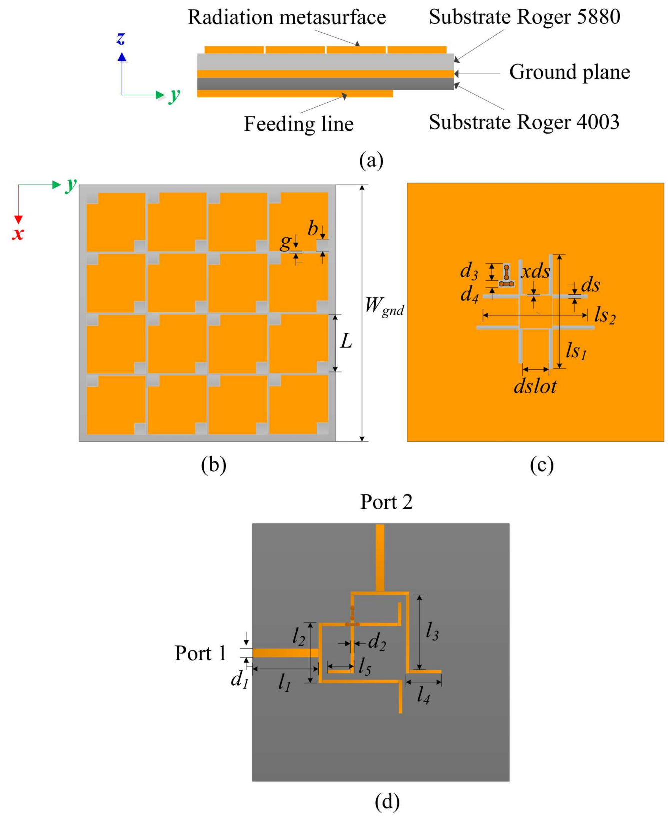


Fig. 6. The geometry of single element antenna: (a) Side view, (b) Radiation metasurface, (c) Ground plane, and (d) Feeding network.

$d2 = 0.3mm$, $l1 = 8.3mm$, $l2 = 7.4mm$, $l3 = 10mm$, $l4 = 4.2mm$, $ls1 = 14.2mm$, $ls2 = 12.8mm$, $ds = 0.44mm$, $xds = 0.1mm$, $dslot = 1.9mm$.

IV. SIMULATED RESULTS

For verification, the dual circularly polarized metasurface based antenna is simulated via the ANSYS electronics desktop. The simulated S−parameters of the proposed antenna are shown in Fig. 7. It can be seen that the simulated −10dB fractional bandwidth of Port 1 is about 8.2%, or 790 MHz (9.25–10.04 GHz), corresponding to center frequency 9.83 GHz. The measured −10 dB impedance bandwidth of Port 2 is 700 MHz (9.26−9.96 GHz), or about 7.3% to center frequency 9.6 GHz. Therefore, the overlapped bandwidth of Port 1 and Port 2 is 700 MHz (9.26−9.96 GHz). The simulated axial ratios of Port 1 and Port 2 are shown in the Fig.8. In the simulation results, the 3dB AR bandwidth has been obtained from 9.19-9.98 GHz when the antenna is fed by the designed feeding network. The gain characteristic of this antenna is illustrated in Fig. 9. The simulated gain of around 8 dB is observed from 9.32 to 10.22 GHz. The maximum gains of Port 1 and Port 2 are 9.3 dB at the frequency of 9.9 GHz and 9.45 dB at the frequency of 9.8 GHz, respectively. Fig.10 illustrates the simulated radiation patterns and gains of proposed antenna excited by Port 1 and Port 2.

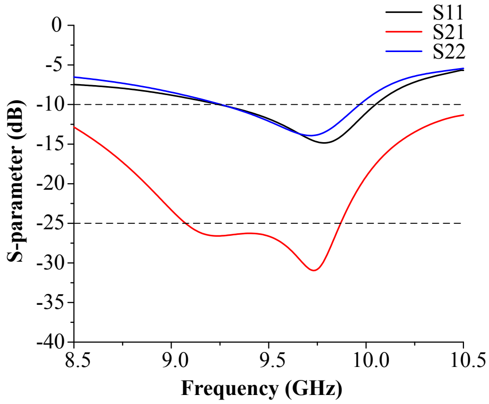


Fig. 7. Simulated S-parameter of proposed antenna.

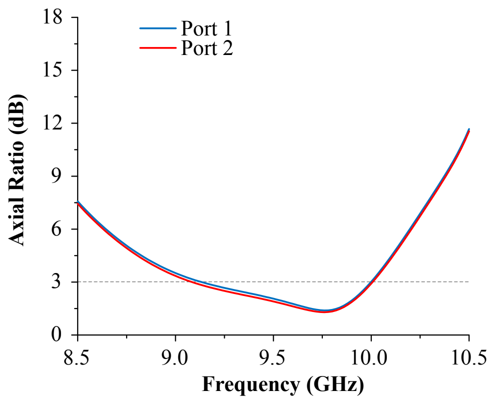


Fig. 8. Simulated axis ratio of proposed antenna

V. CONCLUSION

A dual circularly polarized antenna with high isolation is proposed in this paper. This dual polarized antenna element is simple in structure, low in profile, as well as easy for fabrication. It has wide impedance bandwidth which can entirely cover the entire X band operating frequency band. All the results show that the proposed design is favorable for nowadays synthetic aperture radars systems.

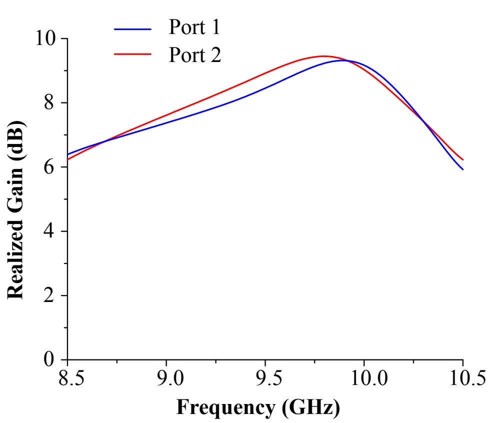


Fig. 9. Simulated gain of proposed antenna.

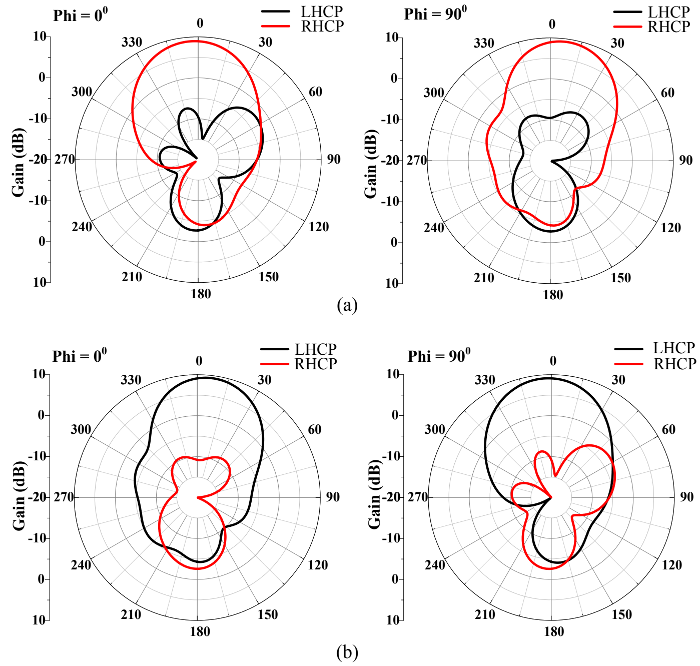


Fig. 10. Simulated radiations and gains of proposed antenna excited by two ports: (a) Port 1, (b) Port 2.

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