Dual-Polarization Multi-Functional Metasurface for Wireless Communications

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***Abstract*—In this paper, a reconfigurable multi-functional metasurface with dual-polarization is presented for operating reflective wave independently. In this design, a simple structure is applied to realize multi-function characteristics, where is composed of the cross patch printed on the thin substrate, four pin diodes and the controlling devices. To show the design performance, the metasurface is simulated to verify the application, which can achieve dual-polarization beam steering, linear polarization (LP) converting to right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP), respectively. Therefore, the proposed design can be the candidate of the terminal device for future wireless communication due to the multi-functionality and reconfigurability.**

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

I. INTRODUCTION

In recent years, with the continuous improvement of capacity and speed in wireless communication, the requirements for wireless communication terminals have also been increasing. At the same time, the scenarios for wireless communication are becoming more diverse. Therefore, wireless communication terminals not only need to meet various functional requirements such as broadband, high gain, and beamforming, but also need to be miniaturized, especially in millimeter-wave communication. Reflective Intelligent Surface (RIS) is proposed in this context to improve wireless communication performance.

Based on the RIS, the optimization of the wireless communication channel is realized [1][2]. For the realization, most of tunable metasurfaces are designed to satisfy. Hence, an independently varying metasurface unit cell is required to enable local control and reconfigurability. In addition, to overcome complex communication environment, the multifunctional reconfigurable metasurface unit cell should be explored and applied. In this way, most functional metasurfaces [3-10] have investigated, where's reconfigurability is realized by the switch diodes such as pin diode, varactor diode, etc. for beam steering, polarization conversation, high direction, and so on. Specially, the detailed design and principle of the multifunctional metasurface is presented in [9], which can realize the absorber, reflector, and polarization conversion by controlling over the complex surface impedance based on the tunable device (pin diodes). In [10], the varactor diode is used for the dual-polarization reconfigurable metasurface for beam steering and polarization conversion, but which has a large unit cell size.

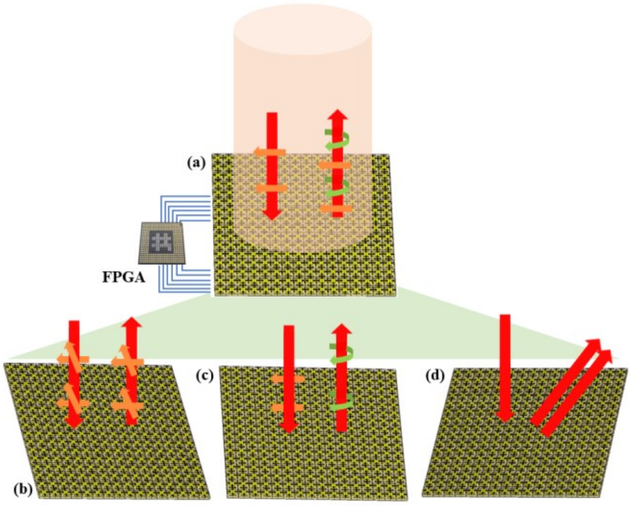

Fig. 1. Geometry of the proposed antenna with potential functions: (a) dual-polarization reconfigurable metasurface with controlling device (FPGA); (b) dual-polarization function; (b) linear polarization to circular polarization (LHCP and RHCP); (d) beam steering function.

In this paper, as shown in Fig. 1, a dual-polarization metasurface composed of 16 × 16 unit cells is presented to explore, where's reconfigurability in two orthogonal polarizations can be controlled independently by the pin diodes along the *x*- and *y*-directions, respectively. Hence, the beam steering can be realized in two polarizations respectively. Furthermore, an arbitrary linear polarization wave at *x*- or *y*-directions can be switched among LHCP and RHCP to reflect in the *ku*-band. The proposed dual-polarization compact and multi-functional metasurface shows the potential application for the future wireless communication system. The outline of this article is as follows. Section II introduces the geometry and principle of the unit cell of the metasurface. Section III shows the demonstrations of the proposed multifunctional metasurface. The conclusion is Section IV.

II. DESIGN AND PRINCIPLE

A. Design processing

As shown in Fig. 2, the proposed unit cell of the metasurface is designed, which consists of the radiating layer, four pin diodes, and the DC signal network layer. The radiating layer is printed on the substrate of Taconic RF-60TC with a dielectric constant of 6.15 and a loss tangent of 0.002, where's the thickness is 1.27 mm. The pin diode is arranged around the radiating layer and connects to the DC network by the metal vias. So the diodes can be controlled independently. Therefore, the proposed design has a simple and compact structure. The center metal via is connected to the ground. The detailed parameters of the unit cell are as the following Table I. The unit cell space is 5 mm. Depending on the above design, the reconfigurable reflection dual-polarization meta-surface is realized with high-efficiency and digitally adjustable capability using the p-i-n diodes (SMP1320-079LF).

TABLE I
GEOMETRICAL PARAMETERS OF THE PROPOSED METASURFACE

Parameter	*L0*	*L1*	*W0*	*W1*	*W2*	*W3*
Units (mm)	3.2	2.3	0.4	0.9	0.3	0.5

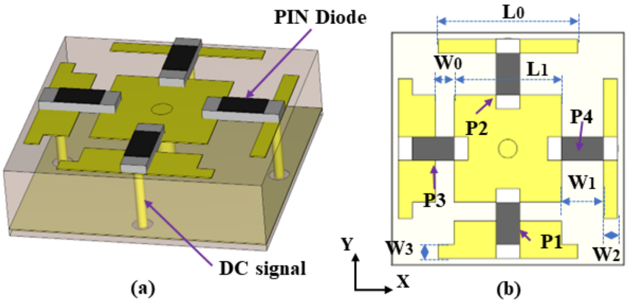

Fig. 2. Geometry of the metasurface unit cell: (a) 3D view; (b) Plane view.

TABLE II
RECONFIGURABLE CAPABILITIES OF THE METASURFACE

State	*On*	*Off*	*Function*
A	*P1, P2*	*P3, P4*	0 phase at *Y*-direction
B	/	*P1, P2, P3, P4*	180 phase at *Y*-direction
C	*P1, P3*	*P2, P4*	RHCP
D	*P1, P4*	*P2, P3*	LHCP

B. Principle

From Fig. 2, noted that the metasurface structure can be changed by four pin diodes. Hence, the radiating characteristics can be controlled by this method. As shown in Table II, different pin diodes working states can realize different functional metasurface. To shown the proposed functions of the metasurface significantly, the different E-field distributions on the patch based on Table II are as follows, which is simulated by the software of CST Studio Suite 2023.

As shown in Fig. 3, the E-field distribution with different pin diodes working states is presented. On the State A, the P1 and P2 are turned on, P3 and P4 are turned off, the metasurface can work on the *y*-direction and reflect 0 degree phase. Similarly, as shown in Fig. 3(b), P1 and P2 are turned off, the metasurface would work on 180 degrees on *y*-direction. Hence, with two working states, the metasurface can realize the phase difference of 180 degrees. Therefore, a one-bit reconfigurable metasurface is realized by this design on *y*-direction. In the same way, the reconfigurable metasurface can realize this on *x*-direction. So the dual-polarization one-bit reconfigurable is realized by this design.

In Fig. 4, as shown in Table II, the pin diodes work on State C, the metasurface has different E-field distributions. When the pin diodes of P1 and P3 is turned on, the EM wave incidents on the *y*-direction, but it would reflect to *y*- and *x*-directions from Fig. 4(a) with the same amplitude. Meanwhile, in Fig. 4(b), the phase changes to 90 degrees, note that it has a different direction of the reflected EM wave. Therefore, the linear polarization can be converted to RHCP to radiate by this metasurface.

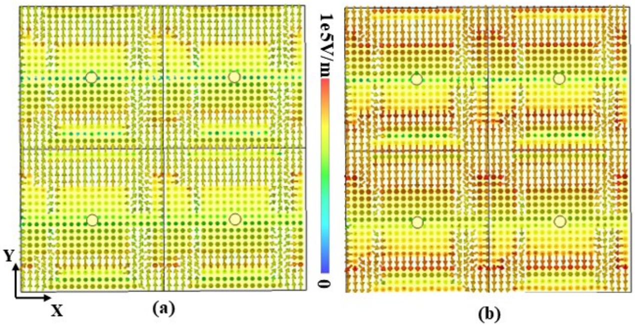

Fig. 3. E-field distribution of the metasurface with different pin diodes working states: (a) State A; (b) State B.

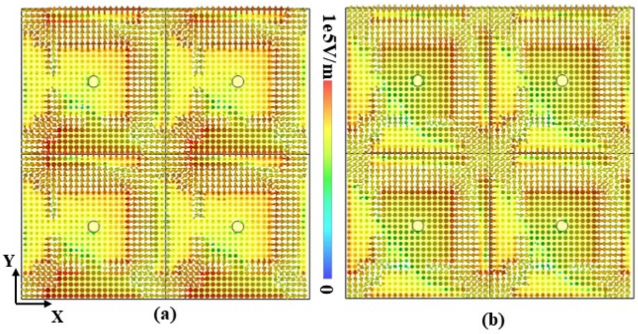

Fig. 4. E-field distribution of the metasurface with State C: (a) Phase 0; (b) Phase 90 deg.

In Fig. 5, based on State D, Same to Fig. 3, the EM wave incidents on *y*-direction, however, the reflected wave has a different direction since the pin diodes have different working states. In this state, P1 and P4 are turned on, P2 and P3 are turned off. Compared with Fig. 5(b), the LHCP wave can be reflected. Therefore, the linear polarization wave can be converted to LHCP wave by this metasurface. In short, from the above analysis, the proposed metasurface can realize multi-functional EM-wave operating by the pin diodes.

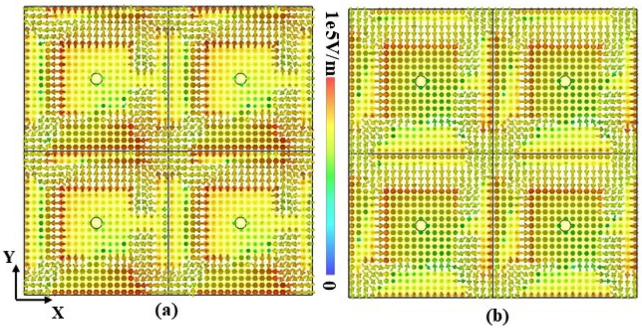

Fig. 5. E-field distribution of the metasurface with State D: (a) Phase 0; (b) Phase 90 deg.

III. PERFORMANCE OF THE METASURFACE

Based on the above the design principle, the unit cell of the metasurface is designed and simulated in the EM wave software to verify our design intention. From Fig. 6 to Fig. 8, the *S*-parameters of the metasurface with different working states are reported to elaborate the performance.

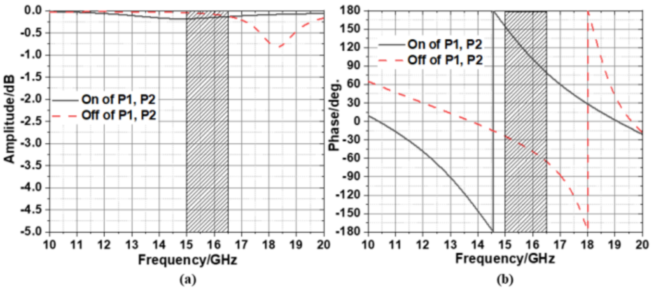

Fig. 6. Simulated reflected parameters of the proposed meta-surface worked on State A and B: (a) amplitude responses; (b) phase responses.

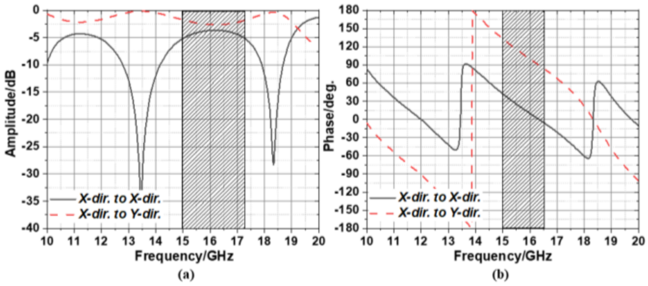

Fig. 7. Simulated reflected parameters of the proposed meta-surface worked on State C: (a) amplitude responses; (b) phase responses.

As shown in Fig. 6, the reflected parameters of the metasurface with State A and B are given when the incident EM-wave is on *y*-direction. Note that the reflected wave has high amplitude responses in the operating band from 15 to 16.5 GHz on two states. Meanwhile, the phase difference between two states is about 180 degrees in the proposed operating frequency band. Therefore, worked on these two states the design realizes one-bit phase reconfigurable function for beam steering capability.

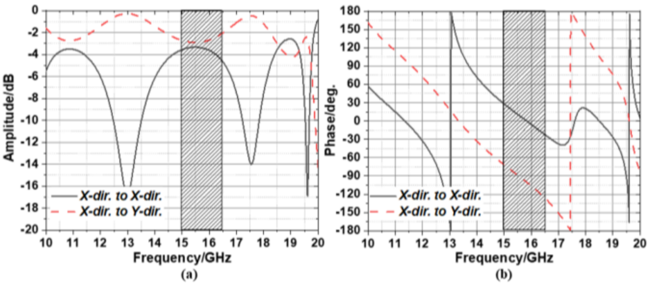

Fig. 8. Simulated reflected parameters of the proposed meta-surface worked on State D: (a) amplitude responses; (b) phase responses.

In Fig. 7, the reflected parameters of the metasurface worked on State C are given to show the polarization conversion performance. In the operating frequency band, we can find that the reflected wave at two directions has the similar amplitude response, meanwhile, the phase has 90 degrees difference between two reflected waves. Although the amplitude of two waves has a little difference, the polarization conversion can be obtained. Therefore, the RHCP wave can be achieved.

Similarly, the reflected LHCP wave can be realized in Fig. 8, as the operation of State D, the incident wave on *y*-direction can be reflected to the wave on *x*- and *y*-directions, respectively. The amplitude responses in the operating band are about -3 dB, meanwhile, the phase difference between two waves has 90 degrees. Hence, the polarization conversion capability is verified by this simulation.

Finally, the performance of the proposed metasurface is confirmed, where can realize beam steering on dual-polarization and polarization conversion for RHCP and LHCP. The proposed metasurface can be applied to future wireless communication for complex environments.

IV. CONCLUSION

In this work, a new concept is presented to design a dual-polarization metasurface which consists of a patch structure printed on the substate and four pin diodes. The proposed design can realize dual-polarization beam steering and polarization conversion by controlling the pin diodes' working state. To explain the metasurface principle, the E-field distribution with different working states is presented. And the simulation is presented to show the performance. Therefore, as shown in Fig. 1, the proposed design can be used for future wireless communication because of multi-function and reconfigurability.

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