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A Dual-Polarized Wide-Angle Scanning Antenna with High Isolation for Van Atta Applications

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Abstract—A dual-polarized wide-angle scanning array antenna is proposed in this paper. The proposed antenna array consists of sixteen elements with the working band from 9.5 to 10.5 GHz. A microstrip patch fed from two orthogonal directions is applied to achieve dual-polarizations. In order to obtain good impedance matching and wide bandwidth of the antenna, capacitive coupling feeding is adopted. The measured results show that the proposed array can cover a wide scanning range of ±58°. The polarization isolations of antenna are higher than 17 dB. The isolations between receiving sub-array and transmitting sub-array are higher than 22.3 dB. The proposed array antenna is suitable for Van Atta applications.

1. INTRODUCTION

A retrodirective array automatically reflects the incident electromagnetic wave in the same direction from which the wave came, and has found many applications in the area of satellite communication and wireless power transfer systems [1–4]. The Van Atta array is one of the major types of retrodirective array which was designed by L. C. Van Atta in 1959 [5]. The signal received by the antenna was retransmitted by its symmetrically disposed antenna. Several types of Van Atta array have been developed in recent years [6-11]. A planar passive circularly polarized retrodirective antenna array is proposed in [6] which covers a scan angle of ±30° from boresight without interference by sidelobes. A planar Van Atta array with equal length transmission lines shown in [7] is designed to illustrate the theory of the passive Van Atta array. An active Van Atta array shown in [8] has used dual feed dual polarized microstrip antennas in conjunction with unidirectional amplifiers. A microstrip antenna is used as a Van Atta array element shown in [9] which analyzes the greatest width of working band. A passive Van Atta retroreflector based on a dielectric-filled open-ended waveguide with a planar feeding network is proposed in [10]. A co-circularly polarized Van Atta array in [11] is enabled by a quasi-monostatic simultaneous transmitting and receiving element consisting of two quadrifilar helix antennas. However, these Van Atta arrays have drawbacks such as narrow band, poor isolation, and limited scanning range, which will influence the performance of power transmission system, especially far-field wireless power transmission.

In this paper, a 2×8 single-layer dual-polarized antenna array is proposed using dual-polarized patch antennas. The array consists of a receiving sub-array and a transmitting sub-array, both of which are composed of 2×4 elements. The polarization isolation and isolation between receiving sub-array and transmitting sub-array are both improved by loading shorting vias and slots. A wide working band is achieved by using capacitive feed. By optimizing the distance between the antenna elements, high isolation and wide-angle beam scanning are realized. The measurement results demonstrated a reasonable agreement with simulation. The proposed array can be used as Van Atta array for retrodirective array and active cancellation systems.

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2. DESIGN AND SIMULATIONS

2.1. Dual-Polarized Antenna Element

The structure of the proposed antenna element is shown in Fig. 1. The element has a single-layer structure using a substrate with relative dielectric constant of 3.0. Two orthogonal polarizations are achieved by feeding two coupled feeding patches at the edge of antenna elements. The capacitance is introduced through the coupling slot to cancel the original inductance of the antenna, thus achieving good impedance matching and wide bandwidth.

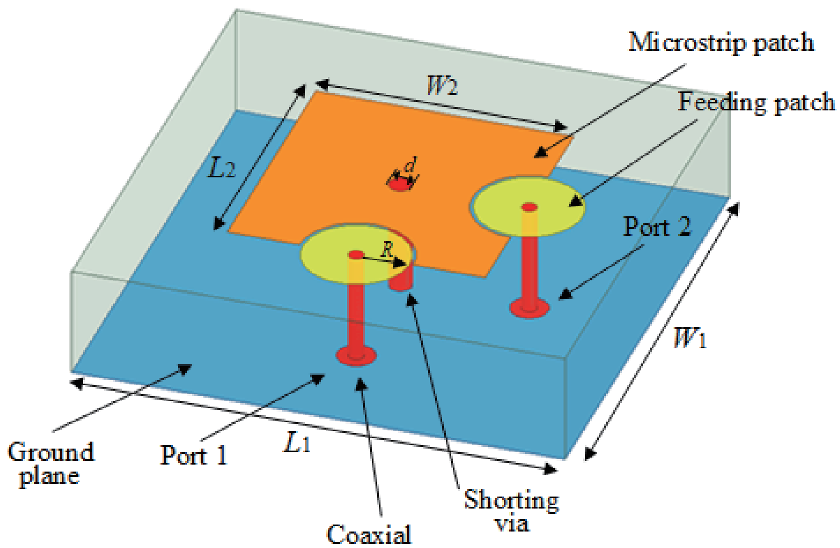


Figure 1. Structure of the dual-polarized antenna element ($L_1 = 13\,\text{mm}$, $W_1 = 13\,\text{mm}$, $L_2 = 6.8\,\text{mm}$, $W_2 = 7\,\text{mm}$, $D = 0.6\,\text{mm}$, $R = 1.4\,\text{mm}$).

To facilitate the connection with the RF network, the back-feed method is employed. The feeding patch is directly connected to the inner conductor of the coaxial cable. The outer conductor of the cable is soldered to the ground. To achieve the miniaturization of the antenna element, a shorting via is introduced in the center of the microstrip patch, which makes the current on the patch grounded to form a voltage zero. The via can also improve the isolation between two ports.

The simulated $|S_{11}|$ and $|S_{22}|$ in Fig. 2 show the bandwidths of the two ports are 9.26–10.67 GHz and 9.25–10.84 GHz, respectively. All the simulation results in this paper are obtained by using the full-wave simulation software Ansoft HFSS 18.0.

2.2. Array Design

Antenna elements are arranged in a 2×8 formation for the array in Fig. 3. The 16-element array consists of a receiving sub-array and a transmitting sub-array, both of which are composed of 2×4 elements. The two sub-arrays are centrosymmetric in structure to obtain higher isolation. The proposed dual-polarized microstrip array is also a single-layer structure, with a substrate size of $44\,\text{mm} \times 168\,\text{mm}$ and a thickness of 3 mm. For the convenience of antenna array installation and reducing the influence of platform on antenna, the metal ground's width is extended outward by 15 mm based on the substrate, with a total size of $74\,\text{mm} \times 168\,\text{mm}$.

To achieve wide-angle beam scanning, the distance between the antenna elements and the distance between the receiving and transmitting sub-arrays are optimized. The distances between the centers of the sub-array elements in the X-polarization direction and Y-polarization direction are 14 mm and 13 mm, respectively. The distance between the centers of the nearest two elements of different sub-arrays is 30 mm. Moreover, six slots with a length of 24 mm and a width of 1 mm are etched on the substrate,

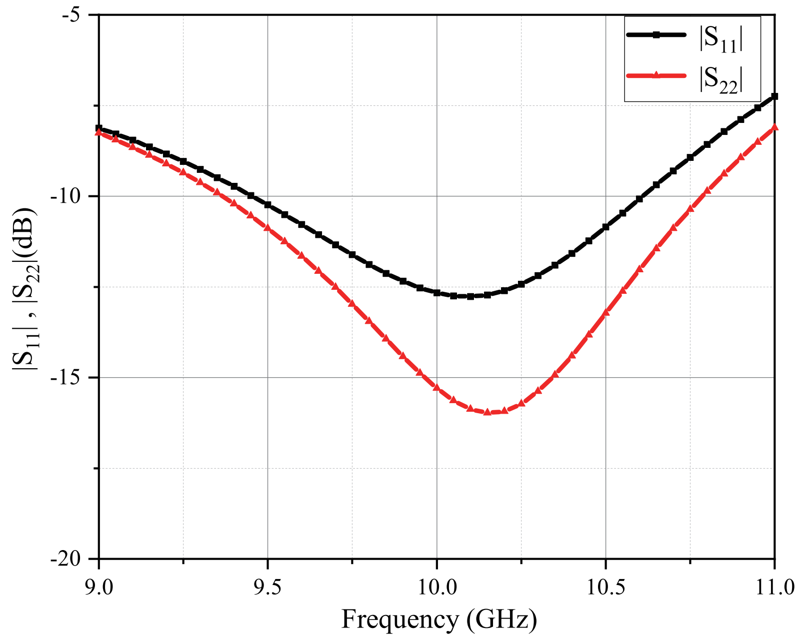


Figure 2. Simulated | S_{11} | and | S_{22} | of the proposed antenna element.

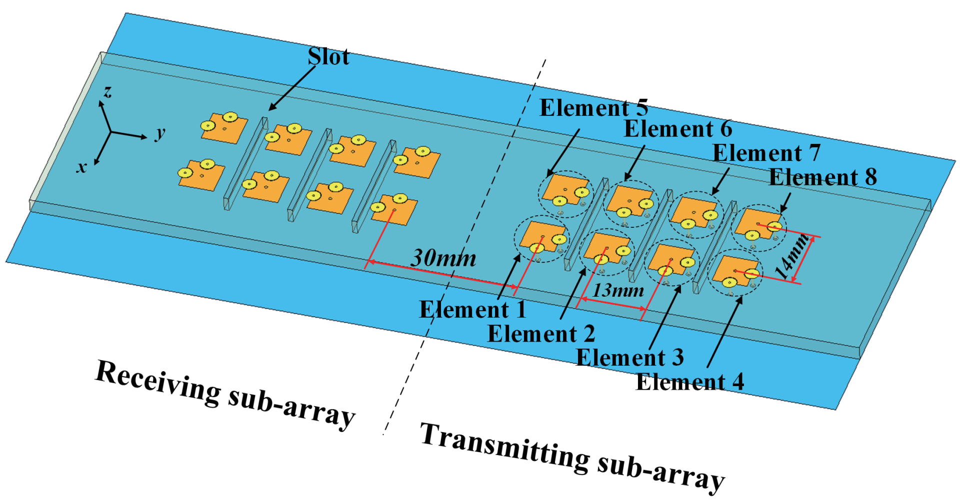
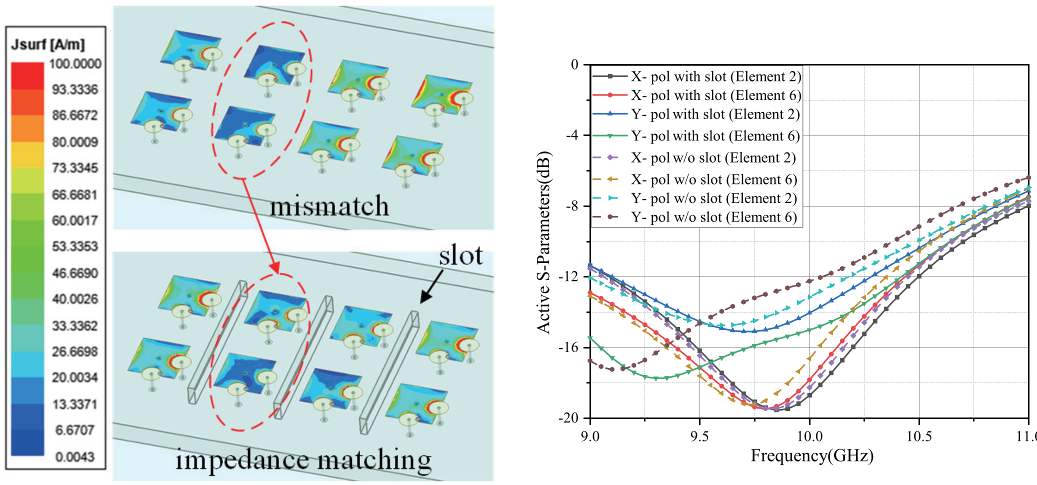


Figure 3. Structure of the dual-polarized microstrip antenna array.

which can further improve the impedance matching of the elements. To verify the effect of slots on impedance matching, the antenna current distribution with and without slots with $\pm 60^\circ$ angle scanning is shown in Fig. 4(a). It can be seen that when there are no slots, antenna elements 2 and 6 are in a mismatched state, while after the slots are added, all antenna elements can maintain good impedance matching. Fig. 4(b) shows active S-parameters of element 2 and element 6 of array with and without slots. The bandwidths of the proposed array are widened in both X-polarization and Y-polarization when the slots are introduced.

The simulation result of polarization isolation between receiving and transmitting sub-arrays is shown in Fig. 5. Within 9.5–10.5 GHz of main operational band, the isolations of X-polarization (Rx-Tx) and Y-polarization (Ry-Ty) between two sub-arrays are above 29.24 dB and above 26.41 dB, respectively. The isolation of two ports of antenna element (Rx-Ry) can reach above 19.47 dB.



(a) (b)

Figure 4. (a) Antenna current distribution with and without slots with ±60° angle scanning. (b) Simulated active S-parameters of element 2 and element 6 of proposed antenna array with and without slots.

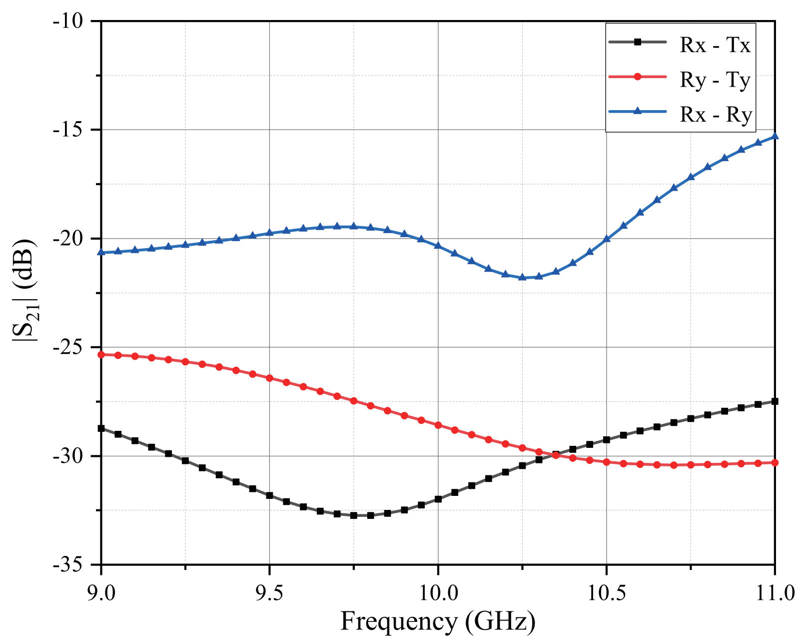
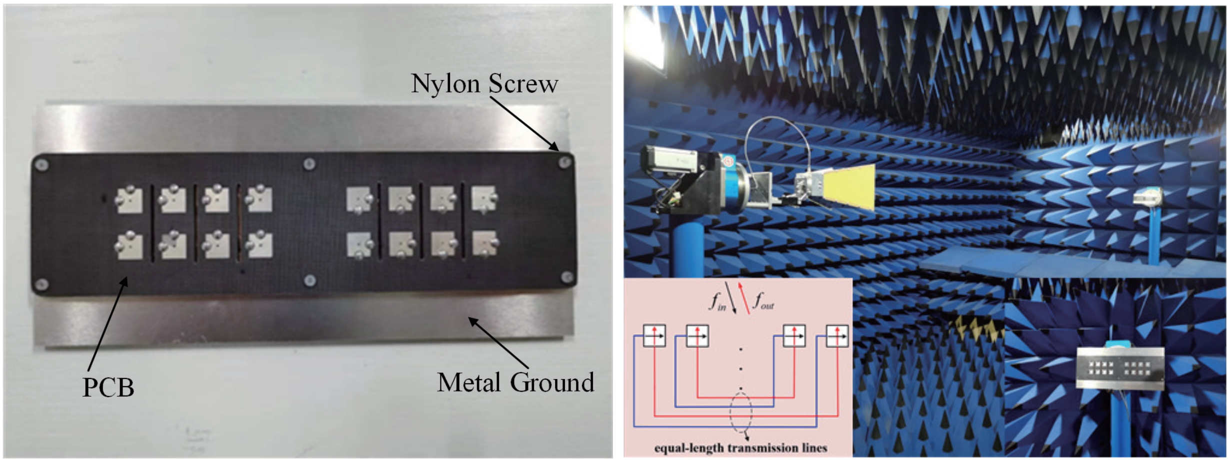


Figure 5. Simulated isolation of proposed antenna array.

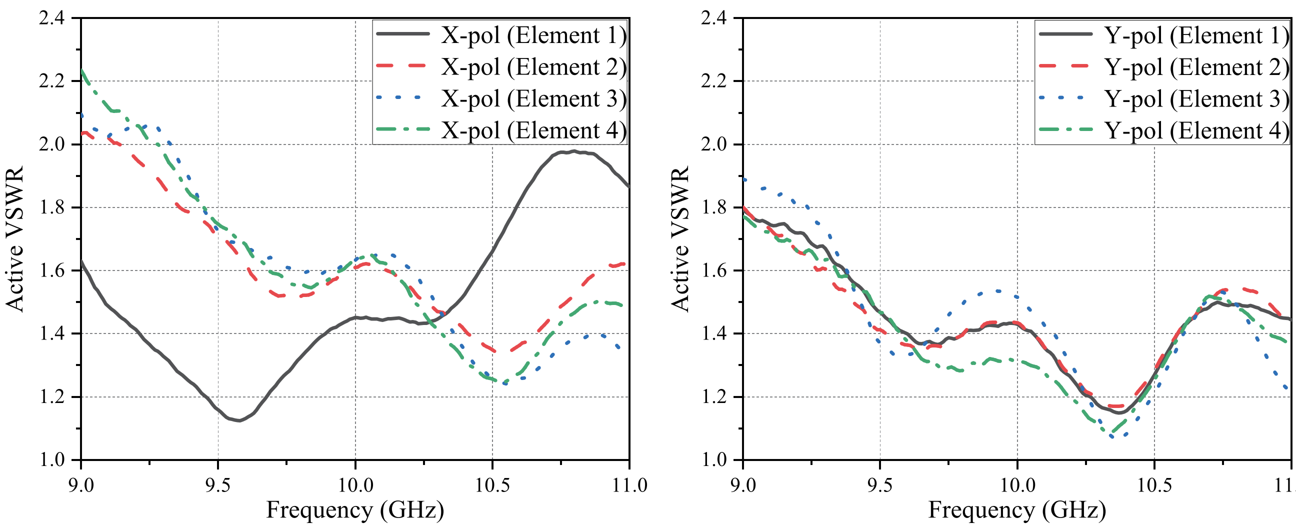
3. EXPERIMENTAL RESULTS

The prototype of the dual-polarized antenna array has been fabricated and measured. The fabricated antenna array and measurement setup are illustrated in Fig. 6. The antenna is manufactured based on printed circuit board (PCB) technology. Ports and shorting vias are processed by metalized vias. The metal ground and antenna are fixed by nylon screws. The connection of the receiving sub-array and transmitting sub-array is equal-length transmission lines. As shown in Fig. 7, the measured active VSWR results of each port are less than 1.75 in the working band of 9.5–10.5 GHz. The isolation characteristics of the proposed array in the working band are shown in Fig. 8. The polarization isolations of antenna element are higher than 17 dB. The isolations between receiving sub-array and transmitting



(a) (b)

Figure 6. The photograph of (a) the fabricated antenna array and (b) measurement setup.



(a) (b)

Figure 7. Measured active VSWR of each port of the antenna. (a) X-polarization; (b) Y-polarization.

sub-array are higher than 22.3 dB.

Due to the symmetry structure of the proposed antenna array, the radiation pattern has been measured from three typical scanning angles, i.e., 0°, 45°, and 60°. The measured normalized radiation patterns of X-polarization and Y-polarization of receiving sub-array are illustrated in Fig. 9 and Fig. 10, respectively. The measured results show that the −3 dB beam coverage reaches ±58°.

The measured and simulated gains with frequency of the proposed antenna array are shown in Fig. 11. The change tendency of the measured result is in good agreement with the simulated result. The small difference between them may be caused by installation errors.

The retrodirective performance of Van Atta array can be represented by reflection pattern. To verify the retrodirective effect of the proposed array, the receiving sub-array and transmitting sub-array are center-symmetrically connected as Van Atta array has 16 channels in equal phases. Fig. 12 shows the measured reflection pattern of array at the center frequency of 10 GHz. It can be seen that the proposed antenna can achieve a good retrodirective effect in the angle range of ±53°.

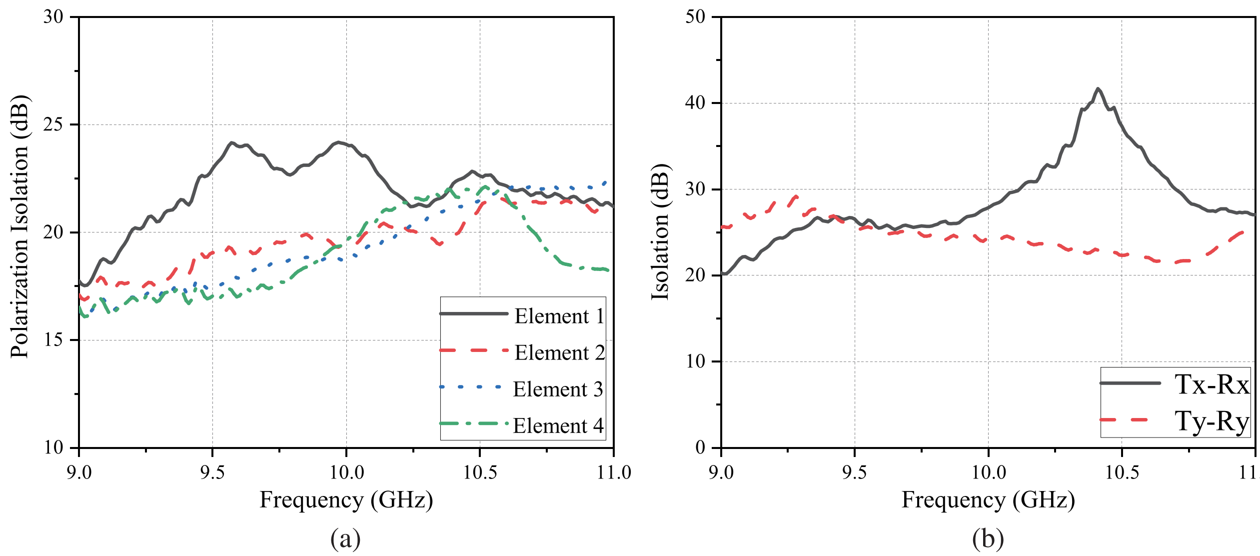


Figure 8. Measured isolation characteristics. (a) Antenna element polarization isolation; (b) Isolation between receiving array and transmitting array.

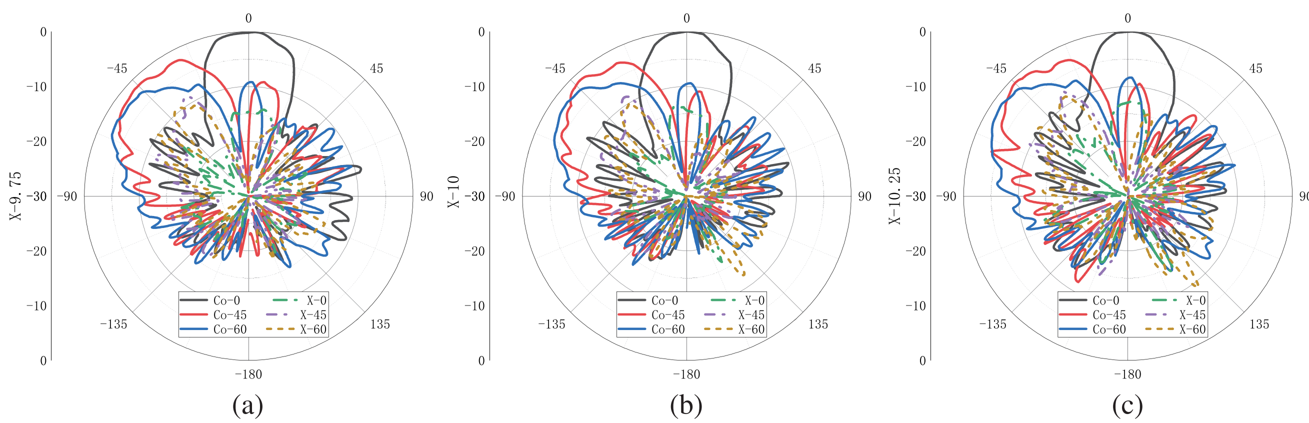


Figure 9. Scanning patterns of the receiving sub-array in X-polarization. (a) 9.75 GHz; (b) 10 GHz; (c) 10.25 GHz.

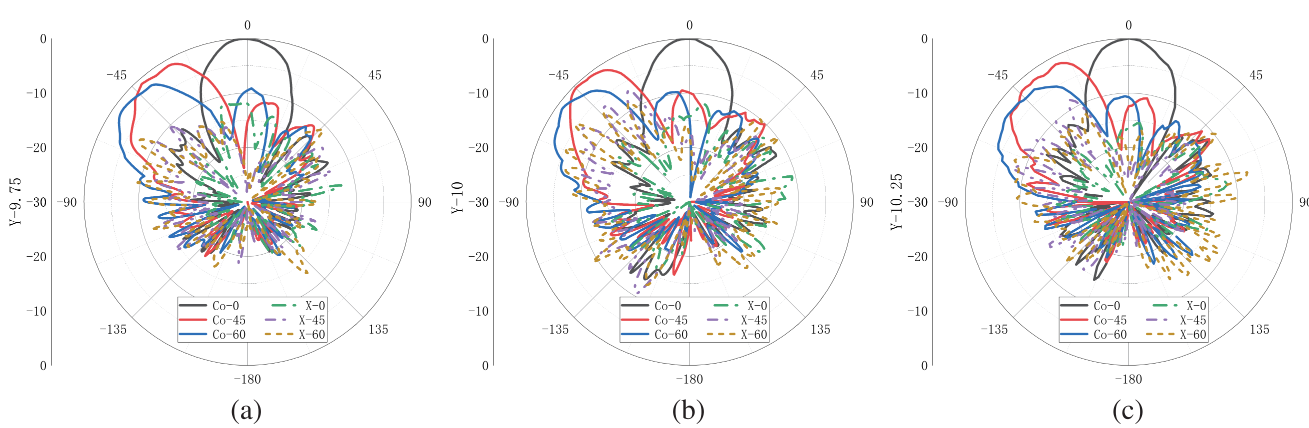


Figure 10. Scanning patterns of the receiving sub-array in Y-polarization. (a) 9.75 GHz; (b) 10 GHz; (c) 10.25 GHz.

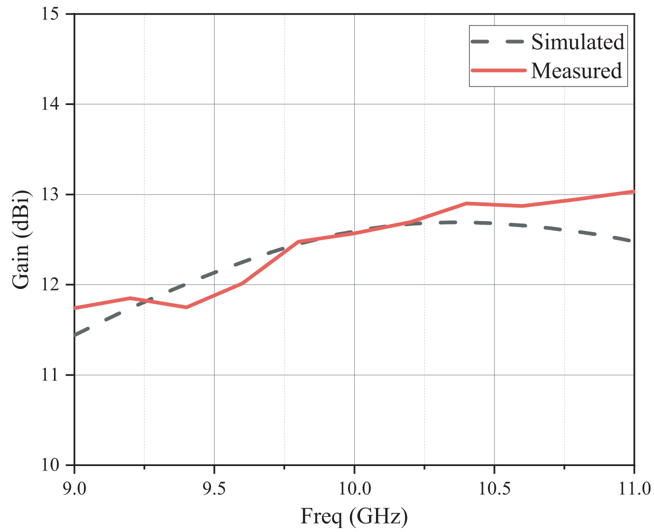


Figure 11. Measured and simulated gain with frequency of transmitting sub-array.

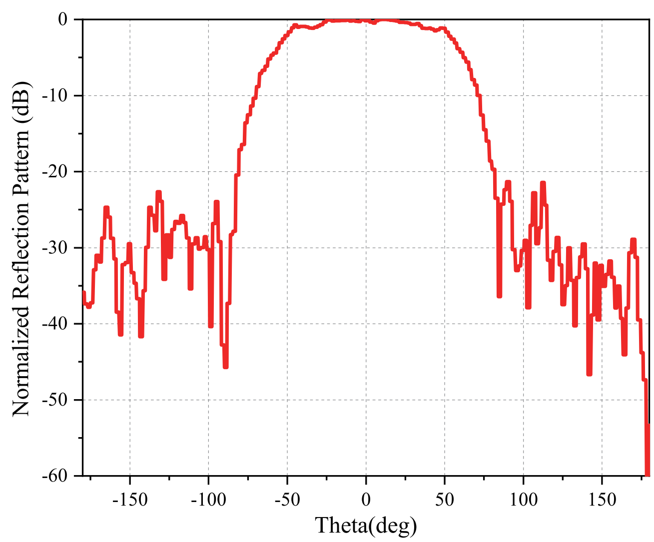


Figure 12. Measured reflection pattern of the proposed array.

Table 1. Comparisons among referred arrays and this work.

Reference	Bandwidth	Isolation	Scan ability	Polarization	Unit number	Active/ Passive
[1]	4.8–6.2 GHz	/	±50°	LP	8	Passive
[2]	9.75–10.75 GHz	/	±40°	LP	9	Passive
[3]	2.4 GHz*	/	±30°	CP	4	Active
[4]	5–6.6 GHz	/	±55°	LP	21	Passive
[6]	24.85–25.45 GHz	/	±30°	CP	32	Passive
[8]	2 GHz*	/	±55°	Dual-Polarization	4	Active
This work	9.5–10.5 GHz	22.3 dB	±58°	Dual-Polarization	16	Passive

* Only the central frequency is given.

Table 1 represents the comparison of the isolation and scanning range among previously reported Van Atta arrays and the antenna array proposed in this work. It is worth mentioning that recent studies on Van Atta arrays have not analyzed the isolation feature. However, isolation is one of the key indicators affecting wireless communication systems. Low isolation can easily cause system self-excitation, which is also the focus of this work. Moreover, the proposed array has advantages in scanning ability.

4. CONCLUSION

A single-layer dual-polarized microstrip array antenna is proposed, which consists of a receiving sub-array and a transmitting sub-array with sixteen elements. The array can achieve $\pm 58^\circ$ scanning range in the working band of 9.5 GHz–10.5 GHz. The measured polarization isolations of antenna element are larger than 17 dB. The measured isolations between receiving array and transmitting array are larger than 22.3 dB. For the advantages of wide-angle scanning and high isolation, the proposed antenna is suitable for Van Atta applications.

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