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Research Article

Research on a Novel Kind of Dual Polarized Stacked Printed Antenna

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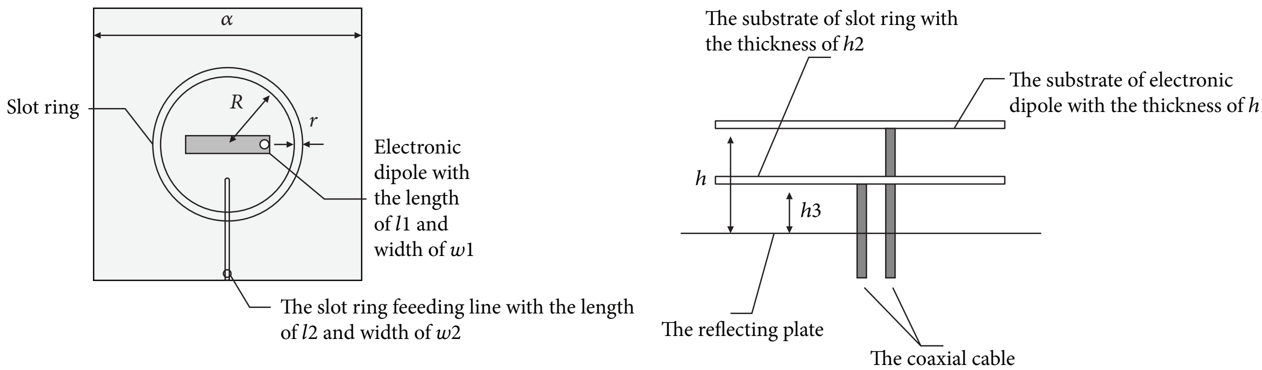
This paper presents a dual polarized antenna with high isolation for a wide-angle scanning phased array radar. For the proposed antenna, the electronic and magnetic resources are realized through a printed monopole antenna and a slot ring antenna, respectively. A metal reflector ground was introduced to achieve the unidirectional pattern, and the ratio of front to back of the pattern was improved. The printed monopole and slot ring antenna are fed by the coaxial and electromagnetic couplings, respectively. The radiation fields emitted by the electronic current resource and magnetic current resource are approximately orthogonal to each other among large space ranges. The measured port isolation of the designed antenna is above 20 dB, and the wide beam performance can be observed. The feasibility of the proposed antenna scheme is verified.

1. Introduction

A dual polarized antenna is the key component in full polarization radar, navigation, and wireless communication system, and its function is to realize the full polarization signal processing algorithm through radiation or receiving two orthogonal polarization components of electromagnetic wave. The design and implementation of dual polarized antenna have become a hotspot in the field of antenna technology [1–3]. In terms of structure, dual polarized antennas include dual polarized dipole antennas, dual polarized microstrip antennas, and dual polarized mouth antennas [4–6]. From the radiation mechanism, the dual polarization antenna can be divided into the electric current source and magnetic current source with orthogonal placement. In the application of the dual polarized antenna, the main forms are the phased array and MIMO array. Compared with a traditional literal antenna, a dual polarized antenna also needs to consider the port isolation of polarization and cross-polarization level of a radiation field, the purpose of which is to achieve two better orthogonal polarization channels [7]. In the application of full polarization phased array antenna, the dual polarized antennas need to have the radiation and polarization patterns with sufficient width to achieve the expected beam scanning range. As for engineering applications, the installation of the antenna array space is usually limited; therefore, the structure of dual polarized antenna units needs to adapt to the antenna array structure, and the antenna unit is miniaturization. Generally, feeding is introduced from the bottom of the antenna platform, connector size is small enough, and the installation is firm and reliable. Therefore, the design and implementation of dual polarization array antenna are important and challenging tasks.

Considering the design difficulty, electrical performance, and tooling cost of dual polarized antenna unit, an optional implementation scheme is a dual polarized printed antenna. A dual polarized microstrip antenna is the most common type of dual polarized printed antenna [8, 9] and is widely used. The dual polarization microstrip antenna using printed circuit technology processing has the advantages of low profile, small size, lightweight, and low cost. In regard to the electric properties, a double polarization structure has more implementation type and flexible feeding, such as microstrip line edge feed, feed microstrip line angle feed, and electromagnetic coupling feeding [10, 11]. However, the working bandwidth of the microstrip antenna is narrow, and the polarization port isolation and radiation field of the dual



(a) Top view (b) Side view

Figure 1: Antenna schematic.

polarized antenna are higher. Although the improvement measures can extend the impedance bandwidth and the polarization performance of the microstrip antenna, the structure of the dual polarized antenna is complex and the implementation of the project is more difficult. Both the printed dipole and the printed slot antenna are the common forms of microwave radiators, which also have the advantages of a microstrip antenna in structure and processing, and their impedance bandwidth is wider. A printed dipole antenna is fabricated based on a medium substrate, and it is generally fed by coaxial line or coplanar waveguide (CPW). In order to realize the ultrawideband performance, the dipole shape can be designed to be rectangular, butterfly, round, oval, and many other shapes [12–15]. A slot antenna usually can be the equivalent magnetic current source and is a kind of microwave radiator coupling with a dipole antenna. A printing slot antenna structure is simple, and the aperture shape can be rectangular. A dual polarized antenna based on the current element and the slot magnetic current element was designed and realized. According to the demand, it can be designed into narrowband, broadband, and ultrabroadband types. In the field of feeding, the printed slot antenna can use various forms [16–19], electromagnetic coupling feed, coplanar waveguide feed, etc. Therefore, the printed slot antenna is also a microwave antenna.

Based on the engineering demand, a cascading printing dual polarized antenna structure is proposed in this paper. A printing dipole and circular aperture radiator are introduced, which radiate and receive two orthogonal polarization electromagnetic wave components that are separately placed to realize a double polarization mode. In a cascade structure, the two polarization port feedings are introduced from the bottom of the antenna unit without affecting each other, and using this method can improve the antenna polarization isolation and is more suitable for the installation structure of the phased array antenna. Printing electric dipole can be equivalent to a current source, and printing circle aperture to the magnetic current source; therefore, the proposed dual polarized antenna radiation principle is based on the radiation of orthogonal electromagnetic source, which is different from the traditional dual polarized antenna and has stronger innovation. In the second section, the design and simulation of cascading printing dual polarized antenna are described. In the third section, antenna processing and test results are provided to verify the feasibility and effectiveness of the design. And the last part is the conclusion of the paper.

2. The Structure and Design of Dual Polarized Stacked Printed Antenna

As an antenna complementary to a metal ring, a slot ring can be equivalent to an array of two half-wave slots. Ideally, the half-wavelength slot should be complementary to the half-wave dipole. A slot ring dipole antenna is designed based on the most common and the most basic microstrip quarter-wave dipole. The microstrip vibrator is characterized by thin section, lightweight, easy processing, and low cost. The cross-polarization simulation results of the dual polarization antenna are shown in Figure 1. It can be seen from the figure that the cross-polarization of both ports in the main radiation direction is less than −20 dB, where the cross-polarization of the electric dipole in the main radiation direction is less than −35 dB and less than −30 dB in almost all angles. The one in the aperture circle in the main radiation direction is less than −23 dB, and the angle which is less than −20 dB has a range of about from −40 degrees to 40 degrees, which meets the design requirements of the dual polarization antenna for cross-polarization. The design of the dual polarized antenna structure is shown in Figure 1; the dual polarized antenna is composed of the electric vibrator and slot ring: the upper layer is for the electric vibrator, which is fed directly by the coaxial line at one end of the vibrator; the lower layer is the slot ring, in which the one end of the coaxial line is connected to the open road microstrip line to conduct the coupled feeding. Because both the electric vibrator and the slit ring have the characteristics of bidirectional radiation, the metal plate part of the slit ring can also be used as the reflector of the vibrator at the same time, and a piece of metal reflector can be arranged at a distance of about $\lambda/4$ below the slit ring.

When designing the dual polarized antenna, firstly, the Rogers 5880 sheet with the dielectric constant $\varepsilon_r = 2.2$ from Rogers Co. Ltd. should be selected as the dielectric substrate. The size of the dielectric sheet is 32 mm × 32 mm × 1 mm, and the basic structure and feeding form of the antenna were

Table 1: Rule of the parameters of the aperture circle varies with the width of the aperture.

Aperture width (mm)	Inner diameter (mm)	Isolation (dB)	Cross-polarization (dB)
0.5	9	−23	21
0.8	11.2	−19	−16.5
1	12	−18	−16

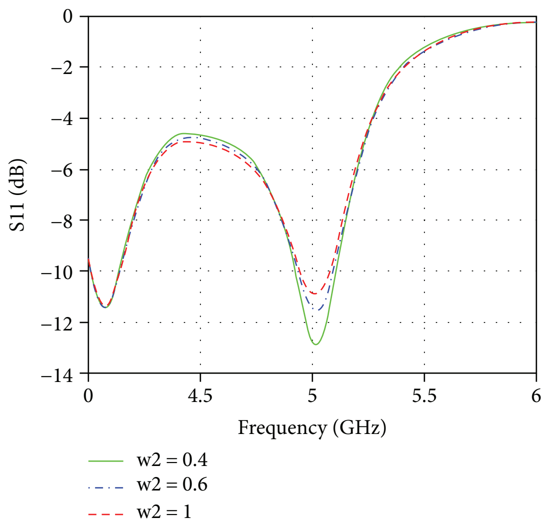


Figure 2: Curve of return loss of aperture circle varies with open loop feed wire width.

determined. As for the radius R of the ring, we can estimate the size of the ring by the empirical formula based on the previous theoretical analysis. For the width r of the slot and the width $w2$ of the feeding line, we consider optimizing the influence of the mutual coupling between the feeding line and the electric vibrator on the gain and cross-polarization of the pattern. Table 1 shows the change of the parameter values when the gap width is changed within the slit ring vibration of 5 GHz. It can be seen that the smaller the slit width is, the smaller the inner diameter R of the slit ring is, and in the meantime, cross-polarization of the slit ring and the isolation between the two ports will be better.

The open microstrip line of the slot ring exerts a certain impact on the return loss, as shown in Figure 2, and the changing curve of the slot ring port return loss with the open microstrip line is shown. As can be seen from the figure, the thinner the open microstrip line, the smaller the return loss of the slit ring is, but in order to meet the processing precision and the convenience of welding, the feeder line cannot be too thin. For the electric vibrator part, the width and length are the most influential. Since we use a quarter-wave vibrator, the vibrator length is about $\lambda_g/4$. We can fine-tune the height between the two dielectric plates and the ground on the basis of the initial determination of $\lambda/4$. According to the designed dual polarized antenna structure, the implementation scheme of dual polarized antenna can obtain and realize broader bandwidth and higher efficiency. Moreover, the kind of dual polarized antenna has a simple structure, so the design procedure is simplified. Due to the low cost of fabrication, the proposed dual polarized antenna is suitable for practical engineering application.

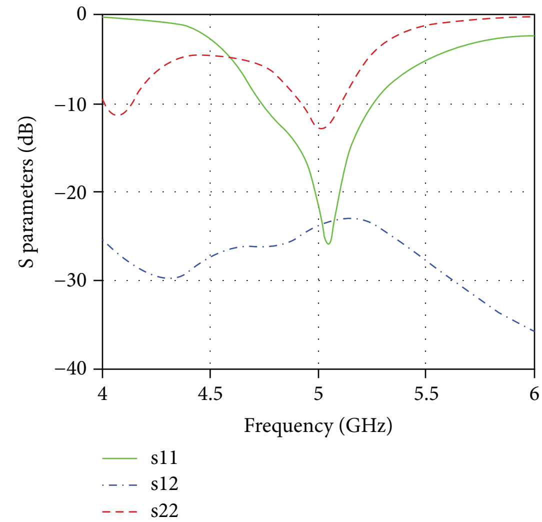


Figure 3: S parameter curve of the antenna.

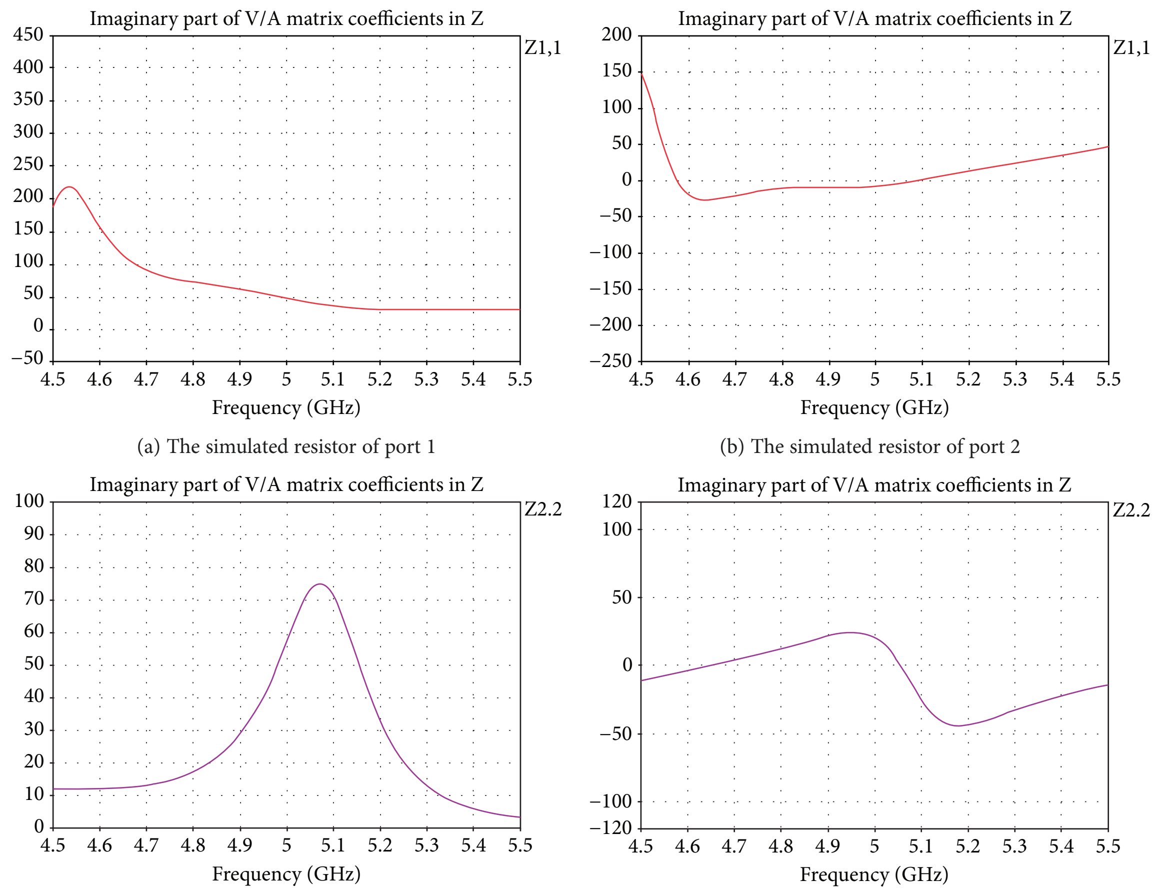
3. Analysis of Simulation Results of Dual Polarized Antenna

The full-wave electromagnetic simulation is adopted to optimize the antenna performance and structure, and a set of parameter meeting the design requirements is obtained: $a = 32$ mm, $R = 9.1$ mm, $r = 0.5$ mm, $l1 = 7.3$ mm, $w1 = 1.5$ mm, $l2 = 14$ mm, $w2 = 0.4$ mm, $h = 11.3$ mm, $h1 = h2 = 1$ mm, and $h3 = 5.3$ mm. The simulation results of the antenna are obtained, and the S parameter curve of the antenna is shown in Figure 3.

When the return loss of antenna is less than 10 dB, the working frequency of stacked dipole port is from 4.75 GHz to 5.25 GHz, aperture circle port 4.9 GHz to 5.1 GHz, and whole antenna bandwidth 4.9 GHz to 5.1 GHz, and the isolation of two ports within the bandwidth is under −23 dB. The simulated input impedance characteristics of two ports are shown in Figure 4. The designed antenna is resonant at 5 GHz according to Figure 4.

The current flows through the feed line to the monopole, and the electronic current density distribution is large on the printed monopole. The current, through another feed line, is coupled to the slot ring. On the slot ring, the magnetic current density distribution is large. The radiation fields emitted by the electronic current resource and magnetic current resource are approximately orthogonal to each other among large space ranges.

The simulated three-dimensional gain patterns of two polarization ports for the designed dual polarized are shown in Figure 5. According to Figure 5, we can see that the good patterns for both ports are achieved with the frequency range from 4.9 GHz to 5.1 GHz. The wide beams and high efficiencies are observed at all ports. Because the two ports are not symmetric, the gains of the two ports are different at each frequency. The simulated gain of printed dipole port is



(a) The simulated resistor of port 1

(b) The simulated resistor of port 2

(c) The simulated resistor of port 1

(d) The simulated resistor of port 2

Figure 4: The simulated input impedance characteristics of two ports.

higher than that of the port of slot ring port. So in the practical application, the compensation algorithm should be employed to obtain the ideal the dual polarized channels, and the problem can be solved by the digital signal processing technique, which can be realized based on the advanced signal processing hardware.

The pattern of two ports with the center frequency of 5 GHz is shown in Figure 6, from which it can be seen that the dual polarized antenna pattern is regular, the far field maximum gain of electric dipole is 5.6 dB, and the lobe width is bigger; thus, 3 dB lobe width is 87.9° at $\varphi = 0°$ and 100.4° at $\varphi = 90°$. The maximum gain of the aperture circle port is 9.0 dB, and the 3 dB lobe width is 56.8° at $\varphi = 0°$ and 68.3° at $\varphi = 90°$.

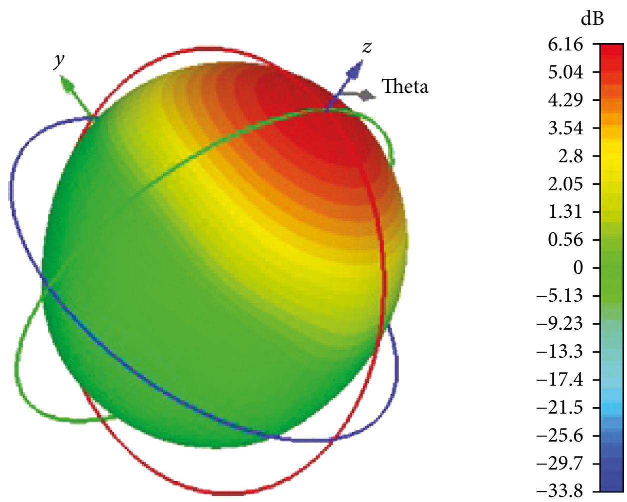
The cross-polarization pattern of two ports at $\varphi = 0°$ and $\varphi = 90°$ is shown in Figure 7. It can be seen from the figure that the cross-polarization of both ports in the main radiation direction is less than −20 dB, where the cross-polarization of the electric dipole in the main radiation direction is less than −35 dB and less than −30 dB in almost all angles. The one of the aperture circle in the main radiation direction is less than −23 dB, and the angle which is less than −20 dB has a range of about ±40°, which meets the design requirements of the dual polarization antenna for cross-polarization.

The polarization orthogonal performances at the far field space of the designed dual polarized antenna were calculated and observed according to simulation results through the full-wave electromagnetic simulation technique. The polarization orthogonal ranges of the designed dual polarized antenna for $\varphi = 0°$ and $\varphi = 90°$ are shown in Figure 8. From Figure 8, it can be seen that the two polarization electrical fields of two ports are basically orthogonal within the angle range of ±74° for $\varphi = 0°$ when 80° is regarded as the orthogonal criterion, while the two polarization electrical fields of two ports are basically orthogonal within the angle range of ±36° for $\varphi = 90°$.

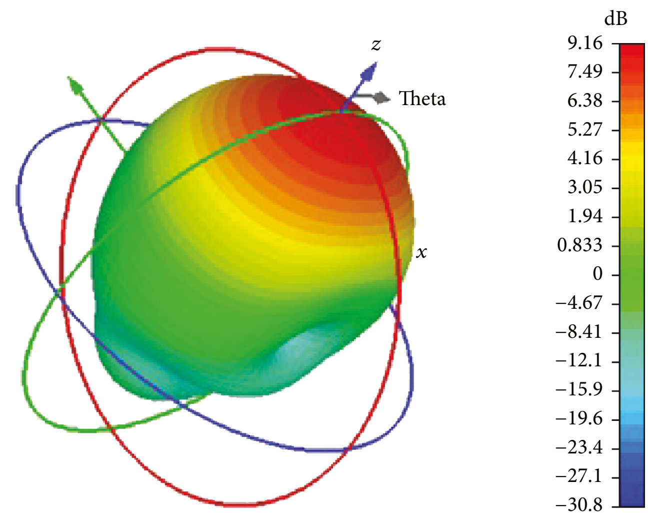
4. Processing and Testing of Cascade Printing Dual Polarized Antenna

According to the structure and size of the designed cascade printing dual polarized antenna, the prototype is assembled and the physical image of the antenna sample is shown in Figure 9.

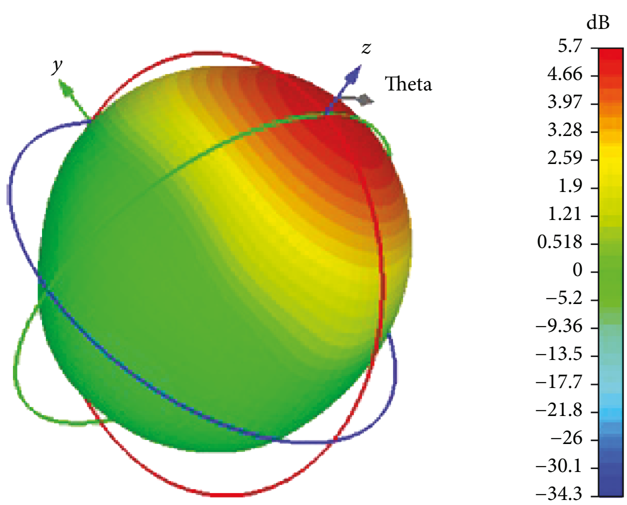
Figure 9 shows the designed antenna employing cable feed. A copper reflector ground was used as ground. The printed monopole and slot ring antenna are fed by the coaxial and electromagnetic couplings, respectively. Electronic dipole is printed on the substrate of electronic dipole. Figure 9 clearly presents the processed antenna structure.



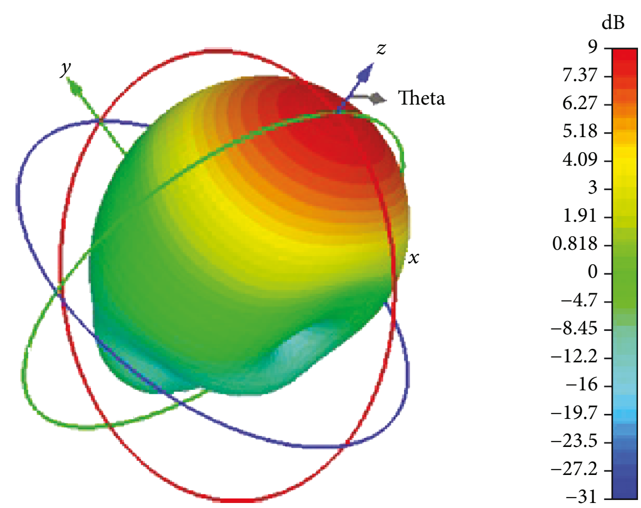
(a) Pattern of port 1 at 4.9 GHz



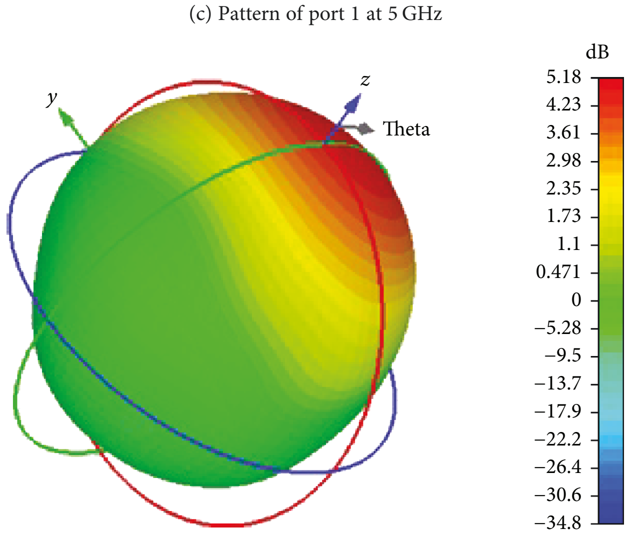
(b) Pattern of port 2 at 4.9 GHz



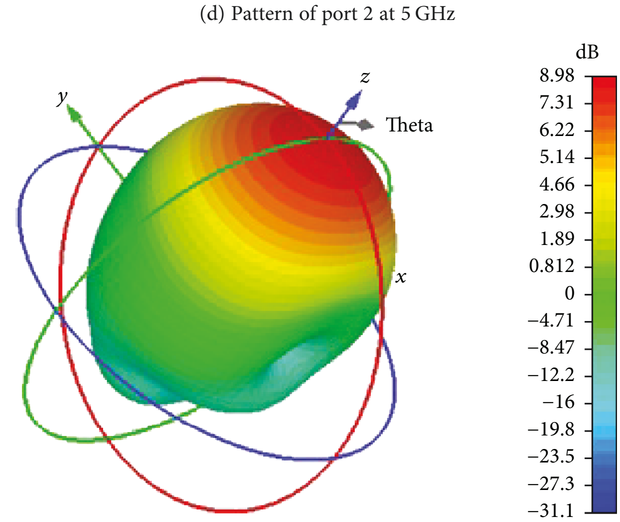
(c) Pattern of port 1 at 5 GHz



(d) Pattern of port 2 at 5 GHz

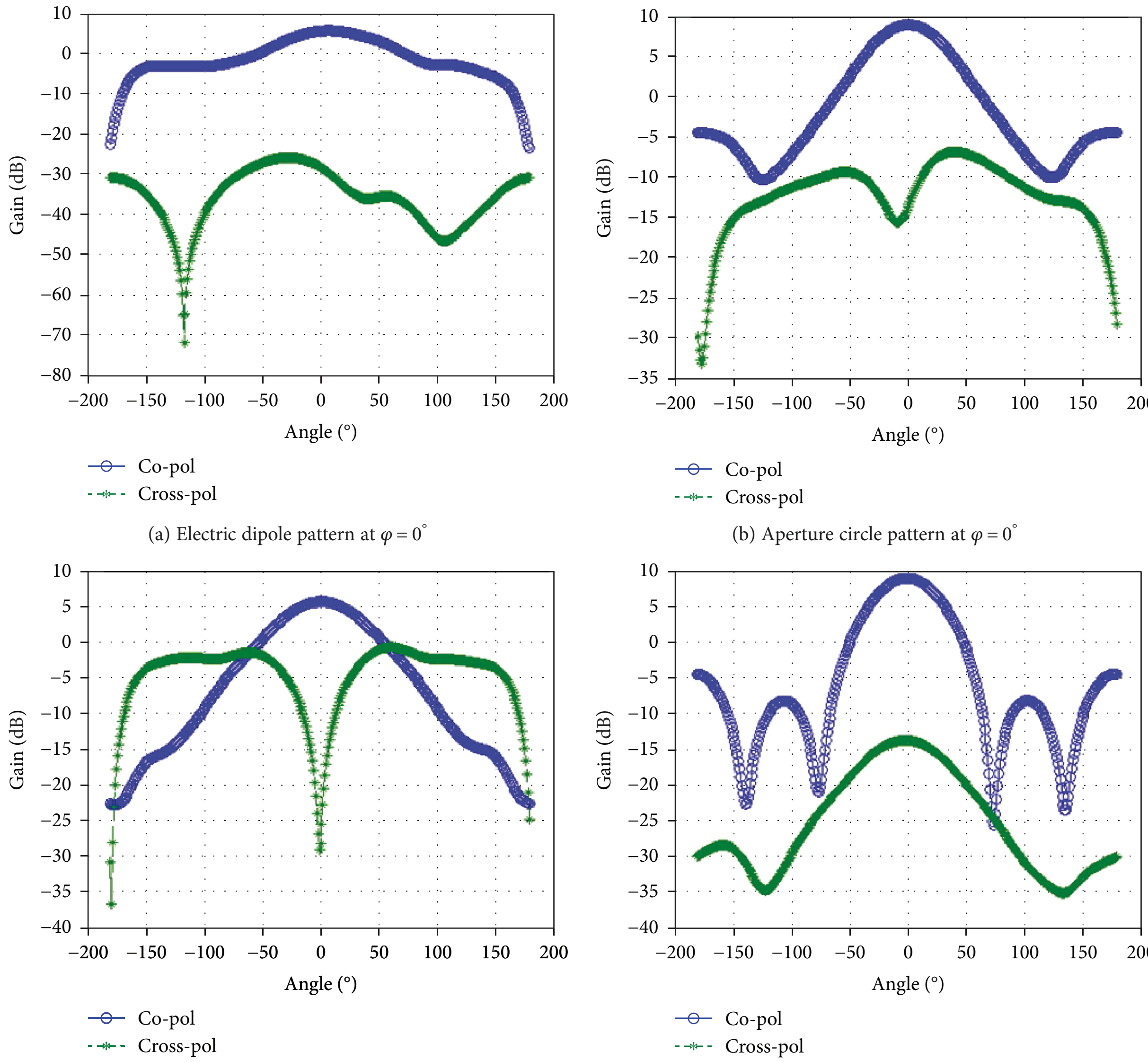


(e) Pattern of port 1 at 5.1 GHz



(f) Pattern of port 2 at 5.1 GHz

Figure 5: The simulated three dimension gain patterns of the designed antenna.

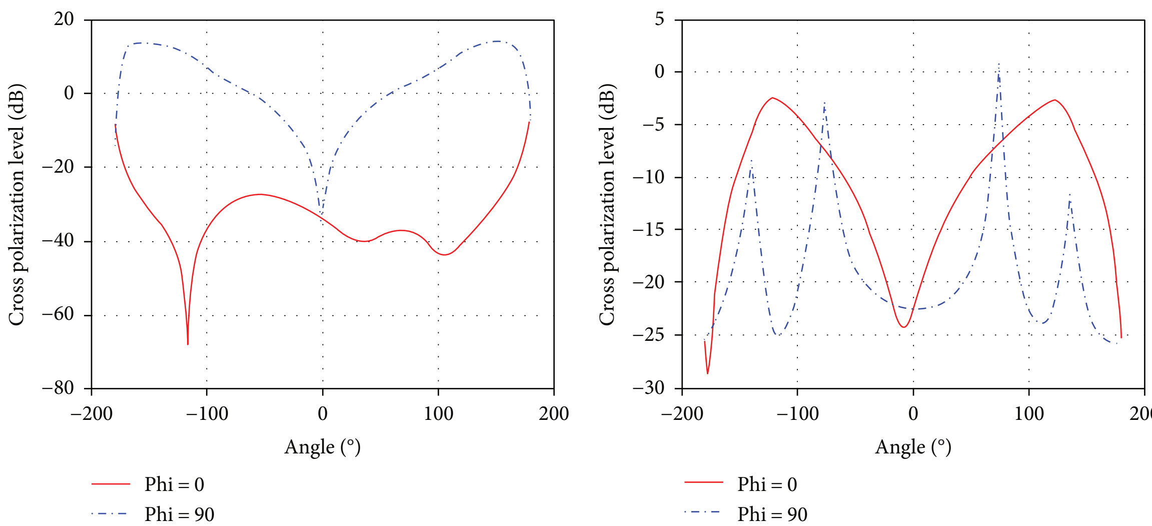


(c) Electric dipole pattern at $\varphi = 90^\circ$
(d) Aperture circle pattern at $\varphi = 90^\circ$

FIGURE 6: Simulation pattern of dual polarized antenna.

The two polarization ports' voltage standing wave ratio and isolation test results are shown in Figures 10(a)–10(c), respectively. Between the bandwidth, the average voltage standing wave ratio of the two polarization port is about 2, the one of port 2 slightly tall, the simulation performance is less than 2, the one of port 2 slightly tall, and the test performance is slightly worse than the simulation one. The isolation between the two polarization ports is about 24.7 dB at 5 GHz, and the bandwidth of greater than 20 dB is greater than 500 MHz. The simulation performance is within the bandwidth under −23 dB, and the test performance is slightly worse than the simulation one. According to the analysis, the difference between the measured result and the simulation one is mainly caused by the machining precision and the error of assembly.

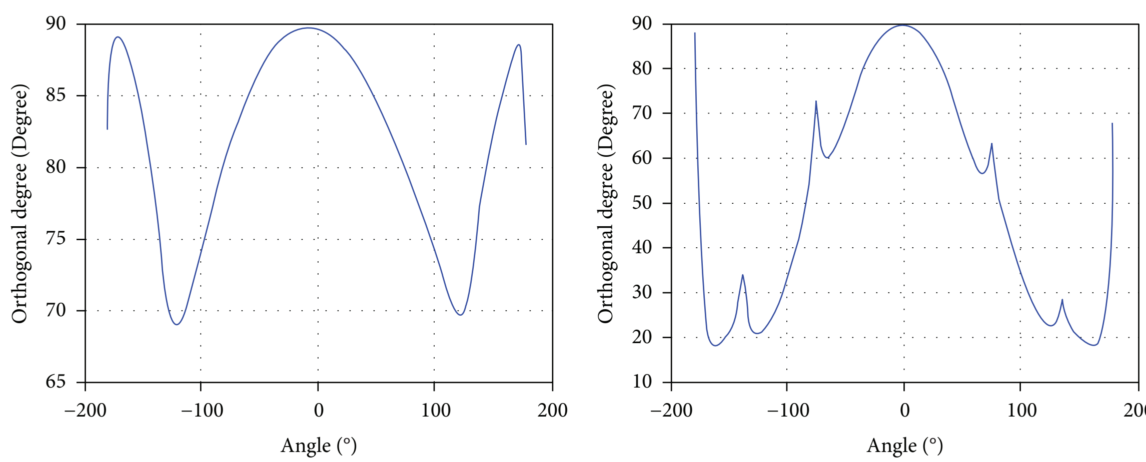
The pattern of the dual polarized antenna is measured in a microwave dark room, and the radiation pattern test results of port 1 (printing dipole port) and port 2 (circle aperture port) are shown in Figures 11 and 12, respectively, in which the E and H plane pattern of the center frequency point of each port is provided. It can be seen that the dual polarized antenna formed the radiation pattern effectively, and the beam widths of the E plane and H plane of port 1 are similar, about 95°. The one of port 2 is about 80°. In the direction of the main radiation, the cross-polarization level of port 1 is −15 dB, higher than the simulation results. The cross-polarization level of port 2 is about −20 dB, which is better than that of port 1. The test results show that the two polarization ports of the dual polarized cascade printing antenna have a wide beam, and the polarization direction pattern is wider and suitable for practical application. At the same time, the design scheme of dual polarized antenna based on electromagnetic radiation source is correct. The test results are slightly worse than the simulation one, which are caused by the antenna processing and test errors.



(a) Cross-polarization of electric dipole

(b) Cross-polarization of aperture circle

Figure 7: Cross-polarization simulation results of dual polarization antenna.



(a) $\varphi = 0^{\circ}$

(b) $\varphi = 90^{\circ}$

Figure 8: The simulated orthogonal range at the far field space of the designed dual polarized antenna.

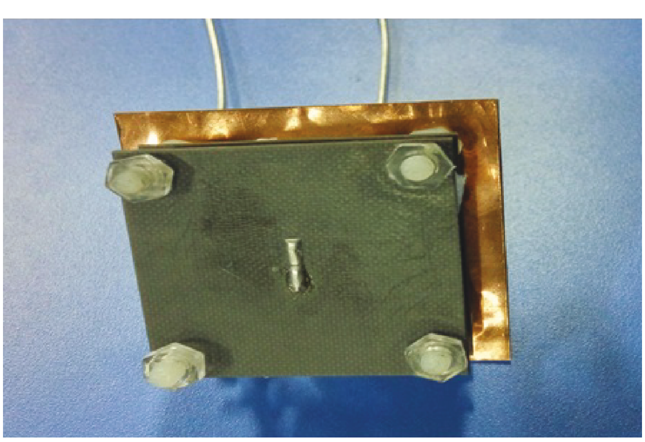
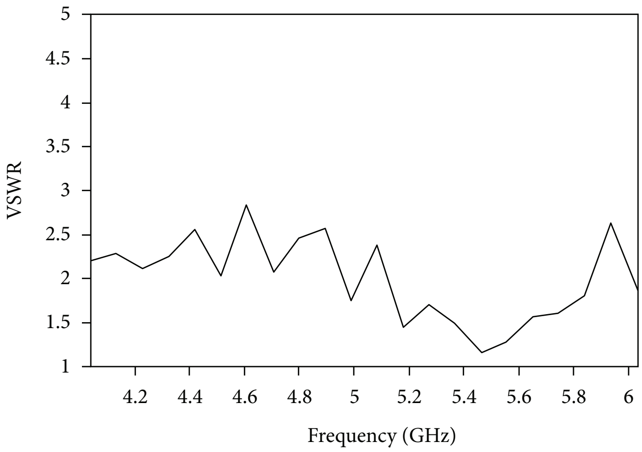


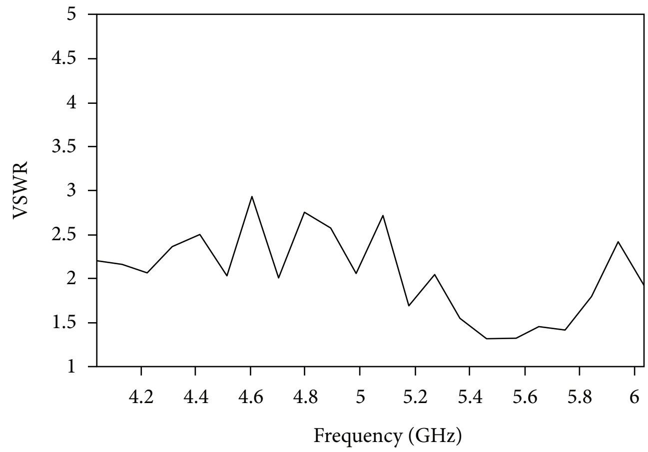
Figure 9: The physical photo of dual polarized antenna.

5. Conclusions

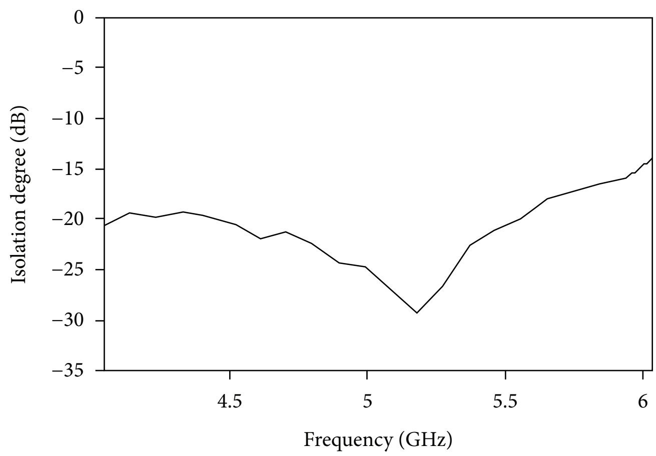
Based on the radiation principle of dual polarization antenna units, a design scheme of dual polarization antenna with electric current source and magnetic current source combined is proposed in this paper, which provides a new technical way for a dual polarization antenna design. According to the equivalent principle of electromagnetic field, a kind of cascade dual polarization printing antenna unit is designed, in which printing dipole and aperture circle are used as the electric current source and magnetic current source radiator separately. The two polarization ports of the antenna unit are introduced from the bottom of the antenna structure and are suitable for the application of phased array. Using full-wave electromagnetic simulation software to simulate the dual polarization antenna design and optimization with the bandwidth between 4.9 GHz and 5.1 GHz, the antenna port



(a) VSWR test result of port 1

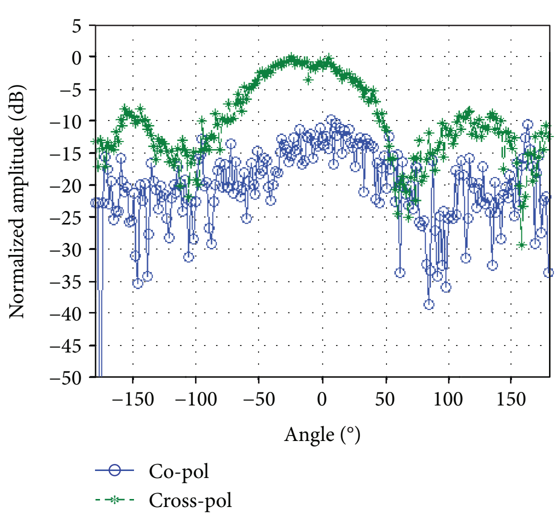


(b) VSWR test result of port 2

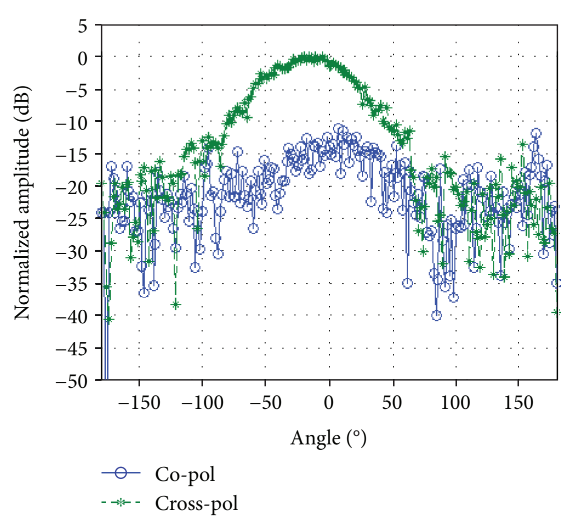


(c) Isolation test result of ports

Figure 10: Photo of dual polarized antenna and test results of electronic principle.

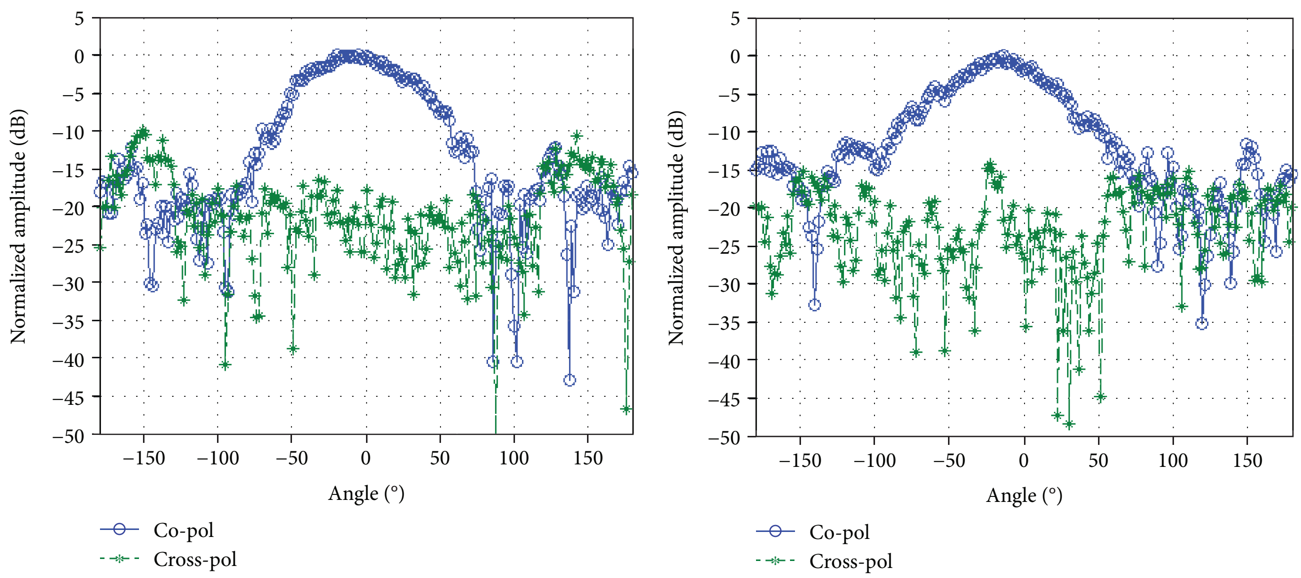


(a) E plane



(b) H plane

Figure 11: Test patterns of printing dipole ports.



(a) E plane

(b) H plane

Figure 12: Test patterns of circle aperture ports.

isolation, cross-polarization level, beam width, and other technical indicators meet the requirements of dual polarization antenna; especially, the dual polarization antenna has a very wide polarization pattern; namely, in the wide range of space angle, the two polarization channel has good orthogonality, which can be used in dual polarization radar and communication systems. The polarization pattern of this antenna is wider than the compact dual polarized slot antenna with an enhanced gain in the literature [1–5]. The designed dual polarization cascade printing antenna is processed and tested, and the experimental results verify the effectiveness of the proposed dual polarization antenna.

Data Availability

The data of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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