A Dual-polarized UWB Antenna Fed by a New Balun for Electronic Reconnaissance System Application

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Abstract **─** For a practical engineering application, a printed ultra-wide band (UWB) antenna with dual polarization is presented in this paper. An integrated Balanced-to-unbalanced (Balun) transformer from microstrip line to coplanar stripline (CPS) is designed, which is employed to feed the symmetrically coplanar Vivaldi radiator. Two substrates are used to support the Vivaldi radiators which are orthogonally mounted. The proposed antenna can build two orthogonal UWB channels and receive two polarization components of incident electromagnetic signal. By bending the balanced coplanar striplines, the cross placement of two polarization radiators can be easily realized, which is suitable for the engineering application. A dual-polarized Vivaldi antenna with the frequency range from 2.5GHz to 6GHz was simulated and fabricated. The measured indicated that the average return loss of designed antenna is less than -10dB and the port isolation degree is about 20dB with the operational frequency range, the gains are about larger than 3dB and the average cross polarization levels are about -20dB. The research results verify the feasibility of the proposed antenna scheme. The presented dual-polarized antenna has the advantages of easy design, high port isolation and convenient engineering application, which can be used in the fields such as electronic reconnaissance system.

Index Terms **─** Balun, CPS, dual polarization, electronic reconnaissance system, UWB, Vivaldi.

I. INTRODUCTION

Radar electronic reconnaissance system usually adopts ultra-wideband antenna to receive various radar signals, and uses signal processing algorithms to realize radar signal detection, feature extraction, target recognition and other functions[1-2]. Ultra-wideband antennas play an important role in radar electronic reconnaissance systems. In order to obtain more comprehensive information on the radar signal, the polarization-sensitive reconnaissance system is the future development trend. The dual-polarization UWB antenna is a key component of the polarization-sensitive radar reconnaissance system. Research on dual-polarization UWB antenna suitable for engineering application has important practical significance [3-4]. The dual-polarized antenna unit provides two polarized signal receiving ports, and simultaneously receives two orthogonal polarization components of the incident electromagnetic wave, thereby sensing the fully polarized information of the electromagnetic wave [5-7]. For dual-polarized UWB antennas, good polarization port isolation and low cross-polarization levels are important considerations, which require antennas with lower return loss over the ultra-wideband range and smooth radiation pattern [8-10]. In the design and development of dual-polarized UWB antennas, antenna types of various types of structures have emerged, such as dual-polarized ridged horn antennas, dual-polarized sinusoidal antennas [11-12], and dual-polarized logarithmic periodic antennas [13-14], dual-polarized slot antenna [15-16]. The dual-polarized Vivaldi antenna has been paid more and more attention and widely used due to its advantages of low cost and simple structure. Vivaldi antennas are broadband tapered slot antennas with ultra-wideband impedance radiation pattern performance. The dual-polarized UWB Vivaldi antenna is usually composed of a printed medium substrate. Two symmetric dielectric substrates are placed at the intersection, and two polarization ports are formed by mechanical assembly. In actual operation, the output port is usually a coaxial connector. In order to solder easily, the output port is generally a microstrip transmission line on the printed medium substrate. Since the microstrip transmission line is an unbalanced structure, it is necessary to introduce an unbalanced device to balanced conversion feeding structure, this unbalanced device is balun [17-19]. Balun is usually used as the conversion from microstrip line to slot line, based on

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electromagnetic coupling, the excitation of tapered slots and space electromagnetic radiation are realized. The traditional microstrip-slot broadband balun structure is complex and has many design parameters, which results in a large amount of design work. For the cross structure of two dielectric substrates, it is difficult to assemble the antenna, it is easily results in the occlusion of two polarization ports and poor assembly consistency. In addition, due to the cross between polarization ports, the isolation degree of polarization ports becomes worse, and the electromagnetic coupling between polarization channels becomes stronger, which makes the measurement error larger [21-22].

Based on the above considerations, this paper proposes an integrated balun-fed dual-polarization UWB antenna based on microstrip line to coplanar stripline conversion. The balun design is simple and easy to connect and match with the Vivaldi radiator. The occlusion of orthogonal polarization ports bends and vertically isolates the coplanar strip lines, which effectively reduces the assembly difficulty and improves the isolation of the polarization ports, which lays a good foundation for engineering applications. In this paper, the structure of the specific dual-polarized antenna is designed and implemented for the frequency range of 2.5GHz~6GHz. According to the working frequency range and technical indicators, the size parameters of the antenna were preliminarily calculated. Finally, the full wave electromagnetic simulation software was used for numerical calculation and performance optimization, and then the structure and size that meet the requirements were determined to complete the design and implementation of the antenna. The research results of antenna processing and test work show that the design of the polarization diversity antenna is effective.

The paper is organized as follows. Section 2 gives the structure of the designed dual-polarized UWB antenna and discusses the simulation and optimization of the dual-polarized UWB antenna. Section 3 describes the test results. Finally, the research conclusion is provided.

II. ANTENNA DESIGN

The schematic diagram of the ultra-wideband dual-polarized Vivaldi antenna designed in this paper is shown in Figure 1. The dielectric substrate of the entire antenna is selected from FR4 plates, and the thickness of the dielectric substrate is 1 mm. Two dielectric substrates of the same size are placed orthogonally, each polarized port corresponds to an ultra-wideband Vivaldi radiator, the feed transmission line is a coplanar strip line, and the Vivaldi radiator uses two exponential curves to constrain its shape in the middle region. An exponentially graded gap is formed to realize an ultra-wideband radiation field. In order to facilitate assembly of the dielectric substrate, the excited coplanar strip line is bent, and in the vertical direction, the two coplanar strip lines are kept at a certain interval, which can improve the port isolation. The input terminal of the antenna is a microstrip line, which is suitable for soldering with the coaxial line. An integrated printing balun is added between the microstrip line and the coplanar strip line to complete the conversion between the unbalanced and balanced structures, at the same time, it can achieve impedance matching. The Balun is a kind of microstrip line-coplanar stripline conversion Balun.

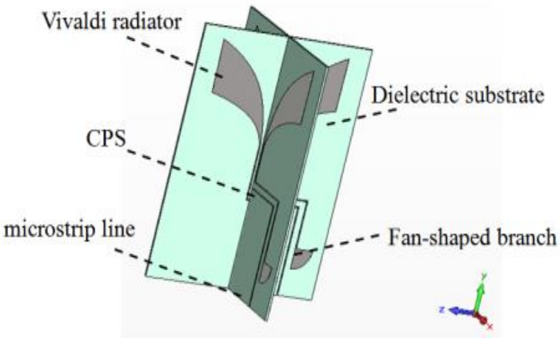
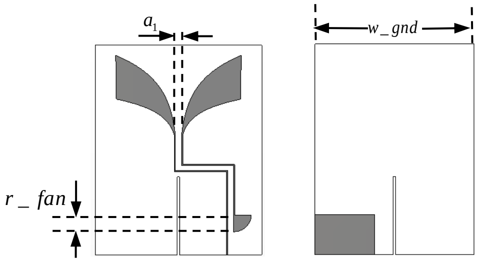


Fig. 1. The structure diagram of dual-polarized UWB antenna.

The geometrical models of the two dielectric substrates of the dual-polarized Vivaldi antenna are shown in Fig. 2 and Fig. 3 respectively. The designed Vivaldi radiator is a symmetrical structure, and the spacing between the excited coplanar strip lines is a_1, the width of the dielectric substrate is w_gnd. The designed microstrip line-coplanar stripline ultra-wideband Balun consists of the microstrip line at the input end, the coplanar strip line at the output end, the fan-shaped mating branch and the partially printed ground plane. The radius of the fan-shaped branch is r_fan.



(a) (b)

Fig. 2. The structure model of the first antenna radiator: (a) front view and (b) back view.

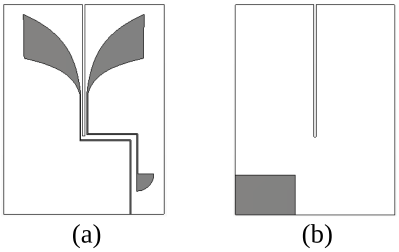


Fig. 3. The structure model of the second antenna radiator: (a) front view and (b) back view.

At the output of the Balun, the coplanar stripline excites the balanced Vivaldi radiator, the radiation impedance of the radiator is matched with the output impedance of the Balun, and the full-wave electromagnetic simulation technique is used to complete the parameter design. The curve equation of Vivaldi antenna as follows:

$$x = ae^{ry}. \tag{1}$$

The characteristic impedance of CPS can be calculated by the following formula [20]:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{re}}}\frac{K(k_1)}{K^{'}(k_1)}(\Omega), \tag{2}$$

$$\varepsilon_{re} = 1 + \frac{\varepsilon_r - 1}{2}\frac{K^{'}(k_1)}{K(k_1)}\frac{K(k_2)}{K^{'}(k_2)}, \tag{3}$$

$$k_1 = \frac{s}{s+2W} = \frac{a}{b}, \tag{4}$$

$$k_2 = \frac{\sinh\left(\frac{\pi a}{2h}\right)}{\sinh\left(\frac{\pi b}{2h}\right)}, \tag{5}$$

$$W_S = W_C = W_0. \tag{6}$$

Where, ε_r is the dielectric constant of the dielectric plate, ε_{re} is the relative dielectric constant, K is the elliptic integral function, h is the thickness of the dielectric plate, W and g are the width of the stripline and the gap between them, respectively.

According to formula (2)-(6), the characteristic impedance of coplanar stripline is calculated, and the structure of Balun and impedance matching is designed and optimized.

The simulated performance curves of polarization isolation for the designed antenna varying with the parameter of r_fan are shown in Fig. 4. It can be seen that the radius of the fan-shaped branch has little effect on port isolation of the low frequency band. In the high frequency band, as the radius of the fan-shaped branch becomes larger, the isolation between the ports is greatly undulated, and the size is preferably 10 mm.

The simulated curves of polarization isolation for the antenna varying with the parameter of a_1 are shown in Fig. 5. It can be seen that with the increase of a_1, the polarization port isolation of the two ports both show a good trend. When a_1 becomes 1.5 mm, it continues to increase by a_1.

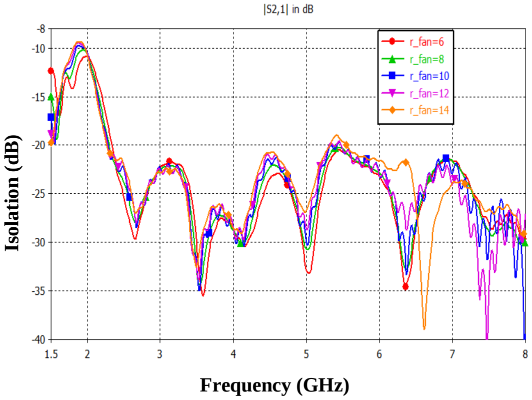


Fig. 4. Port isolation curves varying with r_fan.

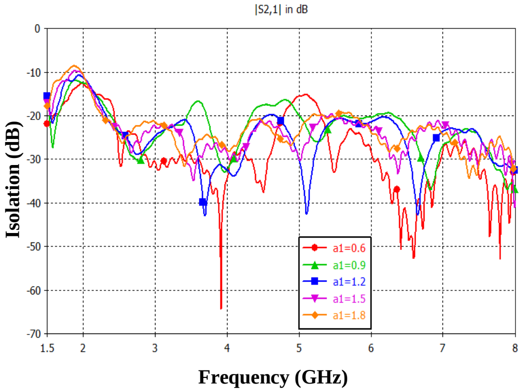


Fig. 5. Port isolation degree curves varying with a_1.
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The dimensions of the dual-polarized UWB Vivaldi antenna are determined as follows: a_1 is 1.5 mm, r_fan is 10 mm, and w_gnd is 80 mm. The simulation results of the return loss and port isolation of the dual-polarized Vivaldi antenna designed in this paper are shown in Figure 6. In the frequency range of 3 GHz to 4 GHz, the average return loss of the two polarization ports of the antenna is about 8 dB, and the average isolation of the polarization port of the antenna is about 20 dB. The performance of the two port circuits is basically symmetrical.

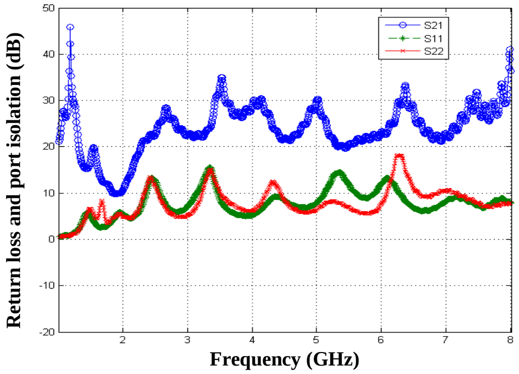
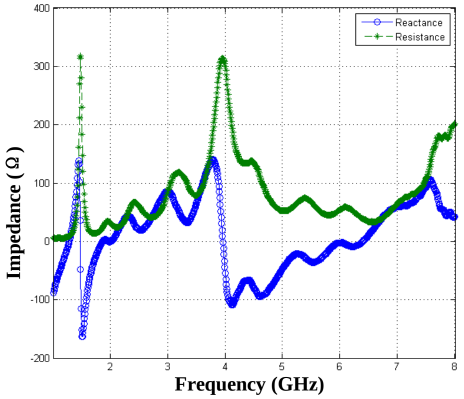
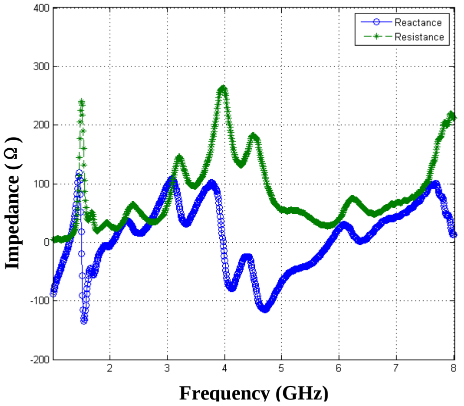


Fig. 6. The simulated return loss and port isolation degree of dual-polarized antenna.

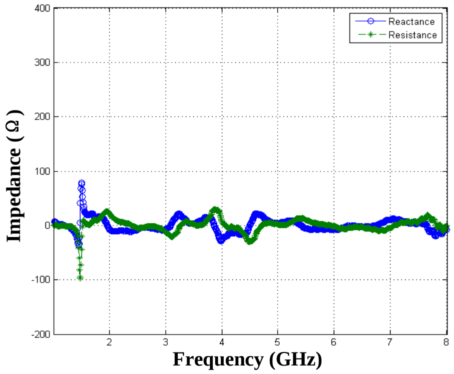
Figure 7 shows the simulation results of the impedance characteristics of the two polarization ports. It can be seen that the average value of the resistance part of the input impedance of the two polarization ports is about 50 ohms in the working frequency band, and the reactance part is small. The mutual impedance value fluctuates near zero, and the average value is close to zero, which reveals the impedance characteristics of ultra wideband.



(a)



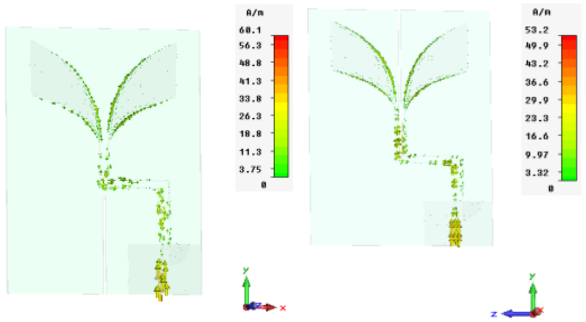
(b)



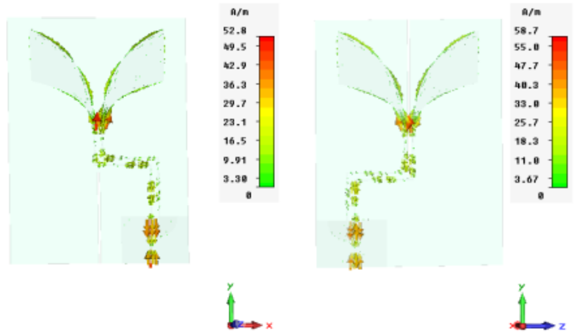
(c)

Fig. 7. The simulation results of the impedance characteristics of the two polarization ports: (a) the self impedance of port 1, (b) the self impedance of port 2, and (c) the mutual impedance between the port 1 and the port2.

Figure 8 shows the current distributions on the surface at 3GHz and 6GHz, respectively. It can be seen that the current distribution on the surface of the antenna changes smoothly with the frequency, the current distribution on the two polarization ports is symmetrical, and the current distribution is concentrated on the slot edge of the radiation dipole. The radiation fields of the two polarization ports are orthogonal, which shows the effectiveness of the design scheme.



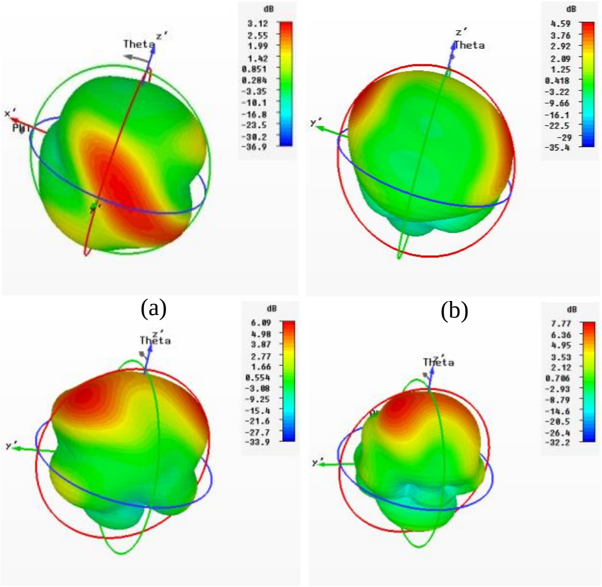
(a) Port 1 at 3GHz (b) Port 2 at 3GHz



(c) Port 1 at 6GHz (d) Port 2 at 6GHz

Fig. 8. The current distributions of the impedance characteristics of the two polarization ports.

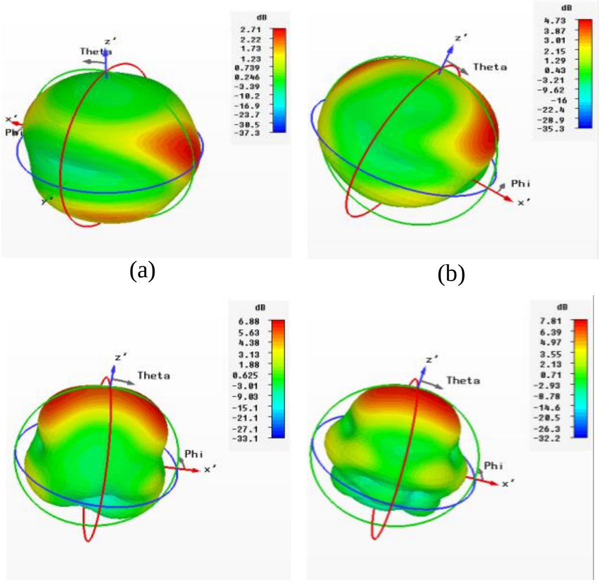
Figure 9 and Fig. 10 show the simulated three dimension gain patterns of two polarized ports at four typical frequencies, respectively. According to Fig. 9 and Fig. 10, the wide beam performances of two polarized ports within the whole working frequency range are observed.



(a) (b)

(c) (d)

Fig. 9. The simulated three dimension gain patterns of port 1: (a) pattern at 3GHz, (b) pattern at 4GHz, (c) pattern at 5GHz, and (d) pattern at 6GHz.



(a) (b)

(c) (d)

Fig. 10. The simulated three dimension gain patterns of port 2: (a) pattern at 3GHz, (b) pattern at 4GHz, (c) pattern at 5GHz, and (d) pattern at 6GHz.

III. RESULTS AND DISCUSSIONS

According to the design result of the dual-polarized UWB Vivaldi antenna, an antenna prototype was fabricated and tested. The antenna performance experiment was carried out in the microwave anechoic chamber. The processed antenna photo is shown in Fig. 11. The test results of return loss and port isolation of the dual-polarized Vivaldi antenna in this paper are shown in Fig. 12. The return loss in the frequency range of 3GHz~6GHz is less than 10dB, and the port isolation is less than 20dB. The return loss and isolation index meet the expected specifications of the dual-polarized antenna.

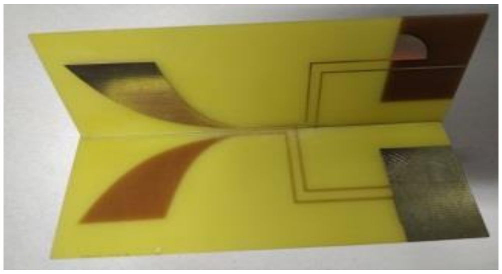


Fig. 11. The photo of the fabricated dual-polarized UWB antenna.

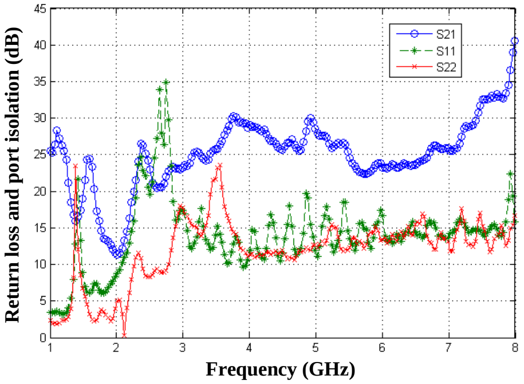
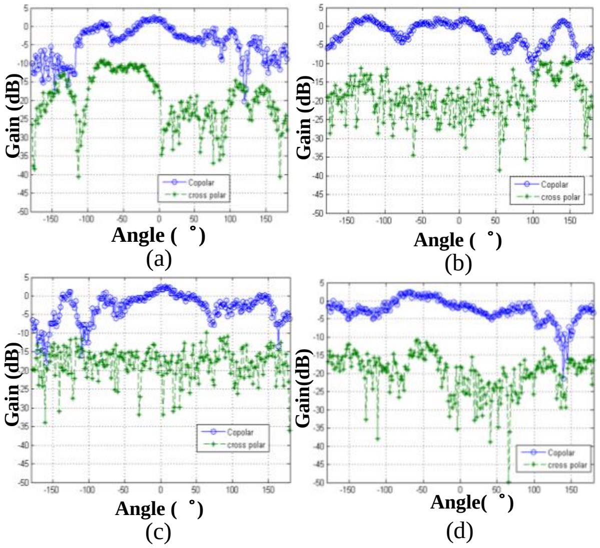


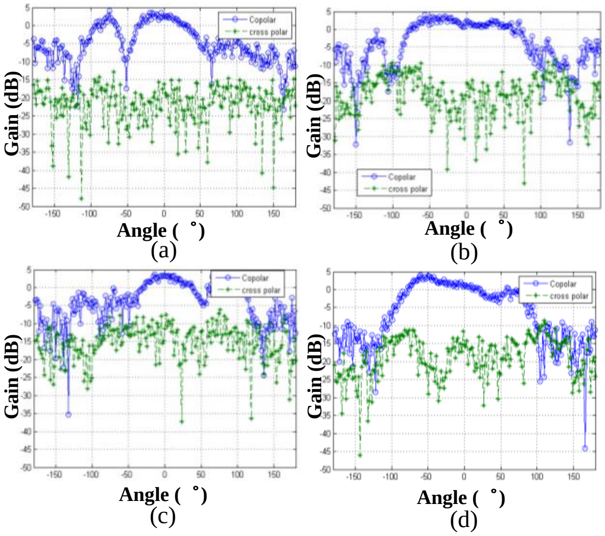
Fig. 12. The measured return loss and port isolation degree of dual-polarized antenna.

Figure 13, Fig. 14, Fig. 15 and Fig. 16 show the radiation pattern tested results at 3GHz, 4GHz, 5GHz and 6GHz, respectively. At each frequency point, the radiation directions of the E and H planes are given respectively. All test results are summarized in Table 1. The test results show that the test direction of the antenna is basically consistent with the simulation results, which verifies the effectiveness of the design. The tested gains are lower than the simulated results. The radiation pattern has a certain fluctuation, which is due to the environmental interference of the test site and machining errors.



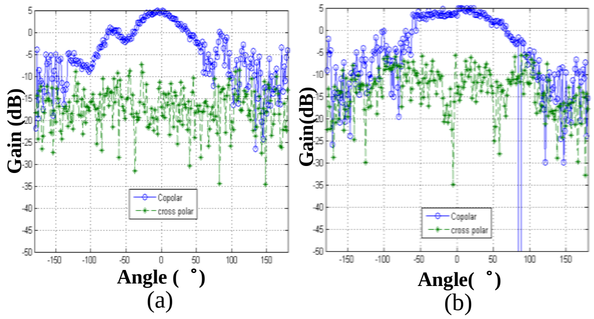
(a) (b)
(c) (d)

Fig. 13. The measured patterns of the antenna at 3GHz: (a) Port 1 at E plane, (b) Port 1 at H plane, (c) Port 2 at E plane, and (d) Port 2 at H plane.

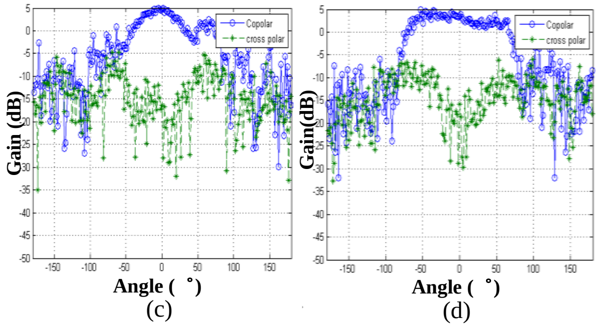


(a) (b)
(c) (d)

Fig. 14. The measured patterns of the antenna at 4GHz: (a) Port 1 at E plane, (b) Port 1 at H plane, (c) Port 2 at E plane, and (d) Port 2 at H plane.

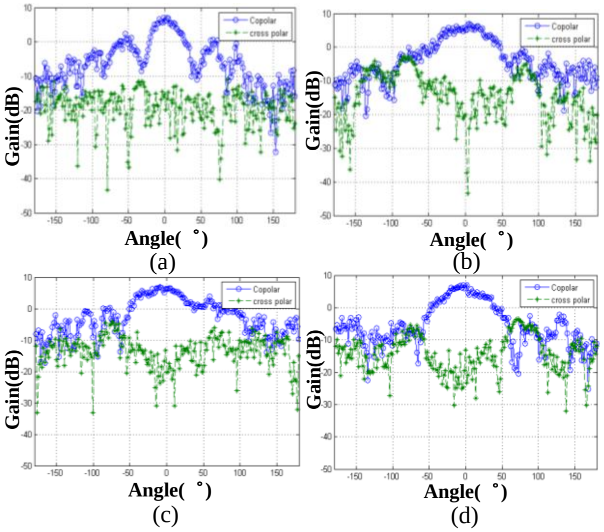


(a) (b)



(c) (d)

Fig. 15. The measured patterns of the antenna at 5GHz: (a) Port 1 at E plane, (b) Port 1 at H plane, (c) Port 2 at E plane, and (d) Port 2 at H plane.



(a) (b)
(c) (d)

Fig. 16. The measured patterns of the antenna at 6GHz: (a) Port 1 at E plane, (b) Port 1 at H plane, (c) Port 2 at E plane, and (d) Port 2 at H plane.

Table 1: The test results of designed antenna

Frequency (GHz)	2.5	3	4	5	6
$\lvert S_{11}\rvert$ **for port 1 (dB)**	-19	-16	-10	-12	-16
Gain for port 1 (dB)	4	3.5	4.5	6	7.5
$\lvert S_{22}\rvert$ **for port 2 (dB)**	-9	-16	-11	-11	-12
Gain for port 2 (dB)	3.5	3	4.6	6.7	7.6
Isolation degree (dB)	-22	-23	-29	-30	-23

IV. CONCLUSION

This paper researched a dual-polarized UWB Vivaldi antenna, which employs an integrated Balun from microstrip line to coplanar stripline to feed the Vivaldi antenna radiator. The bended coplanar strip-lines were used to improve isolation degree of polarization ports. The traditional dual-polarized of the Vivaldi antenna isolation features have greatly improved. The design and fabrication difficulty of dual-polarized antenna have been reduced. It is easy to be used in the practical engineering. A UWB Vivaldi antenna working at 2.5GHz~6GHz is designed by full-wave electromagnetic simulation software. The simulation and experimental results verified the proposed dual-polarized UWB Vivaldi antenna scheme.

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