

Dual-Polarized Complementary Structure Antenna Based on Babinet's Principle

Junrui Zhang and Lizhong Song*

Abstract—Based on the theory of Babinet's principle, a type of dual-polarized antenna working on C band is designed using complementary structures. The structures comprise a wire loop antenna and a slot loop antenna, which is complemented and fed by coaxial lines. A ground is placed to improve the front-to-back ratio of the antenna. The performance of the antenna is hereinafter studied experimentally, followed by the implementation of a prototype antenna. Its stable and symmetric radiation patterns are obtained within the frequency of 4.9 GHz~5.1 GHz, and the port isolation is less than -24 dB. The measured results coincide with the simulated ones. This explains the feasibility of the proposed dual-polarized antenna.

1. INTRODUCTION

Dual-polarized antennas are widely used in the implementation of fully-polarimetric radar systems. They have the advantages of polarization agility, high sensitivity and strong anti-interference ability. In the past decades, various dual-polarized antennas [1] have been proposed with different types of radiators. Dipole antennas [2], patch antennas [3, 4], slot antennas [5–8], and loop antennas [9–11] have been chosen amongst typical radiators for such systems. Most of the ordinary dual-polarized antennas are realized using the same radiators fed by orthogonal feeds [12], otherwise fed by complementary feeds [13]. However, these types of dual-polarized antennas have the disadvantages of limited design flexibility and low port isolation.

According to Babinet's principle [14], complementary antennas have equal E - and H -planes radiation patterns, with which they can be used to design higher performance dual-polarized antennas. Wire-loop antenna and slot-loop antenna are two basic antennas, which have simple structures and are easy to produce with achievable lower cost. They are thus chosen to make this dual-loop antenna.

2. ANTENNA STRUCTURE DESIGN AND SIMULATION

Wire-loop antennas [15, 16] have been widely used in many applications when the perimeter of the loop is equal to about 1λ (a wavelength). Main radiation direction is on the axis of the loop, herein, the maximum value of the radiation pattern is on $\theta = 0^\circ$ and 180° . Slot-loop antenna is an antenna that complements the wire-loop antenna. Its radiation pattern is almost the same as the wire loop's with exchanged E - and H -fields.

The slot loop and wire loop are placed in parallel and coaxial. Aside from this, an additional reflecting plane is used to reduce the back scatter, improve the gain, and suppress side lobe. Two coaxial probes are used as feed. One probe is fed to the wire loop antenna (port1) and the other fed to the slot loop through a microstrip (port2). The schematics is shown in Fig. 1, and the model is in Fig. 2, where the respective ports are also marked.

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* Corresponding author: Lizhong Song (songlizhong@hitwh.edu.cn).

The authors are with the School of Electronics and Information Engineering, Harbin Institute of Technology, Harbin 150001, China.

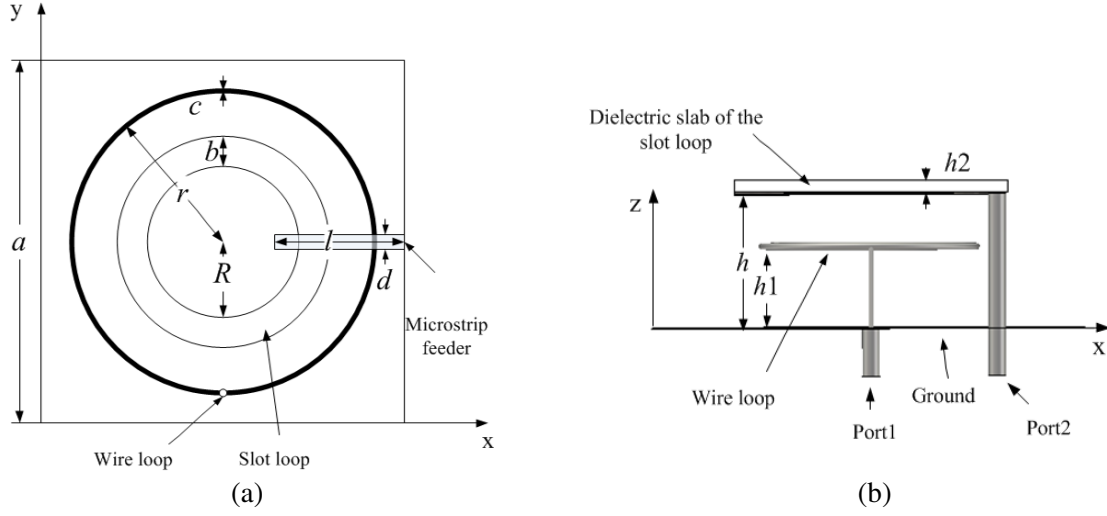


Figure 1. Schematics of the proposed antenna. (a) Top view. (b) Side view.

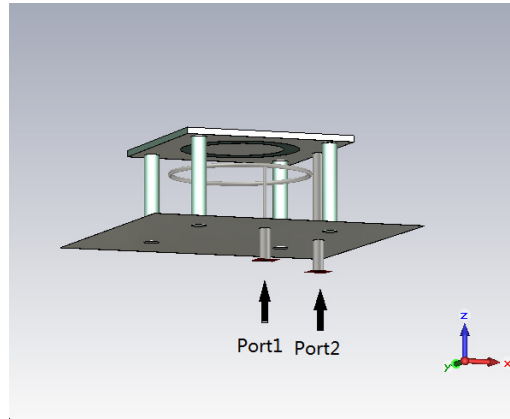


Figure 2. Model of the proposed antenna.

The 1λ -circumference wire-loop antenna is made of brass wires with a diameter of 0.7 mm and has a standing-wave current distribution. The initial radius of the circular loop is decided by $\lambda \approx 2\pi r$ theoretically, where $\lambda = 60$ mm, thus $r \approx 9.6$ mm. The distance between the reflector and wire loop is about 15 mm, which is $\lambda/4$. Considering there exists mutual coupling between the wire loop and the slot loop, the theoretical initial value will not be the final value. Therefore, a parameter scanning is processed. Fine turning radius r around 9.6 mm, regarding the center frequency revealed in S_{11} , the radius of the wire loop is finally optimized to $r \approx 10.8$ mm, and the distance between the reflector and wire loop is adjusted in the same way and determined in $h_1 = 8$ mm. Return loss (S_{11}) of the wire loop versus R and h_1 is shown in Fig. 3, which shows that the resonant frequency decreases as r or h_1 increases.

RT-5880 slab is used in the slot loop, whose relative dielectric constant is $\epsilon_r = 2.2$. The thickness is $h_2 = 1.2$ mm, and thicker dielectric-slab can effectively improve impedance bandwidth.

Figure 4(a) shows the return loss variety versus radius R of the slot loop. The center frequency increases as R decreases, but the return loss also increases as it is affected by the cross coupling of the wire loop. The position of the slot loop also affects the return loss in the same way, shown in Fig. 4(b), and finally determines it in $h = 14$ mm. Fig. 4(c) shows how the width of the slot loop affects S_{11} and S_{22} . The center frequency of the slot loop and the return loss of both ports increase as the width of the slot loop decreases, whereas the center frequency of the wire loop antenna will not shift.

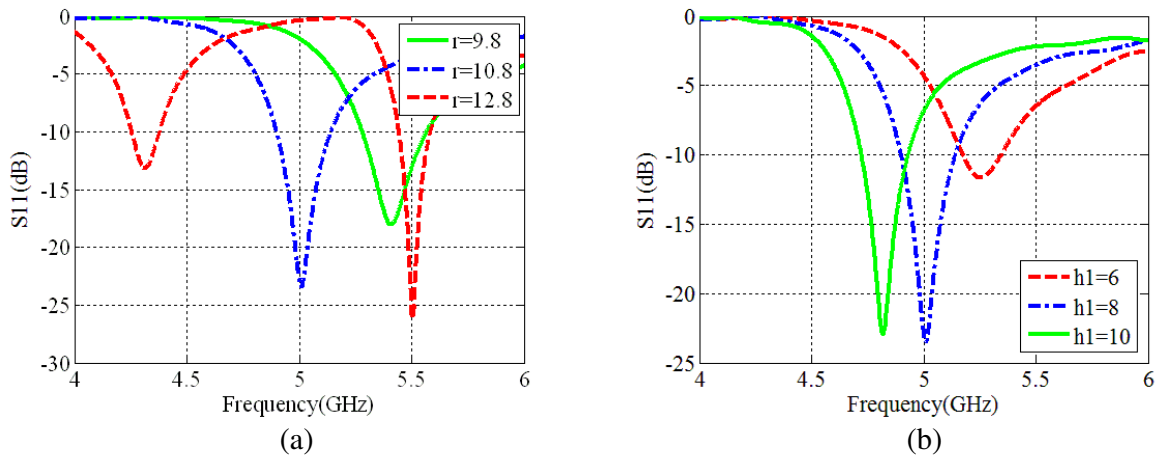


Figure 3. Return loss scanning versus the dimensions of the wire loop. (a) Simulated return loss versus r . (b) Simulated return loss versus h_1 .

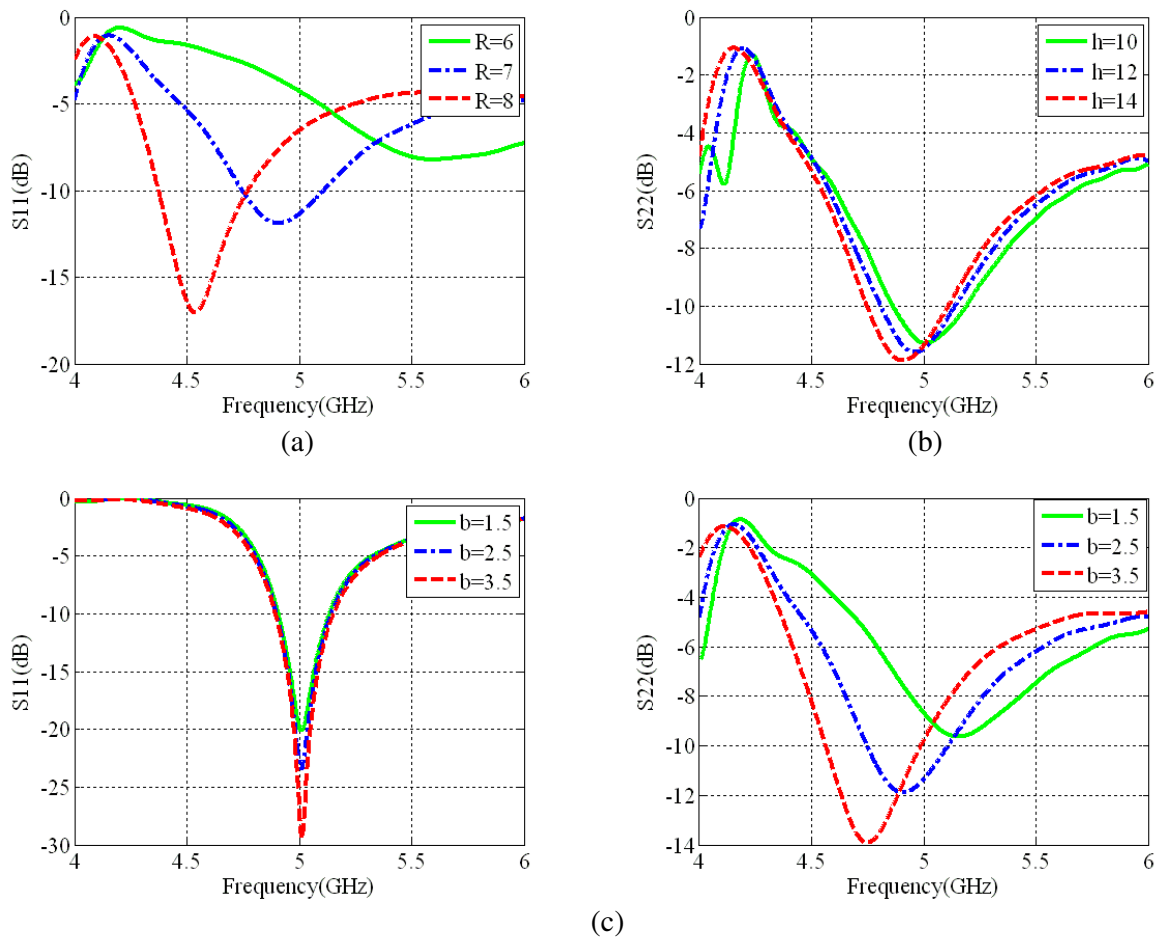


Figure 4. Return loss scanning versus the dimensions of the slot loop. (a) S_{11} versus inner diameter R . (b) S_{22} versus h . (c) S_{11} & S_{22} versus width b .

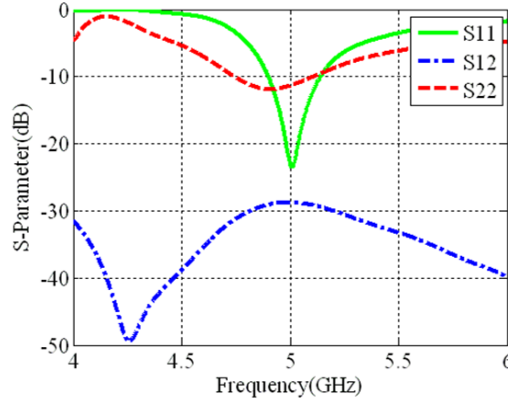


Figure 5. Simulated S -parameter.

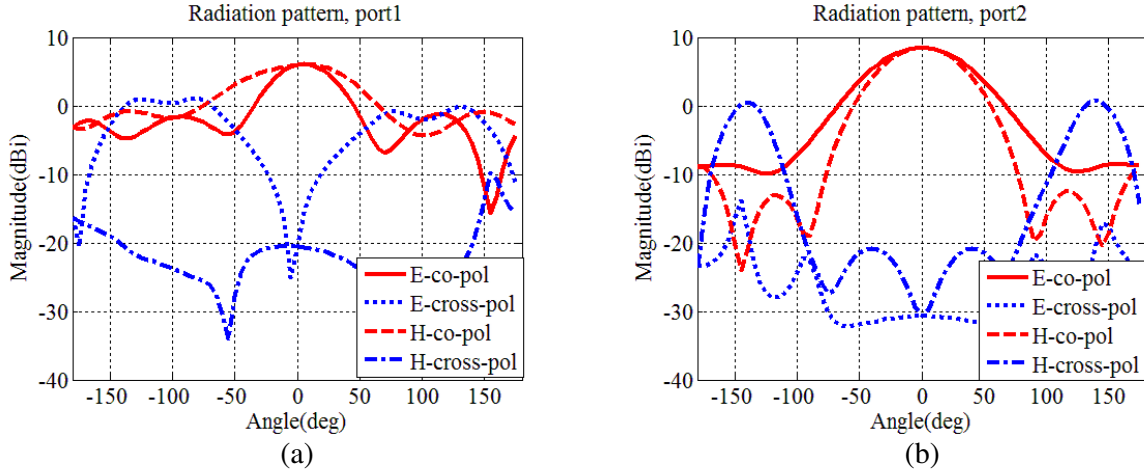


Figure 6. Simulated radiation pattern. (a) Simulated radiation pattern of wire loop antenna. (b) Simulated radiation pattern of slot loop antenna.

The dimension of the antenna is optimized after these discussions and analyses mentioned above, and they together assure the center frequency of 5 GHz and suitable S -parameters. The final optimized dimensions are: $a = 28$ mm, $b = 2.5$ mm, $R = 7$ mm, $r = 10.8$ mm, $d = 1$ mm, $l = 10$ mm, $h_1 = 8$ mm, $h = 14$ mm, $h_2 = 1.2$ mm. Fig. 5 shows the S parameters, which illustrate that the center frequency of the dual-loop antenna is about 5 GHz, the frequency range of the wire loop about 4.9 GHz~5.14 GHz, and the frequency range of the slot loop 4.75 GHz~5.1 GHz, defined by return loss below -10 dB. Therefore, the working band is 4.9 GHz~5.1 GHz, and the isolation is lower than -29 dB.

Figure 6 shows the simulated radiation pattern of the two ports at 5 GHz. The maximum gain of the wire loop is 5.98 dBi; 3 dB E -plane ($\phi = 90^\circ$) bandwidth is 55.9° ; 3 dB H -plane ($\phi = 0^\circ$) bandwidth is 97.2° . The maximum gain of the slot loop is 8.45 dBi; 3 dB E -plane ($\phi = 90^\circ$) bandwidth is 78.4° ; 3 dB H -plane ($\phi = 0^\circ$) bandwidth is 66.4° . The cross polarization of the two ports are both under -20 dB at the main radiation direction; that of the wire loop is -21.8 dB; that of the slot loop is up to -31 dB. It means that the radiation of the wire loop antenna is impacted a bit as it is blocked by the slot loop. But still the radiation patterns of the two ports are almost the same with E - and H -fields exchanged.

Further, the E - and H -fields are tested. Fig. 7 illustrate that E -field is mainly radiated by the slot loop because the current can spread out on the metal sheet, and H -field is mainly radiated by the wire loop because of the current on it. It is another proof of the complement.

In space, the co-polarization (e.g., $E_{\text{wire-loop}}$) and cross-polarization (e.g., $E_{\text{slot-loop}}$) directions are

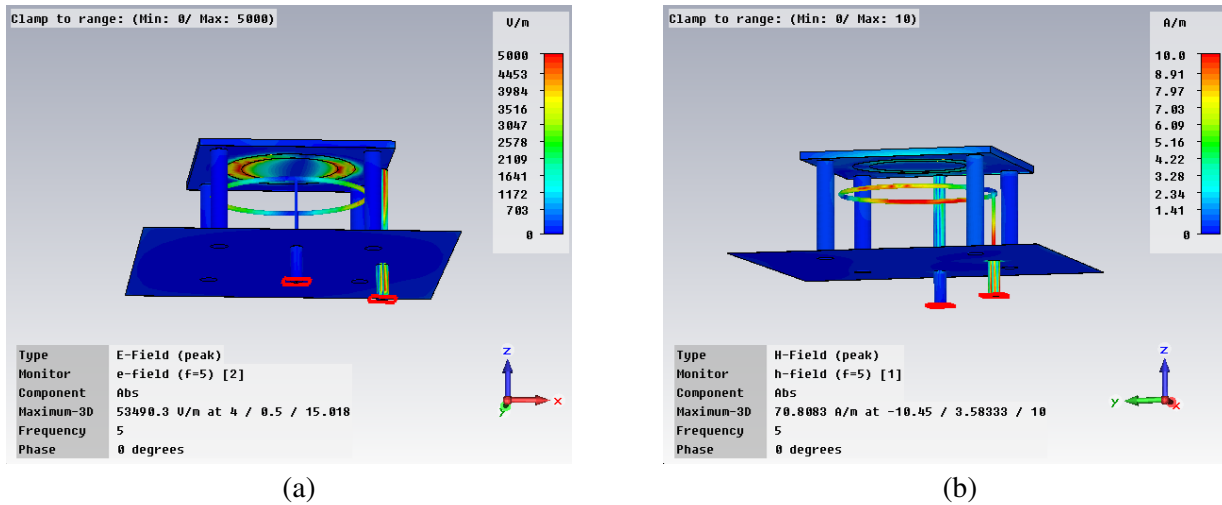


Figure 7. Simulated E and H field. (a) E field. (b) H field.

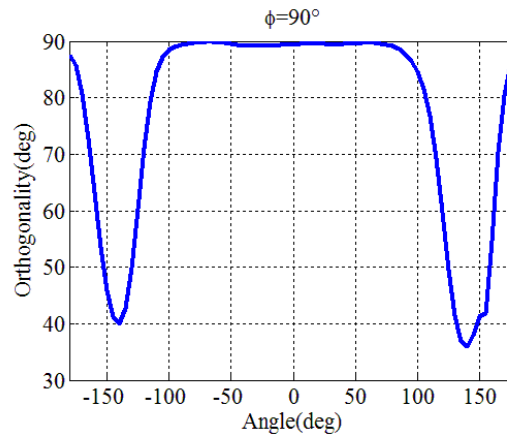


Figure 8. Orthogonality on E -plane.

not always orthogonal, thus we use the angle between the two to define the orthogonality, shown in Fig. 8. It can be seen that in a wide range on E -plane ($\phi = 90^\circ$), the E -fields of the two ports are orthogonal. It determines a reasonable cross-polarization performance of the antenna.

3. FABRICATION AND MEASUREMENT

The dual-loop antenna is fabricated and assembled, as in Fig. 9. The comparison of measured and simulated S -parameters is shown in Fig. 10.

The center frequencies of the two ports are shifted a little bit because of the low level of the assembling precision, but in the working band of 4.9–5.1 GHz, it almost meets the simulated results. As can be seen from the photograph, the wire loop, slot loop, and ground plane are not perfectly parallel, and it will lead to additional E - and H -components in radiation, which will bring coupling and reduce isolation. Still the isolation is below -24 dB in the working band, which meets the design principle.

The radiation patterns measured in microwave chamber are revealed in Fig. 11. The radiation pattern has a regular shape at 5 GHz. The measured gain of the wire-loop antenna is 6 dBi, and 3 dB bandwidth is 60° , both on the E - and H -planes. The measured gain of the slot-loop antenna is 7.55 dBi, and 3 dB bandwidths are 76° and 72° on the E - and H -planes respectively. The measured results approximately agree with the simulated ones, but the gain is slightly smaller. Compared to

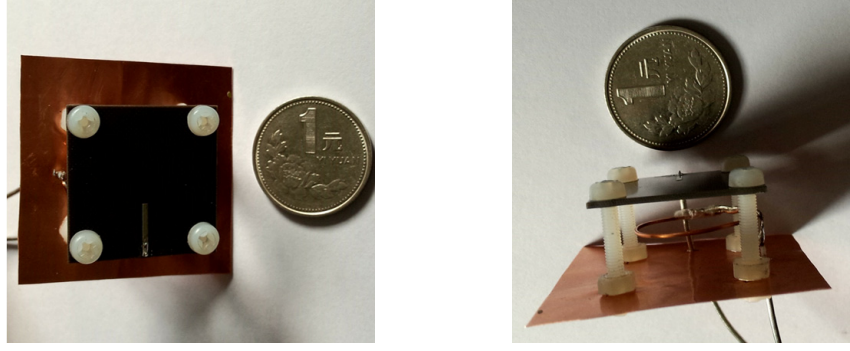


Figure 9. Photography of the fabricated antenna.

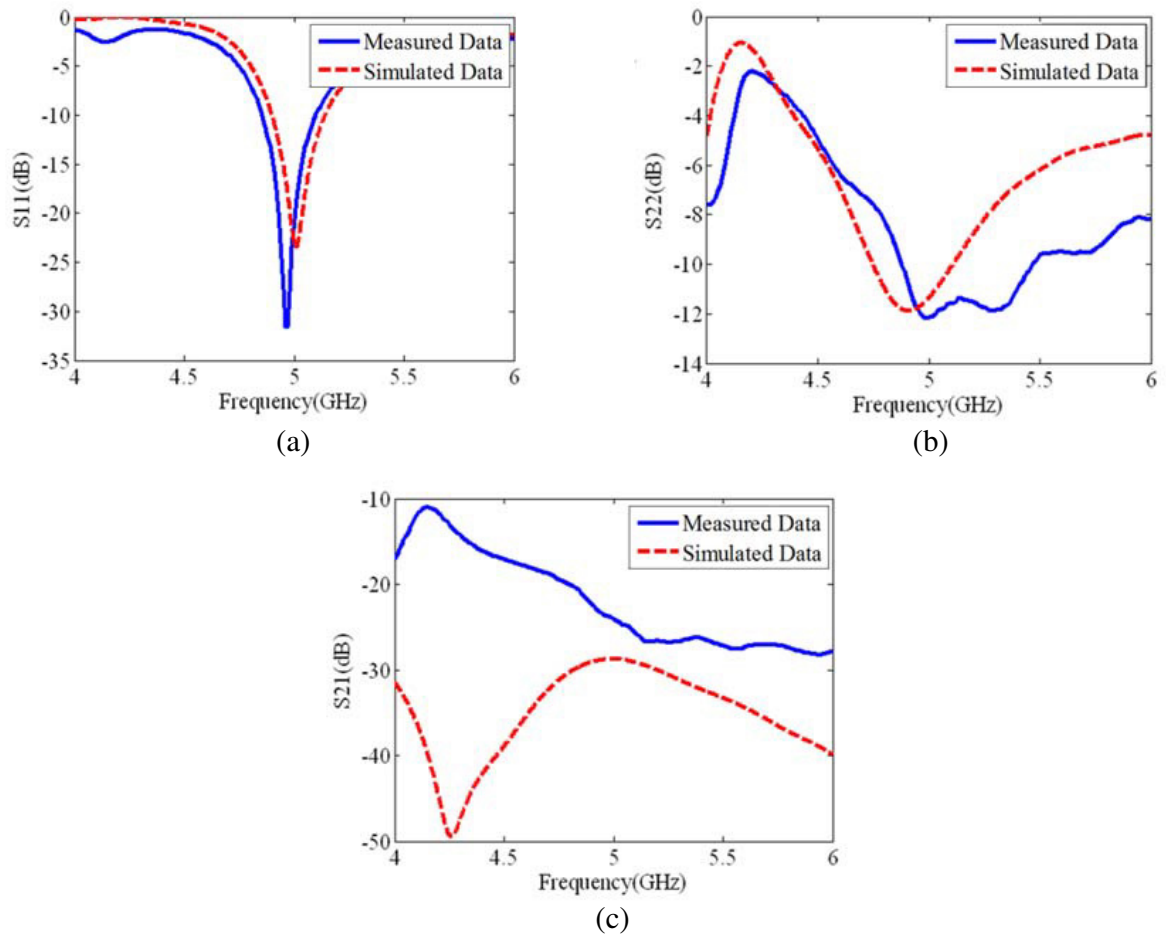


Figure 10. Comparison of measured and simulated S -parameters. (a) Return loss of the wire loop. (b) Return loss of the slot loop. (c) Isolation.

Fig. 6, the measured result of the wire loop is almost the same as the simulated one. The cross polarization of the slot loop varies a certain amount, but it is still around -20 dB in a wide range on the main radiation direction. Differences between the measured and simulated results may be due to manufacturing inaccuracies such as the feed-point implementation and surface roughness of the metallic ground.

From the measured gain, effective aperture can be calculated using $D = 4\pi A_e / \lambda^2$. Afterwards,

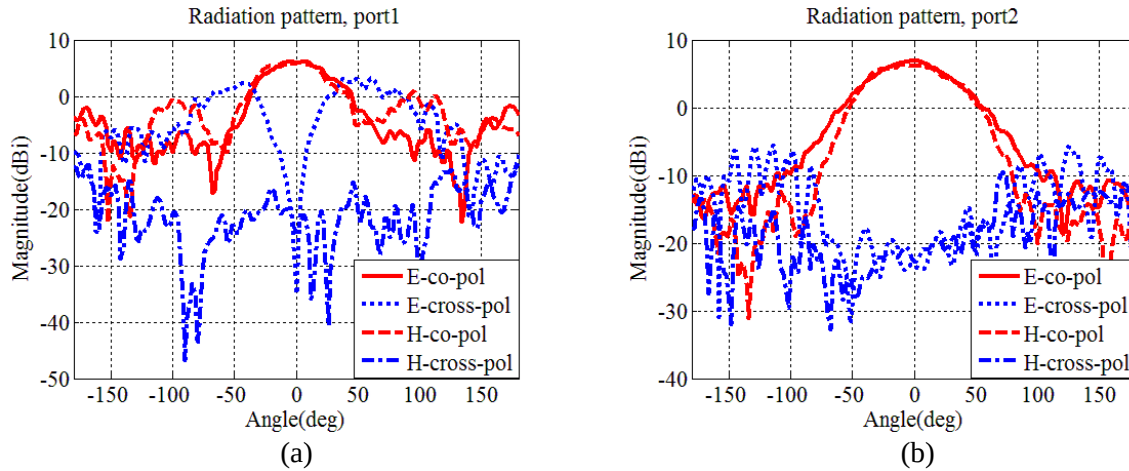


Figure 11. Measured radiation pattern. (a) Radiation pattern of the wire loop antenna. (b) Radiation pattern of the slot loop antenna.

the aperture utilization factor (Aperture efficiency) is estimated using the formula $\varepsilon_{ap} = A_e/S$ (effective aperture divided by the physical aperture (ground area)). The aperture utilization factors of the two ports are about 57% and 78% respectively, which are reasonable.

4. CONCLUSION

This paper proposes a novel design of dual-polarized antenna. Two antennas with complementary structures instead of the same structure with orthogonal inputs are employed. The actual measured data are consistent with the simulated. This proposed method is also applicable to designing other types of dual-polarized antennas, as long as the two involved antennas have complementary structures. In addition, they are slim enough, and the radiations of the two are mostly isolated from each other, which will decrease coupling.

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