High-Isolation Dual-Polarized Microstrip Antenna via Substrate Integrated Waveguide Technology

Sijia LI[1], *Xiangyu CAO*[1], *Jun GAO*[1], *Pengcheng GAO*[2]

[1] Information and Navigation College, Air Force Engineering University, No.1 Fenghao Street, 710077 Xi'an, China
[2] National Key Lab. of Antenna and Microwave Technology, Xidian University, No.2 Taibai Road 710071, Xi'an, China

lsj051@126.com, xiangyucaokdy@163.com, gjgj9694@163.com, 634672961@qq.com

Abstract. *A dual-polarized microstrip antenna with high-isolation is proposed based on the substrate-integrated waveguide (SIW) technology in this paper. According to the SIW technology, the metalized holes (MHs) are inserted into a substrate of the proposed antenna and the electric fields of the feeding parts are enclosed, so the isolation of the antenna is enhanced. The bandwidth is improved due to the MHs in the four sides of the antenna. A prototype of the proposed antenna has been fabricated and measured. Experimental results indicate that the antenna obtains the isolation more than 40 dB and achieves the impedance bandwidths of 21.9 % and 23.8 % (11.8–14.6 GHz and 11.65–14.8 GHz for two ports) of the reflection coefficients less than -20 dB. The cross polarization with the main lobe remains less than -30 dB and the half-power beam width is about 70° for the proposed antenna. Meanwhile, the front-to-back ratio remains to be better than 20 dB. A good agreement between the measured and simulated results validates the proposed design.*

Keywords

Substrate-integrated waveguide, isolation, dual-polarized microstrip antenna, aperture coupled antenna.

1. Introduction

Nowadays, dual-polarized microstrip antennas have popular application in wireless mobile and satellite communication systems, synthetic aperture radars and radio frequency identification systems due to their salient features, such as lightweight, compact, and low profile configurations. The well-known aperture-coupled antenna first proposed and demonstrated by Pozar [1], has been developed into a variety of dual-polarization slot-coupled patch antennas reported in [2–5]. Many efforts have been made on the dual-polarization slot-coupled patch antennas to achieve sufficient bandwidth, low back radiation, low levels of cross-polarization, high efficiency, and high isolation [6–13]. However, the isolation of dual-polarized antennas needs to be more enhanced according to their applications.

In general, two popular techniques for achieving dual polarization using aperture-coupled patch antennas are: (i) crossed slots located at the center of the patch and (ii) two off-center orthogonal coupling slots. The first technique requires a relatively complicated feed arrangement or a multilayer construction to reduce the coupling between two feed lines. Further, several detailed studies on reducing the isolation are proposed in literatures [14–18]. A "T" slot and edge-slots loaded lower patch are presented to improve isolation in [14]. The antenna obtains a 7.8 % bandwidth at -10 dB reflection coefficient and the 30 dB isolation. Obviously, the structure is not advisable to design the broadband antenna. Then the application of air bridge in the dual-polarized antenna has reported in [15–17]. The isolations of these antennas are about than 34 dB, and bandwidth achieves 20 %. A dual-polarized microstrip patch antenna fed by quasi-cross-shaped slot with the ports isolation higher than 35 dB has been discussed in [18]. The profile increases due to the structure of U-shaped folded two feed lines and the antenna covers the band of 3.3–3.9 GHz with the reflection coefficient of -10 dB. It is obvious that the bandwidth of the dual-polarized antenna is not wide enough.

In this paper, a novel design of a high isolation, wideband dual-polarized microstrip antenna is presented, designed and fabricated based on the substrate-integrated waveguide (SIW) technology. The isolation for the antenna is enhanced because the electric fields of the feeding parts are enclosed by the metalized holes (MHs). The bandwidth is improved due to the MHs. Simulated and experimental results of the constructed prototype show that the high isolation of 40 dB can be obtained, and wide bandwidth and dual polarization are achieved for the proposed antenna theoretically and experimentally. This paper is organized as follows: Section 2 presents the design of the proposed antenna structure. The simulated and experimental results are provided and discussed in Section 3. Finally, brief conclusions are given in Section 4.

2. Design and Analysis

The proposed antenna is based on the conventional aperture coupled antenna. The first step is to design an aperture coupled antenna according to the microstrip theory [1–3]. Second step is to insert the MHs into the substrates based on the SIW technology. The last step is the parameters optimization to enhance the isolation. According to the guideline, a high-isolation dual-polarized antenna is proposed. As shown in Fig. 1, two “H” shaped slots are placed under the square radiating patch to excite two orthogonal modes.

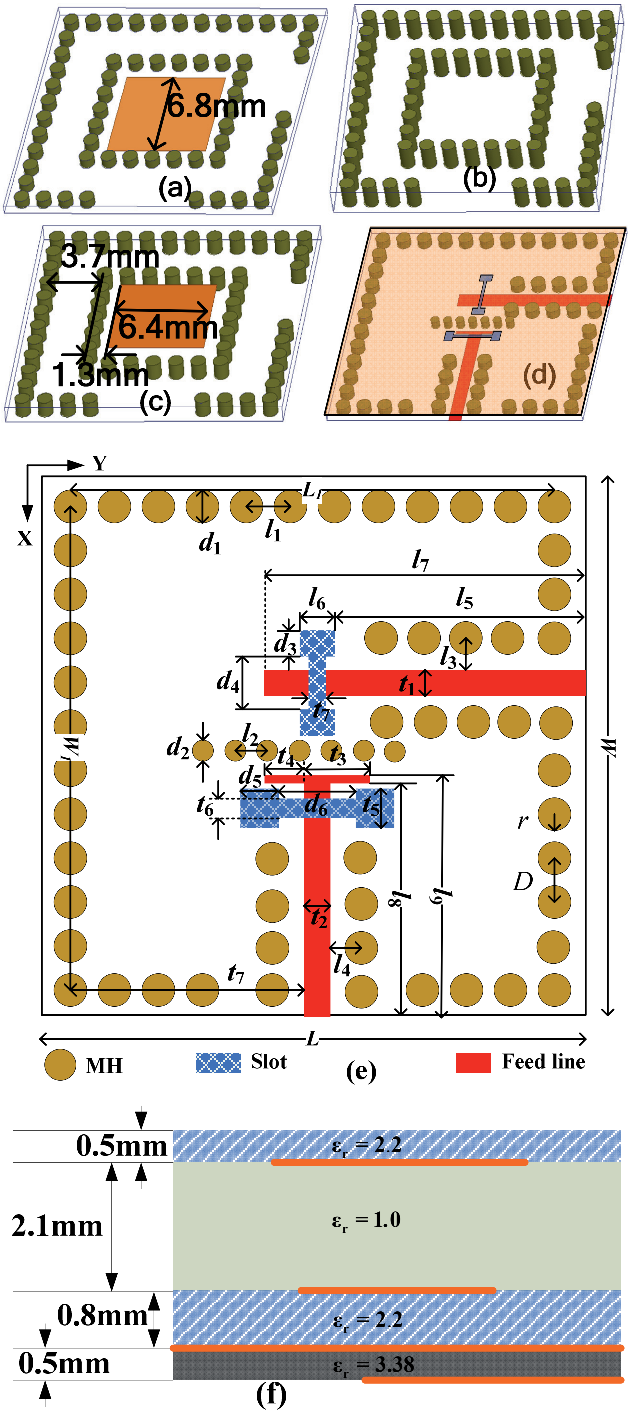


Fig. 1. Geometry of the proposed antenna and the detailed design parameters. (a) Top layer. (b) Second layer. (c) Third layer. (d) Bottom layer. (e) Perspective view for bottom layer. (f) Side view of the antenna without MHs.

One of the feed lines is left open and the other is terminated by a “T” junction. The proposed antenna radiates 0° polarized waves when Port I is excited and Port II is connected to a match load. Similarly when Port II excites, Port I is connected to a match load, it is 90° polarized. The performance is simulated by Ansoft HFSS 12.0, and its detailed optimum dimensions are depicted in Fig. 1. The metal portion of the antenna is modeled as lossy copper with a conductivity of 5.8×10^7 S/m.

Fig. 1 and Tab. 1 give the configuration of the proposed dual-linear polarized coupled antenna with optimized parameters. On one side of an RT/duroid 4003C substrate (the thickness is 0.5 mm and permittivity is 3.38), the feed lines are printed. On the other side it is a ground plane embedded with a coupling aperture. Lots of MHs with the diameter of d_2 between the two feed slots and of d_1 in the four substrates are inserted separately into the substrate to avoid the strong coupling and the leak of electromagnetic wave. The square radiating patch is printed on a 0.8-mm-thick Taconic TLY substrate with permittivity of 2.2. Above the Taconic TLY substrate, it is the substrate with thickness of 2.1 mm and permittivity of 1.0. In fabrication, it is the foam material and $\varepsilon_r = 1.04$. The holes are fabricated by printed circuit board techniques and the metallic columns with a radius of 0.5 mm are used to instead of the MHs. The top square patch is printed on the bottom side of a top Taconic TLY substrate with thickness of 0.5 mm. Outside MHs are inserted into the four substrates for reducing the leakage of the electromagnetic wave for the proposed antenna. The MH with radius (r, $r = 0.5\, d_1$) and distances (l_1) shown in Fig. 1(e) is embedding into the bottom substrate, and it can be described as follows.

$$0.05\frac{c_0}{f_H} < D < 0.25\frac{c_0}{f_H} \,, \tag{1}$$

$$D/4 < r < D/2 \tag{2}$$

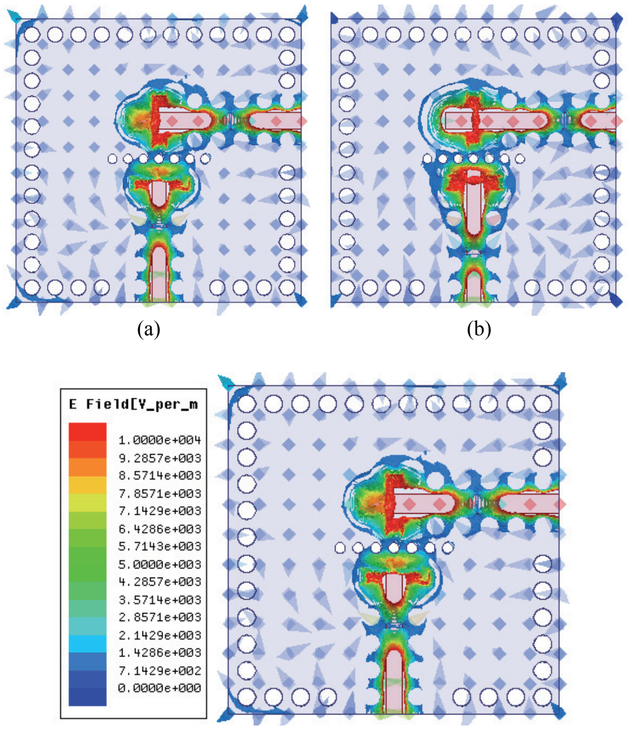
where c_0 is the speed of light and f_H is the low frequency of bandwidth for the proposed antenna. From (1) and (2), we can design 0.5 mm for the radius ($d_1/2 = 0.5$ mm) and 1.5 mm for the distance between the two MHs ($l_1 = 1.5$ mm). The radius of MHs between two slots in the RT/duroid 4003C substrate is 0.3 mm ($d_2/2 = 0.3$ mm) and the distance is 0.9 mm ($l_2 = 0.9$ mm).

To realize the effect of the MHs, Fig. 2 shows the electric field distributions of the feeding ports for the proposed antenna at 12 GHz, 13.5 GHz, and 14.5 GHz when the two ports are both feeding. It is obvious that the electric field flows along the edges of the feed lines and the slots. The different electric fields for two feeding parts are separated by the MHs, and the electric field is enclosed. So the isolation is enhanced due to the MHs. The equivalent impedances for the proposed antenna and the conventional antenna (it is same with the proposed antenna without MHs) are given in Fig. 3. The capacitive character for the proposed antenna is improved and the imaginary part of the equivalent impedance is decreased through embedding the

MHs into the four sides of the proposed antenna. So the impedance bandwidth for this antenna is improved due to the MHs compared with the conventional antenna.

l_1	1.5	t_1	1.1	W_1	16.5
l_2	0.9	t_2	0.9	L_1	16.5
l_3	0.95	t_3	1.85	d_1	1
l_4	0.95	t_4	0.85	d_2	0.6
l_5	8.8	t_5	0.9	d_3	0.6
l_6	0.9	t_6	0.2	d_4	2.7
l_7	11.1	t_7	0.2	d_5	0.6
l_8	8.6	W	18.5	d_6	2.8
l_9	8.8	L	18.5	d_7	7.95

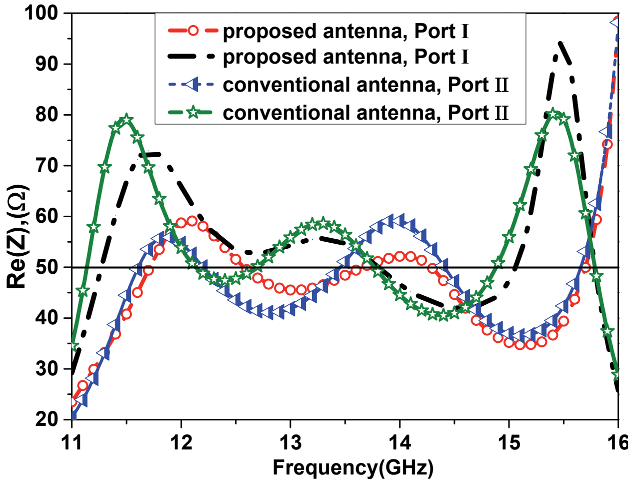
Tab. 1. Parameters of the proposed antenna (unit: mm).



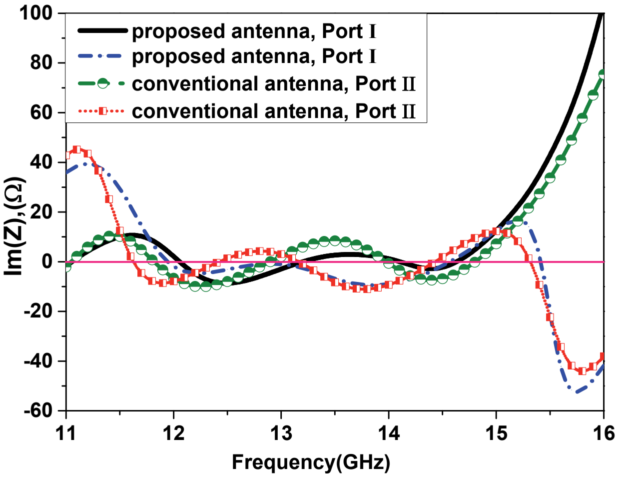
(a) (b)

(c)

Fig. 2. The electric field distributions of the proposed antenna at (a) 12 GHz, (b) 13.5 GHz, and (c) 14.5 GHz when the two input ports are all feeding.



(a)

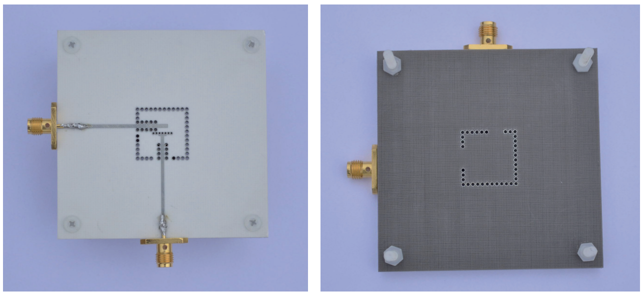


(b)

Fig. 3. The comparison of equivalent impedance between the proposed antenna and conventional antenna. (a) Real parts of equivalent impedance. (b) Imaginary parts of equivalent impedance.

3. Fabrication and Measurement

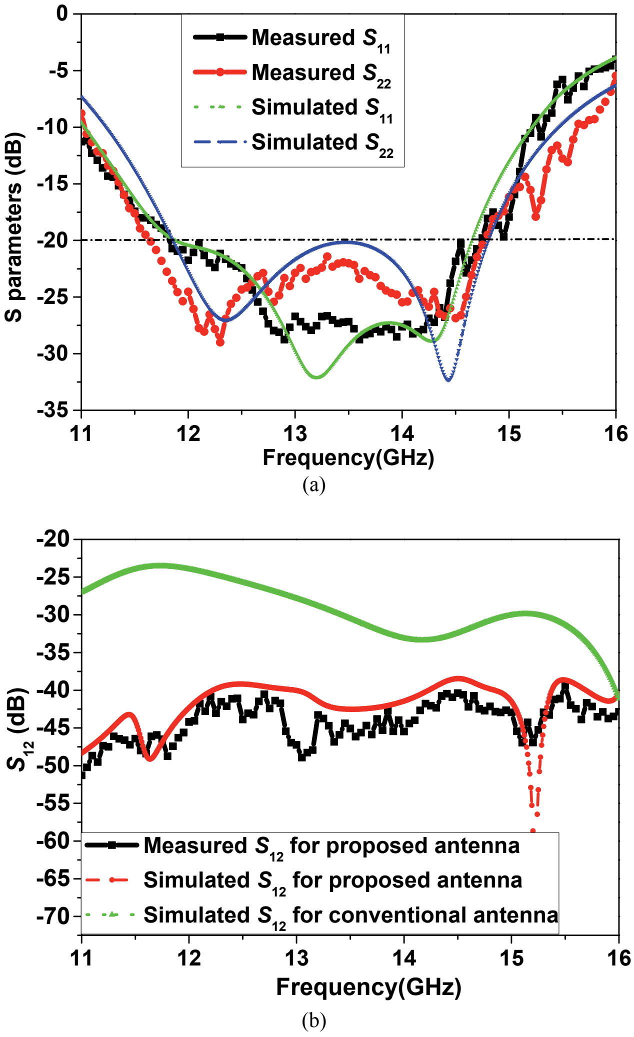
To verify the simulation results, a prototype of the proposed dual-polarized antenna via MHs is illustrated in Fig. 4 and has been experimentally studied. The mounting for the antenna layers in Fig. 4 is necessary to avoid the air gaps between the antenna layers. The mountings hardly affect the antenna performance because the size of prototype is 80 mm × 80 mm. The impedance bandwidth will reduce when there are air gaps between the antenna layers in the antenna prototype.



(a) (b)

Fig. 4. Prototype of the proposed antenna. (a) Front view. (b) Bottom view.

The measured and simulated S-parameters results of the two ports are depicted in Fig. 5(a) and 5(b). From Fig. 5(a), the simulated impedance bandwidth is 22.1 % with $S_{11} < -20$ dB from 11.75 to 14.7 GHz for Port I and 22.5 % with $S_{22} < -20$ dB from 11.82 to 14.81 GHz for Port II. The experimental results show that Port I achieves 21.9 % (11.8–14.6 GHz) and Port II obtains 23.8 % (11.65–14.8 GHz) impedance bandwidth of reflection coefficients less than -20 dB. The S_{12} of the conventional antenna is above -23 dB on the whole bandwidth from Fig. 5(b). When the MHs are loaded, the S_{12} can be improved under -38 dB in simulation. Measured S_{12} is lower than -40 dB over the frequency range. It is observed from the plots that the measurements have good agreement with the simulations.



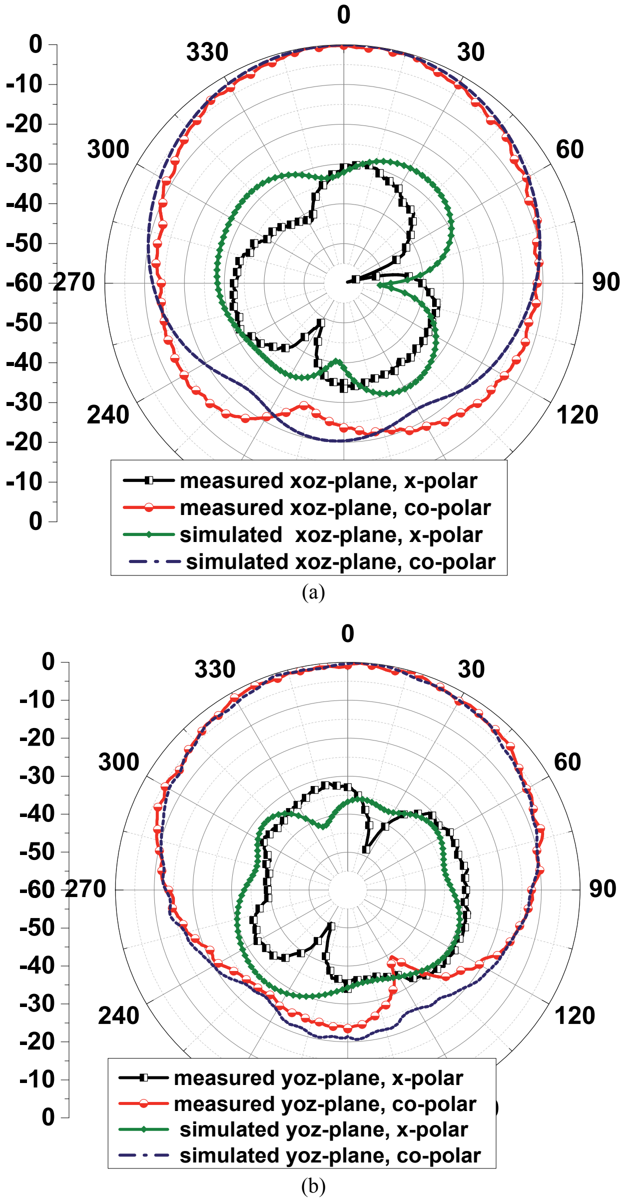
(a)

(b)

Fig. 5. Measured and simulated S parameters for the proposed antenna. (a) S_{11} and S_{22} results. (b) Measured and simulated S_{12} for the proposed antenna and the simulated S_{12} for the conventional antenna.

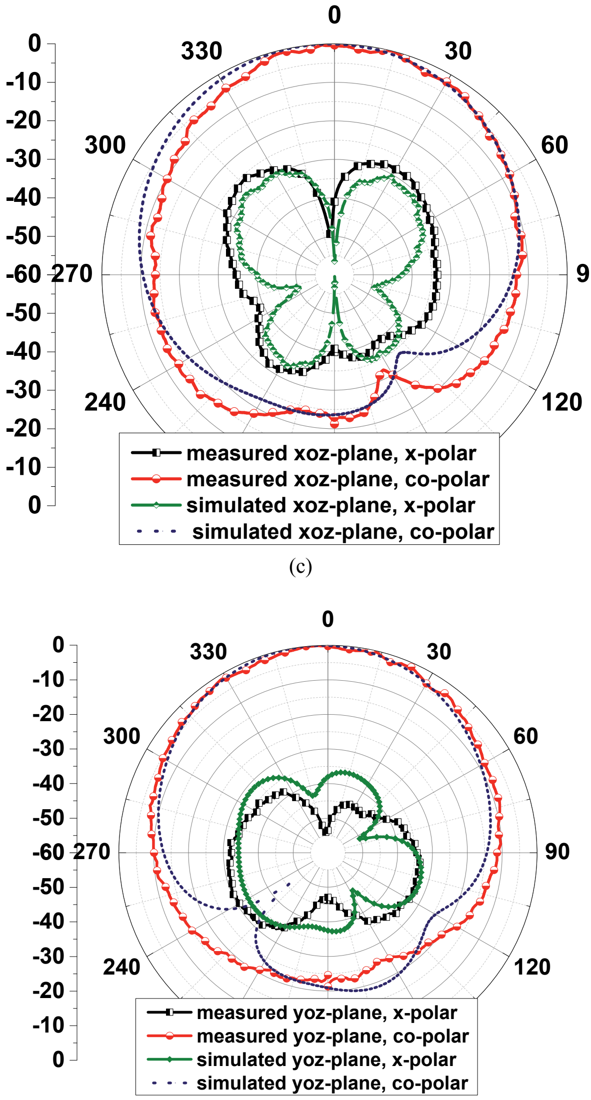
Fig. 6 presents the simulated and experimental radiation patterns for xoz-plane and yoz-plane at center frequency (13.5 GHz) of Port I and Port II for the proposed antenna. From Fig. 6, we observe that the cross-polarization with the main lobe remains less than -30 dB while the front-to-back ratio (FBR) remains to be better than 20 dB, and the half-power beam width is 72° both in xoz-plane and yoz-plane for Port I. Correspondingly, it is shown that the cross-polarization components are all -36 dB down from the copolarization components on boresight within 3-dB beamwidth of 70° and FBR of 22 dB in xoz-plane and yoz-plane for Port II at the same frequency. In conclusion, experimental results indicate that the isolation is more than 40 dB and the impedance bandwidth is above 21 % of reflection coefficients less than -20 dB in frequency range. The measured results are in good agreement with the corresponding simulations. The proposed antenna achieves the low cross-polarization, low back radiation characteristics, wide bandwidth and high isolation.

The gain of the proposed antenna is measured and simulated. The experimental and simulated results are shown in Fig. 7. The simulated gain varies between 8.2 and 8.8 dBi with 0.6 dB variation for Port I and Port II. Within the operating frequency range, the experimental results show that the gain of the proposed antenna is above 7.9 dBi and with 0.7 dB variation for two ports. The gain differences of the dual polarizations are due to the different reflection coefficient for two ports and the difference between measured and simulated results mainly comes from the measurement tolerance and fabrication. In addition, the foams ($\varepsilon_r = 1.04$) were not considered in simulation and may also influence the gain for the proposed dual-polarized antenna.



(a)

(b)



(c)

(d)

Fig. 6. Simulated and measured radiation patterns for xoz-plane and yoz-plane at the frequency of 13.5 GHz:
(a) xoz-plane radiation patterns for Port I.
(b) yoz-plane radiation patterns for Port I.
(c) xoz-plane radiation patterns for Port II.
(d) yoz-plane radiation patterns for Port II.

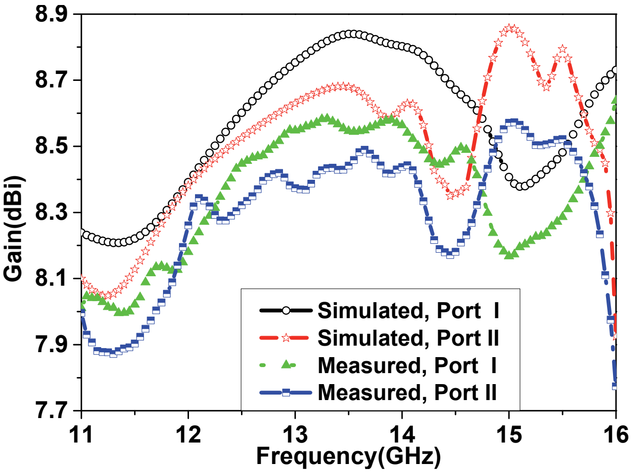


Fig. 7. Simulated and measured gain of the proposed antenna.

For illustrating the antenna performances further, comparisons between the proposed antenna and the previous reported dual-linear polarized microstrip antennas in term of operating frequency range, antenna gain, projection area, height and FBR are given in Tab. 2. According to Tab. 2, the proposed antenna achieves the impedance bandwidth of 21.9 % and 23.8 % at the reflection coefficients less than -20 dB. It is better than that of the antennas in [3], [18]. The antenna obtains 43 % impedance bandwidth in [17], but the standard is reflection coefficients less than -10 dB. The bandwidth is less 10 % in [17] when it is with the reflection coefficients of -20 dB. The isolations of the proposed antenna and antennas in [3] and [18] are higher than 40 dB. However, the complicated feed network is employed for antenna in [18]. The broadside gain variations of antennas in [3], [17] and [18] are about 7.4, 8.2, 9.3 and 9.5 dBi, respectively. The antenna in [17] has the FBR of 19 dB, main cross-polarization lobe of -40 dB and half-power beam width of 60°, but it consists of a large rectangular metal ground (1.18λ × 1.18λ). In summary, the proposed antenna achieves excellent parameter such as high isolation, broad bandwidth, high gain, low main cross-polarization lobe and wide half-power beam width.

Due to its good characteristics, the proposed dual-polarized high-isolation microstrip antenna is potentially suitable to be used with differential microwave and radio frequency circuits for various wireless communication applications. It is needed to point out that the complexity of the proposed antenna is obviously increased due to the metalized holes compared to the traditional dual-polarized antennas. Especially the radius of the metalized hole and its distance are mainly affected the isolation and impedance bandwidth of the dual-polarized antenna.

Antennas	Proposed	Ref [3]	Ref [17]	Ref [18]
Operating Range (GHz, -20dB)	21.9%; 23.8%	14.2%; 14.5%	45%; 43%(-10dB)	16.2%; 16.9%(-10dB)
Isolation (dB)	40	40	38	50
Broadside Gain (dBi)	7.9-8.6	7.4	8.5-10	9-10
FBR	20	13	19	10
Main cross-polarization lobe (dB)	-30	-25	-40	-17
Half-power beam width	70°	45°	60°	45°
Height (λ)	0.18	0.13	0.21	0.11

Tab. 2. Performance comparisons between the proposed and referenced antennas.

4. Conclusion

In this paper, a Ku band dual-linear polarized and aperture coupled antenna with high isolation is proposed based on the substrate-integrated waveguide technology. The metalized holes have been utilized in the substrate of the antenna to enhance the isolation. The prototype of the proposed antenna has been fabricated and measured. Good agreement is observed between the simulation and the measurement. Experimental results indicate that the isolation is more than 40 dB and the bandwidth is obtained 21.9 % for Port I and 23.8 % for Port II of reflection coefficients less than -20 dB. The gain of the antenna is above than 7.8 dBi. The antenna achieves a half-power beam width of 70° and the main cross-polarization lobe of -30 dB. Due to the merits of high isolation and broad bandwidth, the proposed dual-polarized antenna shows a potential use for the satellite communication.

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About Authors ...

Sijia LI was born in Xi’an, Shaanxi province, P.R. China in 1987. He received B. Eng. degree from Guangxi University, Nanning, China, in June, 2009 and M. Eng. degree from the Telecommunication Engineering Institute, Air Force Engineering University of CPLA, Xi’an China, in 2011. Currently, he is working toward Ph.D degree at the Information and Navigation College, Air Force Engineering University. His research activity has been focused in the dual-polarization antennas, tilted beam antennas, perfect metamaterial absorber design and its application for RCS reduction of antennas. He has authored and co-authored more than 40 technical journal articles and international conference papers. He received the excellent Master’s dissertation in 2012. He is awarded the 2012 and 2013 Best Student Paper Prize (First Prize) of the National Graduate Mathematical Modeling Contest in Shanghai in December 2012 and in Changsha in December 2013. He was a recipient of the Best Paper Award at the Forth National Doctor Forum Symposium on Information Science of China in Guangzhou in October 2013. He is awarded the excellent student in the 2014 national summer school of the Microwave Material and Components. Now, he is a reviewer of the Applied Physics Letter, Journal of Applied Physics, IEEE Transactions on Microwave Theory and Techniques, IEEE Transactions on Antennas & Propagation, Microelectronics Journal, and Journal of Electromagnetic Waves and Applications.

Xiangyu CAO received the B.Sc and M.A.Sc degrees from the Air Force Missile Institute in 1986 and 1989, respectively. She joined the Air Force Missile Inst. in 1989 as an assistant teacher. She became an associate professor in 1996. She received Ph.D. degree in the Missile Inst. of Air Force Engineering University in 1999. From 1999 to 2002, she was engaged in postdoctoral research in Xidian University, China. She was a Senior Research Associate in the Department of Electronic Engineering, City University of Hong Kong from June 2002 to Dec 2003. She is currently a professor of School of Information and Navigation, Air Force Engineering University of CPLA. She has authored and coauthored more than 200 technical journal articles and conference papers, and holds one China soft patent. Her research interests include computational electromagnetic, smart antennas, electromagnetic metamaterial and their antenna applications, and electromagnetic compatibility.

Jun GAO received the B.Sc and M.A.Sc degrees from the Air Force Missile Inst. in 1984 and 1987, respectively. He joined the Air Force Missile Institute in 1987 as an assistant teacher. He became an associate professor in 2000. He is currently a professor of School of Information and Navigation, Air Force Engineering University of CPLA. He has authored and coauthored more than 60 technical journal articles and conference papers, and holds one China soft patent. His research interests include smart antennas, electromagnetic metamaterial and their antenna applications.

Pengcheng GAO received the B.S. degree from the National Key Lab. of Antenna and Microwave Technology, Xidian University, China, in 2011. Currently, he is working toward M. Eng. degree at the National Key Lab. of Antenna and Microwave Technology, Xidian University. His research interest is in the substrate integrated waveguide technology, electromagnetic metamaterial and their antenna applications.