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Single-Layer Single-Feed Wideband Omnidirectional Microstrip Antenna with Rotating Square Patches

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Abstract—A single-layer single-feed wideband omnidirectional microstrip antenna with rotating square patches is investigated in this paper. To obtain wide impedance band, the proximity-fed structure is introduced to the antenna to generate dual resonating modes. Two square patches with rotating angle of 90 degrees are used as the main radiator to improve the omnidirectional feature of the radiation pattern. For verifying the design, an antenna prototype with wide operation bandwidth is designed, simulated, fabricated, and measured. The results indicate that the impedance bandwidth ($|S_{11}| < -10\,\mathrm{dB}$) as high as 48.6% (3.02–4.96 GHz) is obtained. Meanwhile, the height of the antenna is only $0.11\lambda_0$ (λ_0 is the free space wavelength corresponding to the lowest frequency). Moreover, omnidirectional radiation pattern is obtained over the operation band. The advantages of wideband, low-profile and simple feed structure make the antenna a good candidate in modern communication systems.

1. INTRODUCTION

With the rapid development of electronic devices, many challenges of antenna technology are faced. More problems need to be considered in antenna design, such as broadband, low profile, and low cost. The planar antenna which has omnidirectional radiation pattern is widely used in wireless communication system. However, the conventional omnidirectional antennas do not have wide operation bands (< 4%) [1–4]. A wideband omnidirectional microstrip patch antenna, which can be attached to the bottom of an unmanned aerial vehicle easily, can be used in an unmanned aerial vehicle communication system.

Many methods have been used for enhancing the impedance bandwidth of an omnidirectional microstrip antenna, such as using the complex feeding structure, multi-layer substrate, and multi-mode resonant technology. In [5], a wideband horizontally polarized omnidirectional printed loop antenna is achieved by using a loop with periodical capacitive loading and a parallel stripline as an impedance transformer. In 2016, a new method called V-slot loaded is introduced to a circular patch antenna to extend the operation bandwidth [6]. However, the geometry symmetry of current distribution is destroyed. Thus, the omnidirectional feature of radiation pattern and the cross-polarization level are affected. A dual-polarized wideband antenna is obtained by using a low-profile monopole and a circular loop to enhance the bandwidth [7]. By using 45° parasitic metallic/dielectric parallelepiped elements and a simple feed structure, 18.04% impedance bandwidth is achieved [8]. In [9], a hybrid omnidirectional resonator (DR) antenna with wideband resonant modes is investigated. Moreover, the antenna in [9] can also obtain a stable radiation pattern in the whole operation band. An omnidirectional circularly polarized antenna is realized by introducing four tilted dipoles which wrap around a cylinder [10]. A novel planar inverted F-antenna has been conceived to obtain a wideband performance [11]. Using different modes, such as TM_{01} mode and TM_{02} mode, the bandwidth of the antenna can be enhanced significantly [12]. A new technology is reported in [13] which introduces shorting vias in a circular patch

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to enhance the impedance bandwidth of the omnidirectional antenna. A wideband omnidirectional antenna [14] has a simple structure which is composed of two-layer substrates, shorting pins, and single feed. A novel omnidirectional antenna, of which the bandwidth is enhanced 24.7%, is reported in [15]. In [16], a wideband omnidirectional patch antenna is designed by using offsetting slots and vertical strips.

In this letter, a novel wideband omnidirectional microstrip antenna is realized by using two rotating square patches and proximity-fed structure. The omnidirectional radiation pattern in xoy-plane is achieved by exciting TM_{01} modes in two square patches. The 48.6% (3.02–4.96 GHz) impedance bandwidth can be achieved by this method. The height of the antenna is $0.11\lambda_0$ (λ_0 is the free space wavelength corresponding the lowest frequency). To verify the validity of this antenna design, a prototype of the proposed antenna is fabricated and tested. With the help of simulation full wave software (HFSS), good agreements between simulated results and measured ones are reached. The antenna configuration, working principle, simulated and measured results are all shown and discussed in the following sections.

2. ANTENNA DESIGN AND ANALYSIS

Figure 1 shows the geometry of the proposed wideband omnidirectional microstrip patch antenna. The antenna is constructed on a single-layer patch, single feed and a metal ground. The thickness of substrate (Rogers5880) is 0.508 mm, and its relative dielectric constant is 2.2. The side length (a) of square patch is 62 mm. Two rotating square patches are used to combine a single-layer patch. The location of the feeding point is at the geometric centre of two rotating square patches, and a ring slot is added in the centre of the patch. The diameter of the ground is 140 mm. The air is filled between the patch and metal ground, and the distance (h) between them is 11 mm ($0.12\lambda_0$). The optimized results are achieved by using electromagnetic software HFSS. The optimized values of the dimensions of the patch antenna are given as follows: $a = 62$ mm, $r_1 = 3$ mm, $r_2 = 11.2$ mm, $h = 11$ mm, $R_g = 70$ mm. The key parameter (a) can be achieved by theoretical analysis. In order to achieve omnidirectional radiation

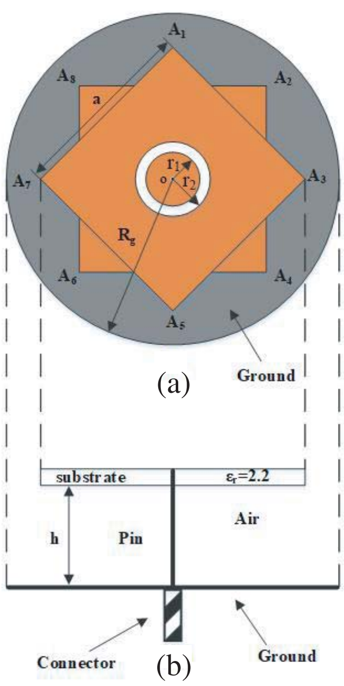

Figure 1. Geometry of the wideband omnidirectional microstrip patch antenna.

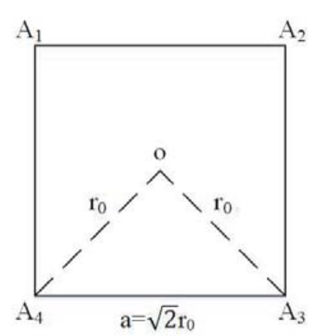

Figure 2. The mathematical derivation about the geometry length of a single rotating square patch.

pattern, the TM_{01} mode is excited at the assumed lowest frequency (3.05 GHz). The rotating square patches can be equivalent to a quasi-circular patch. The physical length of the rotating square patches can be achieved by Equation (1). The mathematical expression (2) is the solution of Equation (1). The theoretical calculating value of length of square patches (a) is 53.1 mm. It is pretty matched with the simulated result. According to the above mathematical derivation, the length of the square patches can be confirmed. Fig. 2 shows the geometrical analysis of a single rotating square patch.

$$\begin{cases} f_{mn} = \dfrac{k_{mn}c}{2\pi r_0\sqrt{\varepsilon_r}} \Rightarrow f_{01} = \dfrac{k_{01}c}{2\pi r_0\sqrt{\varepsilon_r}} \\ a = \sqrt{2}r_0 \end{cases} \tag{1}$$

$$a = \frac{\sqrt{2}k_{01}c}{2\pi f_{01}\sqrt{\varepsilon_r}} \tag{2}$$

where $\varepsilon_r = 1$ and $k_{01} = 2.40$ is the first root of the n order Bessel function.

To improve the omnidirectional feature of radiation pattern, a rotating structure is used in the antenna design. It can be observed that the geometric symmetry is improved. Thus, good omnidirectional radiation is achieved by using this method. The rotating square patches can be equivalent to a circular patch. The diagonal length of the square patch can be equivalent to the diameter of the circular patch. The radiation patterns are achieved by exciting TM_{01} modes in two square patches. The geometry decomposition of the patch is shown in Fig. 3. The current distributions of the antenna operating at 3.4 GHz, 3.9 GHz, and 4.4 GHz are shown in Fig. 4. It can be observed that the current distributions have good geometric symmetry. Thus, good omnidirectional radiation pattern and low cross-polarization level can be achieved by using this method. Thereafter, a proximity-fed structure is introduced in the centre of the rotating square patches to improve the impedance matching [17, 18].

Next, the important parameters (a, r_1, and r_2) of the proposed antenna are discussed. The relationship between the lengths of square patch (a) and the resonant points is shown in Fig. 5. It

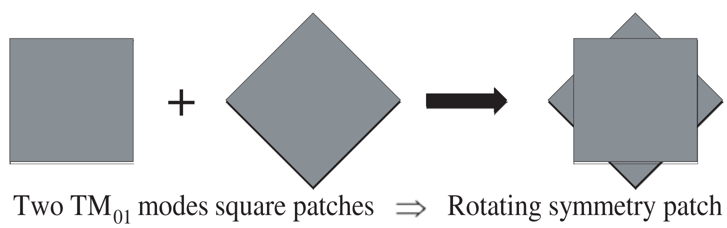

Figure 3. Geometry decomposition of the rotating square patches.

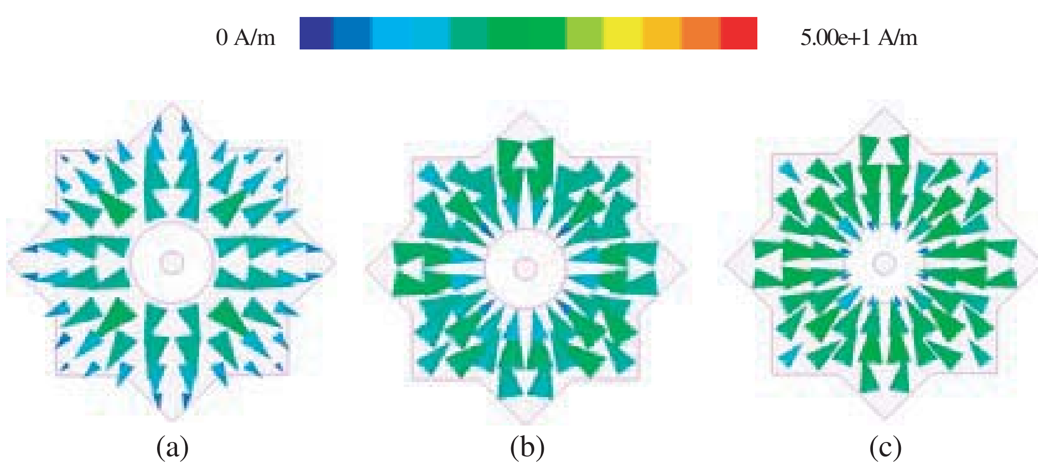

Figure 4. The current distribution of the proposed antenna: (a) 3.40 GHz, (b) 3.90 GHz and 4.40 GHz.

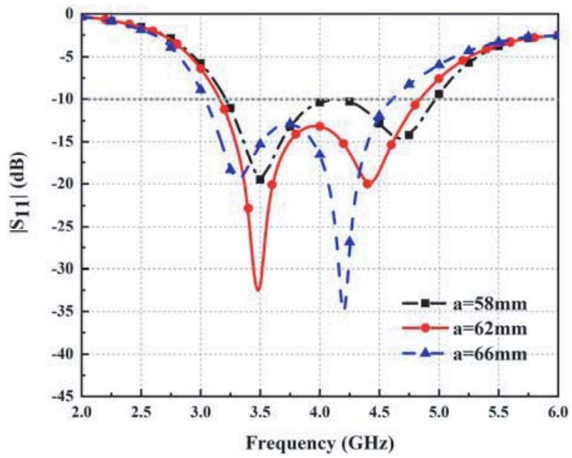

Figure 5. Simulated S_{11} curves at different values of a.

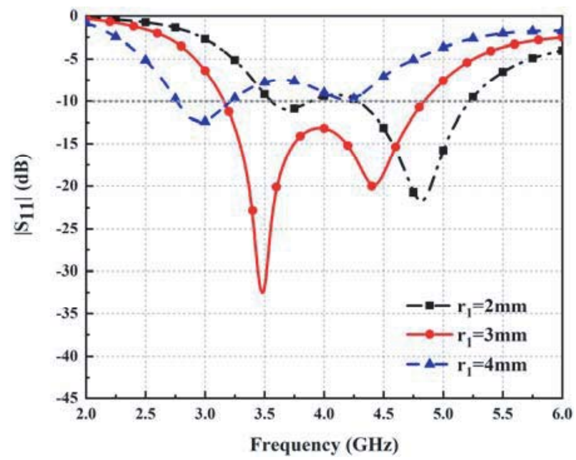

Figure 6. Simulated S_{11} curves at different values of r_1.

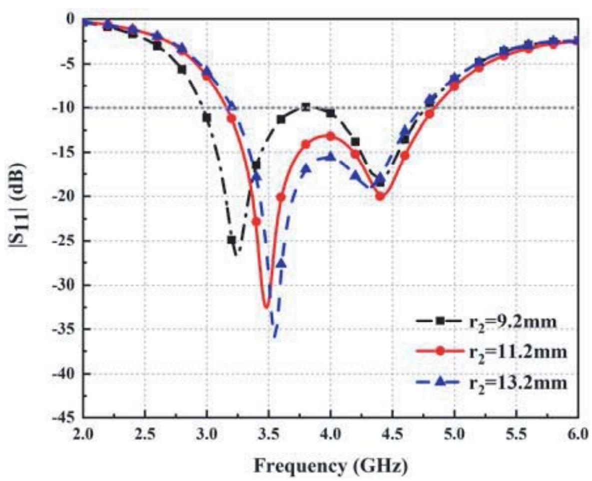

Figure 7. Simulated S_{11} curves at different values of r_2.

can be seen that the higher frequency resonant point at 4.4 GHz moves toward the higher frequency when parameter (a) is decreased and vice versa.

The relationship between the parameter r_1 and resonant points is shown in Fig. 6. It can be observed that the first and second resonant points move toward the lower frequency when parameter (r_1) is increased and vice versa. Meanwhile, we can observe that the input impedance of the antenna is affected by this parameter (r_1).

Figure 7 shows the relationship between the parameter r_2 and resonant points. It can be observed that lower frequency resonant point at 3.5 GHz moves toward the lower frequency when parameter (r_2) is decreased and vice versa.

3. RESULTS AND DISCUSSION

The simulated and measured results are obtained by using full wave electromagnetic simulation software HFSS and experiment. Fig. 8 gives the simulated and measured return losses of the proposed antenna. We can see that the S parameter curve has two resonant points characteristic. The measured result has a good impedance matching ($|S11| < -10$ dB) from 3.02 GHz to 4.96 GHz (relative bandwidth is about 48.6%). The measured and simulated gain curves are shown in Fig. 9. The measured peak gain is

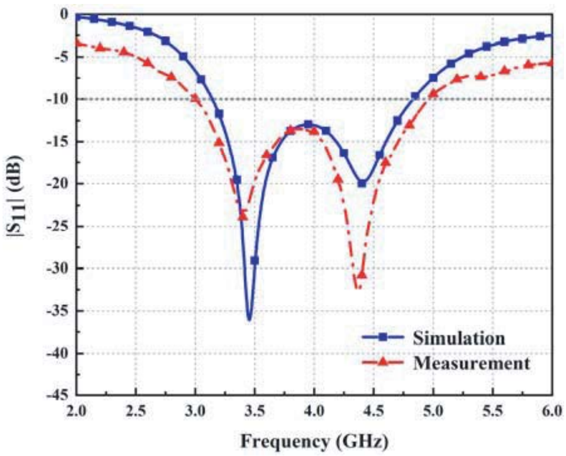

Figure 8. Simulated and measured return loss of the wideband omnidirectional microstrip patch antenna.

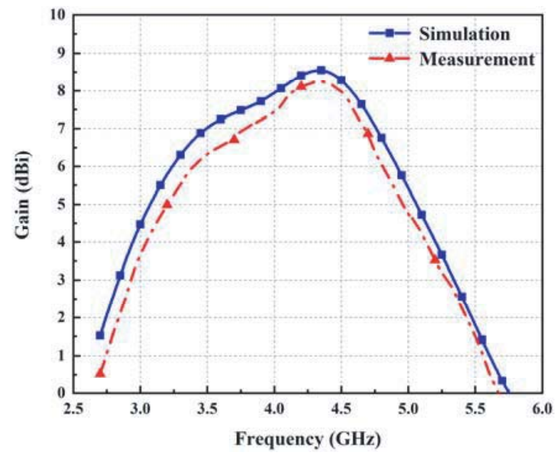

Figure 9. Simulated and measured gains of the wideband omnidirectional microstrip patch antenna.

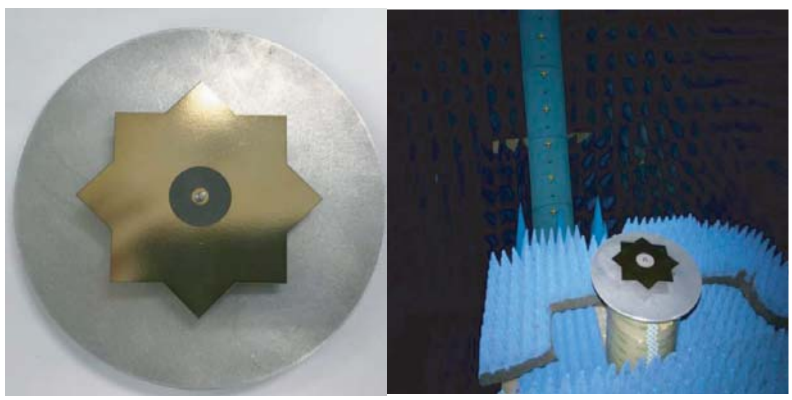

Figure 10. Photograph of the wideband omnidirectional microstrip patch antenna.

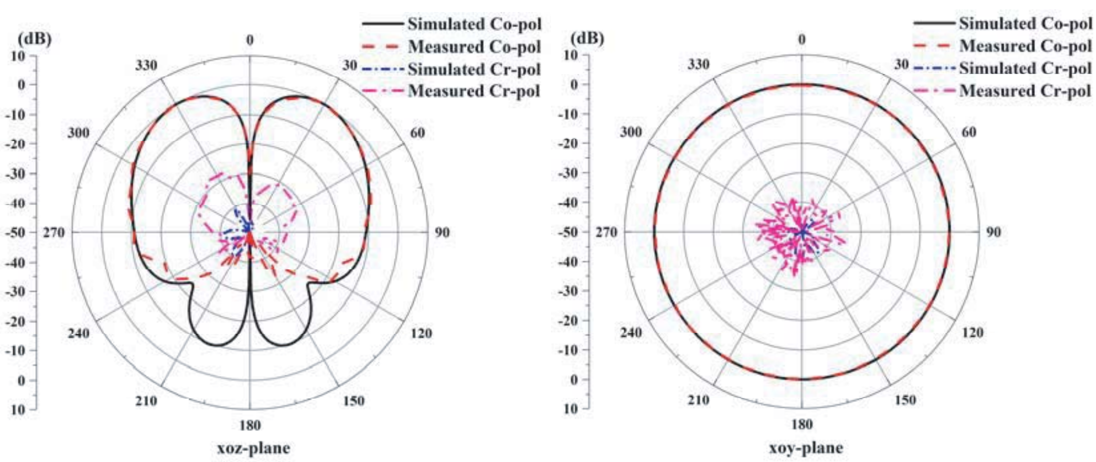

Figure 11. Measured and simulated normalized radiation patterns of the antenna at 3.40 GHz in xoz-plane and xoy-plane.

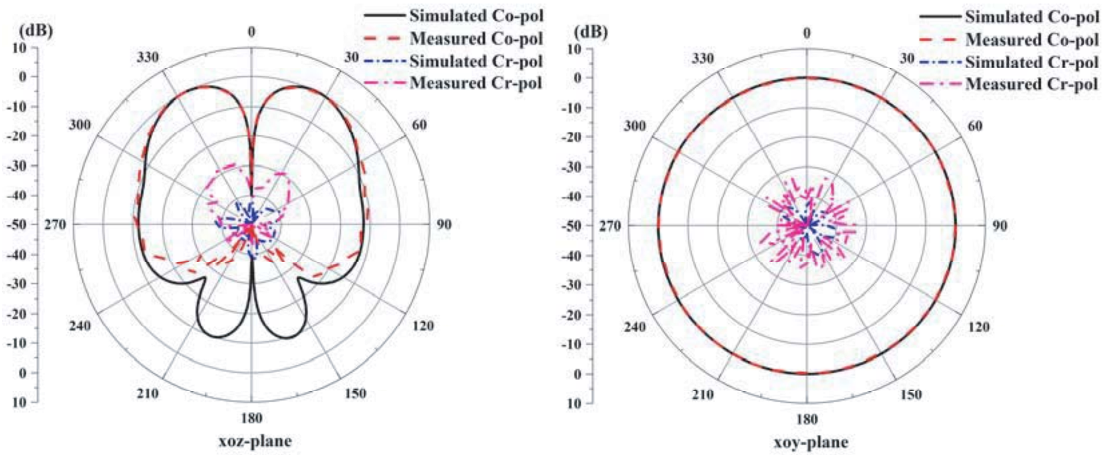

Figure 12. Measured and simulated normalized radiation patterns of the antenna at 3.80 GHz in *xoz*-plane and *xoy*-plane.

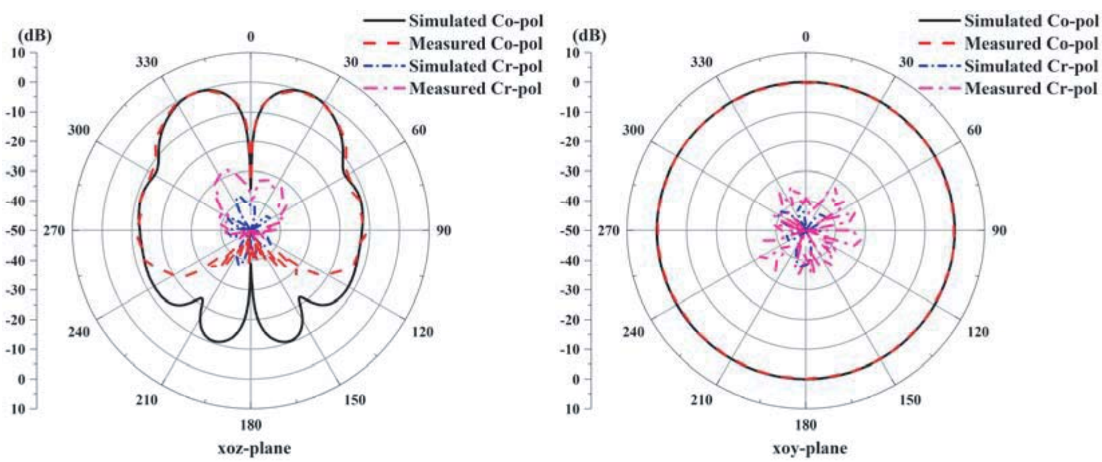

Figure 13. Measured and simulated normalized radiation patterns of the antenna at 4.20 GHz in *xoz*-plane and *xoy*-plane.

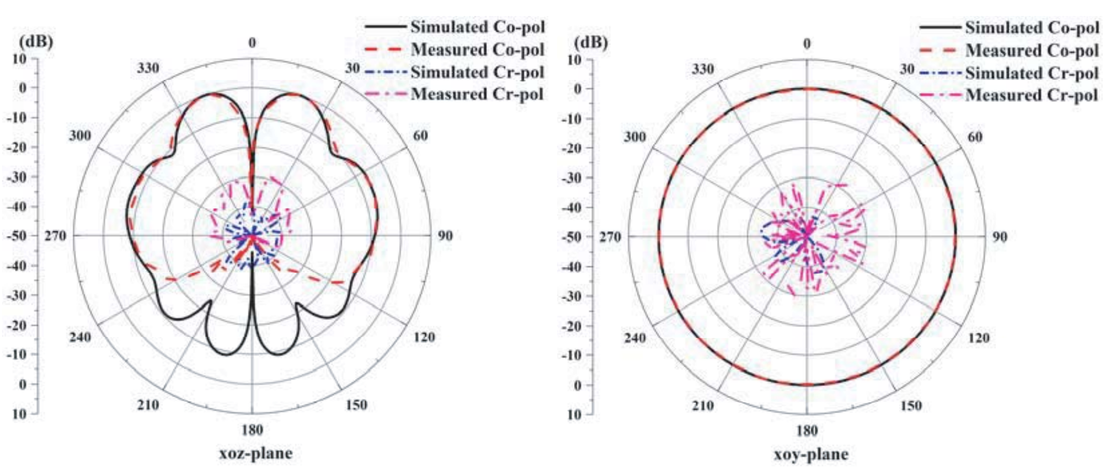

Figure 14. Measured and simulated normalized radiation patterns of the antenna at 4.80 GHz in *xoz*-plane and *xoy*-plane.

8.2 dBi which has a good agreement with the simulated result. The gain of the antenna is pretty stable in the whole operation band. Figs. 11–14 show the normalized radiation patterns at 3.4 GHz, 3.8 GHz, 4.2 GHz, and 4.8 GHz. The cross-polarization levels are below -20 dB in xoz-plane and xoy-plane. Besides, it can be found that the measured values at 120°–240° in E-plane (xoz-plane) pattern are less than simulated ones, especially the direction 180°, which may be caused by the lack of a probe at direction 180° in Satimo multi-probe near-filed measurement system due to the placement of antennas. Meanwhile, the front-back ratio of the patterns is larger than 10 dB. Photographs of fabrication and test for measuring the patterns in the anechoic chamber are shown in Fig. 10.

A comparison between our work and previous works is illustrated Table 1. The proposed single-layer single-feed wideband omnidirectional microstrip antenna provides the widest impedance bandwidth of 48.6% with a peak gain of 12.8 dBi. Hence, these antennas are suitable candidates for modern communication systems.

Table 1. Comparison of wideband omnidirectional antenna.

Ref.	Peak Gain (dBi)	profile	Impedance Bandwidth (dB, GHz, %)
[19]	6	$0.029\lambda_0$	10, 5.05–6.65, 27.4
[20]	5.7	$< 0.03\lambda_0$	10, -, 12.8
[5]	3.2	-	10, 0.217–0.297, 31.2
[13]	6	$0.024\lambda_0$	10, 2.06–2.46, 18
This Work	8.2	$0.11\lambda_0$	10, 3.02–4.96, 48.6

4. CONCLUSION

A novel single-layer single-feed wideband omnidirectional microstrip antenna is realized and analyzed in this article. The bandwidth of the proposed antenna is 48.6% (3.02–4.96 GHz). Double resonant points performance can be achieved in the operation band, which is combined into a wideband characteristic. The measured peak gain in the operation band is 8.2 dBi. Stable radiation patterns can be achieved in the whole operation band. Good agreements between theoretical analysis and experiment results are reached. Meanwhile, the design method of the antenna is given in this paper, which can be used to design antennas in other application bands.

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