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A BROADBAND CIRCULARLY POLARIZED ANTENNA FED BY HORIZONTAL L-SHAPED STRIP

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Abstract—A new design of broadband circularly polarized antenna is proposed. The antenna is composed of a square patch and a horizontal L-shaped stripline that feeds the patch at two orthogonal directions by two probes. The L-shaped feeding structure provides excitements of approximately equal amplitude and 90° phase difference and then good circularly polarized characteristics are obtained. Measured results show that the proposed antenna has 10-dB impedance bandwidth of 14.3% (2.27–2.62 GHz) and 3-dB axial-ratio bandwidth of 13.1% (2.3–2.62 GHz). Moreover, the measured gain is over 7 dBic within the effective band.

1. INTRODUCTION

Circularly polarized (CP) antennas are widely used in wireless communication applications such as navigational systems, radar tracking and radio frequency identification (RFID) readers [1–4] because they allow more flexible orientation between the transmitter and receiver antennas. Circular polarization can be realized by exciting two orthogonal modes of equal amplitude and 90° phase difference. For the single-fed antennas, CP waves are yielded when asymmetry is introduced to the geometry of the patch. Stacked structures are usually used to broaden the axial-ratio (AR) bandwidth and horizontally strip feed technique in [5, 6] is proposed to achieve good impedance matching. For the single-port and double-feed antennas, modifications are not required on the radiated patch and the approach of 90° hybrid or power splitter can obtain wide AR bandwidth but has the disadvantages of complicated structure and large antenna size [7].

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In some papers [8–11], L-shaped strip feeding structure acts merely as an impedance matching technique because the capacity introduced by L-shaped strip can compensate the long inductive probe when thick substrate is adopted. While the horizontal L-shaped coupling strip can also be used to feed the symmetric slot for CP operation in [12–14] and the AR bandwidths of 1.5%, 6% and 37.5% are obtained, respectively. Another ring slot feed by double-bent stripline achieves a 3-dB AR bandwidth of 10.5% [15]. The horizontal L-shaped strip feeding technique is proved to be an effective way to excite CP waves but the mentioned four antennas focus on slot antennas and are not likely to have a wide AR bandwidth and high gain. In paper [16], the feed network consists of a suspended microstrip feed line and four probes which are spatially positioned to obtain 90° phase difference between each feed point. The corners of the patch are truncated and a parasitic patch is placed above the main patch to further enhance the AR performance. Though a wide 3-dB bandwidth of 16.4% is achieved in this design, the feeding configuration is still complex compared with the L-shaped feeding structure.

In this paper, a single-port, double-fed broadband CP patch antenna operating around 2.45 GHz is proposed. The feeding structure comprises a horizontal L-shaped strip and two probes which connect the patch and strip. By properly selecting the positions of the two probes and optimizing the parameters of the L-shaped strip, good CP performance is achieved. The measured results show that the antenna presented in this literature can cover the band of 2.3–2.62 GHz with acceptable performance in terms of AR, impedance matching and gain. In addition, the antenna configuration is simple and easy to fabricate.

2. DESIGN OF ANTENNA

The geometry of the proposed broadband CP antenna is shown in Figure 1. A square patch with length of L_3 and L-shaped strip are printed on two square FR4 substrates with length of L_2 (thickness of 0.8 mm and relative permittivity of 4.4). The ground plane has a length of L_1. The heights of the two air layers between the two FR4 substrates and the ground are H_1 and H_2, respectively. The two arms of L-shaped strip are set along x-axis and y-axis with lengths of S_2 and S_1 and widths of W_2 and W_1, respectively. One end of the arm along x-axis is connected to the patch by a probe while the other end of the arm along y-axis is connected to a SMA port. Another probe is located on the arm along y-axis with a distance of a from the centre of the square patch. The radiuses of the inner conductor of the SMA port and the two probes are all 0.65 mm. The distances of the positions of

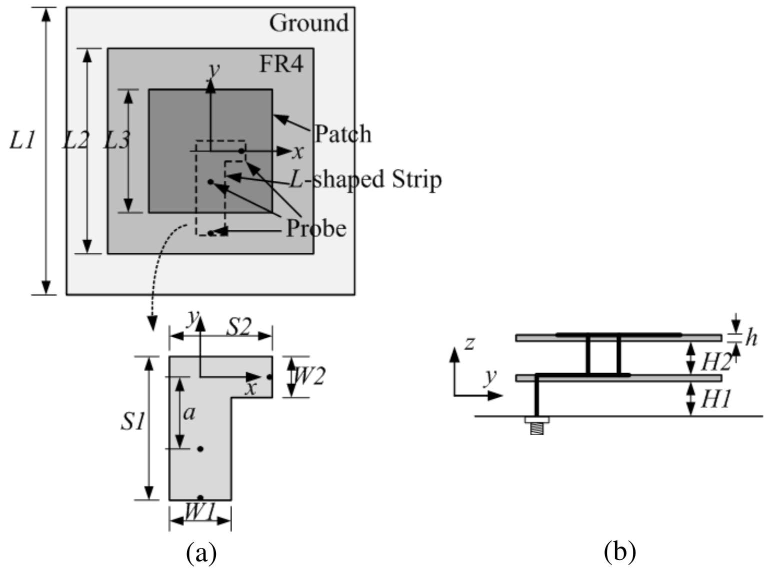


Figure 1. Geometry of the proposed antenna. (a) Top view. (b) Side view.

the two feeding probes from the centre of the patch are equal which means the parameter a should be set as S_2-$W_1/2$-0.65 mm. With aid of Ansoft high-frequency structure simulator (HFSS 13) software, the optimized parameters are $L_1 = 100$ mm, $L_2 = 70$ mm, $L_3 = 38$ mm, $H_1 = H_2 = 8$ mm, $h = 0.8$ mm, $S_1 = 34$ mm, $S_2 = 18.65$ mm, $W_1 = 10$ mm, $W_2 = 5$ mm and $a = 13$ mm.

From the simulated current distributions shown in Figure 2, it can be seen that two orthogonal currents with 90° phase difference are excited on the two arms of the L-shaped strip. As the current phase on the probe at x-axis has a 90° delay of that on the probe at y-axis, right hand circular polarization (RHCP) characteristics are then yielded. A simulated study about the current amplitude difference on the two feeding probe is carried out in Figure 3 using CST Microwave Studio software. The amplitudes of the current at the two feed points are approximately equal around 2.45 GHz and the minor difference in amplitude and the inaccurate quarter phase delay determine the AR bandwidth of the antenna.

The two probes we propose in this design enhance the coupling between the L-shaped strip and the radiating patch. Moreover, the inductance of the two long probes can also compensate the capacity between strip and patch. As a result, the impedance bandwidth is broadened to cover the wide AR bandwidth.

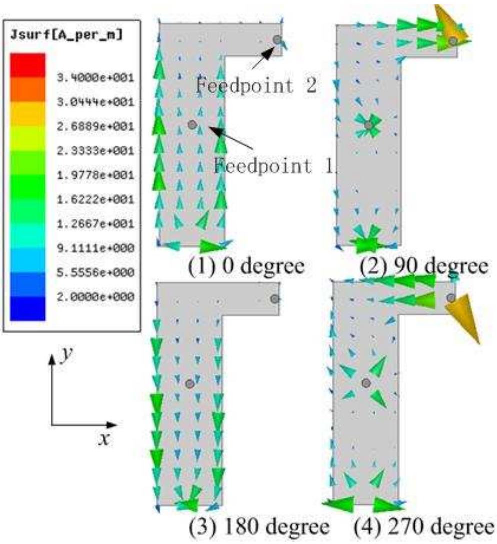


Figure 2. Current distributions on the L-shaped feeding strip simulated by HFSS software.

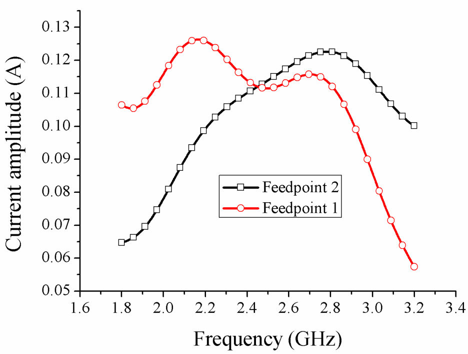


Figure 3. Current amplitudes at the two feeding point (Simulated results from current monitors in CST Microwave Studio software).

3. PARAMETRIC STUDIES

Parametric studies of the proposed antenna are presented to provide best matching and optimum performance. Since the effects of some parameters such as the size of the radiating patch, sizes of the probe, and size of the ground, have been well known, the parameters under study focus on the antenna height and size of the L-shaped strip.

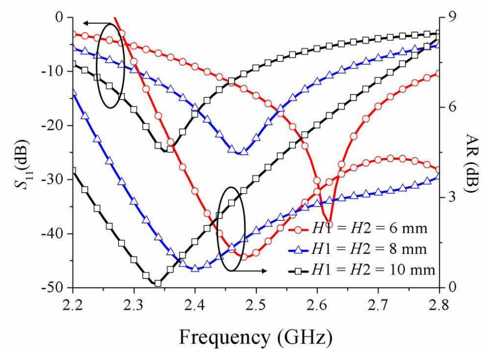


Figure 4. Effects of antenna height on antenna performance.

3.1. Antenna Height H_1 and H_2

It is confirmed in paper [8] that antenna AR bandwidth is broadened when thick and low permittivity substrates are used. In our design, air substrates of heights H_1 and H_2 are adopted and the effect of antenna heights is studied as shown in Figure 4. It can be seen from Figure 4 that thicker air layer brings wider AR bandwidth and lower AR minimum value. However, narrower impedance bandwidth is obtained for higher substrate because the capacity between the radiating patch, the feeding strip and the ground decreases and the probe inductance increases when the heights increase. The effective band ($S_{11} < -10\,\text{dB}$ and AR $< 3\,\text{dB}$) of antennas with different heights are tabulated in Table 1. An effective bandwidth of 13% is obtained when H_1 and H_2 are set as 8 mm. While antenna with larger H_1 and H_2 achieves 10.2% bandwidth for poorer impedance matching and improper feeding strip dimension. The 3-dB AR bandwidth in reference [8] is 14% for $0.2\lambda_0$ air substrate and 9.9% for $0.15\lambda_0$ antenna height in reference [6]. The height of our proposed antenna is just the same as that in [6] but gets wider AR bandwidth of 13% because the single-port and double-feed L-shaped structure provides more flexibility in AR-broadening design.

Table 1. Bandwidths of antennas with different heights.

$H_1 = H_2$	Effective band
6 mm	2.42–2.59 GHz (6.8%)
8 mm	2.31–2.63 GHz (13.0%)
10 mm	2.23–2.47 GHz (10.2%)

3.2. Long-arm of the Feeding Strip S_1 and W_1

The effect of altering the dimension of the long arm along y-axis is shown in Figure 5. The length S_1 is a critical parameter which decides the resonant frequency of the S_{11} curve. When S_1 is increased from 30 to 34 mm, the S_{11} and AR move to lower frequency and the AR has smaller value but narrower bandwidth. This can be explained that, for lower frequency corresponding to longer wavelength, longer strip is needed to generate 90° phase shifts. When S_1 is fixed to be 34 mm, W_1 is varied to obtain good impedance matching. The smaller strip width W_1, the greater capacitance value is introduced in impedance matching. Thus in this design, the S_{11} drops down when increasing width W_1.

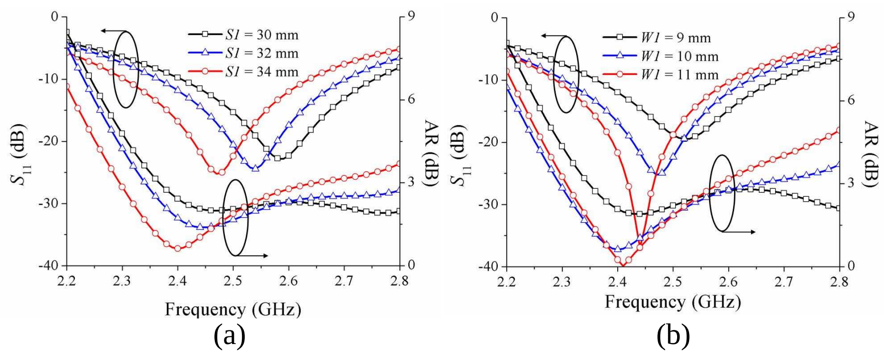


Figure 5. Effects of long-arm strip size on antenna performance. (a) Length S_1. (b) Width W_1.

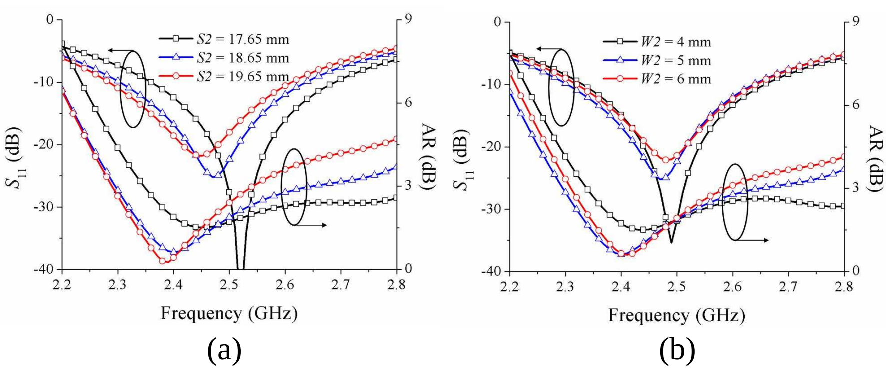
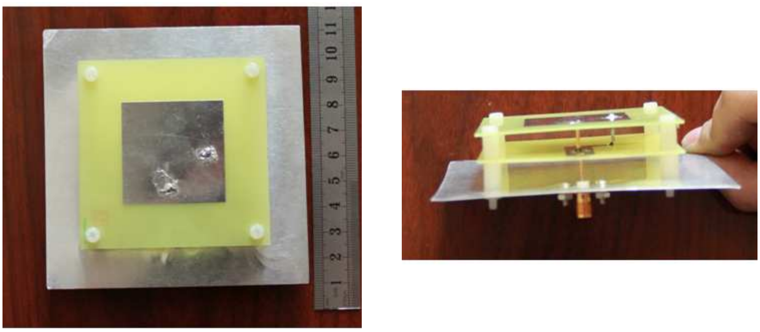


Figure 6. Effects of short-arm strip size on antenna performance. (a) Length S_2. (b) Width W_2.

3.3. Short-arm of the Feeding Strip S_2 and W_2

In Figure 6, the short-arm size is varied. Similar to S_1, S_2 also has a great influence on the impedance matching and AR bandwidth. The S_{11} and AR move to higher frequency for shorter strip arm. Compared to W_1, W_2 has a lesser effect on the antenna performance, as shown in Figure 6(b). Owing to smaller area of and less current distribution on the short arm, the minor impact of width W_2 on antenna performance is acceptable. Because the simple structure of the L-shaped strip cannot provide excitements of accurate equal amplitudes, obvious effects of the strip size on AR characteristic can be observed.



(a) (b)

Figure 7. Photograph of the antenna prototype. (a) Top view. (b) Side view.

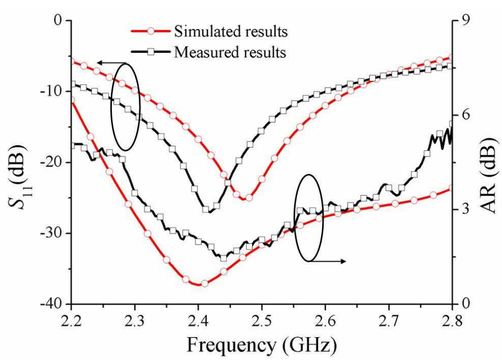


Figure 8. Measured and simulated S_{11} and axial ratio.

4. MEASURED RESULTS

To validate the design strategy, a prototype of the proposed antenna is fabricated and measured, as shown in Figure 7. The radiating patch and the L-shaped feeding strip are printed on two pieces of FR4 substrates and the substrates are supported by plastic posts which have little influence on antenna's performance. The measured and simulated S_{11} and AR results are shown in Figure 8. It can be seen that the impedance bandwidth ($S_{11} < -10$ dB) of 14.3% (2.27–2.62 GHz) and the 3-dB AR bandwidth of 13.1% (2.3–2.62 GHz) are obtained. The measured and simulated results have a good consistency except that the centre frequency of the measured S_{11} is lower than the simulated S_{11} which may due to the measurement loss and fabrication errors. The measured and simulated *xoz*-plane and *yoz*-plane radiation patterns

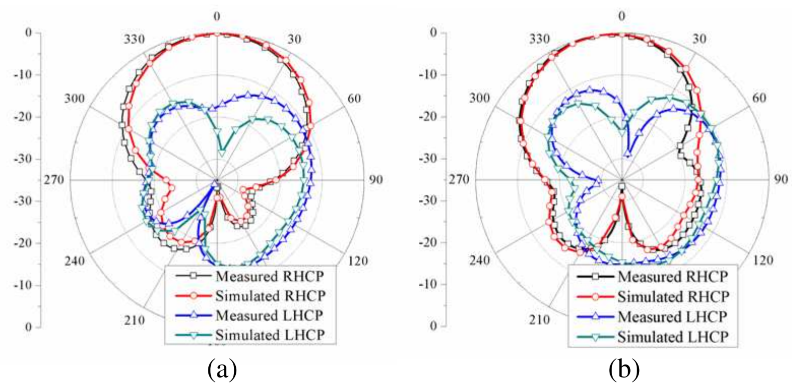


Figure 9. Measured and simulated radiation patterns at 2.45 GHz. (a) *xoz*-plane. (b) *yoz*-plane.

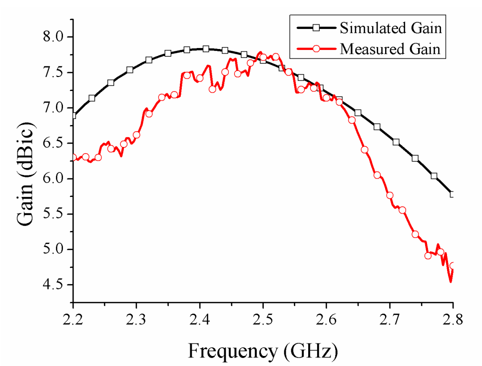


Figure 10. Gain of the proposed CP antenna.

at 2.45 GHz are plotted in Figure 9. The RHCP is stronger than the LHCP by over 18 dB in the $+z$ direction. The reason why the CP radiation patterns are not symmetric is that the L-shaped feeding strip is an asymmetric structure. The front-to-back ratio of the antenna is more than 15 dB. Figure 10 shows the simulated and measured gain of the antenna, which is over 7 dBic within the whole effective bandwidth.

5. CONCLUSION

A novel stacked patch antenna fed by an L-shaped strip and two probes for wide circular polarization has been presented. By means of the proposed feeding structure, good broadband circularly polarized characteristics are obtained. The experimental results indicate that the proposed antenna has an impedance bandwidth of 14.3% (2.27–2.62 GHz), a 3-dB AR bandwidth of 13.1% (2.3–2.62 GHz), and a gain level of greater than 7 dBic within the 3-dB AR bandwidth. Additionally, compared with the antenna in reference [16], the antenna has a simple feeding structure without extra parasitic patch and is easy to implement, which makes it a good candidate for wireless communication applications.

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