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A COMPACT STACKED CIRCULARLY POLARIZED ANNULAR-RING MICROSTRIP ANTENNA FOR GPS APPLICATIONS

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Abstract—A novel design of circularly polarized (CP) annular-ring microstrip antenna (ARMSA) working in TM_{11} mode is presented. The CP radiations of the proposed antenna are implemented by a 90° branch-line hybrid coupler placed at the inner part of the ARMSA. Since the ARMSA has narrow bandwidth and high-input impedance, a circular parasitic patch suspended above the ring is employed for not only improving the impedance matching and bandwidth, but enhancing the performances of axial ratio (AR). Due to the utilizing of parasitic patch and circular hybrid, the measured results are shown to attain a 10-dB return loss bandwidth of 31.2% (1300–1780 MHz) and a 3-dB AR bandwidth of 19.2% (1360–1650 MHz) respectively. The CP gain is 8.2 dB at 1.575 GHz. The proposed antenna is low profile and has a simple structure, therefore, it can be a good candidate for GPS portable terminal applications.

1. INTRODUCTION

Circularly polarized microstrip antennas are widely used as effective radiators in many fields such as global positioning system (GPS), radio frequency identification (RFID) with the advantages of low profile and good characteristics [1]. Besides, circularly polarized (CP) microstrip antenna has an advantage of greater flexibility in orientation angle between transmitter and receiver. The well-known method to achieve CP is adopting a feeding structure which can excite two orthogonal linearly polarized modes with a 90° phase difference [2, 3]. Since the two near-degenerate orthogonal modes of equal amplitude and

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90° phase difference are excited, the purity of polarization will be relatively less.

Recently, annular-ring microstrip antenna (ARMSA) has drawn many scholars' attention [4–9]. For the ARMSA, its patch size is smaller than the traditional square and circular patch antenna when operated at the fundamental mode (TM_{11} mode). However, the very large input impedance of ARMSA is an obstacle on its applications [10]. So it is difficult to obtain $50\,\Omega$ input impedance for the ARMSA.

Some techniques have been reported to solve the problem. In [4], a stacked annular ring coupled to a shorted circular patch was presented which offered a large impedance bandwidth and low cross-polarization levels. In [5], the author adopted microstrip line as an impedance transformer to realize impedance matching with $50\,\Omega$, and the transmission loss caused by the very narrow microstrip line has to be considered carefully. In [6, 7], the coupling feeding was applied to improve the impedance matching. But the articles mentioned above usually have narrow impedance and axial-ratio (AR) bandwidths. In [8], a wideband CP annular-ring patch antenna with two L-probe feeds was proposed. But its structure is complex and it is difficult to fabricate.

In this paper, we propose a new configuration of an ARMSA fed by a 90° branch-line hybrid coupler. The hybrid coupler to generate CP, therefore, can be connected to co-planar space of the ARMSA directly without a large-size matching circuit and a very low profile and simple structure can be achieved. A stacked parasitic circular patch is employed to improve the impedance matching and performances of AR. Details simulated and measured results of the proposed antenna are described as below.

2. ANTENNA DESIGN

The configuration of the ARMSA fed by a 90° branch-line hybrid with the parasitic element is illustrated in Figure 1. It consists of a substrate board with an annular-ring patch and hybrid feeding network etched on the top and a square metallic ground at the bottom.

As we all know, when ARMSA operates at TM_{11} mode, it is difficult to achieve good impedance matching because of the very large input-impedance. In order to solve this problem, a stacked parasitic patch above the annular ring is used. And a 90° branch-line hybrid consisted of a $50\,\Omega$ microstrip line determined by the width of W is connected to coplanar space of the ARMSA so that no large size space is needed. The radius R_1, R_2 and R_3 determined the characteristic impedances of $70\,\Omega$ and $50\,\Omega$. The ARMSA is fed by two ports of the

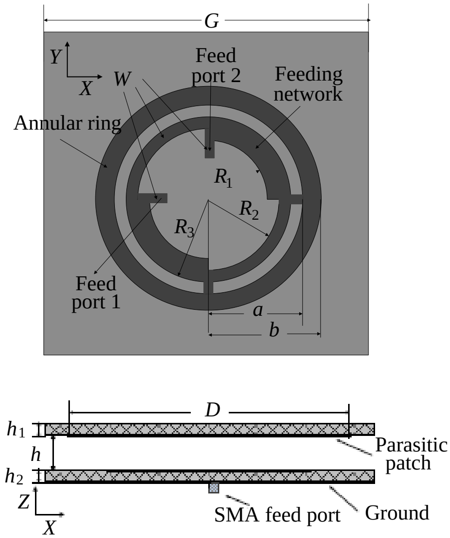


Figure 1. Configuration of the proposed antenna.

hybrid with 90° phase shift to generate CP radiation for TM_{11} mode. As the 3-dB hybrid has two ports, the antenna can support both LHCP and RHCP. When we measure the antenna in the RHCP mode, the antenna is fed from one port, and a $50\,\Omega$ load is attached to the other one. Below, we provide our design step by step.

2.1. ARMSA Patch Design

Firstly, we design the annular-ring patch that operates at the GPS band. A square substrate with relative loss tangent $\tan\delta = 0.001$ and relative permittivity $\varepsilon_r = 2.5$ is used. The annular-ring patch and square metallic ground are etched on opposite sides of the microwave substrate board. The inner radius and outer radius of a and b are determined by the operating frequency. When the annular-ring patch works at TM_{11} mode, its means circumferential length is approximately equal to the wavelength in effective permittivity. The resonant frequency can be expressed as

$$f_{11} = \frac{c}{\pi(a+b)\sqrt{\varepsilon_{eff}}} \tag{1}$$

where c is the speed of light in free space, and a and b are the inner and outer radius of the annular-ring considering the fringing effect. From Equation (1), we can see that when the parameters of substrate are determined, the values of a and b control the operating frequency.

2.2. Circular Hybrid Design

Next, we proceed with the branch-line hybrid design. Some literatures had reported the uses for the inner space of the ARMSA. In [5] the meandered impedance transformer lines are a good choice to adopt, but the impedance bandwidth of which is too narrow. As a result, a branch-line hybrid is designed to achieve equal power splitting with 90° phase shift and provide wider bandwidths of impedance and AR. According to [11], we design a circular 90° branch-line hybrid and place it in the center of the ARMSA for GPS applications. The hybrid is printed at the same side with the ARMSA patch. As a result, a co-planar structure is implemented. The hybrid is set at 1.575 GHz and proceeded to adjust the transmission line width to achieve better impedance match. The simulated S parameters of the design circular branch-line hybrid in [11] are given in Figure 2. As Figure 2 shows, the bandwidth of circular hybrid can cover GPS band with a 90° phase difference between two output ports.

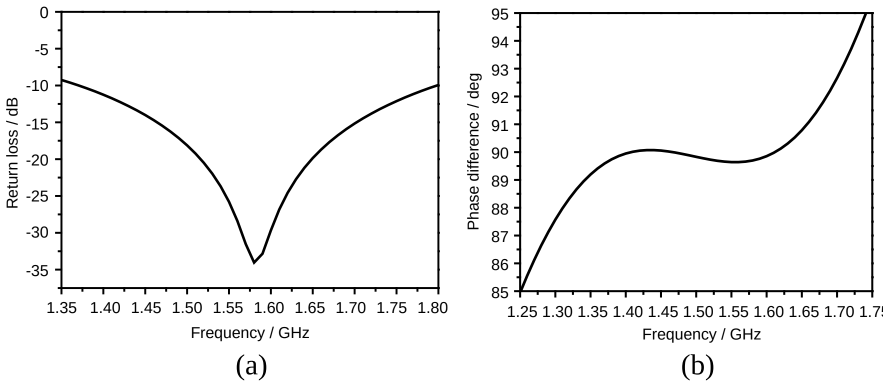
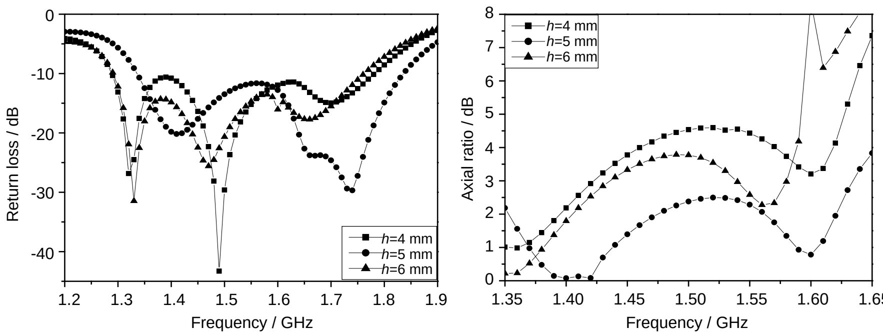


Figure 2. Simulated results of the 90° hybrid coupler. (a) Return loss. (b) Phase difference between two output ports.

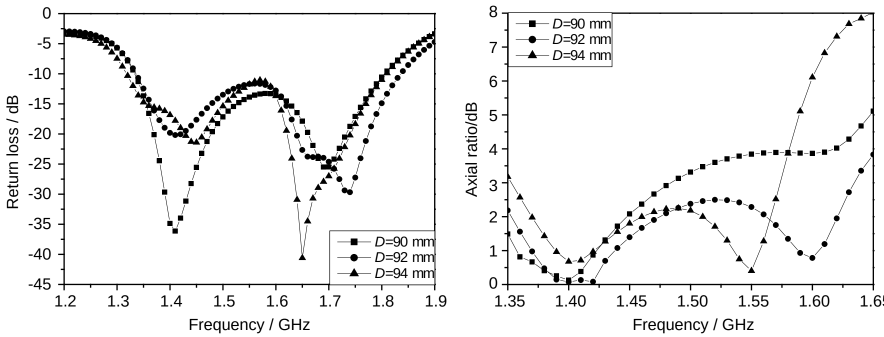
2.3. Parasitic Patch Design

As we all know, the impedance of the ARMSA with TM_{11} mode is large, and the ratio of a to b affects the impedance obviously. For the TM_{11} mode ARMSA, it is hardly to match with $50\,\Omega$ port through adjusting a/b, so a circular parasitic patch is employed not only obtaining good impedance matching but also broadening the AR characteristics of the design ARMSA. The parasitic element is placed above the substrate at the height of h, and is etched on a substrate with thickness $h_1 = 1\,\text{mm}$, relative loss tangent $\tan\delta = 0.001$ and relative permittivity $\varepsilon_r = 2.5$. Different parasitic sizes and height are simulated and analyzed. According to [12], there is a critical space height above which a larger parasitic patch diameter D increases the resonance frequency, and below it, the resonance frequency decreases. Figure 3 and Figure 4 show the S parameter and AR curves with different h and D.



(a) (b)

Figure 3. Simulated S_{11} and axial ratio of the proposed antenna with different h. (a) S_{11}. (b) AR.



(a) (b)

Figure 4. Simulated S_{11} and axial ratio of the proposed antenna with different D. (a) S_{11}. (b) AR.

As [5–7] show to us, traditional approaches hardly provide wide impedance and AR bandwidths because of the single resonant mode. Stacking a parasitic patch above the annular ring can reduce the value of input impedance greatly, and the bandwidth can be broadened obviously due to the excitation of two adjacent modes. So from Figure 3 and Figure 4 we can conclude that the ARMSA presents a feature of double resonant modes. Owing to the added resonant frequency of the parasitic patch, the bandwidths of impedance and AR are greatly broadened. The effect of parameter h and D comes from the strong electromagnetic mutual coupling between the ARMSA and the parasitic patch. In comparison with the parameter, at last we choose $h = 5\,\text{mm}$ and $D = 92\,\text{mm}$.

2.4. The Effects of Other Parameters

According to the design procedure for the stacked ARMSA, the required side length of the ground plane and the thickness of substrate are also considered. When other dimensions are fixed, the change of the two parameters would affect the antenna original performance. In order to get better radiation performance and smaller antenna dimensions, in practice, we choose 140 mm as the ground size.

3. EXPERIMENTAL RESULTS AND DISCUSSION

According to the design procedure described in the above section, an ARMSA for GPS applications is simulated by Ansoft HFSS. To confirm the simulated results, the antenna is fabricated and tested. Figure 5 shows the fabricated prototype of it. Table 1 presents the detail dimensions of the proposed antenna. The reflection coefficients are measured using the Agilent N5230c vector network analyzer, and radiation characteristics are measured in the anechoic chamber.

Figure 5. Photograph of the fabricated antenna.

Figure 6 shows the measured and simulated return losses (S_{11}) as a function of frequency. It is observed that the measured bandwidth

Table 1. Dimensions of the proposed antenna.

parameter	value	parameter	value
R_1	18.3 mm	h	5 mm
R_2	20.2 mm	h_1	1 mm
R_3	23 mm	h_2	1 mm
a	24 mm	D	92 mm
b	28 mm	G	140 mm
w	2.5 mm		

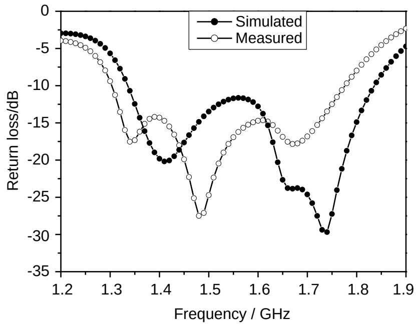


Figure 6. Simulated and measured S_{11} of the proposed antenna.

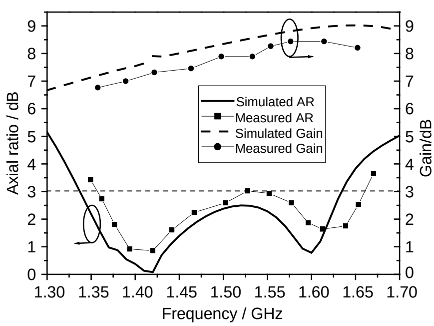


Figure 7. Simulated and measured AR and Gain of the proposed antenna.

(for $S_{11} < 10$ dB) is 31.2% from 1.3 to 1.78 GHz, and agrees well with the simulated one though it slightly shifts toward lower frequency compared to the simulated one. The difference between the measured and simulated values is possibly caused by the manufacture tolerances and anechoic chamber measurement errors.

Figure 7 illustrates the measured AR and gain of the proposed antenna compared to the simulated results at broadside direction. From the figure, the measured and simulated 3-dB AR bandwidths are given by 1.36–1.65 GHz and 1.33–1.64 GHz, respectively. We can conclude that the CP operation consists of two adjacent CP modes with similar radiation patterns and polarization senses, and that the CP modes can be coupled together to obtain a wide CP bandwidth. The measured gain in the band agrees well with the simulated values despite some differences. The gain of 8.2 dB is obtained at 1.575 GHz,

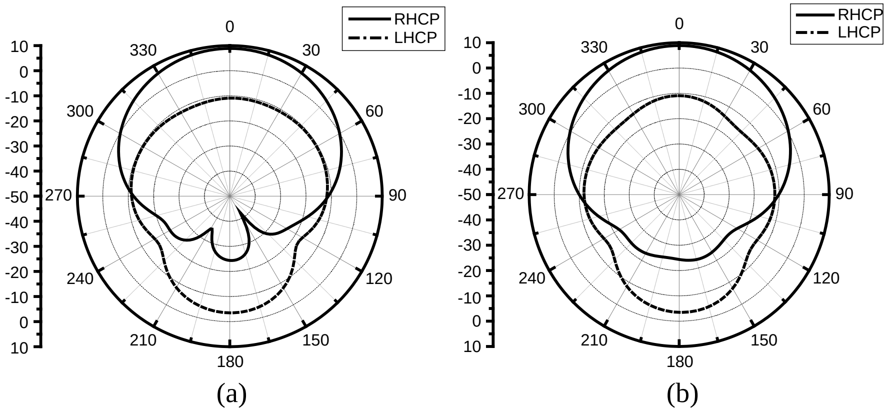


Figure 8. Measured radiation pattern of the proposed antenna at 1.575 GHz. (a) *xoz* plane. (b) *yoz* plane.

and the gain is more than 7.5 dB from 1.55 to 1.60 GHz. Therefore, the proposed antenna has better radiation performances.

Figure 8 shows the measured left-hand circularly polarized (LHCP) and right-hand circularly polarized (RHCP) radiation patterns in the *xoz*-plane and *yoz*-plane at 1.575 GHz. It is obvious that the antenna presents a good RHCP radiation. Also, it can be observed from the pattern that the 3-dB beam widths are about 68° and 65° respectively in *xoz*-plane and *yoz*-plane. And a good symmetrical radiation behavior is acquired; it is mainly because the feeding network is integrated in the ring and does not destroy the symmetry of the entire antenna.

4. CONCLUSION

A novel stacked circularly polarized annular-ring microstrip antenna for GPS application is presented. The annular-ring patch is fed by a circular hybrid which is placed at the inner boundary of the antenna. The parasitic patch is used to improve impedance matching and AR bandwidth. In addition, because two resonant modes are excited, the impedance and AR bandwidth are broadened obviously. The prototype has been designed and fabricated and found to have a 10-dB bandwidth of 31.2% and 3-dB CP bandwidth of 19.2%. The measured gain at 1.575 GHz is about 8.2 dB which is suitable for the use in GPS applications.

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