Gain-Enhanced Compact Circularly Polarized Array Microstrip Antenna

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Abstract ─ A miniaturized circularly polarized microstrip antenna array with sequential-phase (SP) feed is presented. Attributed to the slotted metal walls surrounding the SP feed and the internally slotted patch array with parasitic rectangular patches, the key performance indicators of antennas are greatly improved, such as gain and impedance bandwidth. The numerical results of designed antenna simulated by ANSYS HFSS show that the impedance bandwidth is about 11.89% (5.41-6.09GHz) for the $S_{11} = -10\ dB$ matching criterion, the 3-dB Axial Ratio (AR) bandwidth is about 13.26% (5.64-6.44GHz), and the peak gain can reach to 11.86 dBi at 6.09GHz. When the center frequency of proposed antenna is operated at 5.87GHz, the available bandwidth is 7.71% (5.64-6.09GHz). Based on this, the AR bandwidth is about 450MHz.

Index Terms ─ Antenna array, circular polarization, microstrip, sequential-phase.

I. INTRODUCTION

With the development of microstrip technology in the field of modern wireless radio, the performance of circularly polarized antennas has become increasingly demanding. In this paper, a circularly polarized microstrip antenna arrays with enhanced gain has been proposed. Because of its compact structure, light weight, strong anti-jamming capability, and easy circuit integration, the circularly polarized microstrip antenna arrays exhibit important application prospects in modern radio fields, especially for electronic countermeasures and wireless communications.

At present, two common ways are used to constitute circularly polarized microstrip antenna array: (1) Uniformly feed each circularly polarized antenna to form an array [1]; (2) Construct a circularly polarized antenna array using a continuous phase rotation feed excitation microstrip antenna [2]. In general, by using two spatially orthogonal linearly polarized electric field components with equal amplitude and 90 degree heterogeneity, a circularly polarized antenna can be achieved. This property determines that the antenna structure in the form of sequential phase rotation can better suppress cross polarization and extend the antenna bandwidth. On the other hand, the sequential phase rotation method can well reduce the coordination of feeders through reasonable layout improving the performance of the antenna [3-4]. Therefore, the AR bandwidth of the circular polarization array antenna can be effectively improved. At the same time, the gain performance of the antenna can be increased. Due to the expansibility of the antenna array, the general research is focus on microstrip patch antenna array that can generate circular polarized waves on the sequential phase rotation [5]. Reference [6] introduces a cross-dipole sub-circular polarized antenna with a parasitic loop resonator and its array. By using the sequential phase of the four branches, cross-dipoles can produce broadband circular polarization performance. In order to achieve a wider circular polarization bandwidth, the literature uses a parasitic open-loop resonator. Attributed to the half-wavelength resonator, the proposed antenna can achieve a 3-dB AR bandwidth of about 28.6% (0.75GHz, 2.25-3.0GHz) through the two orthogonal branches coupling with the resonator. Reference [7] proposed a circularly polarized microstrip antenna array with double-layered feed structure. Meanwhile, a thicker substrate is used to reduce the inherent quality factor, thereby increasing the bandwidth of the antenna. Generally speaking, the design of a multi-layer patch can lead to excessive antenna size and possible shortcomings, such as distorted patches and inconvenience handling. In addition, thicker substrates are also prone to increase the difficulty of antenna coupling. In this case, the article used a H-type coupling feeder as impedance matching network to improve antenna coupling. A slotted metal wall structure around the feed is proposed in Ref. [8] to improve the antenna's radiated gain. Reference [9] proposes a 2×2 antenna array with broadband circular polarization performance composed of four parasitic rectangular patches. The feed structure of this antenna is

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consist of circular strips. Then the array elements are capacitively coupled with the four strips connected to the feed network. Finally, four parasitic patches are introduced to improve gain flatness.

In [10-11], a reflector structure is added below the radiation piece of the circularly polarized antenna to increase the gain. Compared with other antenna structures described above, the use of reflector can greatly reduce the sizes of antenna, that is, the gain can be enhanced by using a single radiating element. In addition, Ref. [11] also uses a short-circuit pin structure to optimize the bandwidth. In [12], a single-feed method is used to excite the radiation patch, and a phase-shifted network is used to construct a circularly-polarized antenna array. According to the chamber mode theory, the microstrip antenna that is excited by a single feed can produce two degenerate modes of equal amplitude and perpendicular to each other. On this basis, the perturbation unit is introduced by a rectangular chamfering angle to separate the resonance frequency, forming a circular polarization. The article uses a SP network as the power splitter to radiate patch arrays, effectively improving the antenna gain. However, such a splitter structure greatly reduces the bandwidth of the antenna, and makes the antenna size larger. Therefore, the Ref. [13] adds parasitic patches to optimize the antenna bandwidth, but the sizes of antenna have not changed much.

Inspired by the above progresses, a circularly polarized antenna with four radiating patches with parasitic patch is designed. The antenna is excited by a probe, and the feed section directly contacts the feed network. Besides, most of the feed network is isolated from the patch. Ultimately, it minimizes the parasitic radiation. In the optimization of proposed antenna, the bandwidth of the antenna can be improved by changing the structures of the patch. By cross-grooving the circular radiating patch, not only the current of the guiding patch is bent, but also the effective length of the current path is increased, and the resonant frequency is reduced. In addition, the outer circle is chamfered so that the array element is capacitively coupled with the four strips. At the same time, during the optimization process, it was found that by adding a parasitic patch next to the radiating patch, the impedance bandwidth of the antenna can be effectively increased. Finally, the available bandwidth of 450MHz can be achieved.

II. ANTENNA DESIGN

The configuration of the antenna array proposed in this paper is shown in Fig. 1. A 1.75mm thick Rogers RT/duroid 5880 (tm) dielectric plate (ε_r = 2.2, loss tangent = 0.0009) is adopted. The size of the dielectric board is L×L. A square loop is truncated from an angle of 1×1 on the inner side of a circle to realize SP rotation. A slotted metal wall surrounding the feed structure is introduced to improve the gain characteristics of the antenna. The radiating patch of the antenna is a square structure of L5×L5, and located on the center of the square diagonal line, and the half diagonal is the radius R1 on the upper and lower sides of the square. Based on the simulation optimization, the final dimensions of the antenna are shown in Table 1.

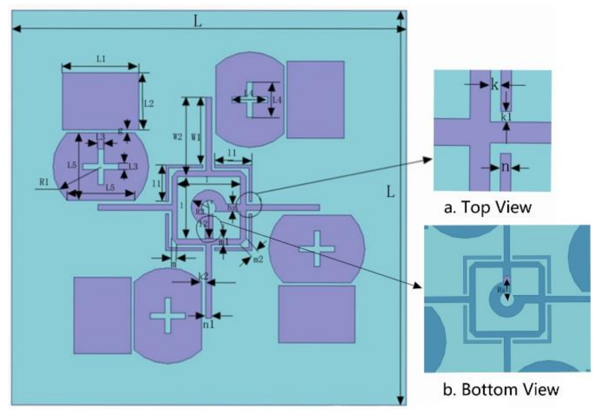


Fig. 1. Geometry and dimensions of the proposed antenna array.

Table 1: Detailed dimensions (unit: mm)

L	L1	L2	L3	L4
67	13	9.7	1	6
L5	l	l1	l2	m
11.5	10.64	6.3	5.32	0.98
m1	m2	W1	W2	hz
0.98	1.38	11.48	13.46	1.3
n1	g	r	R2	Rs
1	0.5	1.2	3	3.3
k	k1	k2	n	
0.5	0.5	0.5	0.7	

III. EXPERIMENTAL RESULTS

Through the strips protruding from the SP loop and the capacitors placed beside them, the antenna array excites the radiating patch in the form of a single feed point coupling, and the center cross-shaped slot acts as a perturbation unit to separate the antenna resonant frequencies. When the degenerate mode separation unit is properly selected, for the operating frequency of the antenna, the equivalent impedance phase of one mode leads the phase, and the equivalent impedance phase of the other mode lags behind, resulting in a phase difference of 90°, thereby forming circular polarization. According to the cavity mode theory, it is generally known that an antenna in the form of a rectangular patch can be understood as a cavity in which all the patches are open, and the corresponding equation is:

$$\nabla^2\phi_{nm} + k^2\phi_{nm} = 0, \quad (1)$$

$$\frac{\partial\phi_{nm}}{\partial n} = 0. \quad (2)$$

Based on the analysis of rectangular radiating patch, it is assumed that the rectangular structure of the microstrip antenna can only excite the working mode of the primary mode. When it is added to the perturbation unit Δs, a pair of characteristic modes can be obtained, and a pair of characteristic function ϕ' can also be obtained. Corresponding to the wave number k', which ϕ' is satisfied:

$$\phi' = P\phi_{01} + \phi_{10}. \quad (3)$$

According to the orthogonality of characteristic function, the separation unit of ϕ' is a pair of modes whose polarization directions are perpendicular to each other and have the same amplitude. CP radiation is obtained when the phase between the two modes is ± 90°. As shown in the Figs. 2 and 3, it can be found that the AR bandwidth varies greatly by optimizing the distance g from stripe to patches in the ANSYS HFSS optimization process. By studying the current distribution, it is considered that the electric field generated by the induced current on the parasitic patch is the same as that on the original radiation patch. Comparing the array with or without parasitic patches, it was found that the electric field distribution was affected. Since the added parasitic patches are not connected to the original feed structure, two or more modes can be excited, and these modes can be approached by adjusting the geometric parameters of the parasitic patches to increase the bandwidth. Therefore, according to the Figs. 4 and 6, compared with a single array, the parasitic patch not only affects the return loss, but also controls the direction of antenna radiation. Figure 5 shows that the AR bandwidth of the antenna is improved when the antenna is attached with metal wall and parasitic patch. It is found that the influence of metal wall on heat sink varies with the thickness and position of metal wall.

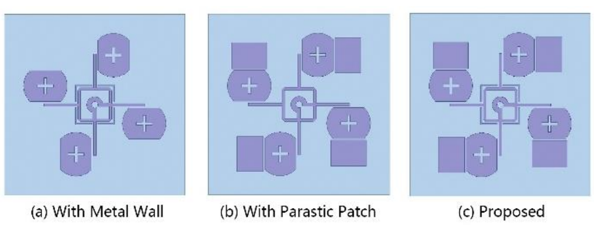


Fig. 2. Stages of antenna development: (a) with metal wall, (b) with parasitic patch, and (c) proposed antenna.

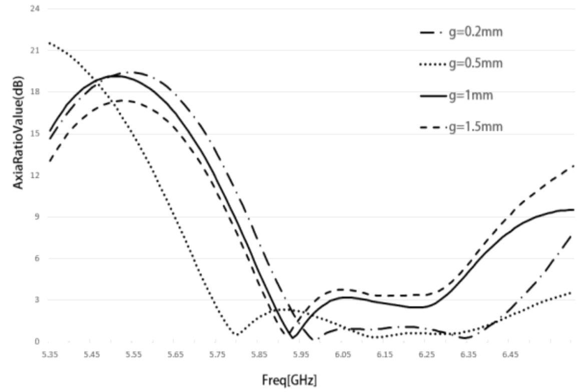


Fig. 3. Simulated AR of the 2×2 array with different g.

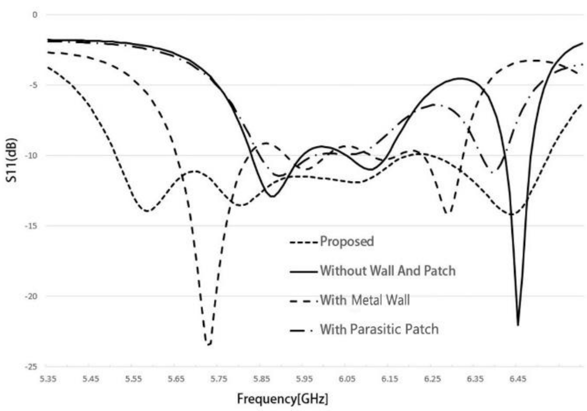


Fig. 4. Simulated return loss of the 2×2 array.

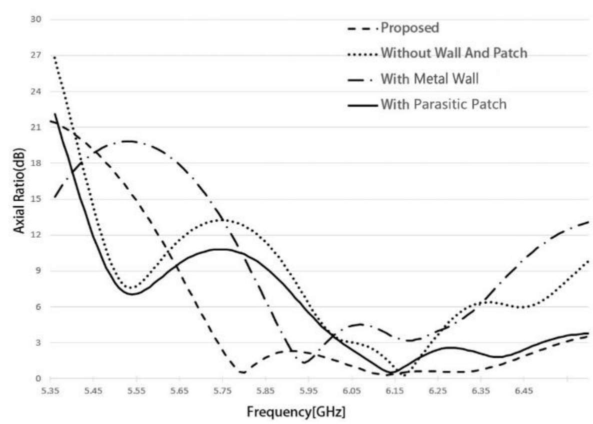


Fig. 5. Simulated AR of the 2×2 array.

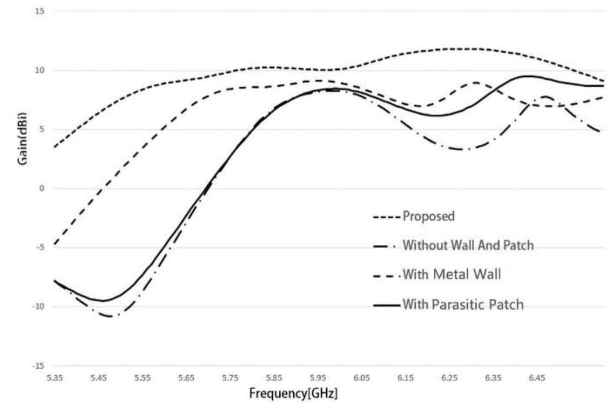


Fig. 6. Simulated gains of the 2×2 array.

According to the Fig. 6, it can be found that the gain of lower frequency band is significantly reduced without metal walls and parasitic patches. In order to analyze the influence of parasitic patch and metal wall on the gain and the impedance bandwidth, the electric field distribution of different antennas at 5.87GHz are shown in Fig. 7. Compared with the un-added metal wall, the placement of metal wall contributes to the quasi-traveling wave propagation, thereby achieving impedance matching of the antenna and increasing the antenna bandwidth. Figures 8 and 9 show the the current vector direction of different antennas at 5.87GHz. The induced current on the rectangular parasitic patch contributes to the original patch coupling energy, and the direction of electric field vector excited on the parasitic patch is the same as that of original patch. Therefore, the antenna gain is improved due to the disturbing effect of parasitic patch on the surface current of original patch. Meanwhile, by analyzing the electric field distribution of different phases, the electric field component is rotated counterclockwise to achieve a right circular polarization (RHCP) wave in the +z direction. The electric field distribution was found to be slightly affected by comparing the presence or absence of parasitic patches of the array elements. Therefore, the application of parasitic patches not only improves the gain of low frequency band, but also maintains the performance of the CP. Figure 10 shows the effect of parasitic patches and metal walls on the performance of antenna array at 5.87GHz. It can be seen that after the addition of the metal wall, the 3 dB beam-width is significantly narrowed in the xoz plane. The peak gain of antennas with or without metal walls are 10.5 and 9.5 dBi, respectively. Moreover, the gain difference is more obvious in the low frequency band.

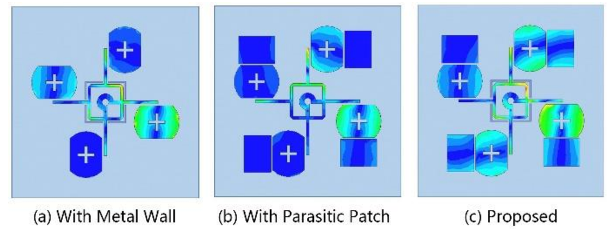


Fig. 7. Simulated vector electric field distributions at 0°, 5.87GHz: (a) with metal wall, (b) with parasitic patch, and (c) proposed.

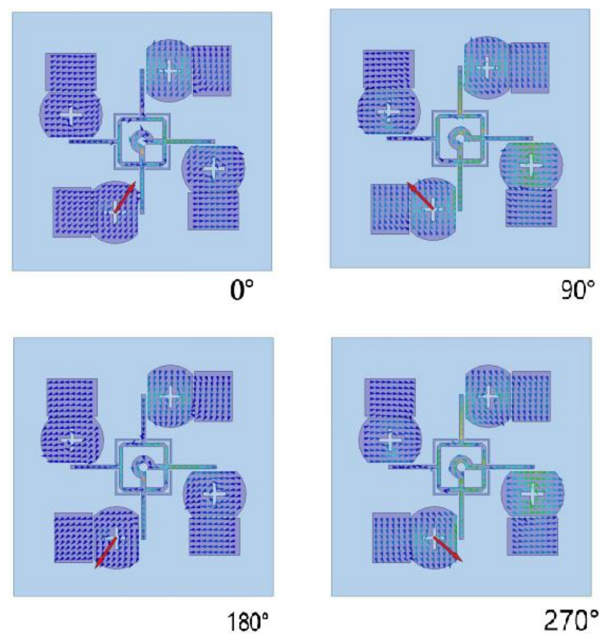


Fig. 8. Simulated current distributions at 5.87GHz.

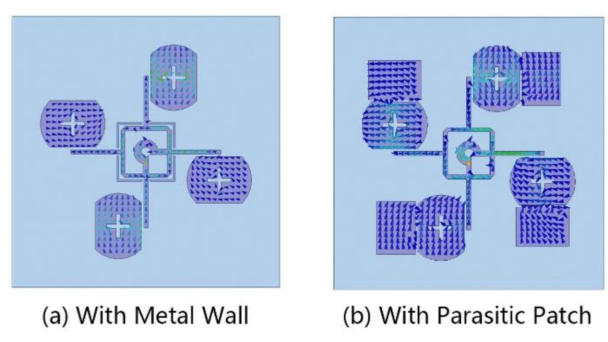


Fig. 9. Simulated current distributions at 0°, 5.87GHz: (a) with metal wall and (b) with parasitic patch.

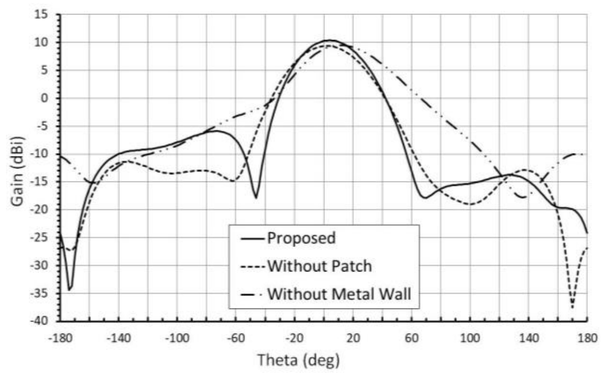
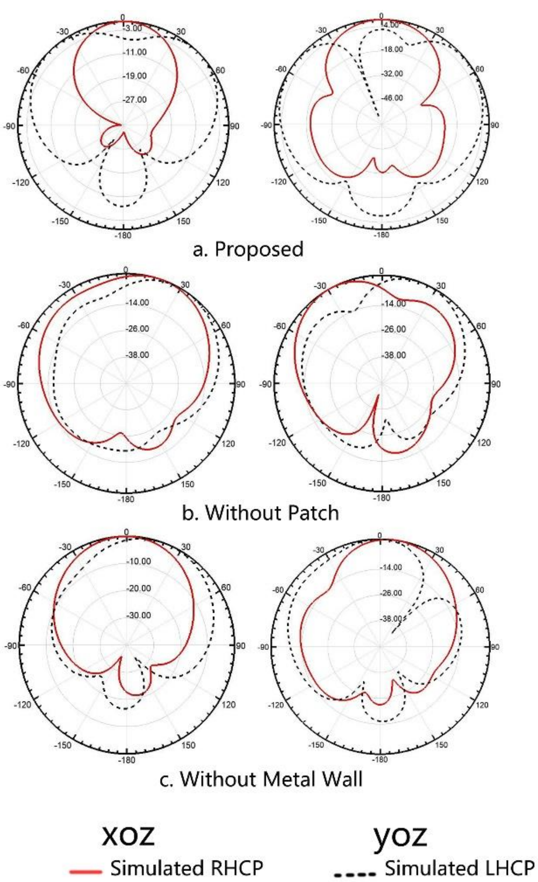
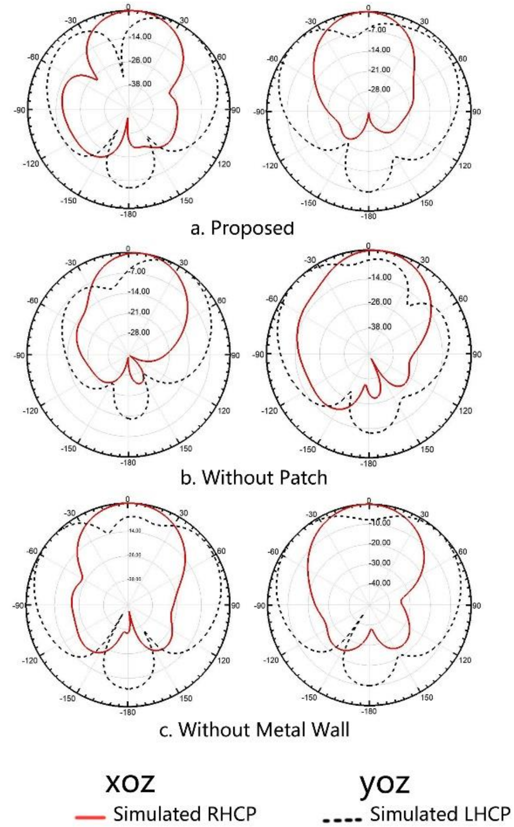


Fig. 10. Pattern comparisons of the proposed antenna at 5.87GHz (xoz-plane).

The normalized far field radiation pattern is shown in Fig. 11. Good RHCP radiation can be observed. Besides, in the CP band, the 3dB beam-width measured on the xoz plane is 54.2° (5.65GHz), 50.3° (5.87GHz), and 40.2° (6.09GHz). The performance of beam-width is desirable for radar and wireless communication systems. Table 2 shows the performance of the proposed antenna compared with that of the references. The results show that the proposed antenna has relatively small size and high gain.



(a)



(b)

Fig. 11. Simulated and measured normalized radiation patterns in different planes: (a) 5.65 and (b) 5.87GHz.

Table 2: The comparison on the performance of the proposed CP antenna with other works

Ref.	CP Center Frequency (GHz)	10dB Return Loss BW (GHz/%)	3-dB ARBW (GHz/%)	Gain (dBic)	Dimension (mm×mm×mm)
[8]	4.99	0.3/6	0.29/5.8	10.05	100×100×3.5
[11]	5.50	1.03/18	0.7/12.5	12	75×75×1.5
Pro.	5.87	0.68/11.9	0.8/13.3	11.86	67×67×1.75

IV. CONCLUSION

This paper presents a compact circular polarized antenna array. According to the simulation results of ANSYS HFSS, the antenna can obtain flat antenna gain in the effective bandwidth of 450MHz (5.64-6.09GHz) with small size. Moreover, at the CP center frequency of 5.87GHz, the antenna gain is 10.04dBi. This designed antenna has the characteristics of small size, flat gain, wide impedance and AR bandwidth, which can satisfy the requirements of current miniaturized development of military and civilian circular polarized antenna arrays.

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