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Broadband Circularly Polarized Slot Antenna Array with Fan-Shaped Feed Line and L-Shaped Grounded Strips

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Abstract—A broadband circularly polarized (CP) slot antenna array fed by a coplanar waveguide (CPW) is proposed. A fan-shaped feed line and three L-shaped grounded strips are embedded in the square slot antenna element to enlarge the bandwidth. Simulated results show that the antenna element can obtain a wide impedance bandwidth with -10 dB reflection coefficient covering 1.7–6.3 GHz (about 115% relative bandwidth) and 3 dB axial ratio (AR) bandwidth covering 2.6–5.2 GHz (about 66%). Using four elements with sequential phase feed, the measured impedance bandwidth and axial ratio bandwidth of the antenna array can be enhanced to 105% (1.65–5.35 GHz) and 71.3% (2.3–4.85 GHz), respectively. Good radiation characteristics with the peak gain of 10.8 dBic over the operating band can be obtained.

1. INTRODUCTION

With the rapid progress of modern wireless technology, circularly polarized (CP) antenna arrays have received increasing attention in satellite and mobile communication systems, because they are less sensitive to the orientation of the corresponding mobile device and can reduce multipath loss [1, 2]. Microstrip CP antenna arrays have become an excellent choice due to their simple structures, low profile, ease of fabrication and good performance [3–13]. Most designs have narrow impedance and axial ratio (AR) bandwidth [3–5]. But wideband circular polarization is desirable in many applications such as satellite, radar tracking, and mobile communications.

In the past few years, the designs of coplanar waveguide (CPW)-fed square slot antennas are getting more attention owing to their wide bandwidth [4–13]. Various effective techniques used to expand the CP bandwidth of slot antennas have been introduced as follows: inserting inverted-L or T-shaped grounded strips in the slot [7–10, 13], embedding a lighting-shaped feed line [9], implanting a spiral slot in ground plane [11], and employing arc-shaped grounded metallic strips [12]. And the sequential rotation technique has been generally used to improve the bandwidth performance of CP arrays [1, 5, 13–15]. Through proper sequential rotation with the excitation of sequential phases, the CP antenna array can achieve a remarkable CP bandwidth.

In this letter, a broadband CP slot antenna array with modified structures and sequential phase feed is presented. A fan-shaped feed line and L-shaped strips are embedded in the antenna element to expand the bandwidth. Using the sequential rotation technique, an excellent circular polarization covering a wide frequency bandwidth can be obtained.

2. ANTENNA ELEMENT CONFIGURATION AND DESIGN

Figure 1 shows the configuration of the proposed square slot antenna element. The proposed slot antenna is printed on a commercially cheap FR4 substrate with a relative permittivity of $\varepsilon_r = 4.4$ and

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a loss tangent of $\tan\delta = 0.02$. The square slot with a side length of L is located at the center. A $50\,\Omega$ CPW transmission line with a signal strip of width W_f and two identical gaps of width g is used to excite the proposed antenna from the center of the top layer.

In order to enlarge the bandwidth, two main structures have been embedded in the antenna: one is the fan-shaped feed line, and the other is three L-shaped strips. The dimension of the fan-shaped feed line is optimized for good impedance matching. Through numerous simulations, suitable dimensions are obtained. To investigate the effect of modified structures on antenna performance, four antennas with or without the modified structures are defined as shown in Fig. 2. Simulated results of the antennas with or without the fan-shaped feed line and the L-shaped strips are shown in Fig. 3. It is observed that the two structures can improve the impedance and AR bandwidth effectively. And owing to the modified structures, the proposed antenna (Antenna 4) can obtain a wide impedance bandwidth with $-10\,\mathrm{dB}$ reflection coefficient covering 1.7–6.3 GHz (about 115% relative bandwidth) and 3 dB AR bandwidth covering 2.6–5.2 GHz (about 66%).

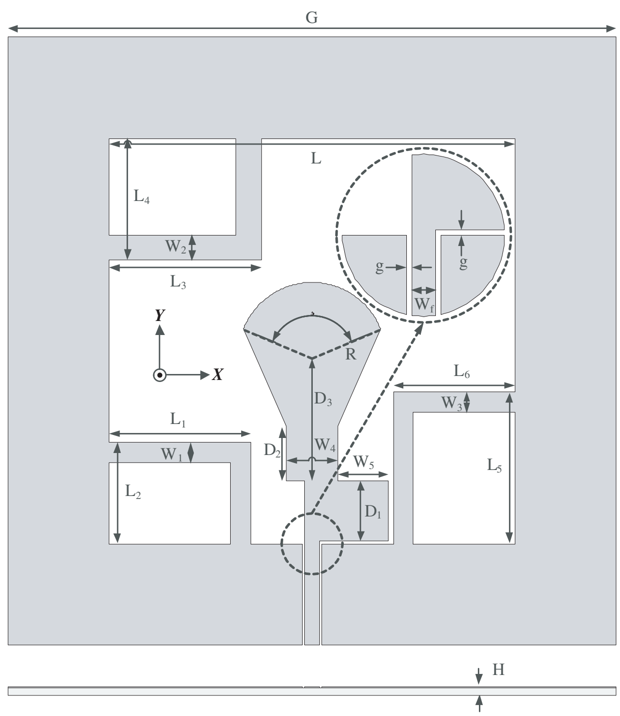


Figure 1. Configuration of the proposed square CP antenna element. ($H = 0.8\,\mathrm{mm}$, $G = 60\,\mathrm{mm}$, $L = 40\,\mathrm{mm}$, $L_1 = 14\,\mathrm{mm}$, $L_2 = 10\,\mathrm{mm}$, $L_3 = 15\,\mathrm{mm}$, $L_4 = 12\,\mathrm{mm}$, $L_5 = 15\,\mathrm{mm}$, $L_6 = 12\,\mathrm{mm}$, $W_f = 1.5\,\mathrm{mm}$, $W_1 = 2\,\mathrm{mm}$, $W_2 = 2.5\,\mathrm{mm}$, $W_3 = 2\,\mathrm{mm}$, $W_4 = 5\,\mathrm{mm}$, $W_5 = 5\,\mathrm{mm}$, $D_1 = 5.9\,\mathrm{mm}$, $D_2 = 5.4\,\mathrm{mm}$, $D_3 = 12.1\,\mathrm{mm}$, $g = 0.2\,\mathrm{mm}$, $R = 7.3\,\mathrm{mm}$, $\theta = 135\,\mathrm{deg}$).

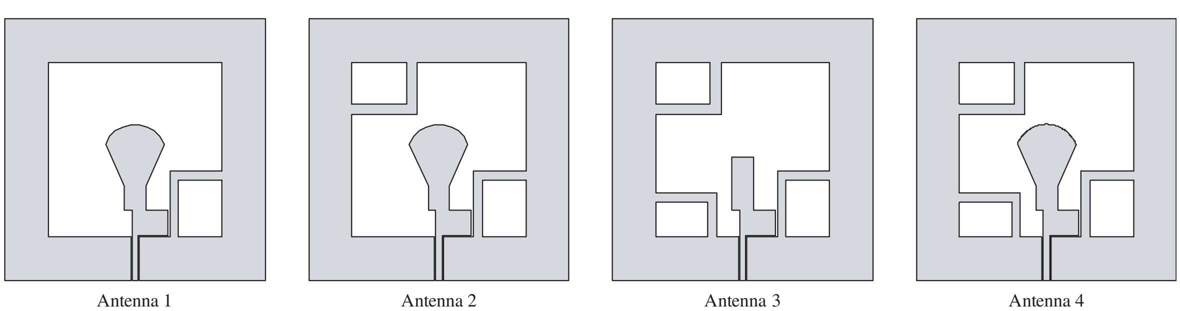
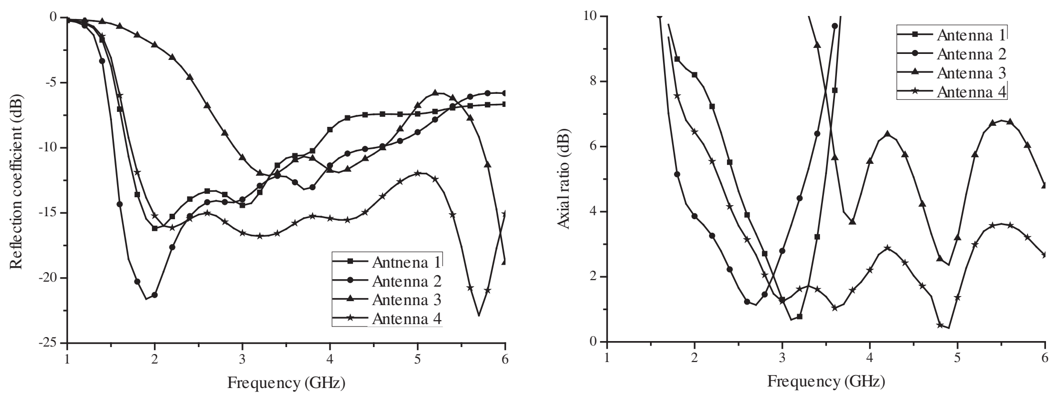


Figure 2. Four antenna prototypes with or without the modified structures.

To perceive that the CP operation can be generated by the proposed antenna (Antenna 4), the vector surface current distribution on the feed and ground varying with time is examined. Fig. 4 shows the simulated surface current distributions of Antenna 4 at 3.4 GHz for four different time instants. It is observed that the predominant vector surface currents in 180° and 270° are equal in magnitude and opposite in phase of 0° and 90°, respectively. And the current rotates in the right-hand direction viewed from the $+Z$-direction, which means that the antenna can radiate the right-hand circular polarization (RHCP) in the upper-half space.



(a) (b)

Figure 3. Simulated results of the antennas with or without the modified structures: (a) reflection coefficient; (b) axial ratio.

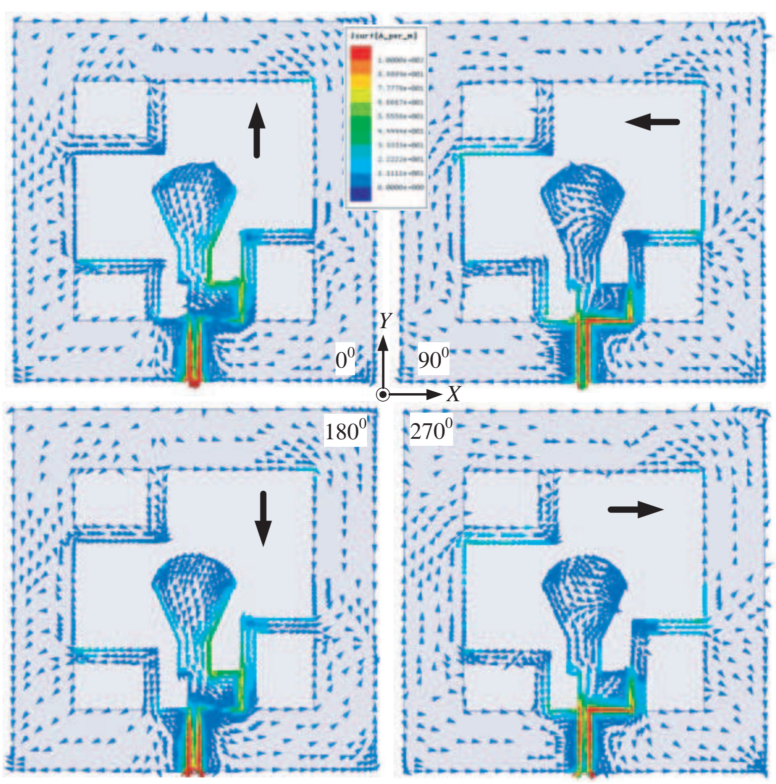


Figure 4. Distributions of the surface current on the feed and ground of Antenna 4 at 3.4 GHz in phase of 0°, 90°, 180° and 270°.

3. BROADBAND CIRCULARLY POLARIZED ANTENNA ARRAY

Figure 5 presents a 2×2 planar antenna array using the proposed slot antenna element and sequential rotation technique. In order to improve the transition, via pins are used to connect the microstrip line to the CPW feed of antenna element [5, 13]. The circular arc feed lines are applied to improve the performance of feeding network. And a star-shaped ground plane is inserted to the lower layer of the antenna array to improve the impedance and AR bandwidth.

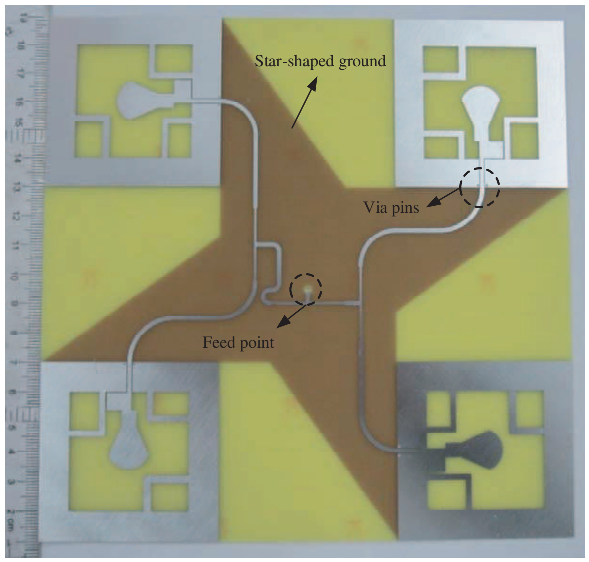


Figure 5. Photograph of the proposed antenna array.

4. EXPERIMENTAL RESULTS AND DISCUSSION

To optimize structural parameters, Ansoft HFSS was utilized in the design procedure. The reflection coefficient of the antenna array was measured by an Agilent E5071B vector network analyzer and the far-field performances were obtained using a far-field measurement system.

Simulated and measured reflection coefficients of the proposed antenna array are shown in Fig. 6. The discrepancy may be due to the fabrication tolerance and the unsteady substrate parameters of FR4 substrate. The measured -10 dB reflection coefficient bandwidth covers 1.65–5.35 GHz (about 105%).

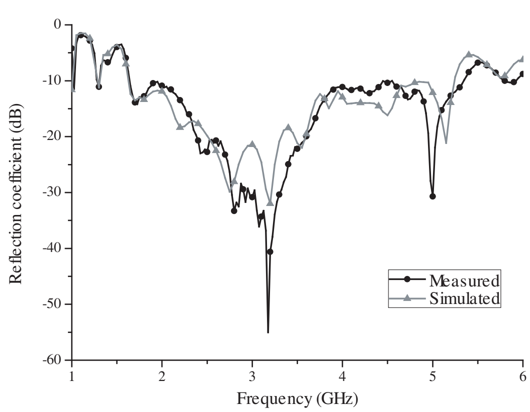
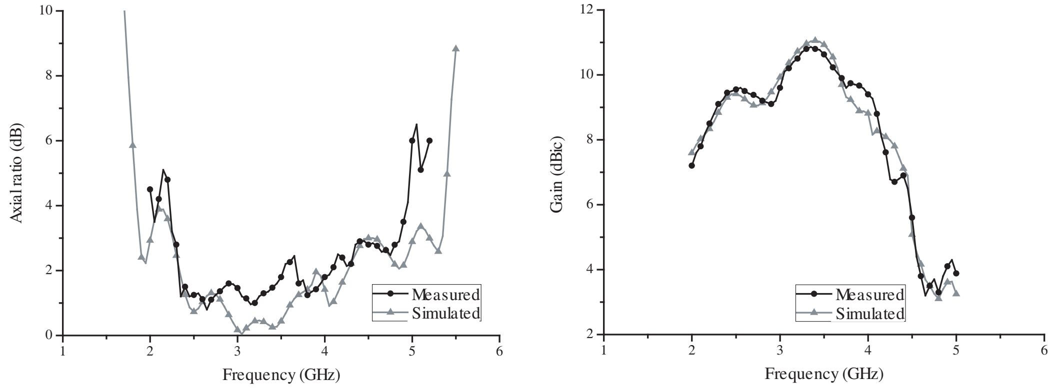


Figure 6. Simulated and measured reflection coefficients of the antenna array.

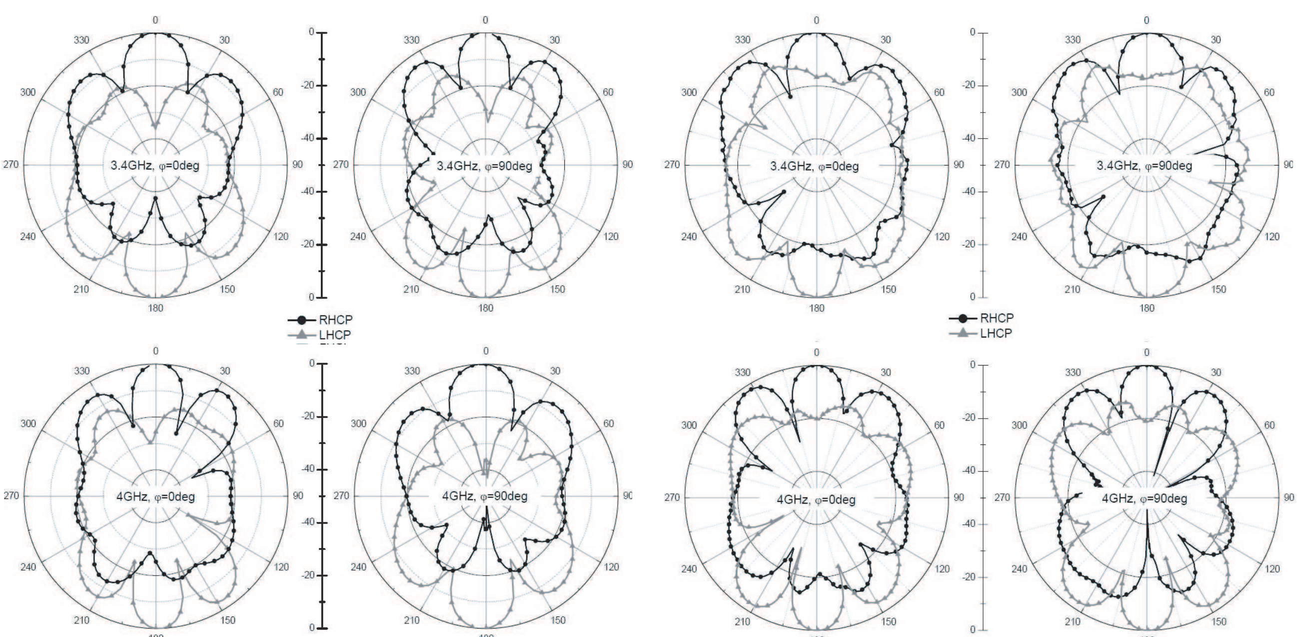


(a) (b)

Figure 7. Simulated and measured axial ratios and gains of the antenna array: (a) axial ratio; (b) gain.

Figure 7 presents the simulated and measured ARs and gains of the antenna array. As can be found, the measured 3 dB AR bandwidth covers 2.3–4.85 GHz (about 71.3%). The measured gain is more than 6 dBic covering 2.3–4.45 GHz over the CP band with the peak gain of 10.8 dBic at 3.4 GHz.

Simulated and measured normalized radiation patterns of the proposed array at 3.4/4 GHz are shown in Fig. 8. The curve trend of the measured patterns agrees with the simulated ones and the differences are mainly due to the test environment. It can be seen that the patterns are bidirectional with right-hand circularly polarized (RHCP) radiation in the upper-half space and left-hand circularly polarized (LHCP) radiation in the lower-half space. Table 1 shows a comparison between the proposed antenna array and the antenna arrays presented in [5, 13]. It shows that the proposed antenna array has a broader CP bandwidth compared to the previous works.



(a) (b)

Figure 8. Simulated and measured normalized patterns of the antenna array at 3.4/4 GHz: (a) simulated; (b) measured.

Table 1. Comparison of the CP bandwidths and peak gains between the proposed antenna array and antenna arrays in the previous works.

Ref.	3 dB AR bandwidth	−10 dB reflection coefficient bandwidth	Peak gain (dBic)
[5]	31% (5.1–7 GHz)	52% (4–6.825 GHz)	7.5
[13]	49% (1.15–1.9 GHz)	52% (1.15–1.95 GHz) ($S_{11} < -15$ dB)	8
Proposed	71.3% (2.3–4.85 GHz)	105% (1.65–5.35 GHz)	10.8

5. CONCLUSION

A 2×2 CP slot patch antenna array with fan-shaped feed line and L-shaped grounded strips employing a microstrip-line-to-CPW feeding network is proposed. The two main features are embedded in the antenna element to expand the bandwidth. Using a sequential phase feed, the proposed antenna array can obtain wide impedance and AR bandwidth. The measured −10 dB reflection coefficient bandwidth is 105% (1.65–5.35 GHz) and 3 dB AR bandwidth is 71.3% (2.3–4.85 GHz). Good radiation characteristics can be obtained with gain more than 6 dBic covering 2.3–4.45 GHz over the CP band with the peak gain of 10.8 dBic at 3.4 GHz.

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