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Broadband Circularly Polarized Slot Antenna Array Using a Compact Sequential-Phase Feeding Network

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Abstract—A broadband circularly polarized (CP) slot antenna array fed by an asymmetric coplanar waveguide (CPW) with stepped and inverted T-shaped strips is proposed. Using four square slot antenna elements with sequential rotation oblique feed and a modified sequential-phase (SP) feeding network, broadband CP can be achieved. The measured -10 dB reflection coefficient bandwidth and 3 dB axial ratio (AR) bandwidth are 55.4% (1.63–2.88 GHz) and 58% (1.65–3 GHz), respectively. Good radiation characteristics with gain more than 6 dBic over the operating band are obtained by the proposed antenna array with a compact size of $155 \times 155 \times 0.8\,\text{mm}^3$. Details of the proposed antenna array design and experimental results are presented and discussed.

1. INTRODUCTION

With the rapid development of wireless technology, most satellite and mobile communication systems use circularly polarized (CP) antenna arrays to overcome the problems of mobility and adverse weather conditions [1, 2]. Microstrip CP antenna arrays have become an excellent candidate owing to their light weight, simple structure, low profile, and ease of fabrication [2–11]. But most designs have narrow impedance and axial ratio (AR) bandwidth [3–5]. In order to obtain better propagation characteristics, CP antenna arrays with good performance over a wide frequency bandwidth are then required in many applications.

In recent years, the designs of coplanar waveguide (CPW)-fed square slot antennas have received much attention due to their wide bandwidth [2–10]. Various structures have been proposed to increase the bandwidth of square slot antennas [6–11]. And sequential rotation techniques are generally used to improve the bandwidth performance of CP arrays [2, 3, 12, 13]. Proper sequential rotation with the excitation of sequential phases is an effective solution to improve the circularly polarized bandwidth. Several sequential-phase (SP) feed designs have been reported [3, 12, 13]. However, most of them are complex and have a large size.

In this letter, a broadband CP slot antenna array employing a compact SP feeding network is proposed. The presented SP feed uses only four transformer segments, making the whole SP feed very compact and simple. An elliptically CP antenna element fed by an asymmetric CPW with stepped and inverted T-shaped strips is used to realize the proposed antenna array.

2. ANTENNA ELEMENT CONFIGURATION AND DESIGN

Figure 1 shows the geometry of the proposed square slot antenna element, which is printed on an FR4 substrate with a side length of G, a thickness of H, a relative permittivity of 4.4 and a loss tangent of 0.02. The square slot with a side length of L is located at the center of the top layer, which is fed by a $50\,\Omega$ CPW transmission line with a signal strip of width W_f and two identical gaps of width g. To

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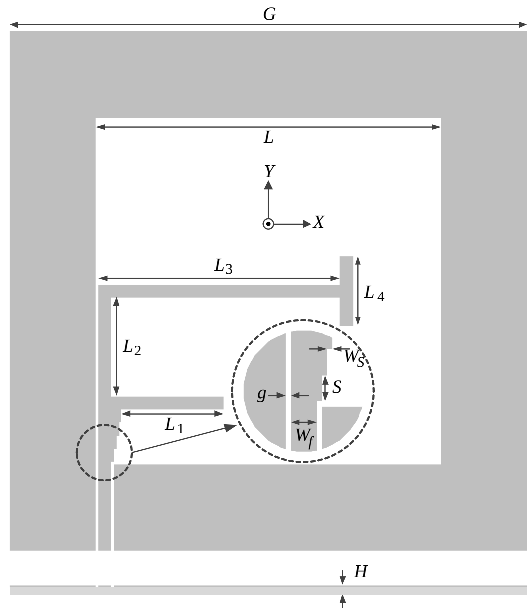
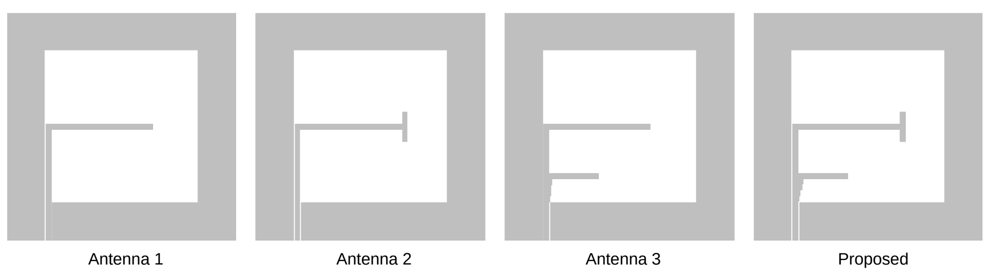
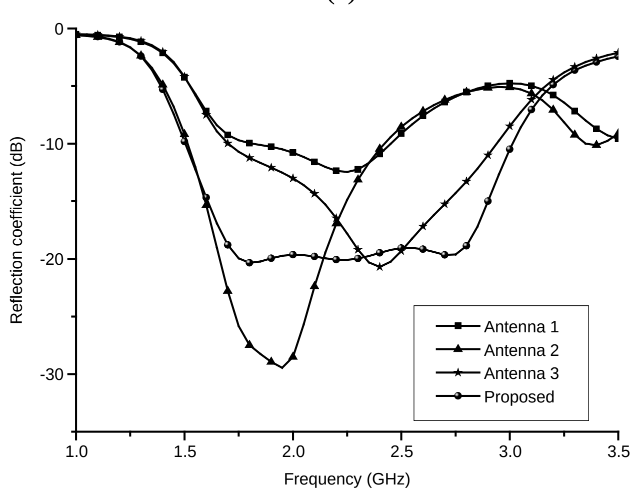


Figure 1. Geometry of the proposed antenna element. ($G = 60\,\text{mm}$, $L = 40\,\text{mm}$, $W_f = 1.5\,\text{mm}$, $W_S = 0.2\,\text{mm}$, $L_1 = 12.2\,\text{mm}$, $L_2 = 11.55\,\text{mm}$, $L_3 = 28\,\text{mm}$, $L_4 = 8\,\text{mm}$, $S = 1.5\,\text{mm}$, $g = 0.2\,\text{mm}$, $H = 0.8\,\text{mm}$).



(a)



(b)

Figure 2. Simulated reflection coefficients of the antenna prototypes: (a) antenna prototypes; (b) simulated reflection coefficient.

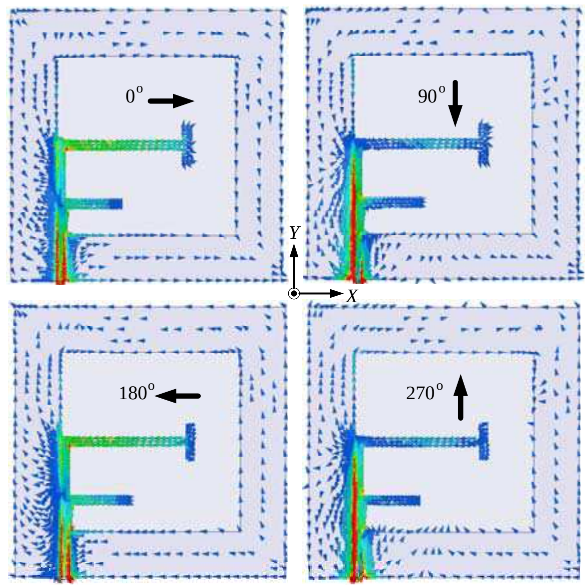


Figure 3. Distributions of the surface current on the feed and ground of proposed antenna element at 2.25 GHz in phase of 0°, 90°, 180° and 270°.

enlarge the impedance bandwidth, two main structures have been embedded in the feeding structure: the stepped strip and the inverted T-shaped strip. The dimensions of the modified structures are optimized for better impedance matching. Simulated reflection coefficients of four antenna prototypes with or without the modified structures are shown in Figure 2. It is observed that the former structure mainly affects the higher resonant mode, while the latter affects the lower resonant mode. A wide impedance bandwidth with a smooth curve trend covering 1.5–3.0 GHz (about 66.6%) can be obtained by the proposed antenna element.

Simulated vector surface current distributions of the proposed antenna element at 2.25 GHz are shown in Figure 3. It is observed that the predominant vector surface currents in 180° and 270° are opposite in phase of 0° and 90°, respectively. And the current rotates in the left-hand direction viewed from the $+Z$-direction.

3. THE COMPACT SEQUENTIAL-PHASE FEEDING NETWORK

Figure 4 illustrates the equivalent circuit of SP feed using a traditional serial power divider. For impedance transformations and sequential-phase rotation, it requires at least seven quarter-wave transformer segments [3, 12].

As shown in Figure 4, Z_0, Z_n ($n = 1{\sim}7$) and 90° represent the terminal load impedances, the characteristic impedances and the electrical lengths of the transmission line, respectively. Here, Z_n

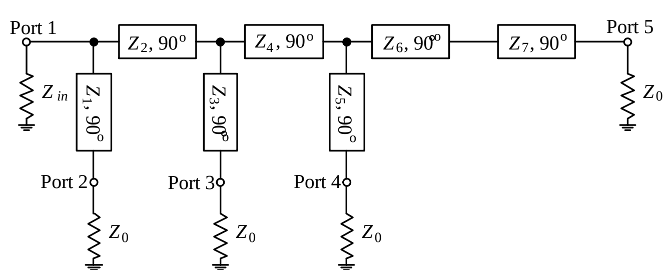


Figure 4. Equivalent circuit of SP feed using a traditional serial power divider.

is calculated such that the SP feed diverts one quarter of the power to each port, while the input impedance Z_{in} is invariant. So that

$$Z_1 = 2\sqrt{Z_0 Z_{in}}. \tag{1}$$

In order to reduce the size, four segments with the characteristic impedance of Z_i ($i = 1, 3, 5, 7$) is deleted, as shown in Figure 5(a). Thus, we have

$$Z_0 = 2\sqrt{Z_0 Z_{in1}}, \tag{2a}$$

$$Z_{in1} = \frac{1}{4} Z_0. \tag{2b}$$

To transform Z_{in1} to Z_{in}, a transmission line segment with the characteristic impedance of Z_8 and the electrical length of 90° is inserted. So the equations can be expressed as

$$Z_8 = \sqrt{Z_{in1} Z_{in}}. \tag{3}$$

Using (2b), (3) is simplified to

$$Z_8 = \frac{1}{2}\sqrt{Z_0 Z_{in}}. \tag{4}$$

For equal dividing and sequential-phase rotation, the following equations can be obtained

$$Z_2 = \frac{1}{3} Z_0, \quad Z_4 = \frac{1}{2} Z_0, \quad Z_6 = Z_0. \tag{5}$$

In this design, the SP feed is designed at the center frequency 2.25 GHz and $Z_{in} = Z_0 = 50\,\Omega$. The configuration and optimized dimensions are shown in Figure 5(b). Simulated results show that the -10 dB reflection coefficient bandwidth covers from 1.55 GHz to 2.85 GHz (about 59%). And the magnitude balance level among the output ports ($\Delta|S_{j1}|$, $j = 2{\sim}5$) is less than 1 dB over the same impendence band [12].

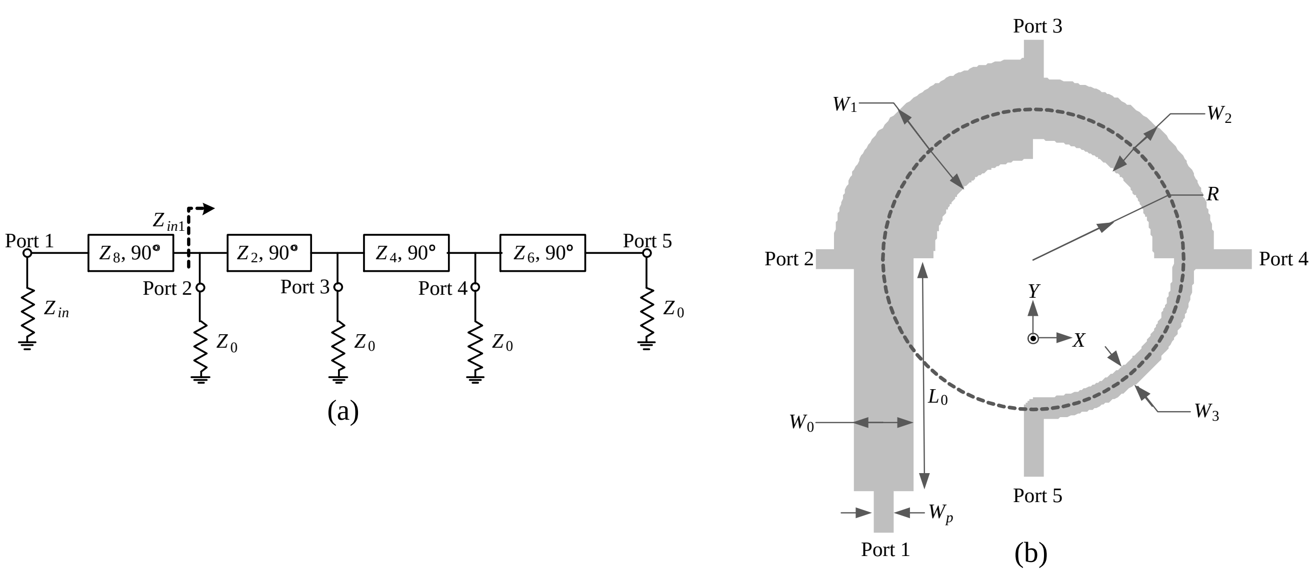


Figure 5. Proposed SP feed using a modified serial power divider: (a) equivalent circuit; (b) configuration. ($R = 11$ mm, $L_0 = 17$ mm, $W_p = 1.5$ mm, $W_0 = 4.4$ mm, $W_1 = 7.4$ mm, $W_2 = 4.5$ mm, $W_3 = 1.6$ mm).

4. BROADBAND CIRCULARLY POLARIZED ANTENNA ARRAY

Figure 6 presents a 2×2 sequentially rotated planar antenna array using the proposed elliptically CP slot antenna element and SP feed. The spacing between elements is taken to be 95 mm (about $0.7\lambda_0$, where λ_0 is the wavelength of center frequency). In order to improve the transition, via pins are used to

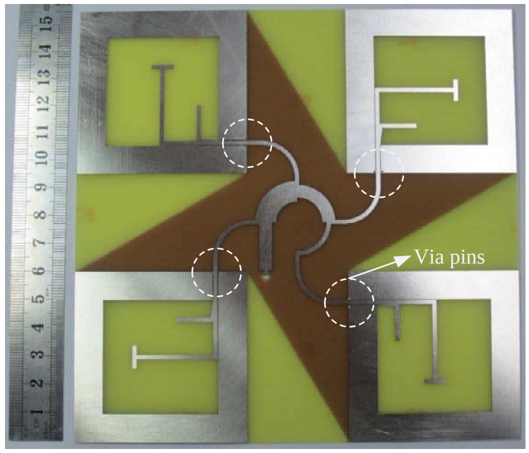


Figure 6. Photograph of the proposed antenna array prototype.

connect the microstrip line to the asymmetric CPW feed of antenna element [2, 3]. And a star-shaped ground plane is applied to improve the impedance and AR bandwidth. The side length of the square antenna array is 155 mm (about $1.16\lambda_0$).

5. EXPERIMENTAL RESULTS AND DISCUSSION

Ansoft HFSS is utilized in the design procedure to optimize structural parameters. An Agilent E5071B vector network analyzer and a far-field measurement system have been used to measure the reflection coefficient and far-field performances of the proposed antenna array, respectively.

Simulated and measured reflection coefficients of the proposed antenna array are shown in Figure 7. The movement of resonant points may be due to the unsteady substrate parameters of FR4 substrate. The measured −10 dB reflection coefficient bandwidth covers 1.63–2.88 GHz (about 55.4%).

Figure 8 presents the simulated and measured gains and ARs of the antenna array. As can be found, the measured 3 dB AR bandwidth covers 1.65–3 GHz (about 58%). The measured gain is more than 6 dBic over the operating band. Normalized radiation patterns at 2.25 GHz of the proposed array are shown in Figure 9. The discrepancy between simulated and measured results is mainly due to the test environment and the effect of the SMA connector in the lower layer. The patterns are bidirectional

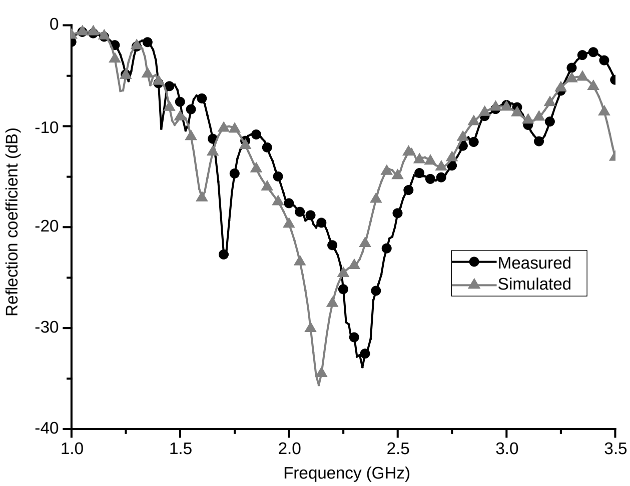


Figure 7. Simulated and measured reflection coefficients of the antenna array.

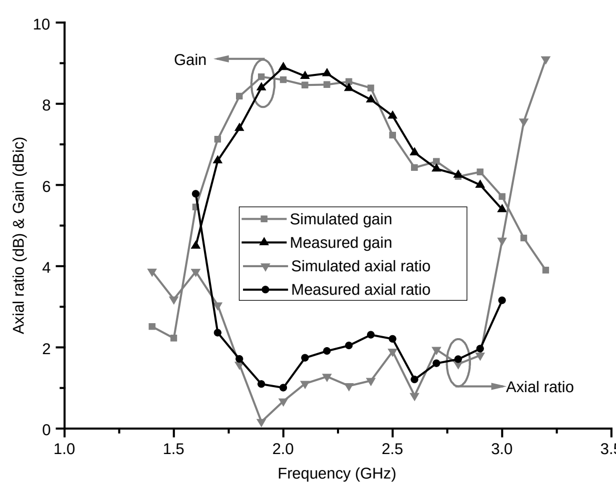


Figure 8. Simulated and measured gains and axial ratios of the antenna array.

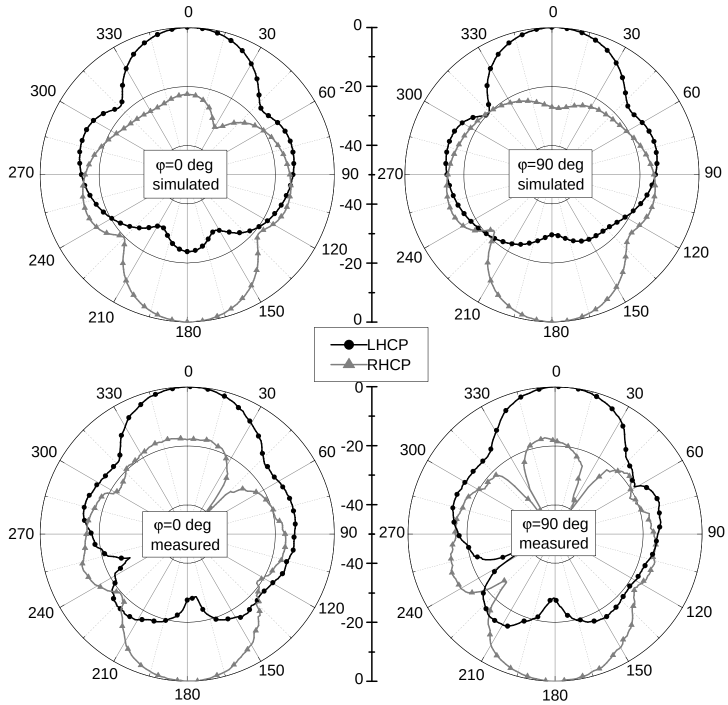


Figure 9. Simulated and measured normalized patterns of the antenna array at 2.25 GHz.

Table 1. Comparison of the CP performances and dimensions between the proposed antenna array and antenna arrays in the previous works.

Ref.	3 dB AR bandwidth	−10 dB reflection bandwidth	Side length of square antenna	Peak gain (dBic)
[2]	49% (1.15–1.9 GHz)	52% (1.15–1.95 GHz) ($S_{11} < -15$ dB)	$1.1\lambda_0$ (200 mm)	8
[3]	31% (5.1–7 GHz)	52% (4–6.825 GHz)	$1.81\lambda_0$ (92 mm)	7.5
Proposed	58% (1.65–3 GHz)	55.4% (1.63–2.88 GHz)	$1.16\lambda_0$ (155 mm)	8.9

with left-hand circularly polarized (LHCP) radiation in the upper-half space and right-hand circularly polarized (RHCP) radiation in the lower-half space. A comparison between the proposed antenna array and the antenna arrays presented in [2, 3] has been shown in Table 1. It is observed that the proposed antenna array has a good CP performance with a compact size.

6. CONCLUSION

A 4-element CP slot patch antenna array employing a microstrip-line-to-asymmetric-CPW feeding network is proposed. Stepped and inverted T-shaped strips are embedded in the feeding structure to expand the bandwidth of the antenna element. Using a modified SP feed, which comprises only four segments for impedance transformations and sequential-phase rotation, and via pins to improve the transition between microstrip line and asymmetric CPW feed line, the proposed antenna array can obtain wide impedance and AR bandwidth. The measured −10 dB reflection coefficient bandwidth is 55.4% and 3 dB AR bandwidth is 58%. Good radiation characteristics can be obtained with gain more than 6 dBic over the operating band.

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