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RESEARCH PAPER

Broad band circularly polarized square slot array antenna with improved sequentially rotated feed network for C-band application

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In this paper, an array antenna with asymmetric antenna fed network is presented. Total size of the proposed array antenna (with 2 × 2 elements) is 90 × 90 mm² and distance between elements (fed by fed) is $\lambda_o/2$ (λ_o = wavelength in free space). The proposed antenna is fed by coaxial cable that isolated input impedance from impedance of the array antenna feed network. The measured impedance bandwidth of the coaxial fed circular polarization array ($S_{11} < -10$ dB) is 47.9% from 4.6 to 7.5 GHz (1.63:1), and the measured 3-dB axial-ratio bandwidth is 42% from 4.7 to 7.2 GHz. The peak gain of antenna is 9.1 dBic.

Keywords: Planar antenna, Slot antenna, Array antenna, Circularly polarized, Feed network

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I. INTRODUCTION

The use of circularly polarized (CP) antennas have advantages such as: very effective in combating multi-path interferences or fading, able to reduce the "Faraday rotation" effect due to the ionosphere and no strict orientation between transmitting and receiving antennas are required [1]. CP arrays which are light weight and low cost are important for applications that need a high gain to overcome the free-space loss due to the long distance between radio transmitter and receiver.

As is well known, the main disadvantage of a microstrip antenna is its narrow impedance bandwidth. For a CP microstrip antenna, both axial-ratio and impedance bandwidths need consideration. Heretofore much work to improve 3-dB axial-ratio and impedance bandwidths has been reported [2–10]. Some methods have been previously proposed to increase the bandwidth of CP antenna. In [2], using a four-way power divider, an array antenna with sequential rotated feeding technique was able to produce a novel CP antenna with good circular polarization and low-voltage standing-wave ratio over a wide frequency band. The elements of antenna were fed by series-fed slot-coupled structure. In [2], the employment of four-way power dividers instead of two-way splitters in cooperate feed network makes the layout much easier.

In ordinary sequentially rotated feed networks, seven quarter-wave transformers are linked together in sequential rotation (0°, 90°, 180°, and 270°) which causes an increase of the bandwidth of CP antenna – this is presented in [3–9]. The main disadvantage of this method, is due to the use of a multiple quarter wave transformer, which leads to decreased gain of array antenna. As the above discussion attests [1–10], two factors are effective in improving the results of a CP array antenna. These are: (1) the use of a broadband low loss feed network, with the ability to create a 90° phase difference between adjacent elements; and (2) utilize the broadband CP antenna elements without sidelobe.

In this paper, in order to increase impedance and 3 dB axial-ratio bandwidths, a CP array antenna employing two mentioned factors is utilized. Innovations used in this paper are:

- Slot element with broadband impedance and 3 dB axial-ratio bandwidths;
- Centralized feed network without using quarter wavelength transformer which: (i) create balanced pattern and enhance CP purity; (ii) increase 3-dB axial-ratio and impedance bandwidths;
- Decreased mutual coupling between element and feed network and increased gain of array antenna.

The proposed CP antenna array with low variation of gain in whole of impedance and 3 dB axial-ratio bandwidths can be used in C-band applications such as: WLAN/WiMAX, RFID, etc. Details and results of antenna parameters are discussed in the following sections.

II. SINGLE-ELEMENT DESIGN

The single-element of antenna is designed on the FR4 substrate with relative permittivity of $\varepsilon_r = 4.4$ and loss tangent of $(=\tan\delta) = 0.02$. The antenna is fed by coplanar waveguide (CPW) with 200 Ω input impedance. The main feed of the CPW (W_f) is 0.75 mm, and to provide 200 Ω input

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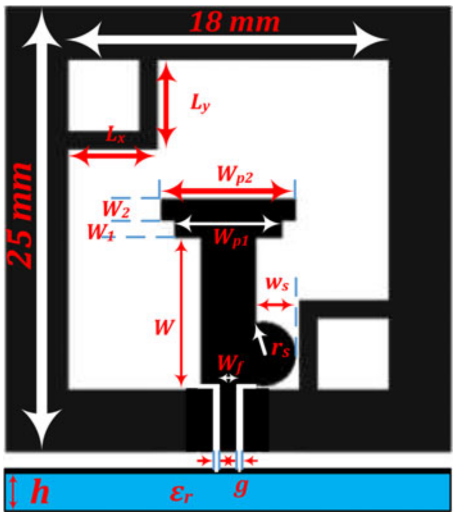

Fig. 1. Geometry of the proposed CP single-element antenna.

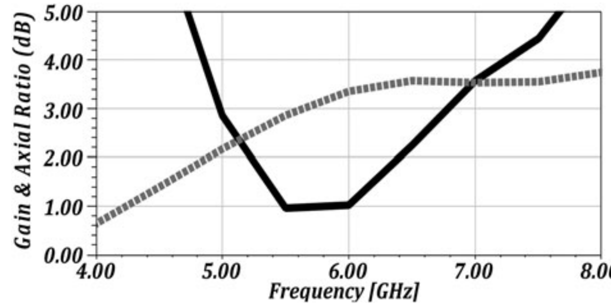

Fig. 3. Simulated gain (dash line) and axial ratio (solid line) of the single-element antenna.

impedance, the gap distance (g) between coplanar ground and the main feed of the CPW (W_f) is obtained as 0.3 mm, as shown in Fig. 1. To prevent the accumulation of surface flow current in the corners and also the rotation of the current on ground-loop, two cross L-shaped structures are embedded at the two opposite corners. (The influence of the other parameters on the antenna performance can be referred to [10].) Other dimensions of the antenna parameters are presented in Table 1. In Figs 2 and 3, the simulated results of S_{11} and axial-ratio bandwidth of the antenna that are fed by 200 Ω input impedance, are shown, respectively.

The proposed CP antenna has an area of 625 mm^2 (25 × 25 mm^2), which is considerably less than the previously published slot antennas, as summarized in Table 2 along with other salient parameters. Compared with other similar types of CP slot antennas fabricated on the same substrate, the proposed antenna exhibits an impedance bandwidth which is significantly larger and with no reduction in the gain performance, as well as having a larger circular polarization bandwidth. The gain is comparable with previous designs. The simulated pattern of single-element antenna is shown in Fig. 4. (The antenna radiated RHCP in the −z-direction and LHCP in the +z-direction.)

Table 1. Dimensions of the antenna parameters (all value in mm).

W_f	r_s	w_s	W_{p2}	W_{p1}
0.75	2	2.25	7.6	6
W_1	W	L_x	L_y	W_2
1	8.5	5	5	1.2
h (substrate height) = 0.8				

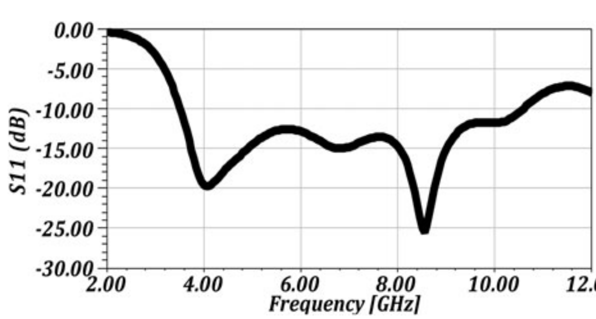

Fig. 2. Simulated S_{11} of the single-element antenna.

III. FEED NETWORK DESIGN

It is a well-established fact to provide circular polarization in antenna array. To enhance the 3 dB axial-ratio bandwidth and pattern balance, each element must be rotated at 90° between adjacent and 180° between opposite elements and phase delay of feed line, has to change according to elements rotation. In Fig. 5, feed line of antenna is presented. As shown in Fig. 5, the antenna input is fed by coaxial that isolated microstrip impedance from input impedance. The microstrip feeding network is a tree network in which the phase shift of each output is adjusted by the length of line. One of the most important

Table 2. Comparison of the proposed CPSSA antenna size and measured characteristics with other references.

Ref.	Size (mm^3)	BW (GHz)	ARBW (GHz)	P. G. (dBic)
[11]	70 × 70 × 1.60	0.85 (1.75–2.6)	0.4 (1.7–2.1)	3.7
[12]	70 × 70 × 1.60	0.20 (1.5–1.7)	0.3 (1.5–1.8)	3.5
[13]	70 × 70 × 1.60	0.80 (1.6–2.4)	0.2 (1.8–2.0)	3.5
[14]	60 × 60 × 0.76	0.80 (1.7–2.5)	0.7 (1.8–2.5)	3.5
[15]	60 × 60 × 0.74	1.40 (1.6–3.0)	0.7 (2.3–3.0)	4
This work	25 × 25 × 0.80	7.3 (3.3–10.6)	1.8 (5–6.8)	3.7

Dielectric substrate used is FR4 with $\varepsilon_r = 4.4$, tan$\delta = 0.02$. The impedance bandwidth is for a frequency range where the VSWR ≤ 2, and ARBW is the 3-dB axial-ratio bandwidth.

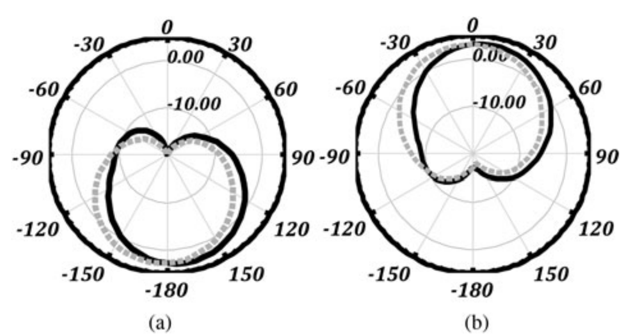

Fig. 4. The simulated pattern of single-element antenna (a) RHCP and (b) LHCP at 5.5 GHz.

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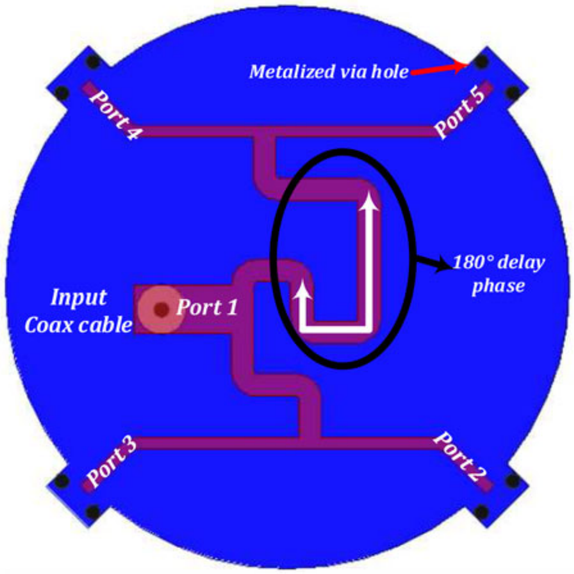

Fig. 5. Feeding network of the CP square slot array.

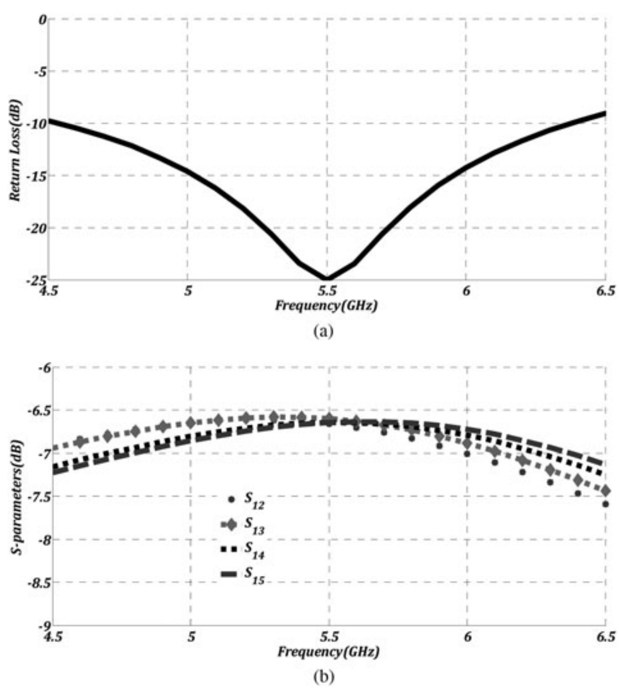

Fig. 6. (a) The simulated S_{11} values of the feed network and (b) the simulated S_{12}, S_{13}, S_{14}, and S_{15} values of the feed network.

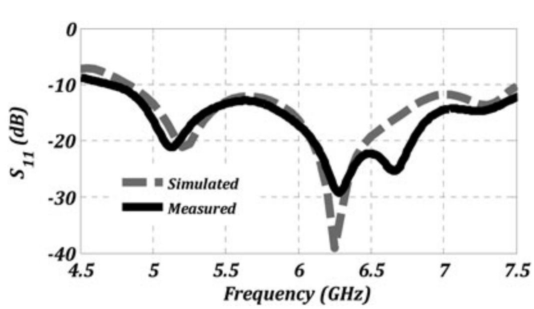

Fig. 7. Comparison between the simulated and measured return loss of the proposed array antenna.

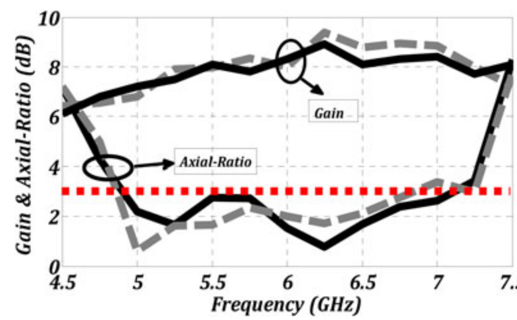

Fig. 8. Comparison between the simulated and measured gain and axial ratio of the proposed array antenna (dash line = simulated, solid line = measured).

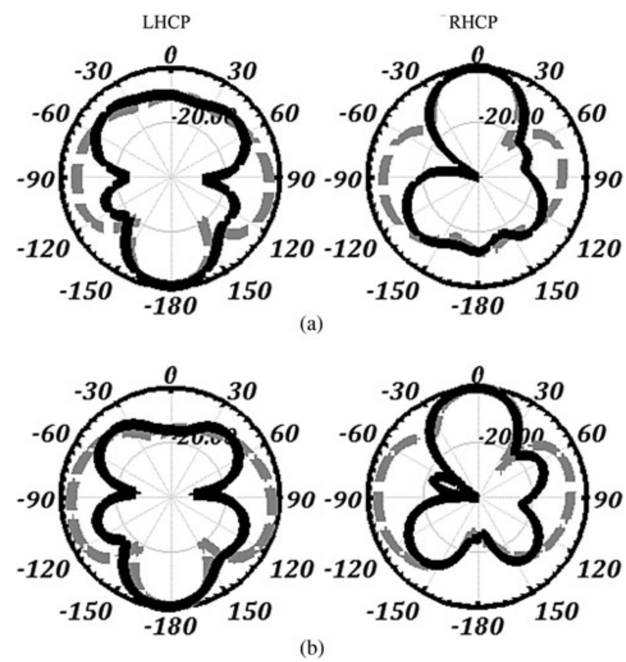

Fig. 9. Comparison between simulated and measured LHCP and RHCP patterns of the proposed array antenna at 6.25 GHz. (a) Simulated. (b) Measured.

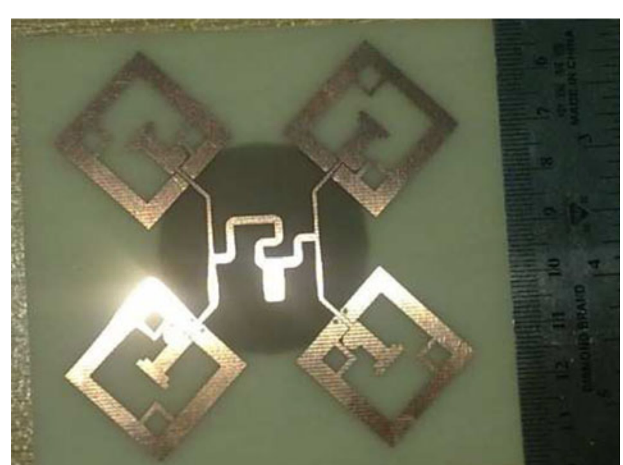

Fig. 10. Prototype of the fabricated array antenna configuration.

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Table 3. Comparison of the proposed feed network structure and measured characteristics with other array antennas.

Reference	Feed network	BW (GHz)	ARBW (GHz)	P.G. (dBic)	Substrate
[16]	Asymmetric CPW	0.80 (1.1–1.9)	0.80 (1.1–1.9)	~7.5	FR4
[7]	Aperture coupled	0.80 (1.6–2.4)	0.60 (1.7–2.3)	~15	Rogers 5880
This work	Asymmetric CPW	2.9 (4.6–7.5)	2.5 (4.7–7.2)	9.1	FR4

The impedance bandwidth (BW) is the frequency range where the VSWR $\leq$ 2, and ARBW is the 3-dB axial-ratio bandwidth.

advantages of this antenna feeding network is employed in any quarter wavelength transformer. The antenna element is fed by CPW. To attain impedance matching and power transition efficiency between microstrip line (in feed network) and CPW line (in antenna element), two via in connection place are used. The distance between two via has important role in the impedance matching.

The configuration of the array network was designed and simulated by using Agilent™ Advance Design System commercial software. The simulated S_{11}, as a function of frequency is presented in Fig. 6(a).

The impedance bandwidth of this feeding network, defined as the frequency with an S_{11} above 10 dB, covered the frequency band from 4.56 to 6.41 GHz. Figure 6(b) plots the S parameters of the five-port feed network. According to this figure, all ports were matched, and the transmission coefficient was −6.6 dB from the input port to each output port.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The return loss of proposed array antenna was measured by Agilent TM 8722ES network analyzer. Comparison between the simulated and measured return loss of antenna arrays is illustrated in Fig. 7. As evident from Fig. 7, the simulated impedance bandwidth is 43.9% from 4.8 to 7.5 GHz and measured impedance bandwidth is 47.9% from 4.6 to 7.5 GHz. In Fig. 8, simulated and measured axial ratio and peak gain of antenna are presented. The 3 dB bandwidth of axial ratio is 42% from 4.7 to 7.2 GHz and the minimum value of axial ratio is 0.9 at 6.25 GHz. The peak gain of CP array antenna is 9.1 dBic at 6.25 GHz and the average gain of antenna is 7.5 dBic. The comparison between simulated and measured pattern of antenna in the minimum value of axial ratio at 6.25 GHz is presented in Fig. 8. The comparison between the simulated and measured radiation pattern of the proposed CP array antenna is shown in Fig. 9. The half-power bandwidth of antenna is 52°. The prototype of fabricated proposed antenna is shown in Fig. 10.

The design comparison with the previous CP array structures with sequential feed network and arc feed line, is presented in Table 3. As illustrated in Table 3, the impedance and axial-ratio bandwidths are significantly increased, i.e. the impedance and axial-ratio bandwidths are more than three- and twofold wider than the previous designs, respectively.

V. CONCLUSION

In this paper, an array antenna with 2 × 2 elements was presented. The impedance bandwidth of CP array antenna was 47.9% from 4.6 to 7.5 GHz and 3 dB of axial-ratio bandwidth was 42%. The coaxial cable to isolate between microstrip feedline and input impedances was utilized. Impedance bandwidth, 3 dB axial-ratio bandwidth, and gain of CP array antenna were increased by eliminating quarter wavelength transformer and focusing feed network. In addition, in order to match impedance between microstrip line (in feed network) and CPW feed line (in each element) two via in input of each element was utilized. Using of via has caused to enhance cross-polarization in antenna and finally has led to bandwidth of circular polarization.

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