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Broadband Circularly Polarized Bowtie Antenna Array Using Sequentially Rotated Technique

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ABSTRACT A circularly polarized bowtie antenna array for wideband application is presented, which employs a dual-polarized bowtie antenna with electromagnetic coupling feed as the radiating element. By introducing a swallow-tailed feed-strip and an end vertical loading, a wide impedance bandwidth is achieved with a reduced antenna size, without using any impedance matching circuits. Four array elements are used in a 2×2 configuration to obtain high gain performance. To improve the axial ratio (AR), the array elements have been sequentially rotated. The proposed antenna has an impedance bandwidth for VSWR $\leq$ 1.5 of 46% ranging from 1.1 to 1.77 GHz. The AR results are better than 0.75 dB within the impedance bandwidth. The gain of the array varies from 10.8 to 12.2 dBi within the operating band. Acceptable agreement is found between the simulated and measured results, verifying the proposed design with wide impedance, AR, and gain bandwidths.

INDEX TERMS Circular polarization, bowtie antenna, wideband array.

I. INTRODUCTION

Patch, loop and helical antennas [1]–[4] have been used in a large number of modern communication systems, such as radio frequency identification, mobile communication and Global Positioning System (GPS). The radiation of these antennas is circularly polarized (CP) [5], [6], which is insensitive to respective orientations and reduces multipath effects.

Many approaches have been reported to broaden the bandwidth of traditional CP antennas. The stacked patch antennas with aperture coupling feed [7]–[9] can provide a wider bandwidth. However, this multi-layer structure leads to high cost and difficult adjustment. Broadband patch elements fed by two probes [10], [11] are introduced. In [12]–[16], wideband dual-polarized crossed dipole antennas are proposed, which can realize simple structure and stable performance.

The above approaches can be utilized to improve the antenna performance, but each has deficiencies in their implementation. One planar, lossless method proposed initially for linear polarized array antennas [17] is to provide the feeding ports with equal amplitude and opposite phase. Then this can be extended for the CP patch arrays [18]–[23] by sequentially rotating the orientation of each array element, in which way can suppress the cross polarization and increase the AR bandwidth simultaneously.

A wideband circularly polarized bowtie antenna array using sequentially rotated technique is presented in this paper. The array consists of 2×2 DPBAs as radiating elements and a broadband phase shifting network. Each DPBA includes two swallow-tailed feed strips and four end vertical loadings. The bowtie antenna element has simple structure and presents excellent impedance performance. The swallow-tailed feed strips are introduced to improve impedance matching of the DPBA. The phase shifting network is realized by integrating Wilkinson power divider with a modified Schiffman phase shifter. By adopting sequential rotation method, the 3-dB AR bandwidth of the antenna array has been further enhanced. This method can be explained as rotating each DPBA element sequentially with a specific phase shift. A prototype of the proposed antenna array has been fabricated and measured. Good agreement between the simulated and measured results is obtained for the VSWR, AR, radiation patterns, and the gain. This antenna can be a good candidate for the navigation systems.

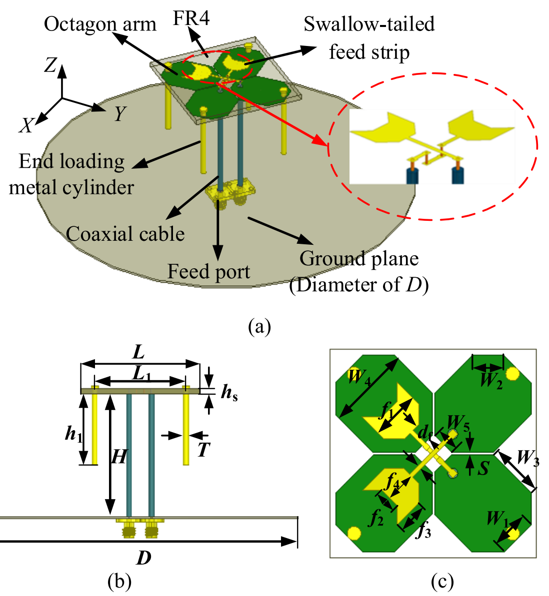

FIGURE 1. Configuration of the bowtie antenna. (a) perspective view. (b) side view. (c). top view.

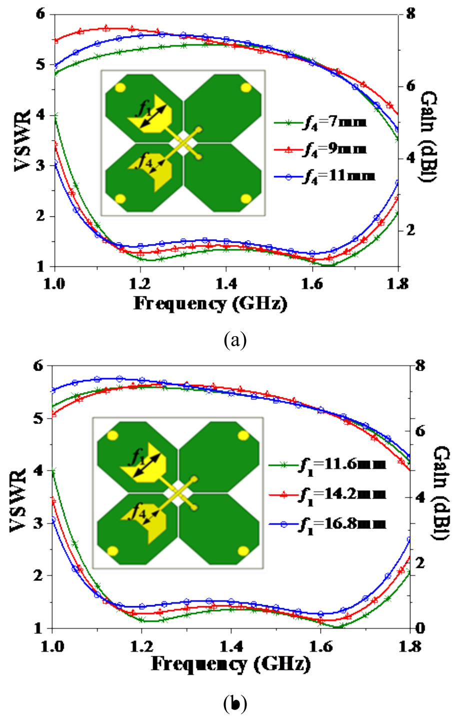

FIGURE 2. Frequency response of the simulated VSWR and Gain with (a) f_4, (b) f_1.

TABLE 1. Dimensions of the bowtie antenna (Unit: mm).

Prarameter	D	L	L_1	h_s	h_1	H	T	f_1	f_2
Dim.	200	60	46	3	36	62	3	14.2	5.8
Prarameter	f_3	f_4	d_f	W_1	W_2	W_3	W_4	W_5	S
Dim.	6	9	5	11	9.2	15.5	24	7	0.64

II. DUAL-POLARIZED BOWTIE ANTENNA ELEMENT

A. CONFIGURATION OF THE DPBA

The configuration of the DPBA is shown in Fig. 1. The DPBA is printed on a 3-mm-thick substrate with a relative permittivity of 4.4, which is located apart from the ground plane with a height H. The antenna consists of a pair of crossed bowtie dipole, two swallow-tailed feed-strips, four end loading metal cylinders, and a ground plane with a diameter of D. The side view and the detailed structure of bowtie dipole are shown in Fig. 1 (b) and (c), respectively. The dual-polarized bowtie dipole is a pair of dipoles whose centers are co-located and whose axes are orthogonal. Each bowtie dipole has a pair of octagon arms. The two bowtie dipoles are printed on the bottom face of the substrate while the two swallow-tailed feed-strips are etched on the top face. One of the swallow-tailed feed-strips has a transition bridge as shown in the inset to Fig. 1 (a). The distance between the crossed bowtie dipole and the ground plane is about a quarter of wavelength at the center frequency. The end vertical loading metal cylinders with a length of h_1 and a diameter of T can reduce the lateral dimensions of the antenna.

The feed mechanism of the bowtie dipole is divided into two parts: a vertical coaxial cable and a swallow-tailed feed strip. As shown in Fig. 1 (c), each dipole is fed by a swallow-tailed coupling feed strip. The swallow-tailed strips are used to achieve impedance matching. The two feed strips are placed orthogonally on the two dipoles. The final optimal antenna parameters are listed in Table 1.

B. PARAMETRIC STUDY

To study the influence of the swallow-tailed feed strip on the impedance matching of the DPBA, the dimension of the swallow-tailed feed strip is investigated and demonstrated in Fig. 2. These dimensions include the length of f_4 and the width of f_1. Fig. 2 (a) shows the simulated impedance characteristics versus frequency corresponding to different values of f_4. It is observed that the VSWR is better in the lower band while getting worse in the upper band when f_4 increases. Here a good impedance match is achieved when $f_4 = 9$ mm. The input impedance variation with f_1 is shown in Fig. 2 (b), and the impedance curves have same trend when f_1 varies as f_4. With optimum impedance matching, the f_1 is equal to 5.8mm.

The parametric study is also conducted to investigate the relationship between the length of the vertical cylinder and impedance characteristics of the proposed antenna. Fig. 3 (a) shows the simulated VSWR and gain when the length of end loading metal cylinder (h_1) is changing from 33 to 39 mm with a step of 3 mm; in Fig. 3 (b), the diameter of metal cylinder (T) varies from 2mm to 4mm. From these figures, it can be seen that the two parameters hardly affect the upper band of the antenna while the lower band of the antenna is badly affected. The matching point moves with the changing of parameters. It should be noted that the size of the antenna is

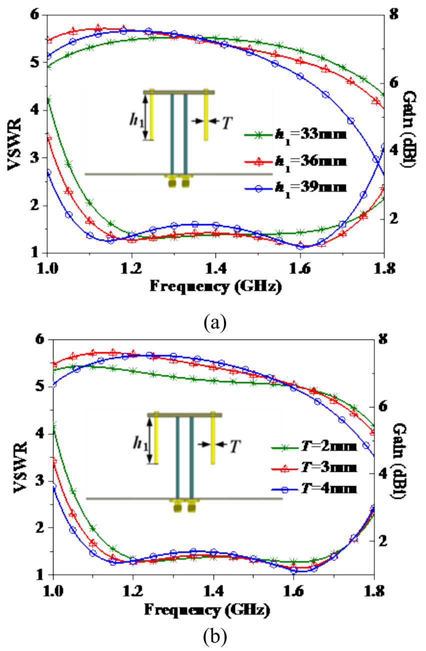

FIGURE 3. Frequency response of the simulated VSWR and gain with (a) h_1, (b) T.

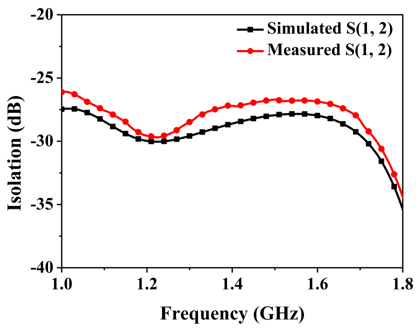

FIGURE 4. The isolations between two input ports of the DPBA.

significantly reduced due to the existence of the vertical metal cylinders. With $h_1 = 36$mm and $T = 1.5$mm, the optimal results are obtained for the proposed antenna. The simulated and measured isolations between the two input ports are depicted in Fig. 4. Note that both the simulated and measured port-to-port isolation is lower than -25 dB. The difference between the simulation and measurement could attributed to fabrication imperfectness and measurement errors.

III. BOWTIE ANTENNA ARRAY

A. CONFIGURATION OF THE ARRAY

In this section, a 2 × 2 antenna array using the DPBAs is designed and investigated. The configurations of the array and feed network are shown in Fig. 5. It consists of four DPBA elements on the ground plane with a radius of 200 mm, where the element distance equals to 135 mm (about $0.63\lambda_0$, where λ_0 is the wavelength at the center frequency). To improve the AR performance, the array elements

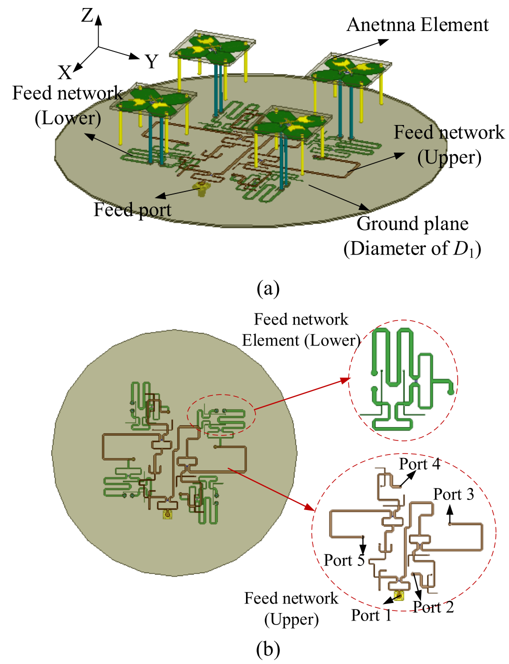

FIGURE 5. Configuration of the proposed antenna. (a) Perspective view. (b) Feed network.

are sequentially rotated in both spatial orientation and phase (0°, 90°, 180° and 270°).

For the feed network in Fig. 5 (b), the array antenna is fed by a broadband phase shifting network, which integrates the Wilkinson power divider with a modified Schiffman phase shifter. An equal amplitude for four output ports (Port 2, 3, 4, and 5) is provided and a required sequential current phase shift of 0°, 90°, 180° and 270° is obtained. Three pairs of $\lambda_g/8$ open and short lines are employed to minify the phase variation, where λ_g refers to the guided wavelength in the substrate. Three 100-Ω chip resistors are used to increase the isolation among the output ports. The feed network of the antenna element is printed on the back side of the 1-mm-thick substrate ($\varepsilon_r = 2.65$). The ground plane is printed on the other side of the substrate as a reflector. Port 1 is connected to a SMA as the input port.

B. DISCUSSION

To investigate the method of rotating each array element by a 90° increment, a comparison on AR performances between the conventional and the rotated 2 × 2 array is carried out. As shown in Fig. 6, the AR of the array with sequential rotation is better than 0.75 dB within the operating band, while the conventional array without rotation has an AR variation from 0.4 to 3.57 dB. Hence, the AR performance has been effectively improved by applying the sequential rotation method.

C. MEASURED AND SIMULATED RESULTS

The proposed 2 × 2 antenna array has been fabricated and tested, the photograph of which is shown in Fig. 7.

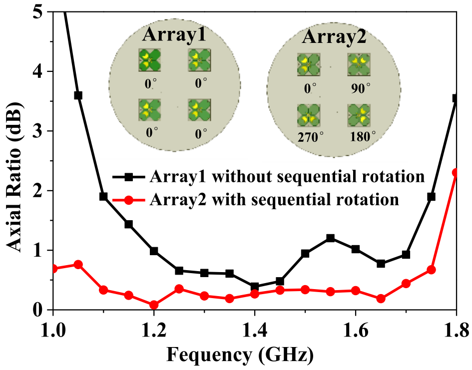

FIGURE 6. Simulated AR of the conventional and the rotated 2 × 2 array.

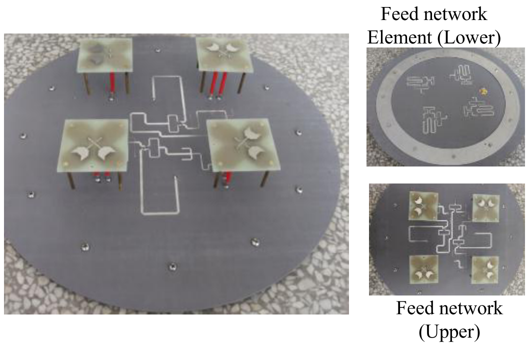

FIGURE 7. Photograph of the fabricated array antenna.

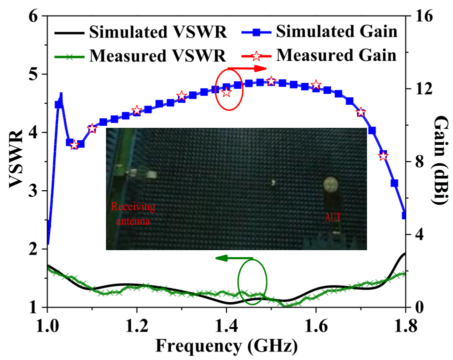

FIGURE 8. Simulated and measured VSWR and Gain of the proposed array.

The impedance characteristics, 3-dB AR bandwidth, gain and radiation patterns are measured using an Agilent E8363B network analyzer and an anechoic chamber. The frequency responses of VSWR and gain for the array are depicted in Fig. 8, and it is obvious that the simulated data and the measurements are in a fairly good agreement. The measured impedance matching bandwidth for VSWR $\leq$ 1.5 is approximately 46% ranging from 1.1 to 1.77 GHz, covering the overall AR bandwidth (AR $<$ 3 dB), while the measured gain varies from 10.8 to 12.2 dBi in the overall band.

Simulated and measured results also show stable HPBW, versus frequency at phi $= 0°$ (XOZ-plane) and phi $= 90°$ (YOZ-plane), and the radiation patterns at 1.2, 1.45, and 1.7 GHz are depicted in Fig. 9, respectively. The results indicate that its co-polarization is right-hand circularly polarized (RHCP) and half-power beamwidths of about 50°, 40°, and 34° are obtained at the frequencies of 1.2, 1.45, and 1.7 GHz, respectively. There is reasonable agreement between the simulated and measured radiation patterns. To verify the good performance of the proposed array antenna, a comparison

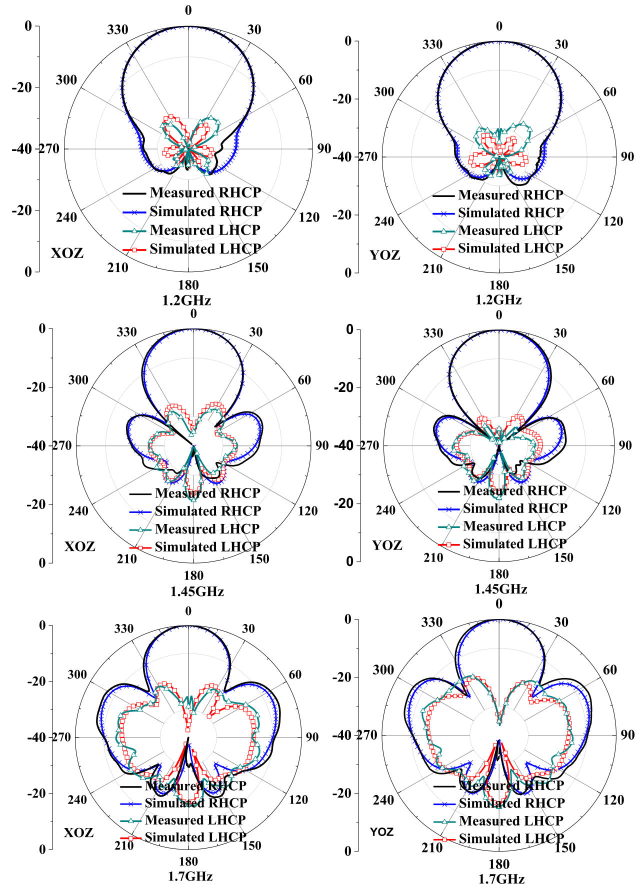

FIGURE 9. Simulated and measured radiation patterns of the array at 1.2, 1.45, and 1.7GHz.

TABLE 2. Comparison with other works.

Ref.	Bandwidth (GHz)	AR bandwidth (GHz)	Peak Gain (dBic)
[2]	RHCP: 12.5% (4.95-5.61) for VSWR<2 LHCP: 14.7% (5.05-5.85) for VSWR<2	RHCP: 12.5% (4.95-5.61) for 3-dB AR LHCP: 14.7% (5.05-5.85) for 3-dB AR	10.3 for RHCP 10.7 for LHCP
[21]	52% (4-6.825) for VSWR<2	31% (5.125-7) for 3-dB AR	7.46
[22]	47.8% (5.1-8.3) for VSWR<2	47.8% (5.1-8.3) for 1-dB AR	18
[23]	54.5% (1.6-2.8) for VSWR<2	19% (1.9-2.3) for 3-dB AR	13.5
This work	46% (1.1-1.77) for VSWR<1.5	55.6% (1-1.77) for 1-dB AR	12.2

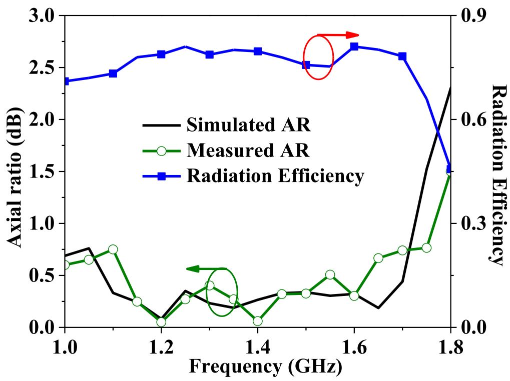

FIGURE 10. Simulated and measured AR and gain against frequency.

with other works on impedance bandwidth, AR bandwidth, and peak gain is carried out in Table 2.

As apparently depicted by the simulated and measured results reported in Fig. 10, the AR is better than 0.75 dB over the entire impedance band ranging from 1.1 to 1.77 GHz. Such good performance is related to the sequential 90° rotation of the array element and a proper phase shift provided by the feed network. In addition, the array antenna exhibits stable and high radiation efficiency which varies from 73% to 83% over the operating band.

IV. CONCLUSION

The radiation characteristics of a bowtie antenna array are investigated in this paper. By loading the swallow-tailed feed strip, the impedance matching of the DPBA has been improved effectively. The sequential rotation technique is introduced to enhance the AR characteristic. The array achieves a good impendence bandwidth for VSWR $\leq$ 1.5 of 46% ranging from 1.1 to 1.77 GHz, an excellent AR better than 0.75 dB within the impedance band, a higher than 10.8 dBi antenna gain, and symmetrical radiation patterns. Due to these performances, the array antenna is a good candidate for navigation systems.

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