A Dual-Broadband Circularly Polarized Halved Falcate-Shape Printed Monopole Antenna

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ABSTRACT: A halved falcate-shape dual-broadband circularly polarized printed monopole antenna is proposed. To generate the equal amplitude orthogonal modes, two halved falcate-shaped antenna are used. Also, to provide the 90° phase difference between the two modes, three stubs are used in the ground plane of the antenna. The proposed antenna provides 22.6 (1.36–1.72 GHz) and 44.4% (5.25–8.25 GHz) 3 dB axial ratio bandwidth over the lower and upper bands, respectively. By adjusting the parameters of the antenna, the lower and upper band center frequencies can be tuned individually. The proposed antenna is fabricated, and results are compared with those of the simulation.
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Keywords: axial ratio; circular polarization; falcate-shape; printed monopole antenna

I. INTRODUCTION

Circularly polarized (CP) printed antennas have received a great deal of attention in recent years for wireless communication systems such as GSM, PCS, WLAN, DRCS, RFID, and UWB with military and biotechnology applications. Generally, a printed monopole antenna produces linear polarized wave, and it is hard to achieve circular polarization radiation. CP radiation plays a very important role for improving the quality of received signals in the wireless communication systems.

Significant research has taken place to increase the applications of the CP printed antennas in wireless communication using single feed [1–5] especially to have multiband behavior [6, 7] and [8]. Generally, CP radiation has been produced by antenna structures such as: a fractal boundary microstrip antenna [1]; annular-ring slot with double-bent microstripline feed [2]; probe compensated single feed CP fractal-shaped microstrip antennas [3]; and aperture-coupled asymmetrical C-shaped slot [4]. All these antennas achieve a 3 dB axial ratio (AR) bandwidth of between 1.6% and 12.4% producing single-band and narrowband CP radiation. Research on CP radiation with 3 dB AR over the UWB range has been done in [5], where a spiral antenna with integrated balun is used.

Dual-band CP radiation has been investigated in [6–8]. In [6], a combination of slit, beveling, and stub either on the monopole antenna or on the ground plane is used to achieve up to 6% LHCP and 23.1% RHCP bandwidth over the lower and upper bands, respectively. CPW fed slot antenna loaded with two spiral slots has been presented in [7]. The antenna has 8.4% CP bandwidth over the lower band and 19.24% over the upper band. In [8], S-shaped slot created on the microstrip antenna provides dual-band circular polarization with 3.6% and 1.1% CP bandwidth over the lower and upper bands, respectively.

In this article, a dual-broadband CP printed monopole antenna with single feed is presented. The antenna is created by connecting two halved falcate-shape patches from a corner, along with three stubs in the ground plane. Results show more than 20% and 40% CP bandwidth in the lower and upper band, respectively. Changing the stub lengths tunes the center frequencies of the lower and upper bands. The proposed antenna is fabricated and the results of simulation as obtained through HFSS software package are compared with the measured results.

II. FALCATE-SHAPE ANTENNA

To have an antenna that can operate over a large frequency bandwidth requires a geometry in which multiresonances can be created. Printed antennas with curved radiating surface, such as the proposed falcate-shape, can meet such requirement.

The falcate geometry is created by overlapping two circles of different radiuses. The right hand section of the smaller circle gives the falcate shape, as shown in Figure 1a.

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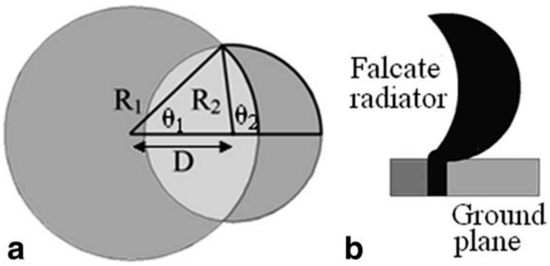

Figure 1 (a) Construction of the falcate-shape element, (b) falcate shaped printed antenna, and (c) current distribution.

The radii of the circles are assumed R_1 and R_2. The distance between the centers is D. Figure 1b shows the final design of the linearly polarized antenna.

Based on the geometry shown in Figure 1, we have

$$L_1 = 2 \times R_1 \times \theta_1 \tag{1}$$

$$L_2 = 2 \times R_2 \times \theta_2 \tag{2}$$

where L_1 and L_2 are the smaller and bigger arcs. Then, we have

$$\cos(\theta_1) = \left(\frac{R_1^2 - R_2^2 + D^2}{2 \times R_1 \times D}\right) \tag{3}$$

$$\cos(\theta_2) = \left(\frac{R_1^2 - R_2^2 - D^2}{2 \times R_2 \times D}\right) \tag{4}$$

To design a falcate-shape monopole antenna, at first one should select the lower resonant frequency. The resonant lengths, L_1 and L_2, can be obtained through the following formula, (5), where $\varepsilon_{\mathrm{eff}}$ is given in Eq. (6).

$$f_{\mathrm{r}} = \frac{c}{4\sqrt{\varepsilon_{\mathrm{eff}}}L} \tag{5}$$

where

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_{\mathrm{r}} + 1}{2s} \tag{6}$$

Replacing (5) and (6) in (3) and (4) gives a system of equations with two equations and three uncertain parameters. One can solve these equations is by considering D as a determined value and obtaining R_1 and R_2 by solving the system of equations.

To generate multiband CP radiation requires multiresonance structures that can support two orthogonal current components with equal amplitude and 90° phase difference (PD). Thus, to meet the desired CP conditions, the basic falcate structure is modified. The falcate structure is halved, one part is rotated 90° around the *z*-axis and connected to the other part from the corner, as shown in Figure 2. Also, shown in this figure is the prototype of the antenna fabricated. Thus, two orthogonal arms for two orthogonal current components are created. It will be shown in the following section that this antenna structure supports two well-defined frequency bands.

To produce the 90° PD between the currents on each arm of the halved-falcate shape and correct the current distribution on the arms, stubs can be placed on the ground plane of the structure. Such stubs operate as reactance. These stubs can be used to tune the phase difference to reach 90° between the two arms. Also, each stub balances the CP radiation and improves the 3 dB AR. The effect of the stubs on the input impedance is shown in Figure 3. A stub when placed in the antenna structure changes the imaginary part of the antenna input impedance to the required value. As can be seen in the Figure 3, without using the stubs, the reactance of the antenna in the lower and upper bands is large. When the stubs are placed on the ground plane of the antenna, the reactance of the antenna in the lower and upper bands decreases to an

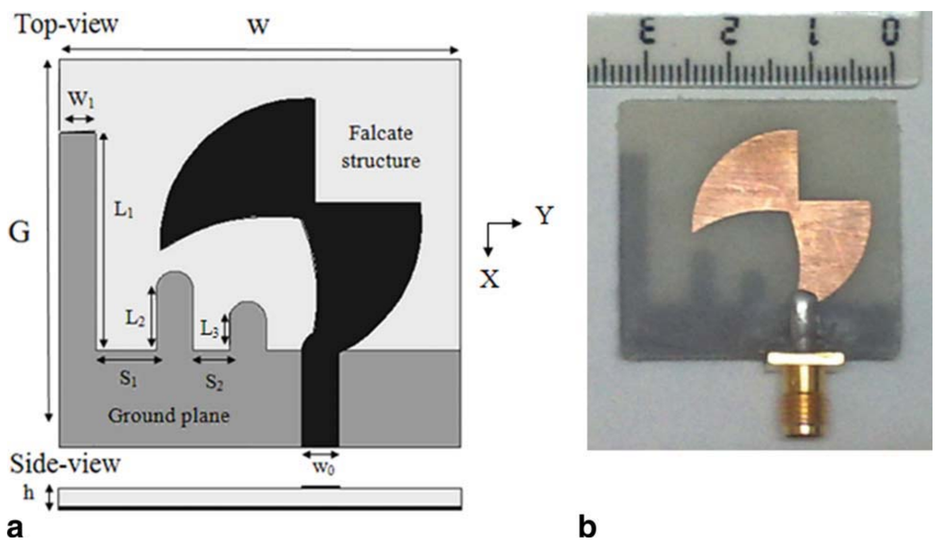

Figure 2 (a) Halved falcate shaped antenna and (b) the fabricated antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

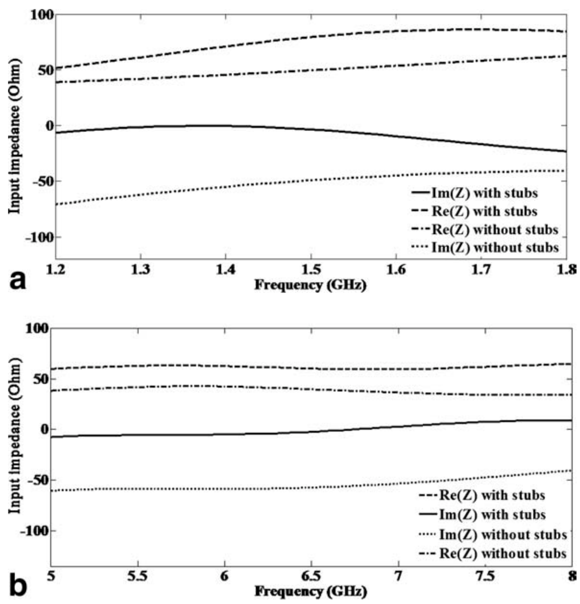

Figure 3 The effect of the stubs on the antenna input impedance. (a) Lower band with and without stubs and (b) upper band with and without stubs.

almost constant low value. So, the phase and amplitude of the antenna excitation modify.

The proposed CP antenna has a substrate of dimensions $G \times W = 30$ mm $\times$ 33 mm, with thickness $h = 1.575$ mm and relative dielectric permittivity of $\varepsilon_r = 2.33$. The halved-falcate shape antenna is fed via a microstrip line with a strip of width $W_0 = 3$ mm and length of 6 mm. The falcate shape has parameters of $R_1 = 16$ mm, $R_2 = 12$ mm, and $D = 14$ mm, which are suitable for the optimized halved-falcate shape antenna. The length of the stubs to improve the AR and produce the required 90° phase shift are found through optimization to be $L_1 = 18$ mm, $L_2 = 5$ mm, and $L_3 = 2.5$ mm.

III. SIMULATION AND MEASURMENTT RESULTS

The simulated return loss of the basic structure, the falcate-shape antenna is shown in Figure 4. The results show that the basic format of the falcate shape antenna has a very wide impedance bandwidth with the lower frequency limit being 1.15 GHz. In this case, the parameters of D, R_1, and R_2 are 14 mm, 16 mm, and 12 mm, respectively.

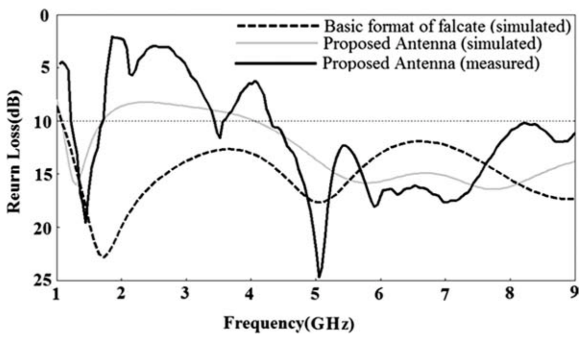

Figure 4 Simulated and measured return loss of the basic format of the falcate shape antenna and the proposed antenna.

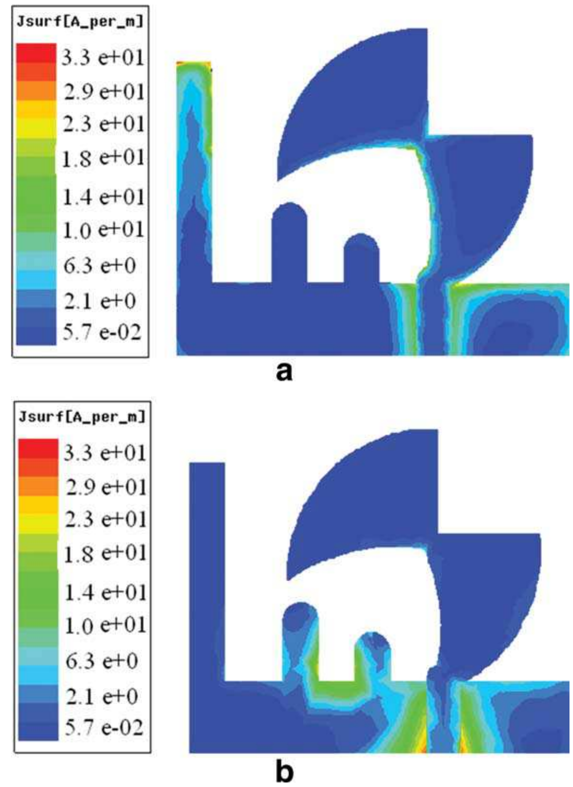

Figure 5 Simulated current surface distribution resonant mode at center frequency of lower and upper band (a) 1.55 GHz and (b) 6.75 GHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

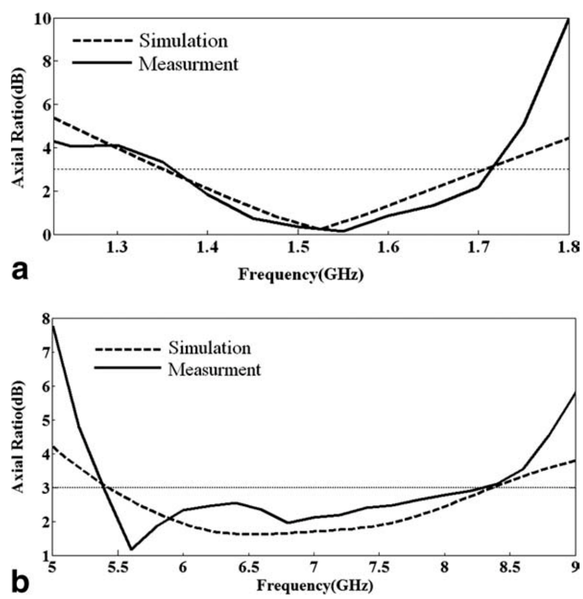

Figure 6 Simulated and measured AR over the (a) lower band and (b) upper band.

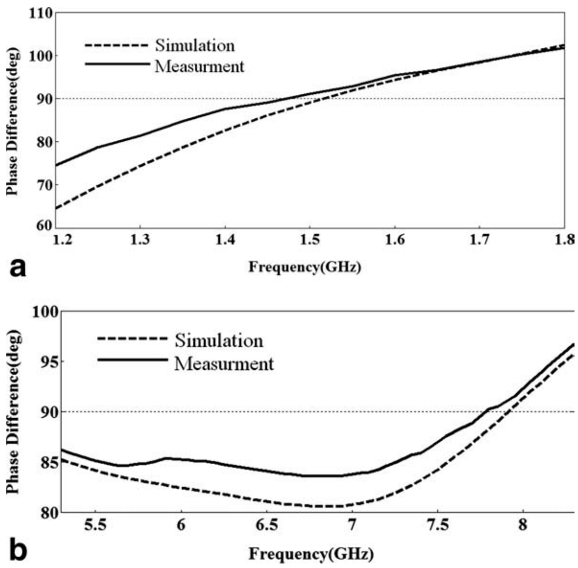

Figure 7 Simulated and measured PD at broadside direction over the (a) lower band and (b) upper band.

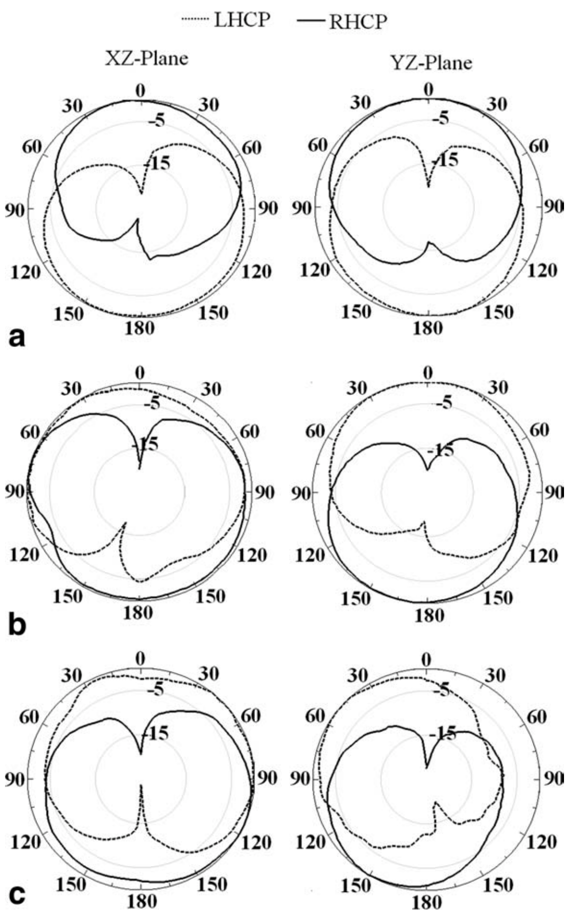

Figure 8 Measured radiation patterns for the proposed antenna (a) lower band at 1.55 GHz, (b) upper band at 6 GHz, and (c) at 7.5 GHz.

TABLE I Beam Width Variation Over the Lower and Upper Bands

		Lower Band	Upper Band	
Frequency (GHz)		1.55	6	7.5
XZ-plane beamwidth	RHCP	107°	99°	106°
	LHCP	153°	63°	85°
YZ-plane beamwidth	RHCP	111°	119°	68°
	LHCP	142°	147°	87°

To obtain circular polarization, the falcate-shape antenna is halved. Through simulation, it is found that to have the highest 3 dB AR bandwidth from the proposed antenna, the following antenna parameters should be used: $L_1 = 18$ mm, $L_2 = 5$ mm, $L_3 = 2.5$ mm, $W_1 = 3$ mm, $S_1 = 5$ mm, and $S_2 = 3$ mm.

The simulated and measured return loss of the proposed antenna is shown in Figure 4. From the results of Figure 4, it is seen that the proposed antenna provides a dual-band impedance behavior, with the lower band being narrower than the upper band. The lower band is over 1.3–1.8 GHz, while the upper band starts from 4.3 GHz. To investigate how the resonant mode operates, simulated surface current distribution is presented in Figure 5 over the upper and lower bands at center frequencies of 1.55 GHz and 6.75 GHz, respectively. Through simulation, one can show that the longest stub is related to the lower band, and the two smaller stubs are related to the upper band. These stubs are responsible for the required 90° phase shift and current amplitude equalizing between the two current components over the halved falcate shape antenna.

Figures 6 and 7 compare the simulated and measured AR and PD over various frequencies. From these results, it can be seen that the proposed antenna has a dual-broadband CP behavior. These results are obtained at the broadside direction. Over the lower band, the antenna shows a 22.6% (1.36–1.72 GHz) 3 dB AR bandwidth while over the upper band the antenna exhibits 44.4% (5.25–8.25 GHz) 3 dB AR bandwidth. From the results, it is clear that there is a slight difference between

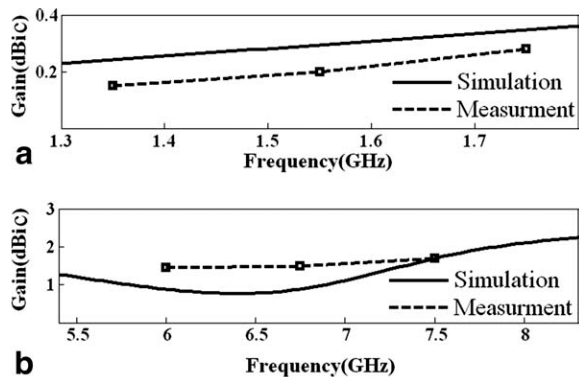

Figure 9 The proposed antenna gain over the (a) lower and (b) upper bandwidth.

TABLE II Comparison of the Simulation Results of Antennas with Various Centre Frequencies, $W = 33$ mm, $W_0 = 3$ mm, $W_1 = 3$ mm, $G = 30$ mm

Antenna Number	1	2	3	4
L_1 (mm)	18	18	12	12
L_2 (mm)	5	6	6	5
L_3 (mm)	2.5	4	4	2.5
S_1 (mm)	5	5	5	5
S_2 (mm)	3	3	3	3
Lower centre frequency (GHz)	1.53	1.51	1.87	1.89
Lower band bandwidth (%)	42.8	67.6	62.5	52.8
Lower band CP bandwidth (%)	22	24.3	24	16.8
Upper centre frequency (GHz)	6.85	6.33	6.52	7.05
Lower limit of upper band (GHz)	> 4.1	> 4.3	> 4.2	> 4.1
Upper band CP bandwidth (%)	44.4	42.8	46.7	50

measured and simulated bandwidth over the lower and upper frequency bands.

Figure 8 shows the measured RHCP and LHCP radiation pattern in the *XZ*-plane and *YZ*-plane over the frequencies of 1.55 GHz, 6 GHz, and 7.5 GHz. RHCP radiation is in broadside direction over the lower band while LHCP radiation is in broadside direction over the upper band. It can be seen that the radiation patterns in the broadside beam is always within the 3 dB level. Table I gives a comparison between the beamwidth of the proposed antenna over *XZ* and *YZ* planes at both lower and upper bands. The simulated and measured gain over the lower and upper bands is shown in Figures 9a and 9b, respectively. The proposed antenna gain is about 0.2 dBic in the lower band and 1.5 dBic in the upper band.

IV. TUNING THE CP CENTER FREQUENCIES

As mentioned earlier, the center frequency for each of the lower and upper bands can be controlled through the appropriate stubs length. It can be shown that by changing the length of the longer stub, the center frequency of the lower band changes while upper band remains almost unchanged. Similarly, if the length of the other two stubs changes, the upper band center frequency shifts. This means that there is little coupling between the longest stub and the other two stubs. When one stub is changed, this little coupling causes a small shift in the center frequency relevant to the unchanged stub. This shift can be corrected by adjusting the spacing between the longer and the two smaller stubs. Simulated results show that the lower frequency band can be tuned within ±250 MHz and the upper frequency band within ±500 MHz. Table II shows how changes in stubs length affect the center frequency of the lower and upper bands. Four antenna structures are considered. It can be seen that for two antennas with two different values of L_1 (which controls the lower center frequency), the same values of L_2 and L_3 results in same upper center frequency. Similarly, for two antennas with same values of L_1, different values of L_2 and L_3 results in different upper center frequency. From these results, one can see that the length of each stub is approximately $\lambda g/8$. The exact length is obtained through optimization.

V. CONCLUSION

A dual-broadband CP halved falcate-shaped printed monopole antenna using two halved falcate shape patches has been presented. The CP antenna structure uses two halved falcate-shape patches to create two orthogonal modes and three stubs in the ground plane to generate the phase shift between the modes. Simulated and measured results show better than 22% and 44% 3 dB AR bandwidth for the lower and upper bands, respectively. Over these bands, the broadside radiation pattern remains within 3 dB. By changing the stub lengths, the center frequency of the lower and upper bands can be tuned.

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BIOGRAPHIES

Ali Frotanpour was born in Tehran, Iran, on September 17, 1985. He received the A.D. degree in electronics from the Islamic Republic of Iran Broadcasting University, Tehran, Iran, in 2006 and the B.Sc. degree in communication engineering from Khayyam University, Mashhad, Iran, in 2008. He is currently working toward the M.Sc. degree in electrical engineering at Shahed University, Tehran, Iran. Since July 2009, he has been collaborating with the satellite communications group of Iran Telecommunication Research Center on traveling-wave tube-amplifier predistortion linearizers, dual-mode waveguide filters, Substrate integrated waveguide filters, and multipactor effect. His research interests include the analysis of multipactor radio-frequency breakdown, printed antennas with linear and circular polarization, and microwave filters.

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