A Novel Broadband Circularly Polarized Printed Monopole Antenna

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***Abstract*— This paper presents a broadband printed circularly polarized monopole antenna. The base antenna consists of a falcate-shaped monopole antenna which provides 43% axial ratio bandwidth. By inserting a falcate-shaped slot in the base patch, 56% axial ratio is obtained. Moreover, inserting a slot in the base patch has no effect on the impedance bandwidth of the original structure. The proposed antenna dimension is 40 × 46 mm^2 and is fabricated on 1 mm FR4 substrate. The simulated return loss and axial ratio bandwidth of the antenna structure with and without the falcate shaped slot are presented and compared. Moreover, circular polarization radiation patterns of the proposed antenna are presented.**

I. Introduction

Circularly polarized (CP) antennas are attractive for modern wireless communication systems such as radio frequency identification (RFID), satellite communication systems, dedicated short range communication systems (DSRC), WLAN and WiMAX. CP antennas with broadband operation can be used in multi-purpose communication systems, thus reducing the required number of antennas. CP antenna can also provide a better immunity over multi-path fading channel [1], and in addition by use of a CP antenna there is no need for precise alignment between the transmitter and receiver antennas.

CP radiation can be generated by printed antennas. Such antennas have great features such as low profile, low cost and ease of fabrication. In the literature there are different methods reported to obtain circular polarization by printed antennas over narrow and wide bandwidth.

A lot of researches have been performed on the printed CP antennas. Use of crossed dipole printed antennas, resulting in 15.6% AR bandwidth is reported in [2]. In [3], a CP loop-like printed strip antenna with a single microstrip feed line along L-shaped sleeve and slit in the ground plane resulting in a 19% AR bandwidth is given. By use of a mesh like slot configuration in the ground plane and fed via a single microstrip feed line, a CP antenna operating over the 5-6 GHz band is presented in [4]. In [5], an H-shaped printed antenna with a T-shaped slot etched in its middle, and fed via a coaxial feed line, appropriate for DSRC is given. By changing the position of the coaxial feed either LHCP or RHCP can be obtained. To obtain CP over a wider bandwidth, [6] has used a

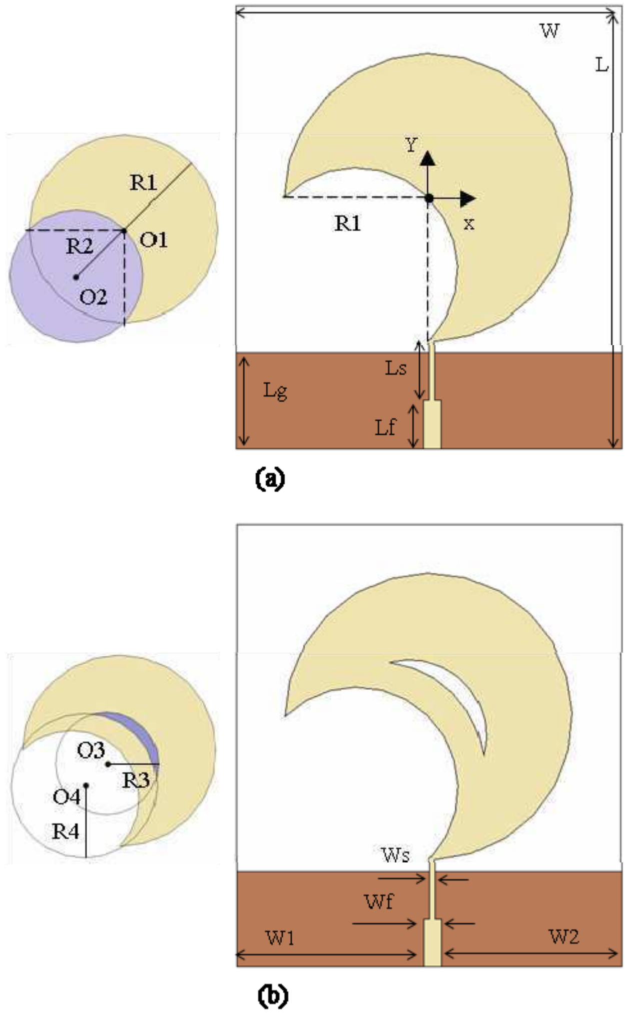

Fig. 1 Broadband circularly polarized monopole antenna (a) simple falcate-shaped patch (b) slot loaded falcate-shaped patch.

three layer structure with a wide slot antenna loaded with a parasitic patch and fed via an L-shaped microstrip feed line. By increasing the thickness of the middle layer between the slot and the patch antenna a maximum of 45% CP bandwidth can be obtained. In [7], a CPW structure consisting of a square slot antenna with lightening-shaped feed line along with

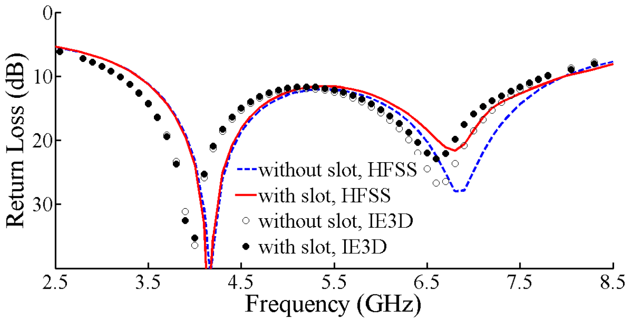

Fig. 2 Return loss of the broadband circularly polarized falcate-shaped antenna with and without loaded falcate-shaped slot.

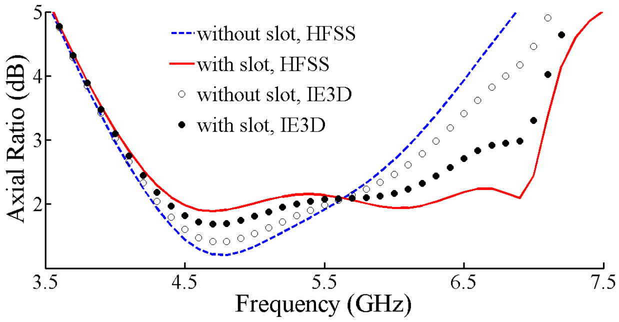

Fig. 3 Axial ratio of the broadband circularly polarized falcate-shaped antenna with and without loaded falcate-shaped slot.

inverted-L grounded strips resulting in a 48.8% CP bandwidth is provided.

To the knowledge of the present authors it seems that a printed antenna with a single feed structure giving more than 50% of CP bandwidth is still a challenge.

In this paper, a broadband printed circularly polarized antenna in the shape of a falcate patch loaded with a falcate-shaped slot is presented. The proposed antenna has a return loss of better than 10 dB over 3.3-8.1 GHz and has a 3 dB axial ratio (AR) bandwidth of 4-7.1 GHz. All the simulations are carried out using both available software packages HFSS and IE3D and the results show good agreement between two different packages.

II. Antenna Design

In this paper, a simple printed falcate-shaped antenna is presented. The proposed antenna is designed for broadband circular polarization applications. To design a CP antenna, the structure should provide several parameters.

Circular polarization can be achieved only when the magnitudes of the two components of current or electrical field are the same and the phase difference between them is odd multiples of $\pi/2$.

$$|J_x| = |J_y| \tag{1}$$

$$\Delta\phi = \phi_y - \phi_x = \pm(\frac{1}{2} + 2n)\pi \tag{2}$$

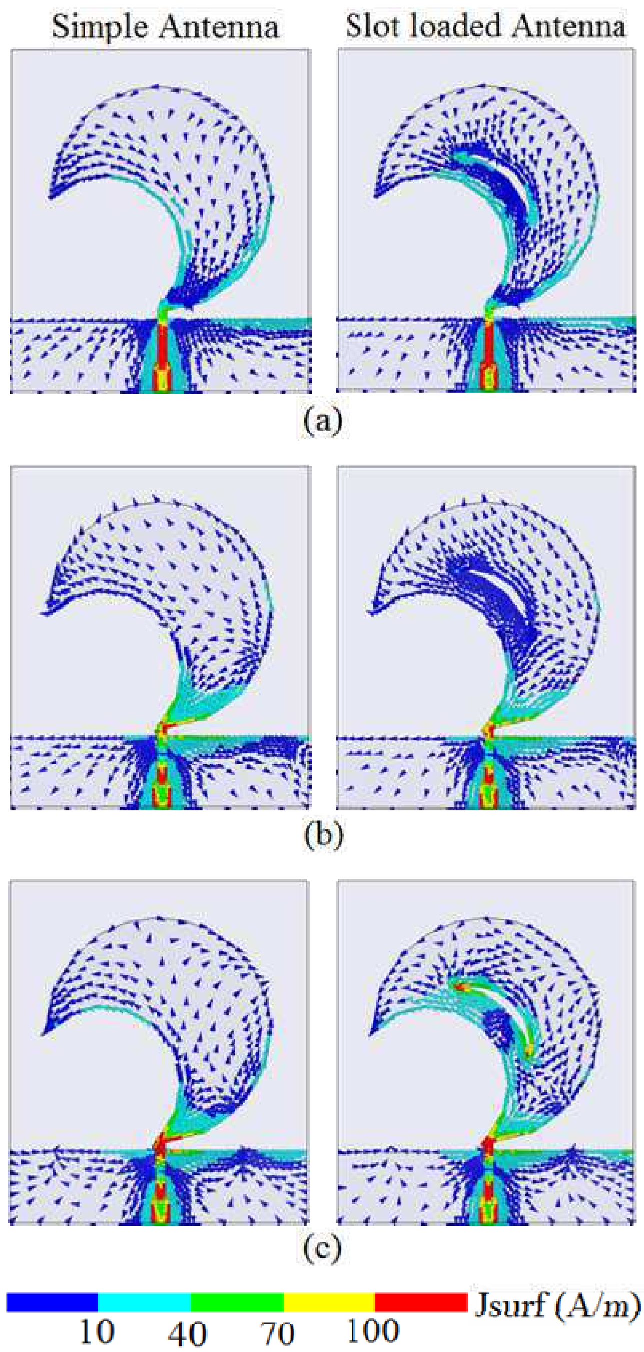

Fig. 4 Current distribution of the broadband circularly polarized falcate-shaped antenna with and without loaded falcate-shaped slot at (a) 4, (b) 5.5 and (c) 7 GHz.

For n=0, 1, 2, ... , (-) shows clockwise rotation of the resultant vector when the propagation is in +z direction. This gives left hand circular polarization, LHCP. Also, (+) shows counter-clockwise rotation of the resultant vector when the propagation is in +z direction. This leads to a right hand circular polarization, RHCP [8].

Depending on the magnitude values of the two current components, the value of AR changes between 1 to infinity.

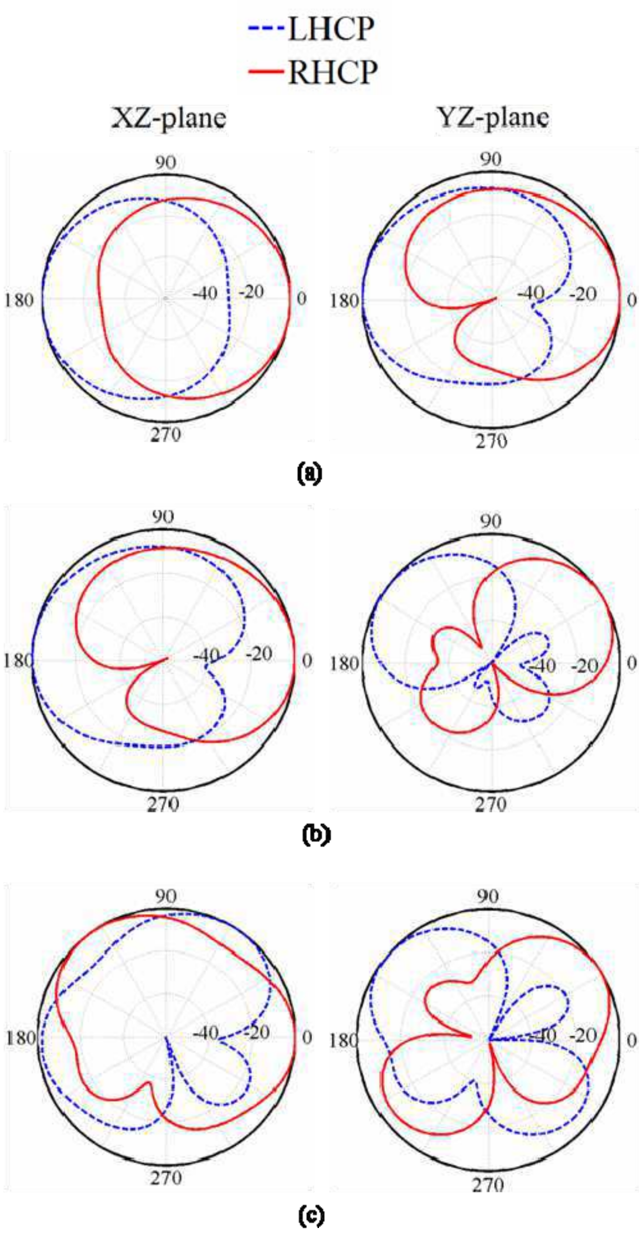

Fig. 5 RHCP and LHCP radiation patterns in XZ-plane and YZ-plane of the broadband circularly polarized falcate-shaped antenna with loaded falcate-shaped slot at (a) 4, (b) 5.5 and (c) 7 GHz, (by using HFSS package).

When the magnitudes of the two components are the same, the AR is equal to 1.

To design a printed antenna which can create circular polarization, a curved structure can be considered as the base radiating patch. This should create two orthogonal current components on the patch with the same magnitudes. The configuration of the falcate-shaped printed monopole antenna to produce circular polarization is shown in Fig. 1(a). As shown in the left side of the Figure, the base radiating patch is created by using a circle with centre at O1 and radius R1 while a small circle with centre at O2 and radius R2 is removed from its corner. The dimension of the antenna is 40 × 46 × 1 mm^3 which is fabricated on the FR4 substrate with

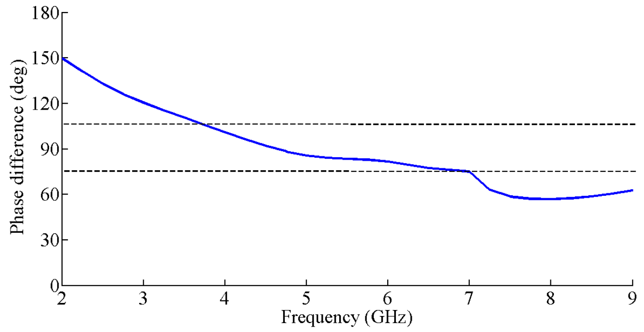

Fig. 6 Phase difference between two orthogonal current components of the broadband circularly polarized falcate-shaped antenna with loaded falcate-shaped slot (φ_x-φ_y), (by using HFSS package).

TABLE I
THE SIMULATED AXIAL RATIO AND RETURN LOSS OF THE SIMPLE AND SLOT LOADED FALCATE-SHAPED MONOPOLE ANTENNA BY USING HFSS

Antenna type	3 dB axial ratio	10 dB return loss
Simple Falcate-shaped of Figure 1(a)	43%	83%
Slot loaded Falcate-shaped of Figure 1(b)	56%	83%

effective permittivity 4.4 and loss tangent of 0.02. The width of the feed line of the designed antenna is fixed at 1.86 mm to obtain 50 ohm characteristic impedance at the input port. A stepped feed line is used to improve the impedance matching to the falcate-shaped patch. The length of the feed line (Lf) is equal to 3 mm. The width and the length of the stepped line are 0.8 and 8 mm, respectively. At the bottom side of the substrate, a rectangular ground plane is used which has dimension of 40 × 9.5 mm^2.

To improve the CP characteristics one can add a slot to the falcate-shaped patch antenna. Fig. 1(b) shows the configuration of this enhanced CP antenna. The falcate-shaped slot is created by using two circles with centres at O3 and O4 with radiuses R3 and R4.

The optimized antenna parameters are as follows:

W = 40, Wf = 1.86, Ws = 0.8, W1 = 19.37, W2 = 20, L = 46, Lf = 3, Ls = 8, Lg = 9.5, R1 = 15, R2 = 10.6, R3 = 8.05, R4 = 11.35, O1 = (0,0), O2 = (-7.5,-7.5), O3 = (-1.95,-1.95), and O4 = (-5.5,-5.5) mm.

III. RESULTS AND DISCUSSION

Fig. 2 shows the return loss of the designed antenna with and without the loaded falcate-shaped slot by using two difference packages. As shown the 10 dB return losses of the antennas are over the 3.3-8.1 GHz frequency range for HFSS and 3.1-8.1 GHz for IE3D. There is slightly variation in resonance frequency of the two packages. Moreover, it is clear that the presence of the loaded slot does not have much effect on the return loss behavior of the original falcate shaped antenna in both packages.

Fig. 3 shows the AR results of the falcate-shaped antenna with and without loaded slot by using two difference packages. It is obvious that the 3 dB AR bandwidth of the antenna without slot in HFSS is 4-6.2 GHz which has a bandwidth of about 43%. Moreover, this value is 4-6.3 GHz for IE3D. Also, Fig. 3 shows that the presence of the loaded slot in the falcate-shaped antenna increases the AR bandwidth, 4-7.1 GHz in HFSS that is almost 56% of the centre frequency. This value is about 4-7 GHz for IE3D. By inserting the falcate-shaped slot in the base patch, the differences between the magnitudes of the two orthogonal currents on the patch decreases leading to improvement in the AR bandwidth. The simulated value of the phase differences between two orthogonal current components in HFSS varies around the 90^{o} over a wider bandwidth as well. In Table I, the simulated results of the two structures are compared.

The current distribution of both antennas simulated in HFSS is presented in Fig. 4. The left figures are simple falcate-shaped antenna which can cover 4-6.2 GHz for 3 dB AR bandwidth. Also, the right side shows the slot loaded antenna. As seen, the Fig. 4(a) and (b) show the current distribution at 4 and 5.5 GHz, respectively. It is clear that the loaded slot has negligible effect on the current distribution of the radiating patch. In Fig. 4(c) the loaded slot is implemented lead to improving the magnitude and phase difference between two current components.

Fig. 5 shows the simulated RHCP and LHCP radiation patterns of the proposed slot loaded falcate shaped patch antenna at 4, 5.5 and 7 GHz over XZ and YZ planes by using HFSS. It is obvious from the radiation patterns that the broadside beam is always within the 3 dB level. Moreover, the structure provides stable CP radiation patterns among the bandwidth.

Figure 6 shows the simulated phase difference between J_y and J_x for the slot loaded falcate-shaped monopole antenna by using HFSS. As shown, two orthogonal currents have phase differences around 90^{o} from 4 to 7.1 GHz. The value of AR bandwidth in Figure 3 and $\pi/2$ phase difference between two components confirm the circular polarization.

IV. CONCLUSIONS

A novel broadband circularly polarized printed monopole antenna has been presented. The basic falcate-shaped antenna has 43% AR bandwidth from 4-6.2 GHz and 83% impedance bandwidth from 3.3-8.1 GHz. By inserting a falcate-shaped slot in the base radiating patch, the AR bandwidth of the base antenna has been improved. The AR bandwidth of the enhanced falcate-shaped antenna is 56% from 4-7.1 GHz while the impedance bandwidths are the same.

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