A Wideband CPW - Fed Circularly Polarized Monopole Antenna for Multi-Band Applications

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Abstract: A CPW-fed circularly-polarized monopole antenna with bandwidth enhancement is presented in this paper. The circularly polarized characteristic is achieved by a C-shaped monopole. To realize the circular polarization a new structure including two semicircles and a spring are etched on CPW-fed ground and at the opposite side of the substrate two metallic closed ring resonators (CRRs) for wide band application.. The proposed antenna has a very small size of $20 \times 20 \times 0.8\,\mathrm{mm}^3$. That cover simulated impedance bandwidth (IBW) 16.5598 GHz- 32.9153 GHz (16.3555 GHz i.e. 77.22 %, at centre frequency 21.18 GHz) with axial ratio bandwidth (ARBW) 1.0755 GHz (23.9453 GHz – 25.0208 GHz i.e. 4.41 %, at centre frequency 24.388 GHz) for microwave 'Ku' , 'K'and 'K_a' band application. The peak gain of the antenna is 4.3648 dBi.

Keywords: Circular polarization, impedance bandwidth, axial ratio, Ku, K and K_a band.

I. INTRODUCTION

With recent progress in the next generation wireless communications, there is an inevitable demand for wireless antennas which support high data rate capacity. In recent years, compact circularly polarized (CP) antennas is becoming more attractive in various applications such as short range wireless communication, satellite positioning, radar and sensing, and radio frequency identification (RFID). As the CP antennas do not affected by multipath and transceiver's orientations, they have several important advantages over linearly polarized ones. On the other hand, in order to overcome polarization mismatch between transmitter and receiver, circular polarization (CP) is becoming popular in wireless communications to enhance system performance. CP feature can be realized when two orthogonal modes with equal amplitude and in phase quadrature are excited. Owing to features such as wide impedance bandwidth, low profile, low cost of manufacturing, and easy integration with monolithic integrated circuits attract more attention in wireless systems. On the other words, the main challenge in design of wideband CP antennas is broadening 3 dB axial ratio (AR) while keeping a compact and low profile design. In recent years, various shapes and designs of CP slot antennas have been developed to overcome the narrow impedance and axial-ratio bandwidths (ARBWs) [1]–[10]. The circularly polarized square slot antenna can provide broad impedance and axial-ratio bandwidths. Also, the right-hand CP and the left-hand CP can be achieved simultaneously with various techniques in these antennas [1]–[10]. Some of the techniques that are used to design these kinds of antennas with broad CP bandwidth and broad AR include the following. A Circularly Polarized (CP) microstrip patch array [1] working at Ku band and in particular between 16.9-17.2GHz is based on a sequential rotation of four linearly polarized rectangular patches and appropriate phase shifts provided by a corporate feed network. A microstrip fed Spidron fractal patch [2] is used on a single substrate for Ku band application to achievable dual CP IBW 8.7 % and 6.6% with ARBW 2.96 % and 1.68 % respectively. Recent reports include for CP [3] by using open ended slot at left end of the antenna. The impedance bandwidth of 7000 MHz (2.0-9.0 GHz) and IBW range of 5.1-5.8GHz has been achieved. Another technique, a single fed wideband circularly polarized slot antenna [4] is designed for multiband applications. The achieved IBW is 60.4% and ARBW is 26.1%. The designed antenna [5] is L strip fed proximity coupled circular microstrip antenna where the radiating patch is loaded by a cross slot of unequal arm's length. The circular polarization is achieved by cutting an asymmetric slot cut on circular radiating patch to produce orthogonal modes, measured return loss bandwidth of 51.8% and axial ratio (AR) bandwidth of 8.43% (AR<3dB). Another technique for CNSS dual-band applications, the designed antenna [6] comprises a small circular patch with embedded four spiral square slots around the boundary and a narrow slot in the centre. It is observed that the lower (1615MHz) and upper (2498MHz) resonance frequencies are controlled by the circular patch and the spiral slots. The CP operation is mainly achieved by the narrow slot. The IBW are 3.5 % and 5.9% with ARBW are 0.87 % and 1.12% respectively. In [7] CP antenna obtained IBW 35 % and ARBW 30% only for lower (L and S) band. Another CP performance only for short range communication [8] is obtained by CPW feed, IBW 51.4% and ARBW is 48.8 %. A new wideband circularly polarized square slot antenna (CPSSA) with a coplanar waveguide (CPW) feed [9] the measured IBW and ARBW are 52% and 25% respectively only for S band communication. Another circularly polarized characteristic is achieved by a C-shaped monopole [10]. To enhance the bandwidth of the antenna, a rectangle stub is adopted on the ground. The demonstrated antenna exhibits the impedance bandwidth of 1650 MHz (2.89-4.54 GHz), while the AR bandwidth is 1060 MHz (3.12-4.18 GHz) only for WiMAX application.

As reported above, till now the IBW achieved is not very large for K_u -K-K_a band communication and ARBW is also very small. In this paper we report enhanced IBW compared to earlier reports for K_u-K-K_a band communication. The measured ARBW is also high compared to earlier reports. In this design a C shaped patched with a CPW ground is used. In order to increase IBW two semicircle are etched from CPW ground. But ARBW is not significantly increase. In order to increase circular polarization a spring is etched from CPW ground. To increase further the IBW and ARBW at the opposite side of the substrate two metallic closed ring resonators (CRRs) have used. By using this technique the achievable IBW is 16.3555 GHz with ARBW is 1.0755 GHz. Compared with some CPW-fed antennas in previous researches, the proposed antenna has a relatively high gain, good impedance matching, wider bandwidth, multifunctional CP bandwidth characteristics simultaneously.

II. ANTENNA DESIGN

The optimized dimension (in mm) of the proposed antenna in Fig. 1a and 1b is illustrated. Fig. 1a represent the top view of step 5. Fig. 1b represent the bottom view of step 8. The antenna structure is consist of a C shaped monopole, a square grounded patch, two semicircle slots with 1.7 mm radius etched on the ground plane and a spring of 0.4 mm width is also etched from ground. The antenna is coupled with two metallic closed ring resonators (CRRs).

The proposed CP antenna is fed by a 50 Ω CPW feed-line with width of 1.5 mm printed on FR4 substrate with thickness of 0.8 with $\varepsilon_r = 4.4$ and $\tan\delta = 0.02$. The gap between feed-line and ground plane is 0.3. The overall dimension is $20 \times 20 \times 0.8\ mm^3$. To obtain CP operation by tuning the length of the C arms and the gap width between the microstrip line and CPW feed ground. The optimal dimensions of the designed antenna are specified in Table I. P_3, P_4, P_5, P_6, Y_f , P_8 (position of the spring), P_{11} (width of the spring) , L_c(X-axis position of CRRs), W_c (Y-axis position of CRRs), are the key parameters to designed of this antenna.

To explain the CP performance of the antenna, the evolution of the antenna structure is depicted in Fig. 2. Eight antennas have been discussed here. At step 1 a ground plane have taken bottom side of the substrate but IBW is very low. In order to increase compactness a square slot is etched from ground at step 2, which increase IBW compare to step 1. At step 3 in state of ground plane on opposite side of substrate take CPW feed ground which increase IBW slightly. At this step, the antenna's AR bandwidth is enhanced but does not possess broadband CP characteristics.

Table 1: Optimal dimension of the proposed antenna

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
W_1	20	L_1	20	h	0.8
X_f	4	Y_f	1.5	X_1	5
X_2	10	X_3	8	X_4	3
P_3	2.6	P_4	0.6	P_5	4.6
P_6	1.7	P_7	1.7	P_8	1.4
P_9	0.6	P_{10}	0.6	P_{11}	0.4
P_{12}	10	e1	0.33	at	0.75
L_c	2	W_c	0.6		

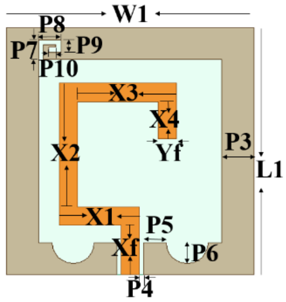


Fig. 1a

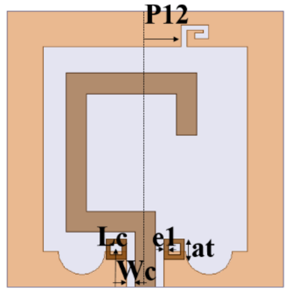
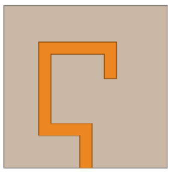


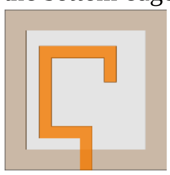
Fig. 1b

Fig. 1: a and 1b Optimized dimension of the proposed antenna step. 5 and step. 6

The C shaped radiator patch, which plays the key role in the frequency bandwidth improvement , is truncated with two triangular notches for decreasing the effect of abrupt discontinuity in the connection point between the CPW feed line and the C shaped patch, as shown in step 3. A step 4 etching the semicircles in the both side of the CPW feed line on the ground plane. Hence, the good impedance characteristics will be obtained. In other words, a balance between vertical and horizontal electrical currents on the C shaped patch will be achieved and the impedance bandwidth and CP performance of the modified patch will be bettered. A step. 5 to improve impedance bandwidth and CP performance of the proposed antenna, a spring is etched from CPW feed ground. Which shows that the C-shaped with microstrip line feeding can not only enhance the impedance bandwidth, but also generate two orthogonal modes with 90 phase difference and achieve CP radiation. At step. 6 to increase IBW spring position is shifted to the left at a position of Y-axis is P_{12}= 10 mm. At step. 7 two half ring resonator are used to increase the IBW and ARBW. In order to significantly change IBW and ARBW two CRRs are used. The antenna is coupled with two metallic closed ring resonators (CRRs) having a dimensions 'a_t' which is the external side-length of CRR, conductor width of the ring is e_1 .The centre of the shunt strips is position at distance L_c from the bottom edge of the substrate.

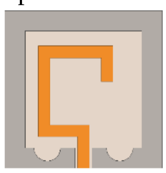


Step. 1

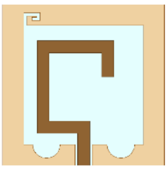


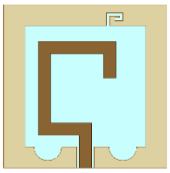
Step. 2

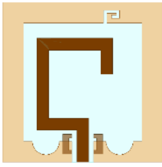
Step. 3



Step. 4


Step. 5


Step. 6


Step. 7

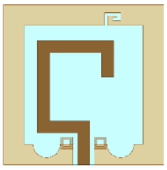

Step. 8

Fig. 2: Eight improve structure of proposed antenna.

In order to understand the working principle of the proposed antenna, the surface current distribution is analysed. Fig. 2 shows the simulated surface current distribution at 20 GHz for phases of 0°, 90°, 180° and 270°. From Fig. 3, it can be seen that the predominant surface current turns in clockwise direction as time increases, thus the polarization sense is left hand circularly polarization (LHRP). When the C-shaped monopole is inverted, opposite CP radiation can be obtained.

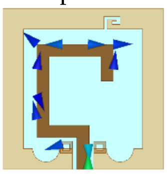


Fig. 3a

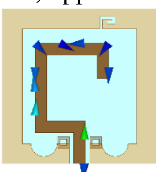


Fig. 3b

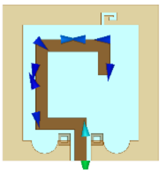


Fig. 3c

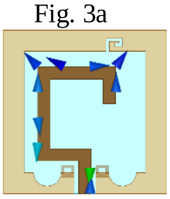


Fig. 3d

Fig. 3 Simulated surface current distribution at 5.5GHz for four time instants. (a) 0°. (b) 90°. (c) 180°. (d) 270°.

III. RESULT AND DISCUSSION

The simulation was performed using HFSS 13. The antenna has four resonance at 17.9760 GHz, 21.5600 GHz, 24.880 GHz and 29.56 GHz and wide band performance is obtained by merging this resonance. The -10dB impedance bandwidth (IBW) of the measured return loss reaches 16.3555 GHz, which cover the range from 16.5598 GHz to 32.9153 GHz. A wide band from 16.5598 GHz to 32.9153 GHz at a centre of 21.18 GHz shown at fig.4. There are three subsection: A) Studying the impedance band width and resonant modes. The simulated return loss of the proposed antenna are discussed. B) Analysing axial ratio. C) Illustrating the simulated radiation pattern and gain. Fig. 4 shows the simulated return loss of the proposed antenna 16.3555 GHz or approximately 77.22% with respect to centre frequency 21.18 GHz for K_u, K and K_a band application.

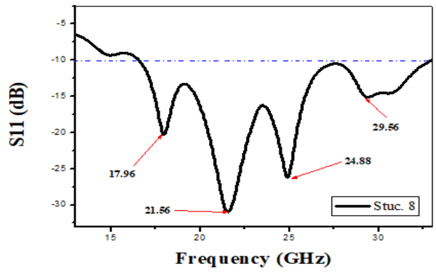


Fig. 4: Simulated return loss of proposed antenna.

Fig. 5 shows comparisons of simulated return loss improvement of the proposed antenna. According to Fig. 5, the proposed antenna performs a wide bandwidth due to four resonant modes which are influenced and excited by the above criteria.

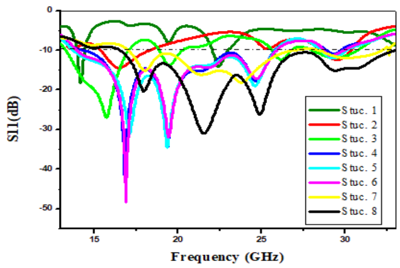


Fig. 5: Simulated S_{11} for Struc. 1, Stuc. 2, Stuc. 3, Stuc. 4, Stuc. 5, Stuv. 6, Stuc. 7, Stuv. 8

The simulated AR results for the broadside direction versus frequency are plotted in Fig.6. The measured 3dB ARBW reach 1.0755 GHz i.e. 4.41 % with respect to centre frequency of 24.388 GHz.

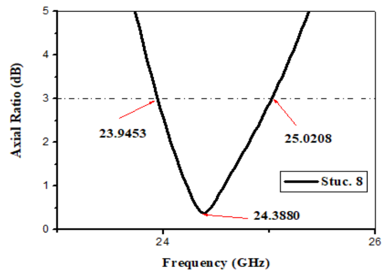


Fig. 6: Simulated Axial ratio bandwidth for proposed antenna.

The peak gain, depicted in Fig. 7, is almost 4.3648 dBi at 22.5120 GHz which is good for wireless communication.

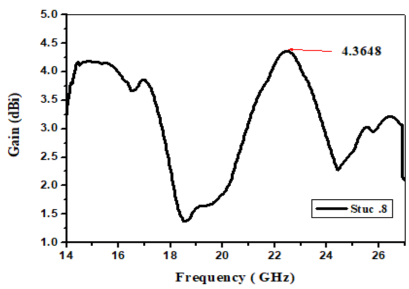


Fig. 7: Simulated gain plot of the proposed antenna.

On Fig. 8a and Fig. 8b are the radiation pattern for the proposed antenna at 0^0 (XZ plane) and 90^0 (YZ plane), have shown for LHCP and RHCP at frequency of 24.388 GHz. A good LHCP and RHCP can be observed from above figures.

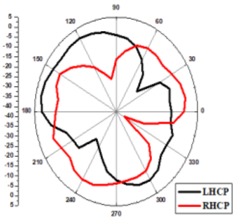


Fig. 8a

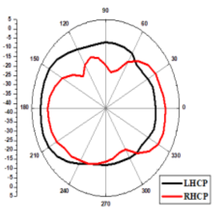


Fig. 8b

Fig. 8a Simulated radiation pattern for the proposed antenna at 0^0 (XZ plane) for LHCP and RHCP at frequency 24.388 GHz.

Fig.8b Simulated radiation pattern for the proposed antenna at 90^0 (XZ plane) for LHCP and RHCP at frequency 24.388 GHz.

IV. CONCLUSION

A CP Monopole antenna with bandwidth enhancement for K_u, K and K_a band application is proposed in this paper. By splitting the fundamental resonant mode into two near-degenerate modes of the C-shaped monopole, the CP characteristic is obtained. In order to enhance the bandwidth of the antenna, two semi hexagonal slot and a spring are etched from CPW ground. To improve significantly the impedance bandwidth and AR bandwidth of the antenna a series of two metallic CRRs has been presented. Furthermore, good radiation performance has been achieved. The antenna is of low cost and simple structure, thus suitable for practical wireless communication systems.

V. REFERENCES

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