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Research paper

Design of CPW fed f-shaped circularly polarized antenna for amateur radio vehicular communications

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Abstract

In this paper a compact circularly polarized antenna is proposed to operate in X-band spectrum. The F-shaped monopole element is used as the radiating structure and the closed coplanar-waveguide ground is used on a FR4 substrate. The proposed feeding mechanism with asymmetric ground planes and the three rectangular strips connected to the feed line. The proposed antenna operates with a -10dB reflection coefficient bandwidth from 9.3 GHz to 13 GHz and the circular polarized performance is attained from 9.8 GHz – 11.2 GHz with axial ratio less than 3dB (AR < 3dB). The antenna gain in the boresight direction is found to be achieved as 4.34dB and radiates with a maximum efficiency of 90% which is suited for amateur radio applications in X-band spectrum based vehicular communications.

Keywords: *Amateur Radio; Asymmetric Ground; Axial Ratio (AR); Circular Polarization; Closed CPW Ground; F-Shaped Monopole.*

1. Introduction

Nowadays the importance of the wireless communications has been emerging under the circumstances of crisis and natural calamities. An emergency communication system is required when a wired line, cellular phones and other traditional communication systems break down. In such a case a dedicated microwave spectrum for recreation and for exchanging the non-commercial messages, emergency communication, self-training purposes. The International Telecommunication Union (ITU) provided the radio regulations for 10-10.5 GHz band allowing the Amateur Radio operations [1]. This is also known as Ham radio and will be helpful for the people to contact with space, town, across the world without any mobiles and information from network. The communication systems with low-profile in dimensional aspect and high in reliability are preferred mostly. The antenna being the most important entity in such a system to work as a key trans-receiving element should possess excellent radiation performance along with its impedance matched bandwidth, polarization capability, radiation efficiency, gain etc.

Printed monopole antennas are most suitable for handheld devices owing to their features of light weight, low cost [2]. Antennas with circular polarized radiation capability mostly preferred because of the reason that the signals propagate through the atmosphere usually become de-polarized which causes undesirable reception of the opposing polarity of the signal and may cause poor quality in reception. To improve reliability of the system the signal can be captured from any direction regardless of the antenna orientation as in case of linear polarization. There are many techniques to achieve CP radiation presented in literature and some of which are outlined here. A square patch antenna with cross-slot coupling which is excited by a microstrip line is used in [3] to obtain circularly polarized performance in 2.4 GHz ISM band. A technique to achieve the CP radiation is mentioned in [4] by using a coplanar capacitive feed and a slot in the rectangular patch which is designed on a suspended substrate. In [5], proposed a new circularly polarized Metasurface Dipole Antenna (MSDA) with wide axial-ratio beamwidth and radar cross section (RCS) reduction properties. An antenna with conical-disc backed Archimedian single-arm spiral is proposed in [6] for X-band applications is exhibiting circular polarization. In [7], the CP radiation performance is achieved through incorporating the branched microstrip feedline which excites the triangular monopole on a compact substrate. To operate the antenna in circular polarization, in [8], a hexagonal shaped patch is used and the diagonal slots are made within the patch and proposed for ITS applications. A broadband CPW fed antenna is proposed with circular polarized radiation is proposed in [9]. It is achieved by placing an open-end slot at the lower side of the antenna structure. A monopole radiator with two orthogonal sections and the parasitic elements provides the quadrature phase difference to create circular polarized radiation performance which was proposed in [10]. In [11], a compact structured planar cross-shaped monopole antenna is proposed with enhanced impedance bandwidth by employing a slot in the ground plane and this broadband nature is attained in CP radiation by extending the one side of the ground plane. A 45^0-rotated square slot in ground plane excited by a microstrip line radiator in [12] caters the CP radiation with the incorporation of a pair of stubs on opposite sides of that slot. Researchers proposed different models with CP with compact dimensions and good axial ratio bandwidth [13-22].

In this work, a planar and compact antenna design is proposed. The geometrical attributes with iterative designs and related specifications are discussed in section II. Further, the design optimization is presented in Section III with parametric study on critical performance effecting parameters. The simulation results and its analysis are outlined in Section IV with clear description of radiation functionality of the proposed antenna.

2. Antenna design

The design process of the compact coplanar waveguide fed antenna initializes with the modelling a CPW structure with two ground planes on either side with width of the ground being 'W_{g1}'. The length of the feed line is considered as 'L_f'. The feed line is extended with an additional length of 'L_1' to make it operating as a radiating stub. The entire structure is designed on a FR4 substrate which is having relative permittivity of 4.4 and loss tangent of 0.02. The substrate is having dimensions of L_s x W_s x h. This structure with only CPW structure and extended feed line forms the first iteration. In the next version of its geometry, two ground planes are connected with a small strip of width 't_1'. This design forms the second iteration and forms the closed ground structure. In the third iteration, some geometrical modification s are applied to the radiating stub and coplanar ground conductors are modified in such a way that the asymmetrical ground lengths are applied with length 'L_{g1}' for the left side ground and length 'L_{g2}' for right side ground. A horizontal rectangular strip with length 'b_1' and width 't_1' respectively is connected to the extended feedline. This horizontal strip is placed at a height 'a_1' from the left side ground. The model in iteration-4 continues with the same geometry with an additional balanced stub with dimensions b_3 x t_3 appended to the left edge of the vertical radiating strip at a distance 'a_2' from the right sided ground plane. The final version of the antenna constitutes another horizontal stub with dimensions b_2 x t_2. This structure forms the F-shaped radiating element. The ground planes with asymmetrical lengths and the three rectangular strips are the major elements in this antenna design for making the antenna to operate in X-band and with circular polarization performance. The geometrical parameters of the antenna are tabulated in Table 1.

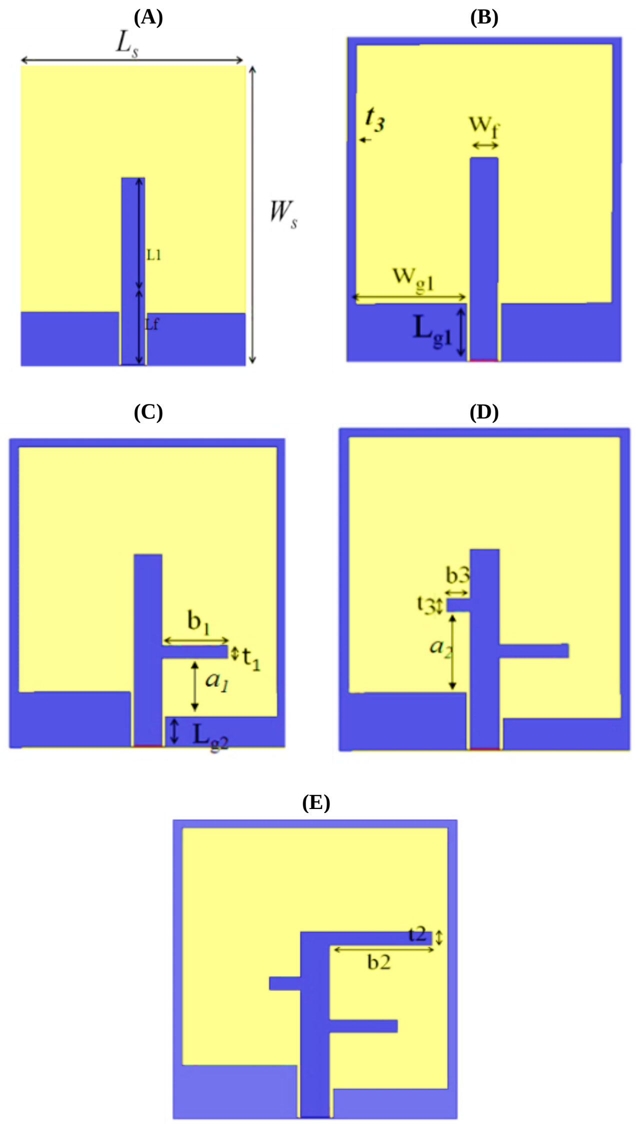


Fig. 1: Antenna Structure (A) Antenna-1 (B) Antenna-2 (C) Antenna-3 (D) Antenna-4 (E) Proposed Antenna.

Table 1: Geometrical Parameters of the Proposed Antenna

Parameter	L_s	W_s	h	L_f	W_f	W_g	L_1	L_{g1}	L_{g2}
Value in mm	37.5	31.5	1.6	10	3.2	13.75	13.5	6.75	3.75
Parameter	t_1	t_2	t_5	a_1	a_2	a_3	b_1	b_2	b_3
Value in mm	1	1	1.6	7.05	9.35	9.4	7.5	11.4	2.5

3. Parametric study

The proposed antenna is modelled with the help of several parameters and processed through several iterations. The modelling of the antenna is carried out in High Frequency Structure Simulator tool in ANSYS Electronics Desktop v.17.2 package. The behaviour of the antenna while changing the values of those important parameters is studied and presented in this section.

3.1. Effect of variation in length of the lower rectangular strip 'b1'

Fig. 2 shows the parametric analysis of length 'b_1'. Here 'b_1' represents the length of the strip on the right side which is near to the ground. This length is varied from the value 5.2mm to 8mm.

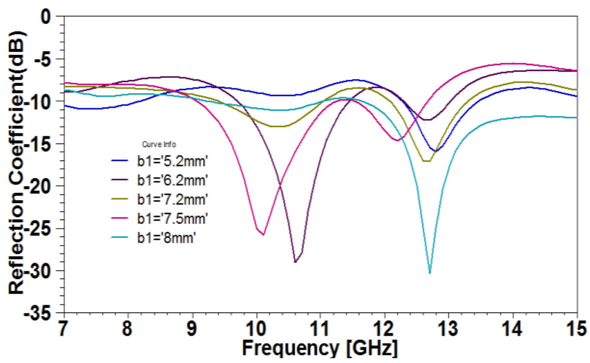


Fig. 2: Parametric Study of 'B_1' on S_{11} Characteristics of the Antenna.

It is found that the increase in the length reduces the reflections in the desired band. Thus, an optimum solution is obtained at 7.5mm. When this parameter exceeds the 7.5mm the lower band below the center frequency 11 GHz is going to be reduced and the resonances are shifted to higher frequencies near 13 GHz.

3.2. Effect of variation in length of the upper rectangular strip 'b2'

The parametric study on length of the upper rectangular strip which is appended on the top of the vertical rectangular strip is varied from 6.8mm to 11.4mm with step variation of 1.6mm which is shown in Fig. 3. The lower the length of the upper horizontal strip is creating the resonant behavior of the antenna in between the 12 GHz-13 GHz band. Further increasing its length significantly introduces the resonance behavior near 9-11 GHz region thus creating a wideband performance at 11.4mm length.

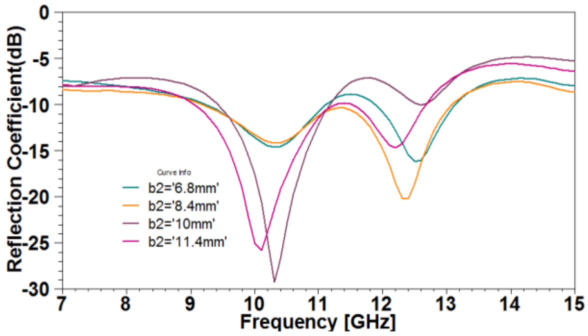
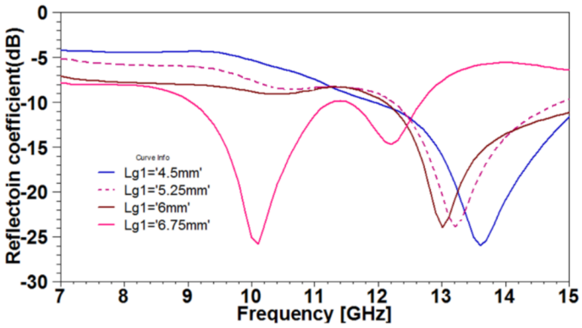


Fig. 3: Parametric Study of ‘B_2’ On S_{11} Characteristics of the Antenna.

3.3. Effect of variation in length of the ground plane ‘Lg1’ and ‘Lg2’

The ground plane plays an important role for an antenna design and hence in this section the lengths of the either ground plane parameters are varied. The length of the left-sided ground plane is varied from 4.5mm to 6.75mm with step incremental variation of 1.25mm which is shown in Fig. 4(a). It can be observed from the Fig. 4(a) that the lower the ground length makes the antenna to operate under 12 GHz -15 GHz band and this behavior continues till the value reaches to 6mm. After another 1.25mm step-incremental variation the resonance which is already existing at 13.6 GHz, 13.2 GHz, 13 GHz is shifted to 12.2 GHz and an additional resonance at 10.2 GHz is attained which shows the better impedance matching and enhanced bandwidth which falls under 9 GHz to 12.5 GHz spectrum.

(A)



(B)

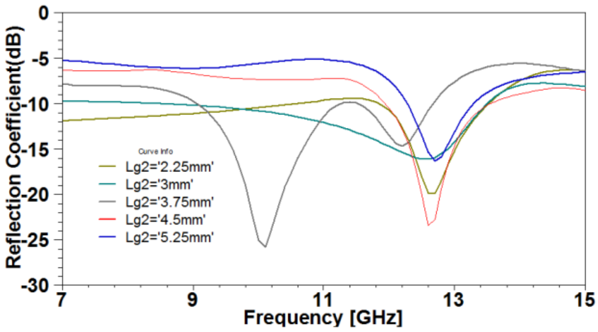


Fig. 4: Parametric Study of (A) Length ‘L_{g2}’ (B) Length ‘L_{g1}’ on the S_{11} Characteristics of the Antenna.

Similar behavior is observed when the length of the right-sided ground plane is varied from 2.25mm to 5.25mm. It is observed that for the variation in the ‘L_{g2}’ parameter from 2.25mm to 3.75mm, the antenna resonates at 12.6 GHz and maintains consistency at its operating resonance. Moreover, the reflection losses are minimized and attained at level nearer to -22 dB reflection coefficient. At 5.25mm length, this resonance shifts towards 12.3 GHz and the additional lower resonance at 10.2 GHz is attained with a reflection coefficient of -27dB. This can be due to the decreasing the distance between the left-sided ground and lower rectangular stub which is connected to the feed line on the right side.

4. Simulation results and discussion

After modelling and parametric study on the different geometrical parameters, the influence of such variations is observed and the optimal parameters are finalized. Finally, the parametrically optimized antenna is simulated for knowing the other quality parameters of the antenna which are discussed in this section.

4.1. Reflection coefficient characteristics

The reflection coefficient is the important parameter for the antenna design which gives the information regarding the effectiveness of impedance matching to a certain frequency fed to the input port of the antenna. The reflection coefficient characteristics of the antenna obtained through antenna simulation in HFSS are presented in Fig. 5. For computing the antenna operating bandwidth, the -10dB line is considered as reference. The characteristics which fall under -10dB will be considered as operating band of the antenna.

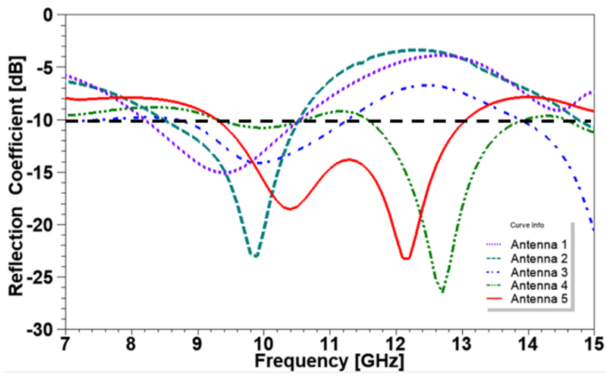


Fig. 5: Simulated Reflection Coefficient Characteristics of Different Geometrical Iterations of the Proposed Antenna.

The antenna structure with the CPW feed and having the extended feed line operates from 8.1-10.4 GHz band, whereas the closed ground structure which is incorporated in the second iteration creates the deeper resonance at 9.8 GHz and operates from 8.5 – 10.45 GHz. The third iteration in which the ground planes with the asymmetrical lengths and appended the lower rectangular strip. By adding the structure, the antenna tends to operate from 8.9 GHz-11.3 GHz and an additional operating band is observed from 13.8 GHz, extends beyond 15 GHz. In this case, the primary operating band which has been existing since earlier iterations is decaying and the second band is shifted from 15 GHz to 12.75 GHz. The antenna iteration-4 thus operates from 11.7 GHz to 13.8 GHz. In the fifth iteration of the antenna design the extension of vertical feedline with a larger rectangular strip on its top is provided. This decreased the obtained resonance frequency towards 12.2 GHz and the primary, secondary operating bands are merged together thus creating wider band width from 9.3 -13 GHz. The proposed antenna iteration covers maximum of X-band spectrum.

4.2. Circular polarization performance of the proposed antenna

Axial ratio parameter is used to assess the antenna whether it is radiating with circularly polarized performance or not. The theoretical value of axial ratio (AR) is 0dB, however, the 3dB value is considered for computation of axial ratio bandwidth of the antenna. In this case, the proposed antenna radiates with circular polarization from 9.8 GHz – 11.2 GHz which covers the amateur radio applications in X-band as shown in Fig. 6.

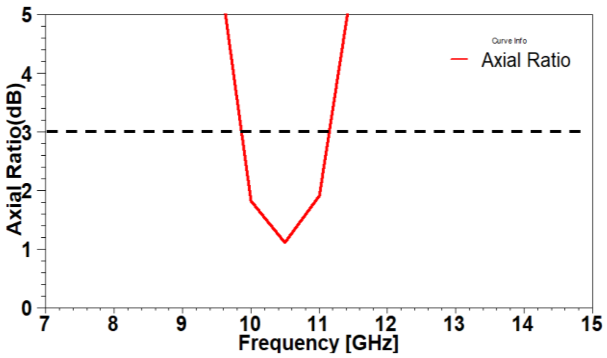


Fig. 6: Simulated Axial Ratio vs. Frequency Characteristics of the Proposed Antenna.

The surface current element distribution patterns also will give the clear idea of the circular polarization in the desired band. These patterns are presented in Fig. 7 simulated at different phase angles. These patterns are simulated at 10.5 GHz at which the minimum axial ratio of 1.15dB is achieved. The patterns at different quadrature phase shifts indicate the orientation and movement of the current elements in a circular motion. The quiet opposite orientation of current elements can be observed for 0^0-phase and 180^0-phase, 90^0-phase and at 270^0-phase respectively. The ground planes with asymmetric lengths and the connected rectangular strips makes the antenna to radiate with circular polarization.

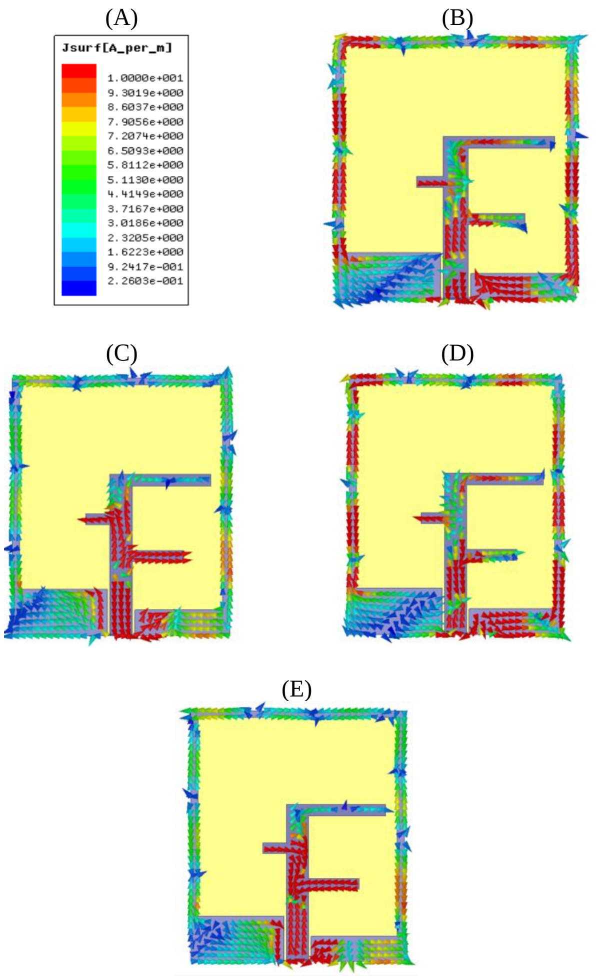


Fig. 7: Surface Current Distribution Patterns of the Proposed Antenna Obtained at 10.5 Ghz Frequency (A) at 0^0-Phase (B) at 90^0-Phase (C) at 180^0-Phase (D) at 270^0-Phase.

4.3. Radiation Performance of the proposed antenna

The radiation patterns of the proposed antenna are presented in Fig. 8. After the determination of circular polarization characteristics of the proposed antenna, the radiation patterns which are plotted below decides the left-handed or right-handed polarization behavior of the antenna.

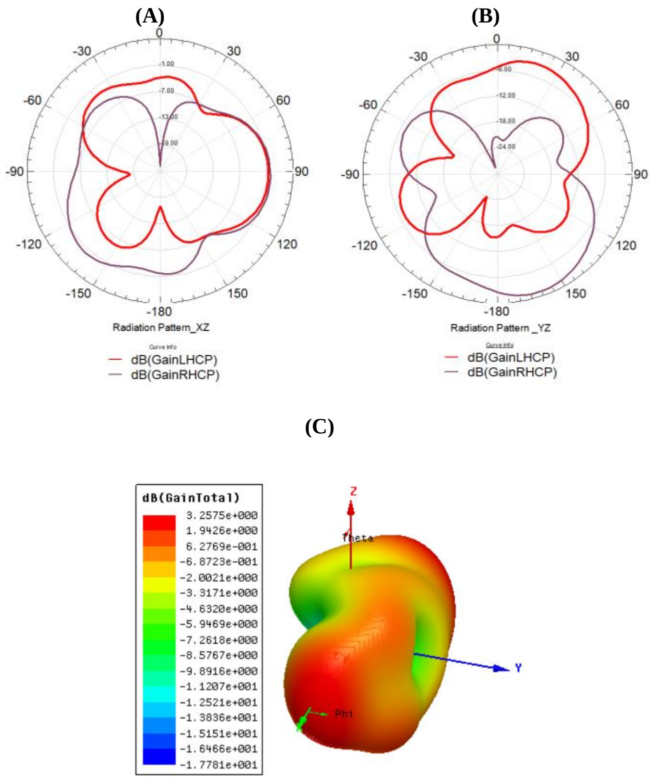


Fig. 8: Far-Field Radiation Patterns of the Proposed Antenna Obtained at 10.5 Ghz Frequency (A) E-Plane (B) H-Plane (C) 3D Far-Field Characteristics.

From the Fig. 8 (a) and 8 (b), in both E- and H-planes the RHCP patterns are slightly dominant one and thus the proposed antenna possess the RHCP radiation. The 3D far-field characteristics are shown in Fig. 8 (c). The overall antenna performance characteristics are presented in Table 2.

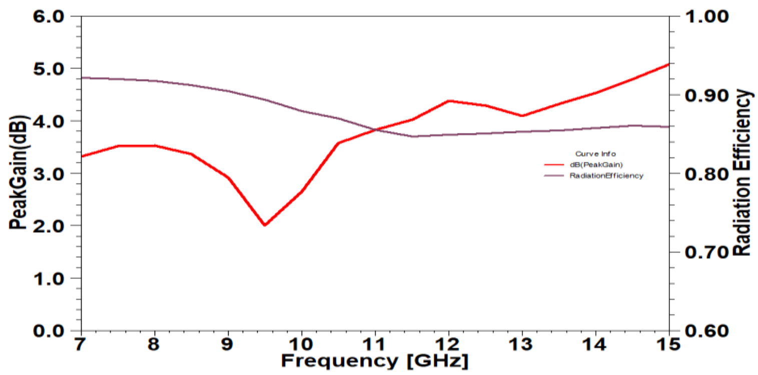


Fig. 9: Simulated Peak Gain and Radiation Efficiency vs. Frequency Characteristics of the Proposed Antenna.

Table 2: Geometrical Parameters of the Proposed Antenna

Antenna Iterations	Operating bands(GHz)	Resonant Frequencies	S_{11} (dB)	Axial Ratio Bandwidth	Peak Gain (dB)	Radiation Efficiency (%)
Ant 1	8.2-10.5	9.4	-15.0	NA	5.1	89.23
Ant 2	8.4-10.6	9.9	-23.0	NA	5.5	89.15
Ant 3	8.4-11.30	9.9	-14.1	NA	4.2	92.20
Ant 4	11.5-14	12.7	-26.5	10.7-11.6	3.968	84.04
Ant 5 (Proposed)	9.3-13	10.5	-9.78	9.8 -11.1	5.3	90.01

5. Conclusion

In this paper, a compact 37.5x31.5x1.6mm3 planar antenna is presented for handheld devices. The CPW structure is used which provides better compatibility to integrate with MMIC circuits. The proposed design not only shows the -10dB impedance bandwidth across 9.3-13GHz over which 37.83% of the bandwidth (13.3% AR bandwidth i.e., from 9.8-11.2 GHz) is having circularly polarized characteristics. Over the entire footprint of the substrate, the radiating elements and ground structures occupies less amount of area and gives good radiation performance of the antenna with a maximum gain of 4.34 dB. The radiation efficiency is excellent noted a value of 90%.

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