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Quadrilateral-Shaped Wideband Circularly Polarized CPW-Fed Monopole Antenna

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Abstract

This paper presents a new type coplanar waveguide (CPW)-fed quadrilateral-shaped compact planar monopole antenna with wideband circular polarization (CP). The antenna operates in the C-band (5.96-8.0GHz), as well as in the X-band (8.0-11.72GHz) and provides circular polarization (CP) in both bands. The fractional axial ratio (AR) bandwidth for CP 55.86% (5.96-10.58GHz) and fractional bandwidth of 118.2% (4.5-17.5GHz) for the return loss (S11) is realized simply by designing a quadrilateral-shape monopole with an asymmetric ground plane. The proposed CPW monopole antenna structure is simple and compact, its design is efficient, and it has a wide impedance matching (S11) band as well as 3-dB axial ratio (AR) operating band. Simulated and experimental results are presented to validate the antenna design and are shown to be in good agreement.

1. Introduction

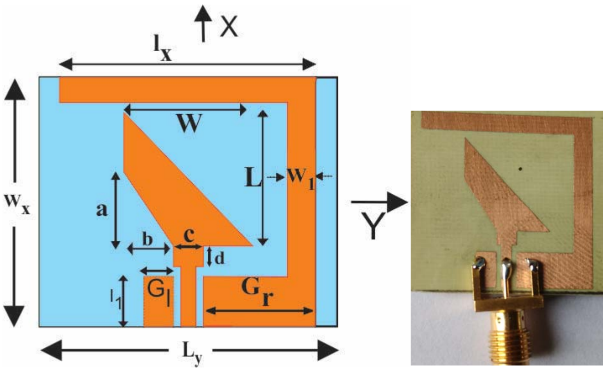
In modern wireless communication system, the demand of circularly polarized (CP) planar antenna is witnessing a rapid increase because CP antennas are polarization independent of the incident wave and, hence, they find many applications in hand-held devices as well as in RFID and rotating systems. It is desirable to use antennas with circular polarization (CP) to avoid the effects of path-loss and displacement of the antennas, when the position of the transmitting and the receiving antennas are changing, or their operation is insecure to the weather conditions. The basic principle of generating the circular polarization (CP) is to excite two orthogonal modes in a phase-quadrature that have equal amplitudes [1]. A variety of approaches to realizing CP antennas have been reported in the literature. These include, for instance, the use of two orthogonal feeds, though this makes the antenna structure complex and bulky [1]-[2]. Circularly polarized (CP) antenna is also designed by using either a single feed at 45^0 along the axis of the patch or by corner truncation of the square patch. However, the single-feed techniques discussed in above references generate CP with a relatively narrow bandwidth [1]– [2], which may not be suitable for many applications.

A review of the literature reveals that considerable effort has been invested by researchers in implementing various techniques [3–8] toward realizing circularly polarized (CP) antennas that are both wideband and compact. Some of the suggested techniques are: using L-slot antenna with single fed by L-shaped feed line [3]; combination of slot and printed monopole [4]; chifre-shape CP monopole antenna [5]; protruded in L-shape strip and inverted L-shape strip [6]; inverted L-strip and asymmetric ground plane [7]; modified L-shaped patch with conjugation of rectangular slot in the ground plane [8].

CPW-fed antennas can be readily fabricated and packaged, making them a suitable choice for MMIC application in wireless communication system. This paper presents the design of a compact planar monopole quadrilateral-shape CPW feeding antenna with asymmetric ground for wideband circular polarization (CP) with an axial ratio bandwidth of 55.86% and impedance matching (S11) bandwidth of 118.2%. The proposed antenna is useful for C-band and X-band communication systems.

2. Antenna Design

Fig.1 shows the layout and fabricated quadrilateral-shaped CPW-fed proposed planar antenna. The radiating surface has a quadrilateral shape and an asymmetric ground plane, both of which are built on the same side of the FR-4 substrate, with an $\varepsilon_r = 4.4$ and thickness of 0.8mm. A step-impedance resonator is inserted in the central feedline to get better return loss (S11) of the proposed antenna. The length and width of the lower line are *6mm* and *1.5mm*, respectively, while they are *c=2.07mm* and *d=3mm* for the upper line. The gap between the feeding line and the ground plane is *0.75mm*. The shape of the radiator is a quadrilateral which is connected to the CPW line. An asymmetrical ground has been added to generate the circular polarization. The detailed dimensions of the proposed antenna structure (see Fig.1) are: *Wx=30mm,* *Ly=25mm, L=13.43, W=13, a=7.43, b=5mm, G_l=3mm, Gr=11.3mm, W_1=2.8mm, l1=5mm, lx=23mm.*

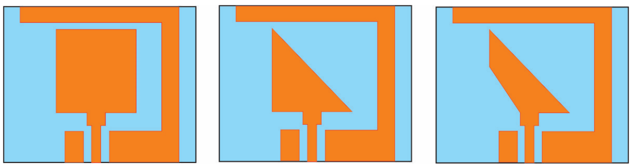


(a)Layout (b)Fabricated antenna

Figure 1. Proposed antenna structure

The primary objective of this paper is to design an antenna with a circular polarization (CP) which has a compact size and yet a wide bandwidth. Hence, the geometry of the antenna is adjusted in such a fashion that it generates two components of electric field (E_x and E_y), with equal amplitudes and a 90^0 phase difference, to generate the desired circular CP. Towards this end, a quadrilateral-shaped patch with an asymmetric ground plane has been used to achieve wideband circular polarization.

Any circularly polarized (CP) antenna should have its 3-dB axial ratio (AR) bandwidth entirely within the 10-dB impedance matching (S11) band. Hence, the primary issue for the designing of circularly polarized antenna is focused on how the quadrilateral-shape radiator and asymmetric ground plane simultaneously improves the 10-dB return loss and 3dB axial ratio (AR) bandwidths of the antenna. Therefore, the proposed antenna is designed in three steps, as shown in Fig. 2 below, with the progressive transformations designated from Step-1 (Ant-1) to Step-2 (Ant-2) and to Step-3 (Ant-3).

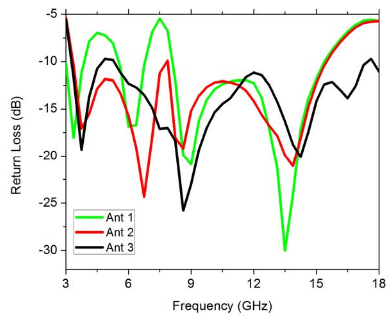


(a) Step-1(Ant-1) (b) Step-2 (Ant-2) (c) Step-3(Ant-3)

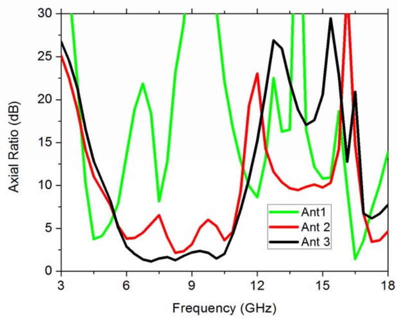
Figure 2. Design steps of the proposed antenna

The proposed antenna structure is simulated by using HFSS version-16. Step-1 which is Antenna-1 has only a square-shape radiator with an asymmetric ground plane, which provides impedance matching (S11) bands at 3.2GHz, 6.0GHz and from 7.5GHz to 15GHz. The length and width of the antenna-1 are 13.43mm and 13mm, respectively. Antenna-2 is designed by diagonally truncating the square patch while antenna-3 has been designed by truncating the lower side of the antenna-2, which is in right angle triangular patch is truncated to derive the antenna-3. The dimensions of antenna-3 are shown in Fig.1. Antenna-2 has an impedance matching band that ranges from 4.5GHz to 15.6GHz while antenna-3 has impedance matching band from 4.5GHz to 17.5GHz as shown in Fig.3a.

Antenna-1 is linearly polarized antenna and antenaa-2 has narrow band circular polarization band (8.5GHz to 9.2GHz) while antenna-3 has wideband circular polarization bandwidth (5.96-10.58GHz) as shown in Fig 3b. The 3-dB axial ratio band improves when the antenna design is progressively modified from step-1 (Antenna-1) to Step-2 (Antenna-2), and then to step-3 (Antenna-3). The ratio of the amplitude of the electric far field components (E_x/E_y) and their phase difference (PD) are shown in Fig.4. To realize the circular polarization (CP), we need to work with two electric far field components (E_x and E_y) that have the same amplitudes

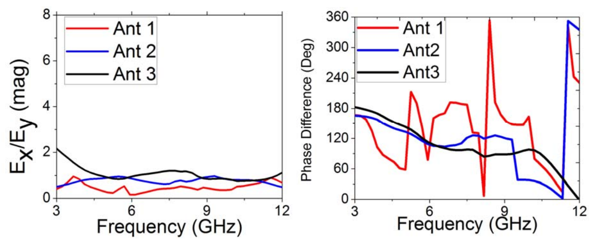


(a)S11 of steps 1-3 (antennas 1-3)



(b) 3dB axial ratio bandwidth at steps 1-3 (antennas 1-3)

Figure 3. Response of Step-1 (Ant-1), Step-2 (Ant-2) and Step-3 (Ant-3)



(a) Magnitude of (Ex/Ey) (b) Phase difference

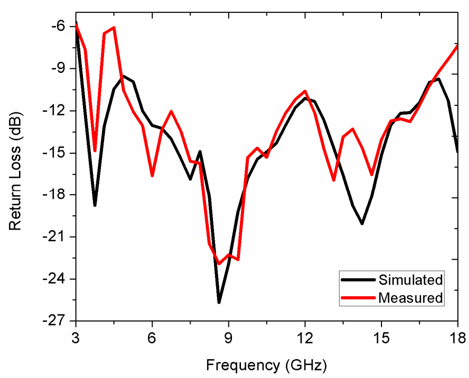
Figure 4. Electric field components (E_x and E_y) Magnitude and Phase difference of antenna-3

but 90^0 phase difference. The electric far field components (E_x and E_y) of Antenna-1 and Antenna-2 have not identical amplitude and both do not have 90^0-phase difference at the same time, as may be seen from Figs.4 (a) and (b). While antenna-3 has identical amplitude and has 90^0-phase difference at the same time.

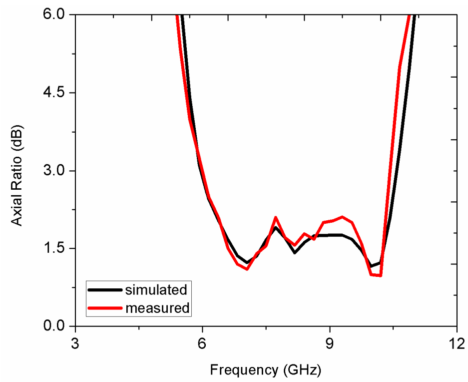
In view of this, next we cut some corners of the upper and lower sections of the square patch to form a quadrilateral-shaped radiator in order to simultaneously improve the return loss and the axial ratio bandwidths of the antenna. The resulting antenna-3 has identical electric fields component (E_x and E_y), together with nearly 90^0-phase difference, as shown in Fig.4, which in turn generates the desired circular polarization (CP) over a wide band.

2. Measured Results

The measured impedance matching bandwidth (S11) and 3-dB axial ratio bandwidth for the final designed antenna-3 are shown in Fig. 5. The proposed antenna-3 has impedance matching bandwidth (S11) from 4.8GHz to 16.87GHz. Measured 3dB axial ratio bandwidth (ARBW) of antenna-3 is from 5.96 to 10.50GHz, representing a 55.16% fractional bandwidth. Simulated and measured results are slightly different, perhaps because of the effect of the SMA connector and due to fabrication error.



(a) Impedance matching bandwidth (S11)



(b) 3dB axial ratio

Figure5. Simulated and measured performances of the final Antenna-3

The gain of the antenna-3(simulated and measured) is shown in Fig. 6. Note, that the measured gain of antenna-3 is in between 3.33 and 5.67dBi with 3dB axial-ratio (AR) band ranges from 5.96 to 10.58 GHz. The simulated and measured far-field radiation patterns of the proposed antenna-3 at 7.5GHz and 9.3GHz are presented in Fig.7 for both the XY- and YZ-planes. Finally, the performances of the proposed quadrilateral shape antenna-3 are compared with the recently published work in [3]–[8]. Our proposed antenna structure has compact size and is found to have improved impedance matching (S11) and 3dB axial ratio (AR) bandwidths.

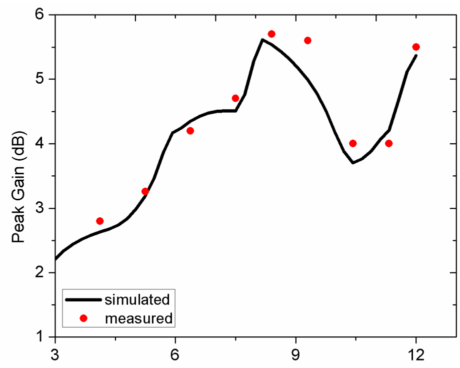
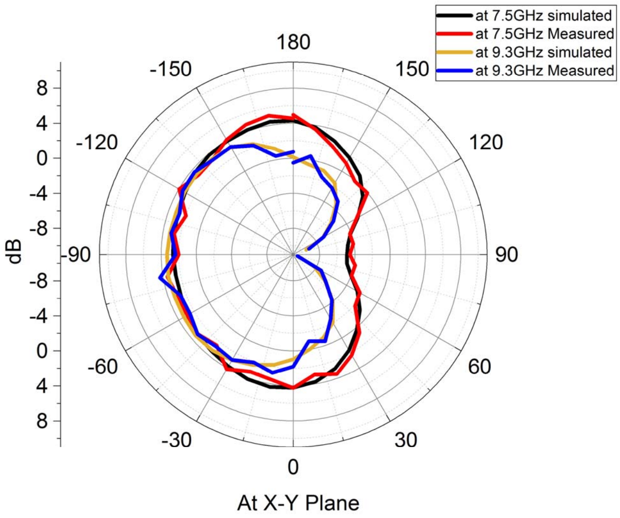


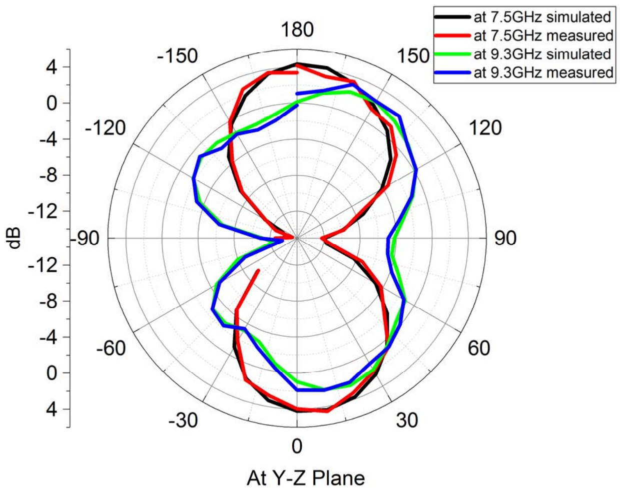
Figure6. Simulated and measured gain of the proposed antenna-3

Table -1 Comparison with the recently published work

Ref.	%IMBW	% ARBW	Size (L×W)	Er , h (mm)	Gain range (dBi)
3	57% (2.18-3.92GHz)	47.8% (2.15–3.5GHz)	82× 82	2.6, 1.524	4.75-7.28
4	51% (1.9-3.2 GHz)	30% (2.0-2.6GHz)	186× 103	2.2, 1.6	1.3-2.9
5	72% (1.5-3.4 GHz)	41.6% (2.1-3.12 GHz)	63× 58.4	4.4, 1.5	2.5-3.7
6	133.41% (1.38-6.4 GHz)	129.04% (1.38-6.4 GHz)	40× 40	4.4, 1.0	2.85-3.54
7	58.8% (4.8-8.8GHz)	47.8% (5.375-8.75GHz)	25× 24	4.4, 1.0	1.5-3.3
8	87.2% (2.2-5.6GHz)	61.85% (2.2-4.17GHz)	50× 45	4.4, 1.6	3.0-4.0
Our	**118.2% (4.5-17.5GHz)**	**55.86% (5.96-10.58GHz)**	**13× 13.43**	**4.4, 0.8**	**3.33-5.67**



(a) XY-plane



(b) YZ-plane

Figure7. Simulated and measured radiation pattern of theproposed antenna-3 at 7.5 GHz and 9.3GHz.

3. Conclusion

A quadrilateral-shaped CPW-fed monopole circularly polarized (CP) antenna has been proposed. A prototype of the antenna is fabricated, and its measured results are presented, which is useful for the modern communication system. The measured results show that the antenna has a wideband circular polarization (CP) with a 55.86% fractional bandwidth and a wide impedance matching bandwidth (S11) of 118.2%. The performance of the proposed antenna has been compared with those of the recently published works and is shown to be favorable. Compared to legacy circularly polarized antennas, the proposed antenna has a compact size, and better impedance matching and 3-dB axial ratio bandwidths. The presented antenna is useful for C-band as well as for X-band.

4. References

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