SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 19, No. 3, October 2022, 261-271

UDC: 621.396.67 **DOI: https://doi.org/10.2298/SJEE2203261C**

Circularly Polarized Quasi-Rectangular Patch UWB Antenna for GPR Applications

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Abstract: In this paper, a Circularly Polarized (CP) rectangular patch Ultra-Wideband (UWB) antenna is presented for Ground Penetrating Radar (GPR) applications. The designed geometry is constructed of a quasi-rectangular radiator and a partial ground plane. It is printed on the low-cost FR-4 substrate that has a compact size of 25×30×1.5 mm^3. The calculated Impedance Bandwidth (IBW) of the proposed CP quasi-rectangular patch antenna is spanning from 3.16 GHz to 13.7 GHz (125.03%). Moreover, the measured IBW of the fabricated prototype is spanning from 3.2 GHz to greater than 14 GHz (>125.58%) which covers the entire UWB range. Besides, the designed antenna reveals a wide Axial Ratio Band-Width (ARBW) extending from 4.23 GHz to 7.02 GHz (49.6%). Therefore, stable radiation patterns with an agreeable peak gain and high radiation efficiency are simulated over the whole working bandwidth.

Keywords: Rectangular patch antenna, Ultra-wideband antenna, Circularly polarized) antenna, Ground penetrating radar applications.

1 Introduction

Since the approval exploitation of the bandwidth extending from 3.1 GHz to 10.6 GHz in 2002 [1], the Ultra-Wideband (UWB) technology has received a considerable appreciation from the academic and industrial researchers specialized in the wireless domain [2]. This appreciation is due to the many advantages that offer, such as: high data transfer rate, reduced size, low cost for short range communication, multipath immunity, vast bandwidth and low power consumption [3, 4]. To guarantee these features, numerous types of antennas have been suggested to be combined within the UWB systems, such as those presented in [5 – 9]. Besides, the circularly polarized (CP) antennas have gained a great interest in wireless communications domain to improve the performance of the

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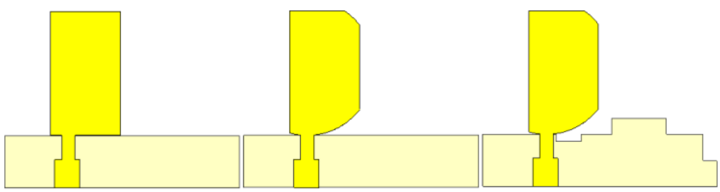
systems by allowing the transmitter and the receiver to be situated without having a polarization mismatch between them [10]. The GPR is a non-ruinous electromagnetic (EM) method that applies EM waves ranging between 0.1 GHz and 15 GHz to enter through surfaces. Within this band, good-resolution images of the sub-surfaces can be obtained and employed to explore the objects inhumed at different depths via the reflection of the transmitted EM waves [12, 13]. In this field, numerous UWB GPR antennas have been formerly presented such as: Vivaldi [14], horn [15], tapered-slot [16], and bowtie antennas [17]. Such antennas can offer some profits for GPR applications, but most of them are bulky and/or have complex configurations. Hence, there is a permanent need to invent simple and low-cost GPR antennas with enhanced performance.

In this work, a CP quasi-rectangular patch UWB antenna is presented and discussed for GPR applications. Section 2 exposes the geometrical configuration of the designed CP UWB antenna, while Section 3 discusses the obtained results and the performance of the antenna. In the last, this work concludes with the main obtained results which make the designed structure a good candidate for the GPR applications.

2 Antenna Geometry and Design

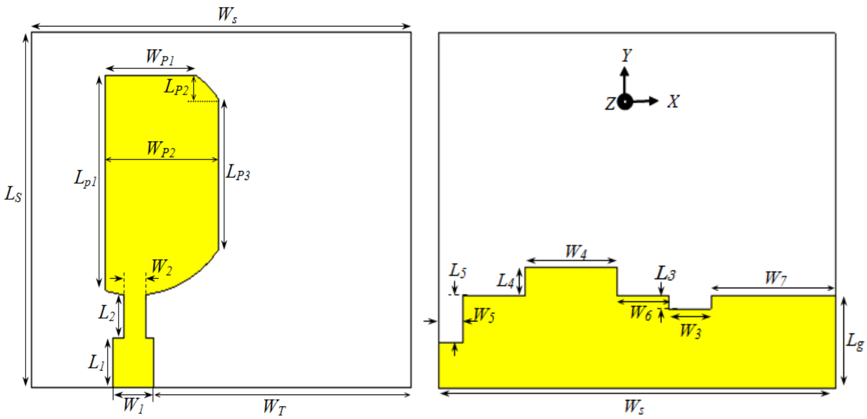
The geometrical configuration of the designed CP UWB antenna is depicted in Fig. 1. It is designed by employing the CST simulator [18]. The antenna is composed by a quasi-rectangular radiator and a minimized ground plane. To enhance the impedance matching, the right corners of the radiating patch are truncated and a number of cuts are applied in the upper border of the reduced ground plane.



(a) (b) (c)

Fig. 1 – *Antenna configuration evolution:*
(a) *Antenna A;* (b) *Antenna B;* (c) *Antenna C.*

Fig. 2 depicts the progress of the antenna during the design process. The designed model is printed on the FR4-Epoxy that has an area of 30×25×1.5 mm^3 and a relative permittivity of 4.4. A 50 Ω microstrip line is exploited to feed the designed CP UWB antenna. The physical dimensions of the proposed antenna are provided in **Table 1**.



(a) (b)

Fig. 2 – *Configuration of the designed CP quasi-rectangular patch UWB antenna:*(a) *Front view;*(b) *Back view.*

Table 1

Geometrical parameters of the designed structure.

Parameters	Dimensions [mm]	Parameters	Dimensions [mm]
L_S	25.00	W_s	30.00
L_{P1}	15.18	W_{P1}	7.12
L_{P2}	1.71	W_{P2}	8.95
L_{P3}	10.59	W_1	3.20
L_1	3.50	W_2	1.70
L_2	3.04	W_3	3.20
L_3	0.90	W_4	7.00
L_4	2.00	W_5	1.80
L_5	3.30	W_6	3.90
L_g	6.50	W_7	9.40
W_T	20.40	–	–

3 Results and Discussions

Fig. 3 indicates that the working bandwidth and the impedance matching are greatly enhanced by truncating the two right corners of the quasi-rectangular patch and by cutting the cooper from the upper corner of the reduced ground plane. Fig. 4 shows that the presented antenna has a wide axial ratio bandwidth (ARBW) spanning from 4.23 GHz to 7.02 GHz (49.6%). Thus, the presented antenna has a CP performance within this band. Furthermore, as depicted in Fig.5, a reasonable input impedance is obtained along the interesting bandwidth that indicates the fine adaptation of the designed model. The real part of the input impedance is near 50 ohms bar while the imaginary part is near zero bars.

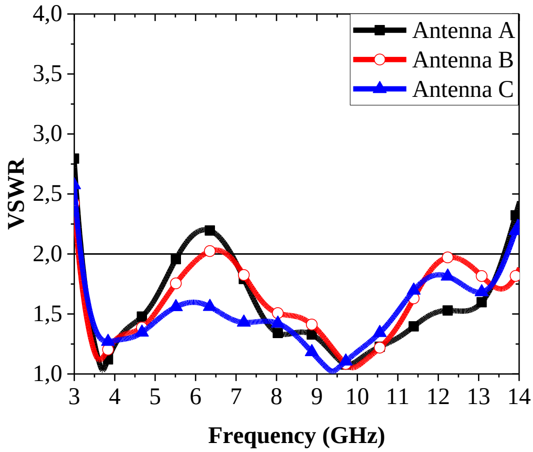


Fig. 3 – *VSWR comparison of the designed antenna with those of the initial antennas.*

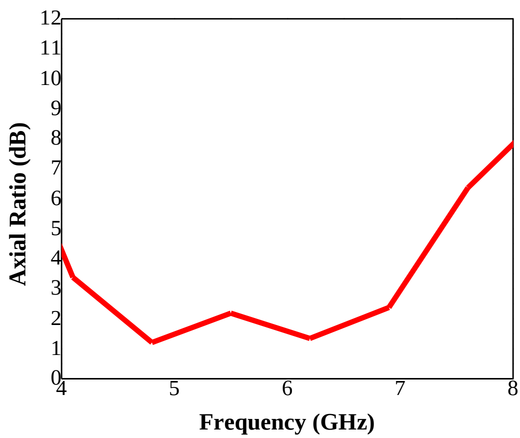


Fig. 4 – *Simulated axial ratio of the CP quasi-rectangular patch UWB antenna.*

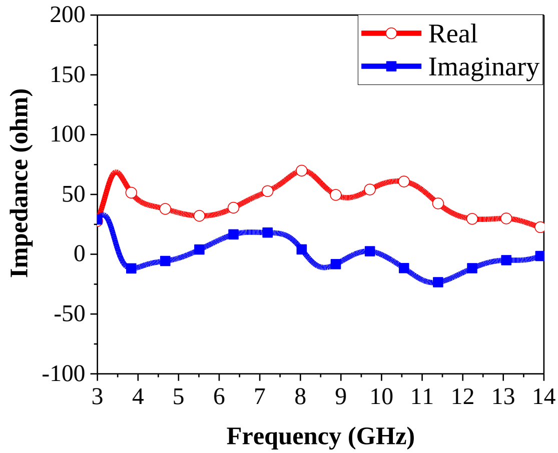
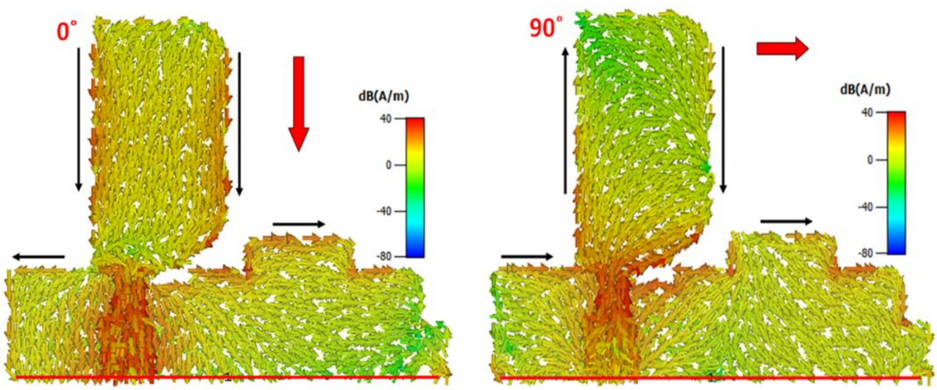


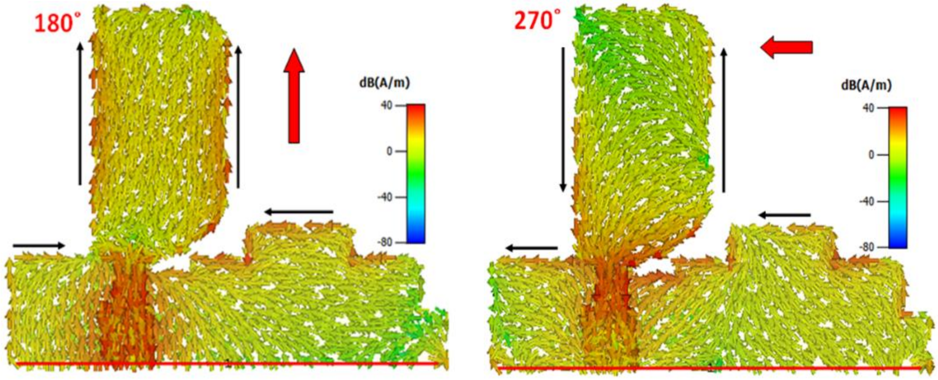
Fig. 5 – *Simulated input impedance of the CP quasi-rectangular patch UWB antenna.*

To show the type of the produced polarization, the current distributions on the antenna at 6 GHz for forth phases (0°, 90°, 180°, and 270°) are presented in Figs. 6 and 7. The main direction of the current is along the negative side of the Y-axis for the phase 0° and it is in the positive side of the Y-axis for 180°. Moreover, the main direction of the current is along the positive side of the X-axis for the phase 90° and it is on the negative side of the X-axis for 270°. Thus, as the phase increases with time, the principal current rotates in anti-clockwise orientation that illustrates a right-handed CP in the +Z-direction.



(a) (b)

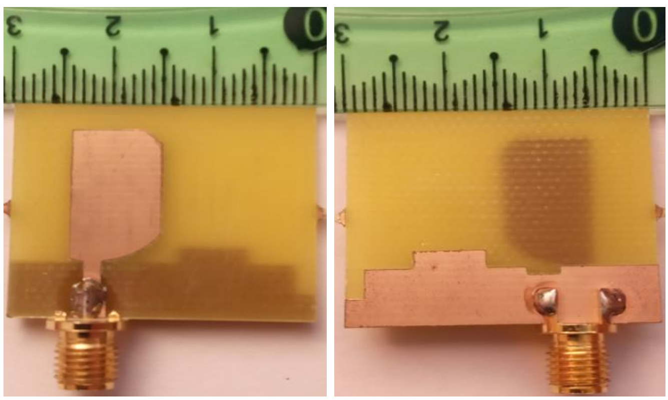
Fig. 6 – *Current distributions at 6 GHz for various phases:*(a) 0°*;* (b) 90°.



(a) (b)

Fig. 7 – *Current distributions at 6 GHz for various phases:(a) 180°; (b) 270°.*

Fig. 8 displays a photograph of the manufactured prototype printed by LPKF S103 laser printer. The operating IBW was measured by using R&S®ZNB Vector Network Analyzer. Excellent agreement is attained between the calculated result and the measured one.



(a) (b)

Fig. 8 – *Photograph of the CP quasi-rectangular patch UWB antenna:* (a) *Front view;* (b) *Back view.*

Fig. 9 reveals that the IBW of the manufactured model ranges between 3.2 GHz and more than14 GHz with a weak peak of VSWR of about 2.41 at 7.4 GHz, which could be due to the losses in the connector. Figs. 10 and 11 present the simulated right-handed circularly polarized (RHCP) and left-handed circularly polarized (LHCP) radiation patterns in *H*– and *E*–planes at three frequencies 4.5, 5.5, and 6.5 GHz. These two figures prove that the presented antenna radiates

RHCP in the positive side of the *z*–axis and LHCP in the negative side of the *z*–axis.

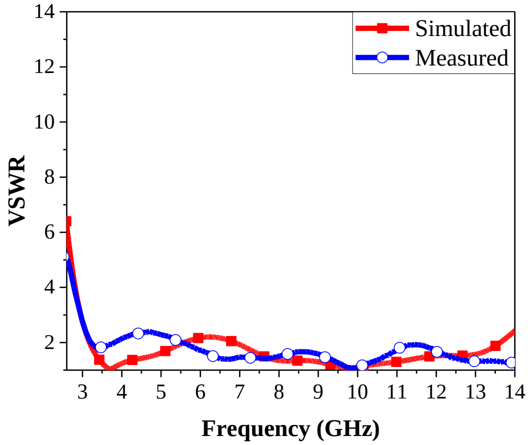


Fig. 9 – *Measured and simulated VSWR of the designed CP quasi-rectangular patch UWB antenna.*

Fig. 12 indicates that the designed antenna reveals acceptable values of the gain and excellent radiation efficiency values within the operating band. The values of the gain are spanning between 1.75 dBi and 5.5 dBi that are better than the ones achieved in [19]. Besides, the radiation efficiency values are nearly over than 75% that are superior to the ones achieved in [20].

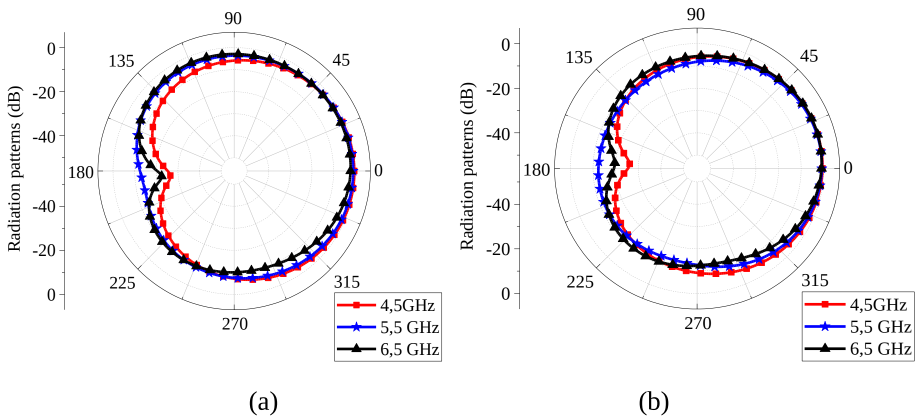
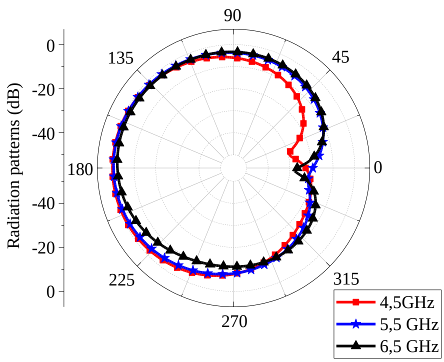
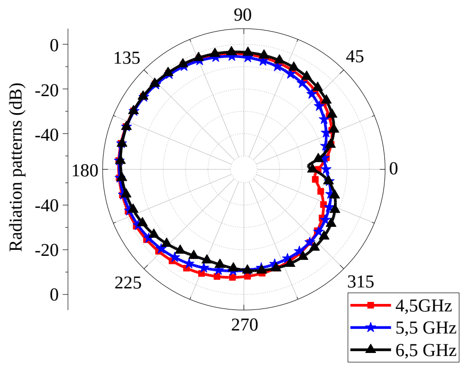


Fig. 10 – *RHCP patterns at various frequencies from the CP band:* (a) *H-plane;* (b) *E-plane.*



(a)



(b)

Fig.11 – *LHCP patterns at various frequencies from the CP band:* (a) *H-plane;* (b) *E-plane.*

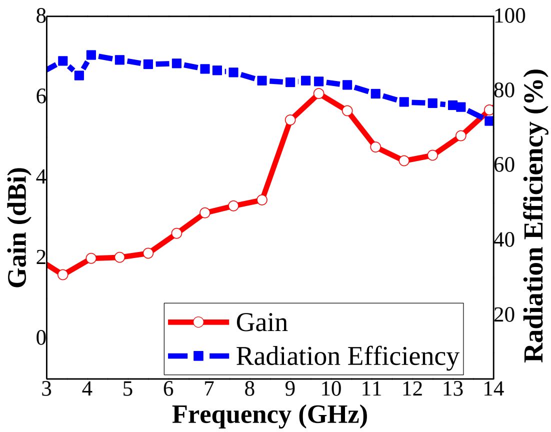


Fig. 12 – *Gain and radiation efficiency obtained by the proposed CP quasi-rectangular patch UWB antenna.*

To show the advantages of the proposed model, its characteristics are compared in **Table 2** with those of some other recently published CP antennas. As we can see, its characteristics are better or analogous to those of the ones presented in some recent literature.

4 Conclusion

In summary, a novel CP quasi-rectangular patch UWB antenna has been presented for GPR applications. A large IBW has been achieved by truncating the right corners of the rectangular patch and by cutting the cooper from the border of the reduced ground plane. The simulated operating IBW extends between 3.16 GHz and 13.7 GHz (125.03%). Furthermore, the proposed model discloses a wide ARBW spanning from 4.23 GHz to 7.02 GHz (49.6%).Besides, the measured IBW shows that the fabricated antenna with the size of 25×30×1.5 mm^3operates between 3.2 GHz and more than14 GHz (>125.58%). Hence, these significant features maintain the usefulness of the designed model for different applications, such as the sub-surfaces inspection.

Table 2

Comparison of the proposed model with some CP antennas.

References	Sizes [mm^3]	ARBW	IBW
[21]	108 × 108 × 29.524	2.26 GHz – 3.47 GHz (42.2%)	1.77 GHz – 3.52 GHz (66.2%)
[22]	75 ×63 × 1.52	2.2 GHz – 3.5 GHz (45.61%)	1.28 GHz – 4.5 GHz (111.4%)
[23]	100 × 100 × 21	1.5 GHz – 1.68 GHz (11.3%)	1.45 GHz – 1.73 GHz (17.6%)
[24]	74.5 × 74.5 × 19.6	2.36 GHz – 3.8 GHz (46.8%)	2.3 GHz – 3.82 GHz (52.2%)
[25]	58 × 58 × 3.175	5.1 GHz – 6 GHz (16.21%)	4.9 GHz – 6 GHz (20.18%)
[26]	54 × 54 × 3.1	5.64 GHz – 7.89 GHz (33.25%)	5.62 GHz – 11.04 GHz (65.06%)
Proposed	25 × 30 × 1.5	4.23 GHz – 7.02 GHz (49.6%)	3.2 GHz – >14 GHz (>125.58%)

5 Acknowledgments

The present study was supported by the Ministry of Higher Education and Scientific Research of Algeria.

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