High-permittivity Cross-Shaped Dielectric Resonator Antenna for Circular Polarization

L. Zou * C. Fumeaux *

Abstract — **This paper presents a wideband circularly polarized (CP) dielectric resonator antenna (DRA). The thin cross-shaped antenna of high permittivity is excited by two orthogonal microstrip lines with 90° phase difference resulting in circular polarization. The general design principles are proposed in this paper and a commercial full field analysis software, based on Finite-Element-Method (FEM), is employed to fine-tune the proposed antenna. The experimental results show a good agreement with simulation and demonstrate a broadside CP bandwidth of 13.2%.**

1 Introduction

Numerous investigations have been carried out on dielectric resonator antennas (DRAs) and have highlighted their attractive features, such as high radiation efficiency, low cost, compact size, light weight and versatility in their shape and feeding mechanism [1, 2, 3]. Recently, some research works have demonstrated relatively wideband circularly polarized (CP) performance of DRAs, which are, for example, useful for satellite communications to overcome polarization rotation effects due to the atmosphere. Some designs employ canonical antenna geometries, including, rectangular [4], cylindrical [5, 6] and cross [7] shapes, combined with simple feed configurations, such as probe [8], slot aperture [5] and vertical strips [9]. The achieved broadside CP bandwidth of such structurally simple antennas remains normally below 7%. In contrast, other designs utilize complex geometries [10, 11], sophisticated feed network [12] or additional hardware [13, 14] to achieve wider CP bandwidth. This does not only increase the manufacturing difficulty and cost but usually results in bulky antenna configurations. To the knowledge of the authors, a maximum CP bandwidth of 20% has been obtained by using a cylindrical DRA excited by an integrated microstrip quadrature hybrid network [12].

A cross-shaped CP DRA excited by slot aperture was firstly proposed by Ittipiboon et al. [7]. The CP operation is obtained by adjusting the length of two arms to resonate in phase quadrature. In their work, a CP bandwidth of 4% has been achieved by using low permittivity dielectric ($\varepsilon_r = 10.8$) material. Later, four cross-shaped DRAs have been utilized to compose a 2×2 array fed by sequential rotation, which increases the CP bandwidth to 16% [15]. In the present paper, a cross-shaped high permittivity DRA with a simple feeding mechanism is proposed. Compared with previous cross-shaped antennas, the length of two arms is equal and the CP operation is achieved by feeding through two orthogonal microstrip lines with quadrature phase difference. Furthermore, the size and dielectric volume of the antenna is reduced by using thin plates of high permittivity material to build the dielectric resonator (DR). Similar type of material has been proposed for a dual-mode bridge-shaped DRAs in [16]. The present paper demonstrates a different configuration, where a wide impedance bandwidth is achieved using such high-dielectric thin plates. With the proposed simple antenna structure, an impedance bandwidth of 21% and overlapping broadside CP bandwidth of 13% have been achieved.

2 Antenna Configuration

The configuration of the CP cross-shaped DRA is sketched in the Figure 1. The DRA consists of a cross-shaped dielectric resonator (DR) mounted on a FR4 substrate with dielectric permittivity of 4.0 and thickness of 1.6 mm. The DR design is based on a 1 mm thickness dielectric material of permittivity $\varepsilon_r = 50$. The cross is composed of two notched rectangular slices of the same size cut from the dielectric board, as shown in the inset of Figure 2. The depth of the notch is the half height of the DR plates to provide mechanical stability of the cross and the width of notch is 1 mm.

The length L and height h of slice are first designed without considering the mutual interaction between the two slices. Given the thickness ($d = 1$ mm) of the slices and the resonance frequency (4.5 GHz), an initial length L and height h are determined using [13]

$$k_L = \pi/L \quad (1)$$

$$k_h = \pi/2h \quad (2)$$

$$k_d \tan(k_d d/2) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_d^2} \quad (3)$$

*School of Electrical and Electronic Engineering, The University of Adelaide, Adelaide, SA 5005, Australia, e-mail: lzou@eleceng.adelaide.edu.au; cfumeaux@eleceng.adelaide.edu.au

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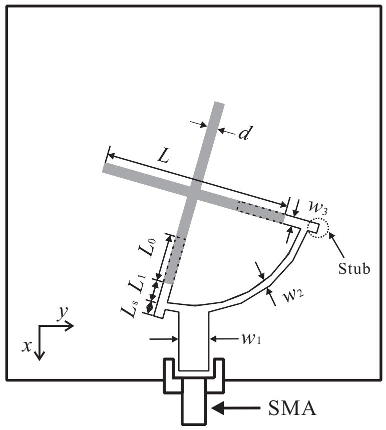
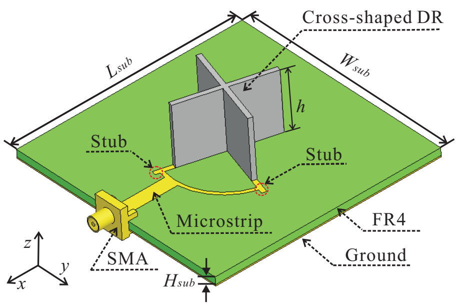


(a) Top View



(b) 3D View

Figure 1: Cross-shaped CP DRA configuration

$$k_L^2 + k_h^2 + k_d^2 = \varepsilon_r k_0^2 \tag{4}$$

where $k_0 = 2\pi/\lambda_0$.

The CP is achieved by exciting two orthogonal TE_{111} modes in the two cross arms with 90° phase difference. Direct coupling is provided by two orthogonal microstrip lines printed on the FR4 substrate. To simplify the feeding network, a T-junction splitter is utilized to connect two curved 100 Ω transmission lines to the feeding 50 Ω transmission line [17]. The 50 Ω line is connected to the network analyser through a SMA coaxial connector. By optimizing the length of the microstrip line underneath the two DR arms, a 100 Ω impedance is achieved at the end of each transmission line. Furthermore, the 90 degree phase difference is obtained by adjusting the angular location of the T-junction. The path difference between the T-junction and the end of the two microstrip lines is a quarter wavelength at 4.5 GHz. Based on this initial design, the DRA element and feeding network are simulated and optimized by using Ansoft® HFSS employing the finite-element method (FEM) in the frequency-domain. Through the simulation process, two small stubs are added to cancel reflection and increase the impedance bandwidth. The final antenna parameters are tabulated in the Table 1.

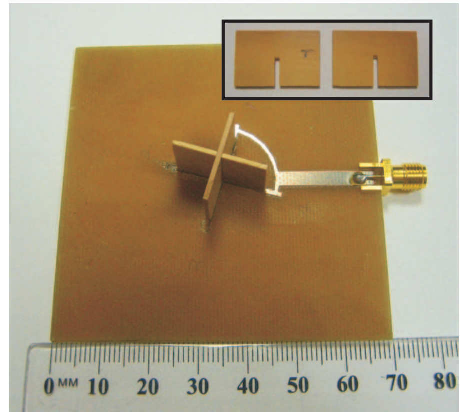


Figure 2: Realized prototype of cross-shaped DRA. Inset: Notched rectangular dielectric plates forming the cross-shaped DRA.

Symbol	Value	Symbol	Value
L	20 mm	h	13 mm
d	1 mm	L_0	5 mm
L_1	2.8 mm	L_s	0.9 mm
w_1	3.2 mm	w_2	0.76 mm
w_3	1 mm	H_{sub}	1.6 mm
L_{sub}	70 mm	W_{sub}	70 mm

Table 1: Antenna parameters

3 Experimental Results

A prototype of the optimized device has been manufactured as shown in Figure 2, with the dimension given in Table 1. Figure 3 illustrates the simulated and measured reflection coefficient. The measured impedance bandwidth (S11 < -10 dB) covers a frequency range from 4.25 to 5.25 GHz. There is a 0.1 GHz offset between simulation and measurement result that most probably arises from fabrication imperfections, e.g. from the glue layer used to mount the DR on the FR4 substrate.

The antenna axial ratio is measured and calculated according to the third definition of Ludwig [18]. Figure 4 shows a comparison between simulated and measured axial ratio around broadside direction ($\theta = 0°$). The minimum axial ratio of 0.36 dB is found at $f = 4.78$ GHz. The 3 dB axial ratio bandwidth extends from 4.6 GHz to 5.25 GHz, which yields an overlap with the impedance bandwidth of 13.2%. As for the impedance bandwidth,

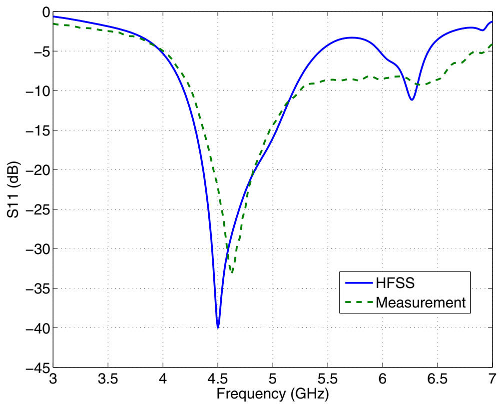


Figure 3: Simulated and measured return loss

the axial ratio is also shifted by 0.07 GHz to higher frequency, which is also attributed to fabrication imperfection. Overall the agreement between simulation and measurement is good and the achieved usable CP bandwidth validates the design concept.

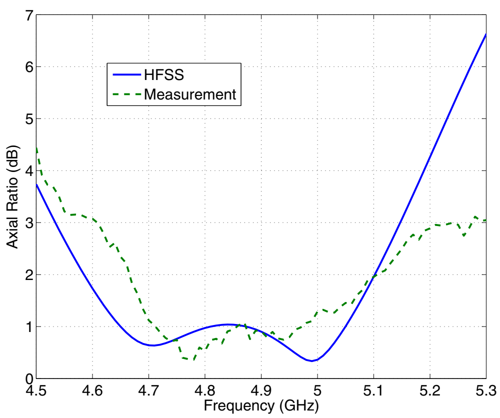
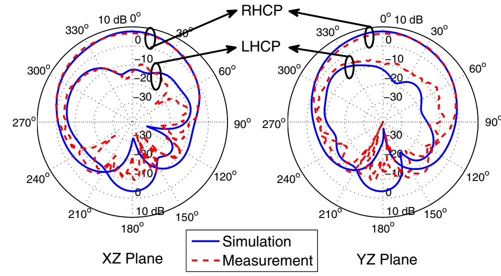


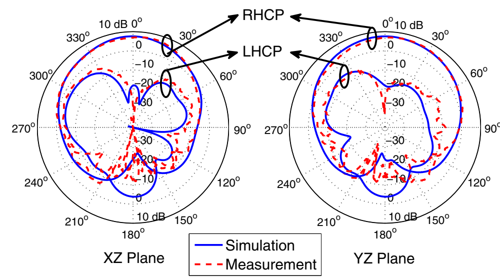
Figure 4: Simulated and measured axial ratio

The measured and simulated radiation patterns are depicted in the Figure 5 at frequencies 4.6 GHz, 4.78 GHz and 5.15 GHz, respectively. Stable broadside patterns with right-hand CP (RHCP) radiation patterns are obtained. The RHCP fields of XZ and YZ plane are at least 15 dB higher than the left-hand CP (LHCP) fields around the broadside direction. The asymmetry of the pattern is most probably due to the influence of the T-junction and the microstrip transmission line.

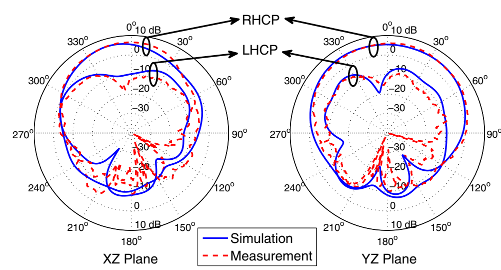
The gain of the prototype antenna is measured by using the gain-transfer method [19]. A comparison between the simulated and measured gain is shown in the Figure 6. A maximum gain of 6.17 dB is measured at 4.7 GHz. Within the usable 3-dB CP bandwidth, the antenna gain remains above 3.5 dB.



(a) Gain pattern at 4.6 GHz



(b) Gain pattern at 4.78 GHz



(c) Gain pattern at 5.15 GHz

Figure 5: Simulated and measured radiation pattern

4 Conclusion

This paper proposed a design of high-permittivity cross-shaped DRA for CP applications. In the two crossed equal-length arms of the DR, TE_{111} modes are excited by two orthogonal microstrip lines with 90° phase difference to generate circular polarization. The combination of high-permittivity material for the DRA and of a quadrature feed results in a compact design with an impedance bandwidth of 21% and a broadside CP bandwidth of 13.2%. Furthermore, the simple antenna configuration and feeding mechanism make this design easily scalable to other frequency bands. In addition, the geometry and feeding mechanism of antenna can

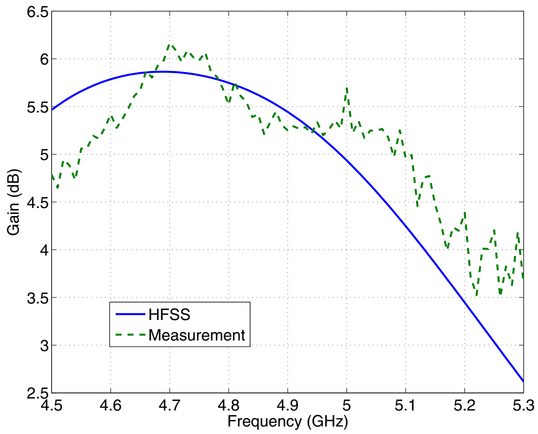


Figure 6: Simulated and measured RHCP gain

be extended or integrated to create multi-function or multi-band antenna.

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