

Square DRA with Orthogonal Slot Excitation and Impedance Matching for GPS L1 Applications

Herick R. S. Rodrigues, Edson R. Schlosser, Juner M. Vieira and Marcos V. T. Heckler

Abstract—This paper presents a square dielectric resonator antenna (SDRA) with right-hand circular polarization (RHCP) for the GPS L1-band (centered at 1.575 GHz). The antenna consists of a dielectric resonator excited by two orthogonal slots etched in the ground plane, enabling the excitation of orthogonal modes in phase quadrature for circular polarization. A microstrip feed with series and shunt stubs is employed to achieve impedance matching below -10 dB over the operating band. The antenna was modeled and optimized in Ansys HFSS, focusing on axial ratio performance. Simulation results show low axial ratio, wide angular coverage, low cross-polarization levels, and high radiation efficiency over the GPS L1 band.

Keywords—Circular polarization; DRA; GPS; Impedance matching.

I. INTRODUCTION

Radionavigation has become an essential component of modern life, enabling accurate positioning anywhere on the planet. This capability is achieved through the transmission of radio signals by satellite constellations and their processing by dedicated receivers. Among these systems, the Global Positioning System (GPS) stands out as one of the most widely used, supporting a broad range of applications, including aerial, terrestrial, and maritime navigation.

In this context, dielectric resonator antennas (DRA) emerge as a promising alternative due to their low conduction loss and high radiation efficiency, especially at microwave frequencies. Typically fabricated from materials with a high relative permittivity, DRAs can be designed in various geometries, such as cylindrical, rectangular, cubic, and spherical, whose resonant characteristics depend on their dimensions, shape and dielectric properties. These features provide significant flexibility in antenna design, enabling compact structures [1], [2].

DRA technology was selected for this work due to its superior bandwidth performance when compared to conventional microstrip antennas [3]. In particular, DRAs can exhibit a significantly larger impedance bandwidth (on the order of 10% for a relative permittivity $\epsilon_r \approx 10$), which is a relevant characteristic for applications requiring enhanced frequency robustness. This behavior is mainly attributed to the radiation mechanism, while microstrip antennas radiate predominantly through fringing fields at the edges, the DRAs radiate over most of their volume, except for the region in contact with the ground plane [4].

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In some cases, satisfactory antenna performance can be achieved solely through an appropriate design of the feeding structure [5], [6]. However, when adequate impedance matching is not achieved, additional design strategies are necessary, such as geometric optimization or the incorporation of impedance-matching networks. These networks, typically implemented using microstrip elements such as series and shunt stubs, play a fundamental role in improving impedance matching and reducing the reflection coefficient [7].

For the proposed application, the antenna element is designed to operate in the GPS L1 band. The desired radiation pattern should exhibit a main lobe covering the upper hemisphere, while reducing sensitivity to low-elevation multipath signals. In addition, the antenna must provide right-hand circular polarization (RHCP) in order to ensure polarization matching with the signals transmitted by the satellites [8], [9].

This paper is organized as follows: Section II presents the DRA design, Section III describes the impedance matching network design, and Section IV presents the results of the final antenna design. Finally, the conclusions are presented in Section V.

II. SQUARE DRA DESIGN

This section presents the design and geometry of the proposed square DRA, along with its main performance results obtained using Ansys HFSS. The antenna was designed to operate in the L1 band of GPS with center frequency of 1.575 GHz.

The design procedure encompasses material selection, geometrical parameter optimization, and the development of the excitation mechanism based on electromagnetic coupling. The antenna performance is evaluated in terms of axial ratio as a function of frequency and elevation angle θ , as well as for the radiation pattern and the reflection coefficient.

The geometry of the proposed antenna is shown in Fig. 1(a). It consists of a square ground plane on which a dielectric resonator with square cross-section is centrally placed. A metallic loading is placed on the top surface of the resonator to improve impedance matching and enhance the overall electromagnetic performance of the structure [6].

In Fig. 1(b), the side view of the proposed antenna is presented. The DRA is implemented using a Rogers TMM10i substrate, with relative permittivity $\epsilon_r = 9.8$, loss tangent $\tan \delta = 0.002$, and thickness $h_{TMM} = 7.62$ mm. The metallization is realized using copper with thickness $h_c = 35$ μ m. The ground plane is fabricated on an FR4 substrate, with $\epsilon_r = 4.35$, $\tan \delta = 0.02$, thickness $h_{FR4} = 1.524$ mm, and copper metallization of thickness h_c .

With the selected DRA geometry, the next step consists of determining its dimensions based on the resonance frequency of the fundamental TE_{mnp} mode, given by

$$f_{TE_{mnp}} = \frac{c}{2\pi\sqrt{\epsilon_r}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{h}\right)^2}, \quad (1)$$

where the indices m , n , and p correspond to the wave numbers in the x , y , and z directions, respectively. The parameters a , b , and h denote the DRA dimensions. For the proposed square geometry, where $a = b$, the dominant mode corresponds to TE_{110} , i.e., $m = n = 1$ and $p = 0$. This mode is typically selected for its suitability for broadside radiation and compatibility with practical excitation mechanisms. Under these conditions, Eq. (1) becomes

$$f_{TE_{110}} = \frac{c}{2\pi\sqrt{\epsilon_r}} \sqrt{2\left(\frac{\pi}{a}\right)^2}. \quad (2)$$

The analytical design procedure resulted in an initial value of $a \approx 43$ mm. Based on this value, the complete antenna structure was modeled and further optimized in Ansys HFSS. Figure 1(c) shows the top view of the ground plane, where two orthogonal slots are etched to excite two near-degenerate orthogonal modes with a 90° phase difference. This excitation mechanism enables the generation of circular polarization through electromagnetic coupling between the microstrip feed and the dielectric resonator. Such a configuration offers several advantages, including high coupling efficiency, ease of integration with printed feeding networks, and reduced structural complexity compared to conventional dual-feed approaches [10]. The antenna was designed to operate with RHCP, which is required for proper reception of GPS L1 signals.

Figure 1(d) presents the bottom view of the ground plane, where the microstrip feeding line is located. This structure includes a series stub that improves impedance matching and ensures efficient power transfer to the dielectric resonator via the slot-coupled excitation mechanism. For the electromagnetic simulations, a wave port was employed as the excitation source in Ansys HFSS.

The dimensions presented in Fig. 1 were optimized using Ansys HFSS and are summarized in Table I. The parameter W_{GND} defines the overall size of the ground plane, while a governs the resonance frequency of the antenna and directly influences the axial ratio (AR) performance. The width W_G corresponds to the ground plane region associated with the DRA and was defined to accommodate the fabrication process, allowing the structure to be assembled by soldering rather than adhesive bonding. The parameter W_L represents the width of the 50Ω microstrip feeding line. The slot lengths L_{F1} and L_{F2} are mainly responsible for the excitation of the orthogonal modes and, consequently, for the optimization of the axial ratio, while the width W_F was maintained at a fixed value throughout the design process. Finally, the parameter L_{TS} is defined from the reference plane, which coincides with the impedance reference plane, and acts as a series stub to provide impedance matching to 50Ω .

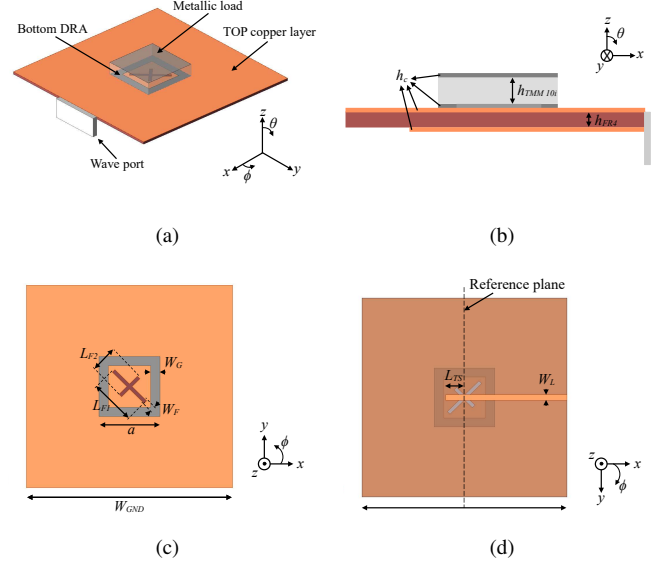


Fig. 1. Geometry of the proposed DRA: (a) isometric view of the complete structure; (b) side view; (c) top view of the ground plane with the excitation slots; (d) bottom view of the ground plane with the feeding line and the series stub.

TABLE I
OPTIMIZED PARAMETERS OF THE PROPOSED DRA.

Parameter	Value (mm)	Parameter	Value (mm)
W_{GND}	110.0	W_L	3.1
a	32.6	L_{F1}	24.0
W_F	2.0	L_{F2}	14.0
W_G	5.0	L_{TS}	10.0

As shown in Fig. 2(a), the axial ratio within the L1 band remained below 3 dB over the frequency range from 1.565 GHz to 1.582 GHz, corresponding to a bandwidth of approximately 17 MHz. At the center frequency, a minimum value of 1.07 dB was achieved. However, the simulated reflection coefficient $|\Gamma|$ was approximately -3.67 dB at the same frequency. Considering the criterion $|\Gamma| \leq -10$ dB, impedance matching is not adequate over the frequency band of interest.

In the Smith chart shown in Fig. 2(b), the reflection coefficient locus remains far from the center, indicating poor impedance matching with respect to 50Ω reference impedance. This behavior explains the relatively high value of the $|\Gamma|$ previously obtained. Fig. 2(c) presents the axial ratio as a function of the elevation angle θ . The antenna achieves an angular coverage of 121.25° for AR below 3 dB, indicating good circular polarization performance over a wide angular region.

The simulated radiation patterns are shown in Fig. 2(d), corresponding to the planes $\phi = 0^\circ$ and $\phi = 90^\circ$. A high Cross-Polarization Discrimination (XPD) is observed in both cases. At 1.575 GHz, the antenna achieves an RHCP gain of 5.65 dBic. In addition, the radiation patterns exhibit good symmetry and broadside directivity, which are desirable characteristics for navigation applications, since they provide robust signal reception under variations in the antenna spatial

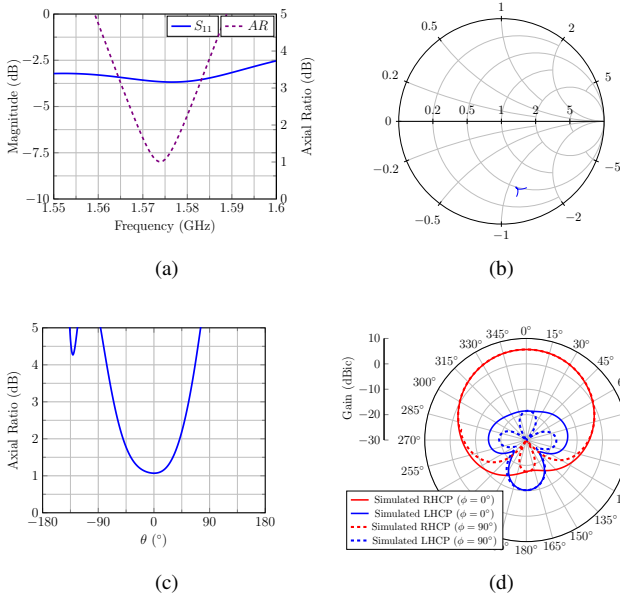


Fig. 2. Simulated results of the proposed DRA: (a) reflection coefficient and axial ratio as a function of frequency; (b) Smith chart of the reflection coefficient; (c) axial ratio as a function of θ ; (d) radiation patterns in the $\phi = 0^\circ$ and $\phi = 90^\circ$ planes.

orientation.

Based on these preliminary results, the proposed antenna exhibits satisfactory performance in terms of AR, RHCP gain, and angular coverage. However, the reflection coefficient does not satisfy the design criterion due to inadequate impedance mismatch. Therefore, the next section focuses on the design of the impedance-matching network, which aims to mitigate this mismatch and improve the overall antenna performance.

III. IMPEDANCE MATCHING NETWORK DESIGN

This section presents the design of the impedance-matching network to improve the impedance matching of the proposed antenna. At this stage, the analysis focused exclusively on the behavior of the reflection coefficient on the Smith chart, aiming to overcome the limitations identified at the end of the DRA design stage.

Figure 3 illustrates the design procedure adopted for the impedance matching network. In the first step, a parametric analysis of the parameter L_{TS} was performed to verify whether a series stub would be sufficient to achieve proper matching. This element introduces series reactance to the input impedance, correcting its imaginary part and moving the impedance locus along constant-resistance circles in the Smith chart. On the reference plane, the initial condition for $L_{TS} = 10$ mm yielded input impedance $z_{ant} = 0.49 - j1.11$. After optimization, the value $L_{TS} = 20$ mm was selected, resulting in $z_{ant1} = 0.44 - j0.11$, as shown in Fig. 4(a).

In the second step, a shunt stub was added to the microstrip line, and a parametric analysis of the parameter L_{TP} was carried out. This element introduces susceptance and allows further impedance adjustment, as the series stub alone was insufficient to achieve satisfactory matching. With the optimized value $L_{TP} = 10$ mm, the input impedance calculated

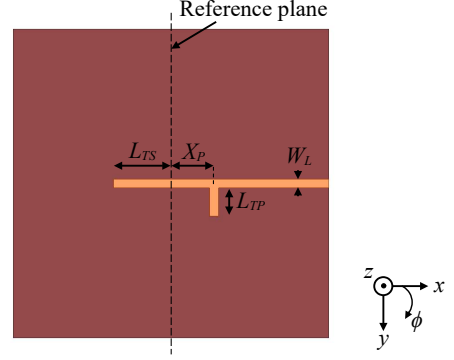


Fig. 3. Design of the impedance matching network.

on the reference plane was $z_{ant2} = 0.41 - j0.02$, as shown in Fig. 4(b).

In the third step, since the matching was still not satisfactory, the parameter X_P was introduced to shift the position of the shunt stub along the transmission line. This displacement promotes impedance transformation, modifying the impedance seen at the stub connection point as a function of distance. In this case, the impedance reference plane is displaced by a distance X_P relative to the antenna center. After optimization, the selected value was $X_P = 15$ mm, resulting in $z_{ant3} = 1.17 - j0.04$, with the corresponding curves presented in Fig. 4(c).

Figure 4(d) presents a comparison between the optimized reflection coefficient obtained after the implementation of the impedance matching network and the initial reflection coefficient of the antenna without the matching structure. A significant improvement can be observed, with the simulated value reaching -21.66 dB at 1.575 GHz. Considering the criterion $|\Gamma| \leq -10$ dB, the resulting impedance bandwidth extends from 1.55 GHz to 1.60 GHz, corresponding to approximately 50 MHz. In contrast to the initial design, which presented a reflection coefficient of approximately -3.67 dB at the same frequency, the improved design clearly demonstrates the effectiveness of the proposed matching network in achieving proper impedance matching while preserving the antenna operating band.

It is worth noting that the obtained result could be further improved by further optimizing the design parameters. However, the main purpose of this analysis is to demonstrate the impedance matching procedure and its behavior on the Smith chart, highlighting the effectiveness of the adopted methodology rather than pursuing the absolute optimum design.

IV. FINAL ANTENNA DESIGN

As previously discussed, the initial analyses of the antenna and impedance-matching network design were carried out using a wave port as the excitation source. In this section, the final results of the proposed square DRA with the matching network are presented, now considering the integration of an SMA connector and additional adjustments related to the prototyping process.

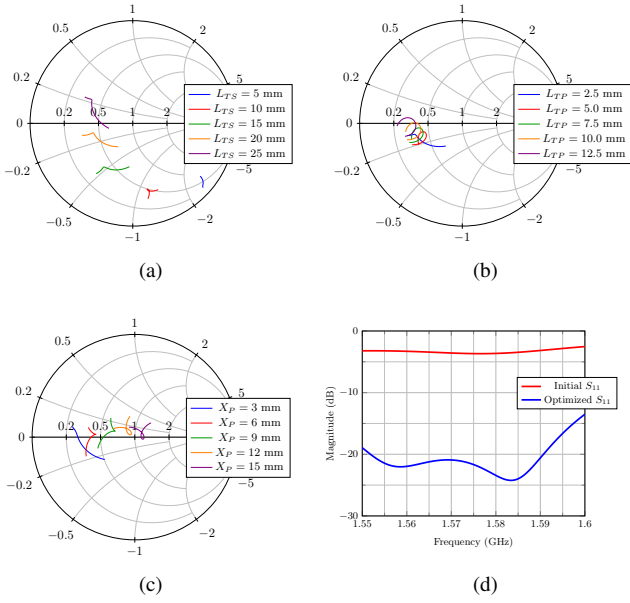


Fig. 4. Results of the impedance matching network design: (a) parametric analysis of the series stub L_{TS} ; (b) parametric analysis of the shunt stub L_{TP} ; (c) analysis of the shunt stub position along X_P ; (d) comparison of the reflection coefficient before and after applying the impedance matching network.

With the inclusion of the SMA connector and two reference holes required for fabrication, a slight frequency shift and minor variations in some geometrical parameters were observed compared to the wave port model. These holes ensure the correct positioning and alignment of the square DRA during the assembly process. However, since the same design methodology was maintained, such effects were easily compensated through small adjustments in the antenna dimensions. The final structure is shown in Fig. 5, and the optimized dimensions of the final DRA are summarized in Table II.

TABLE II
OPTIMIZED DIMENSIONS OF THE FINAL DRA.

Symbol	Value (mm)	Symbol	Value (mm)
W_{GND}	90.0	a	32.6
W_G	5.0	W_L	3.1
L_{F2}	14.0	L_{TS}	20.0
X_P	14.0	Gap	0.5
W_F	2.0	L_{F1}	24.6
L_{TP}	10.0		

In Fig. 6(a), the simulated results of the reflection coefficient and the axial ratio are presented. The simulated reflection coefficient was approximately -19.52 dB at 1.575 GHz. Considering the criterion $|\Gamma| \leq -10$ dB, the impedance bandwidth extends from 1.55 GHz to 1.60 GHz, corresponding to approximately 50 MHz. In this design, priority was given to AR performance, since it is more critical for GPS applications, with the AR centered at the operating frequency and exhibiting a narrower bandwidth than the reflection coefficient. The AR within the GPS L1 band remained below 3 dB over the frequency range from 1.564 GHz to 1.585 GHz, corresponding to a bandwidth of approximately 21 MHz. At the center frequency, a minimum simulated value of 0.12 dB

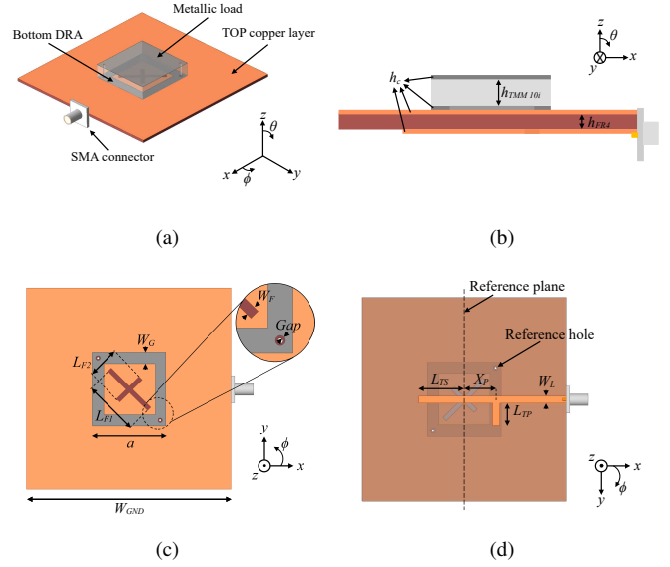


Fig. 5. Geometry of the DRA: (a) isometric view of the complete structure; (b) side view; (c) top view of the ground plane with the excitation slots; (d) bottom view of the ground plane with the feeding line and the impedance matching network.

was obtained. The locus of the antenna input impedance in the Smith chart is presented in Fig. 6(b). It can be observed that the input impedance curve remains close to the center of the chart. Figure 6(c) presents the AR as a function of the elevation angle θ . The antenna achieves a wide angular coverage of approximately 202.47° for AR values below 3 dB. The simulated radiation patterns are shown in Fig. 6(d), corresponding to the planes $\phi = 0^\circ$ and $\phi = 90^\circ$. A high XPD of 43.24 dB is observed. At 1.575 GHz, the antenna achieves an RHCP gain of 5.83 dBic.

Comparing to the initial version of the design, without the impedance-matching network and using a wave port, to the final version, which includes the matching network and the SMA connector, a significant improvement in the overall performance can be observed. The final configuration achieved a radiation efficiency of 87.10% . In addition, the radiation patterns maintained good symmetry and directivity, which are desirable characteristics for navigation applications, as they provide robust signal reception under variations in the antenna spatial orientation. Table III presents a direct comparison between these two configurations.

TABLE III
COMPARISON OF ANTENNA PARAMETERS: INITIAL AND FINAL VERSIONS.

Parameter	Initial version	Final version
AR	1.07 dB	0.12 dB
AR bandwidth	17 MHz	21 MHz
S_{11}	-3.67 dB	-19.52 dB
S_{11} bandwidth	—	50 MHz
Gain	5.65 dBic	5.83 dBic
Efficiency	78.02%	87.10%
XPD	24.22 dB	43.24 dB
$AR \times \theta$	121.25°	202.47°

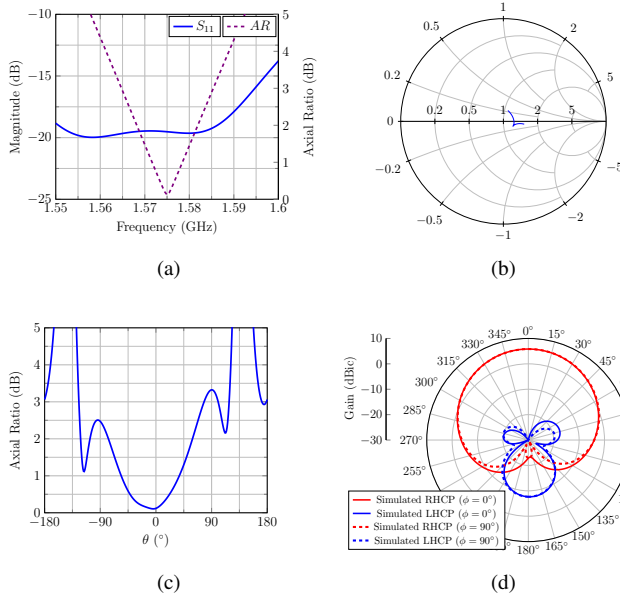


Fig. 6. Simulated results of the DRA: (a) reflection coefficient and axial ratio as a function of frequency; (b) Smith chart of the reflection coefficient; (c) axial ratio as a function of θ ; (d) radiation patterns in the $\phi = 0^\circ$ and $\phi = 90^\circ$ planes

V. CONCLUSION

This work presented the design of a square DRA with RHCP for GPS L1 band applications. The proposed structure, excited through orthogonal slot coupling, demonstrated satisfactory initial performance in terms of axial ratio, gain, and radiation pattern. However, the initial design exhibited limitations in the reflection coefficient.

To overcome this issue, an impedance-matching network was developed using a series stub, a shunt stub, and adjusting the shunt stub position along the transmission line. This approach enabled a significant improvement in impedance matching, reducing the reflection coefficient from -3.67 dB to -19.52 dB at 1.575 GHz.

In the final design, the antenna achieved an axial ratio below 3 dB over the frequency range from 1.564 GHz to 1.585 GHz, with a minimum value of 0.12 dB, an RHCP gain of 5.83 dBic, and a radiation efficiency of 87.10% . In addition, the wide angular coverage and good symmetry of the radiation patterns indicate that the proposed antenna is well-suited for GPS navigation applications, providing robust performance under different spatial orientations.

Future work will include the fabrication and experimental validation of the proposed antenna to confirm the simulated results and further evaluate its performance for GPS L1 band applications.

ACKNOWLEDGEMENTS

This work has been partially supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) (Finance Code 001) and by the National Council for Scientific and Technological Development (CNPq) under grants 300060/2023-8, 305654/2022-5, 407245/2022-7 and

406517/2022-3 (INCT-Signals), and to FAPERGS under grant 24/2551-0001280-0 and by Funding Agency for Studies and Projects (FINEP) under Grant 01.25.0083.00.

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