Progress In Electromagnetics Research C, Vol. 161, 285–290, 2025

(Received 1 August 2025, Accepted 22 October 2025, Scheduled 15 November 2025)

A Compact, Circularly Polarized Truncated-Corner Patch Antenna with a Stable Phase Center for GPS Applications

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ABSTRACT: This paper introduces a compact, circularly polarized (CP) truncated-corners patch antenna with a highly stable phase center for Global Positioning System (GPS) L1 applications. The antenna is excited by a central coaxial feed and features two corner truncations and a square-shaped slot with an integrated tab to generate CP. Designed for the GPS L1 band (1.563–1.587 GHz), the antenna achieves a -10 dB impedance matching bandwidth of 100 MHz (1.52–1.62 GHz), covering the target frequency range. Key performance metrics include a wide 3-dB axial ratio (AR) beamwidth of 190° and a fractional AR bandwidth of 1.5%. A prototype was fabricated and tested, and the measured results show reasonable agreement with simulations, confirming the design's effectiveness.

1. INTRODUCTION

Over the past decade, technological advancements have driven the rapid evolution of antennas for radio-navigations applications. In modern communication systems, antennas play a critical role in transmitting and receiving information. These components have benefited greatly from enhancements that improve both performance and compactness. Specifically, circularly polarized (CP) antennas with a stable phase center have received significant attention for their use in both military and civilian Global Positioning System (GPS) applications [1, 2]. Compared to conventional antennas, microstrip patch antennas offer several key advantages, including ease of fabrication, low cost, simple integration, and a compact physical size [3]. These features make them a primary focus of antenna research, with an ongoing goal of ensuring excellent performance [4].

According to the relevant literature, single and multi-feed CP planar microstrip antennas have been developed recently including truncated corners [5–10], and this well-known method is used to achieve circular polarization or through introducing perturbations as four asymmetric cross slots or four unequal circular shaped slots [11].

An annular shape slotted antenna was presented in [6]. While a single method is used generally to handle antenna analysis, a combination of different techniques could also be used to achieve increased antenna performances [12–17].

The antenna phase center varies in function of the frequency and elevation angle, and the phase center deviation (PCD) and antenna phase center variation (PCV) can be used to evaluate its stability, the structure symmetry and feeding location are the most configuration requirements for high positioning accuracy. Therefore, the conception of symmetric CP antennas with stable (PCD) and (PCV) is still a great challenge [18, 19].

In this work, a truncated corners patch antenna (TCPA) with a square shaped slot is presented. The proposed antenna generates a good CP radiation and can work in GPS L1 band [1.563–1.587] GHz. The simplicity of the antenna geometry and overall structure symmetry are required to achieve phase center stability.

2. ANTENNA GEOMETRY AND DESIGN

The proposed truncated-corners patch antenna (TCPA) features a geometry designed to optimize performance for GPS applications. As shown in Figure 1, the antenna comprises a square radiating patch printed on a multilayer FR-4 substrate. This substrate, characterized by a dielectric constant (ε_r) of 4.4 and a low loss tangent of 0.02, is configured with three stacked layers to achieve a total thickness of $H1 = 4.8$ mm. This specific substrate configuration is employed to enhance both the antenna's gain and bandwidth.

The detailed dimensions of the antenna are provided in Table 1 and summarized as follows: Ground Plane: A square ground plane with an edge length of $LG = 75$ mm forms the foundation of the antenna structure. Radiating Patch: A square patch with an edge length of $LP = 37.3$ mm is centrally excited by a coaxial feed. The central feed location is critical for maintaining the stability of the phase center, which is essential for high positioning precision. Circular Polarization (CP) Generation: The antenna achieves CP through a combination of geometric perturbations. Two truncated corners, each with a length of $T1 = 6.3$ mm, are implemented. Additionally, two pairs of symmetric but unequal-length slots are incorpo-

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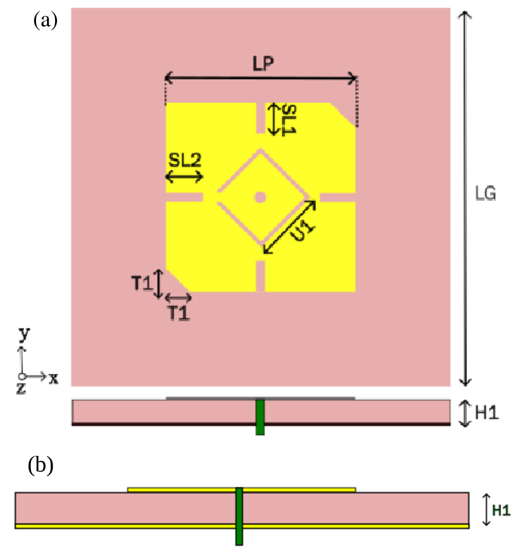

FIGURE 1. Geometry of the proposed truncated-corner patch antenna, showing (a) top view with key dimensions and (b) side view of the substrate layers.

TABLE 1. Optimized design parameters for the proposed antenna.

Parameter	Value (mm)	Description
LG	75	Ground plane length (= width)
LP	37.3	length of the square patch
H	4.8	Substrate high
$T1$	6.3	Length of the truncated corner
SL1	6.2	Length of the slots along y-axis
SL2	7.3	Length of the slots along x-axis
WSL	1.8	Width of *SL1* and *SL2*
WU1	0.8	Square slot's width
$U1$	14	Square slot edge's length
$F(x, y)$	(0, 0)	The feeding location

rated. These slots, designated as *SL1* and *SL2*, have lengths of 6.2 mm and 7.3 mm, respectively, and share a common width of *WSL* = 1.8 mm. Impedance Matching: To improve impedance matching, a square-shaped central slot with an edge length of $U1 = 14$ mm is introduced. An internal tab with a width of *WU1* = 0.8 mm is also included to enhance the connectivity between the internal and external regions of the square slot.

The coaxial feed is positioned at the center of the patch geometry, a design choice that significantly impacts the phase center stability [5]. The antenna's CP performance is achieved through the strategic incorporation of two corner truncations ($T1 = 6.3$ mm) and four symmetric, unequal slots (*SL1* and *SL2*). These slots, while maintaining a consistent width of *WSL* = 1.8 mm, vary in length (6.2 mm and 7.3 mm, respectively), contributing to the desired CP characteristics. A square-shaped slot with a width of $W1 = 0.8$ mm and an edge length of $U1 = 14$ mm is added to the design. Furthermore, a 2 mm tab is included to strengthen the internal-external connectivity of the square slot, which in turn helps to improve the impedance matching. All design dimensions are comprehensively listed in Table 1. This enhanced design not only ensures the antenna's compactness and CP performance but also targets the phase center stability, making it suitable for precise GPS applications. The combination of these geometric features and carefully selected substrate parameters contributes to the antenna's ability to meet the demanding requirements of modern GPS systems.

3. PARAMETRIC STUDY

This section presents a parametric study to analyze the effect of key geometric parameters on antenna performance. Figure 2 shows the simulated reflection coefficient (S_{11}) and axial ratio (AR). The -10 dB impedance bandwidth covers the 1.52–1.62 GHz band (100 MHz, or 6.3%), while the 3-dB AR bandwidth is 24 MHz (1.5%).

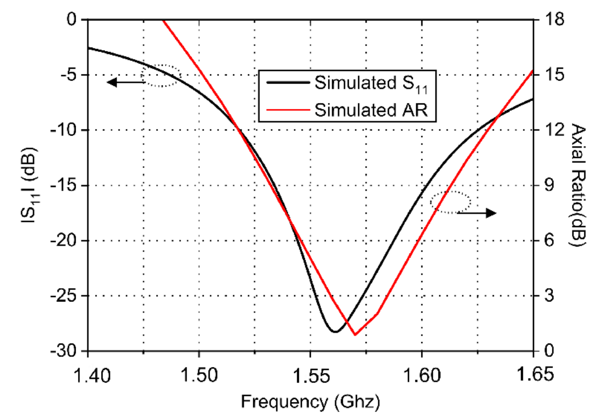

FIGURE 2. Simulated performance of the optimized antenna: Reflection coefficient (S_{11}) and axial ratio (AR).

Figures 3 and 4 illustrate the impact of the central slot dimension ($U1$) and corners truncation length ($T1$), respectively.

It is observed that the slot dimension ($U1$) significantly influences S_{11} parameter, while -10 dB reflection coefficient remains stable as the corner truncation ($T1$) changes. An increase in $U1$ leads to a decrease in the S_{11} resonance frequency. Conversely, the truncation length $T1$ noticeably affects the 3 dB axial ratio bandwidth; the minimum axial ratio value decreases as the truncation length increases.

4. DISCUSSION AND EXPERIMENTAL RESULTS

This section presents both simulated and measured results of the proposed antenna. Figure 5 shows the simulated gain at boresight versus frequency, indicating a peak gain of 3.49 dBi at the center frequency of 1.575 GHz. The simulated 3-dB AR beamwidth, shown in Figure 6, is exceptionally wide at 190° ($-96.0°$ to $+94.1°$), which is highly desirable for receiving satellite signals. Figure 7 plots the radiation patterns for the E-plane ($\varphi = 0°$) and H-plane ($\varphi = 90°$), confirming a broad, directive beam.

To verify the CP generation mechanism, the surface current distribution at 1.575 GHz is plotted in Figure 8 for phase increments of 90°. The rotating current vectors clearly confirm the generation of right-hand circular polarization (RHCP). Phase center against the frequency is demonstrated in Fig. 9, and it

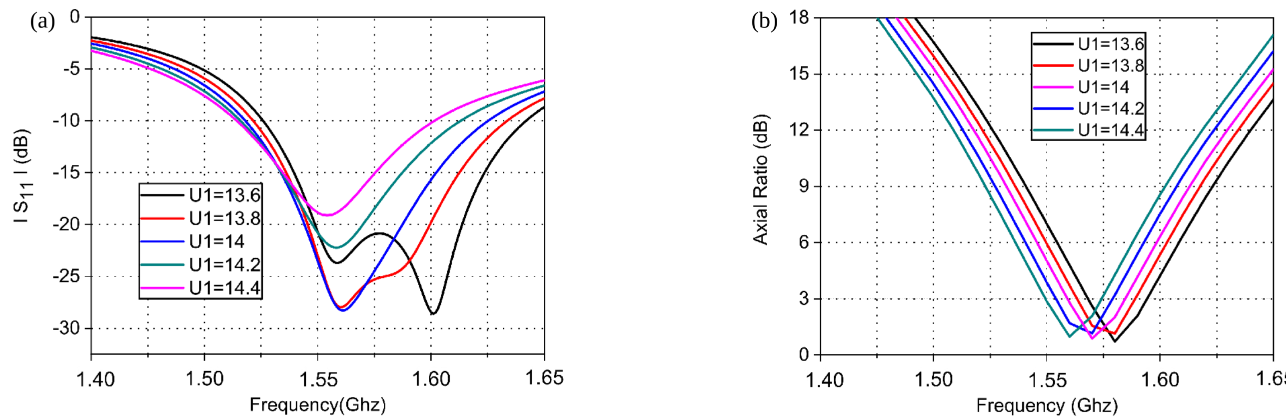

FIGURE 3. Parametric study: Effect of the central slot length ($U1$) on (a) reflection coefficient (S_{11}) and (b) axial ratio (AR).

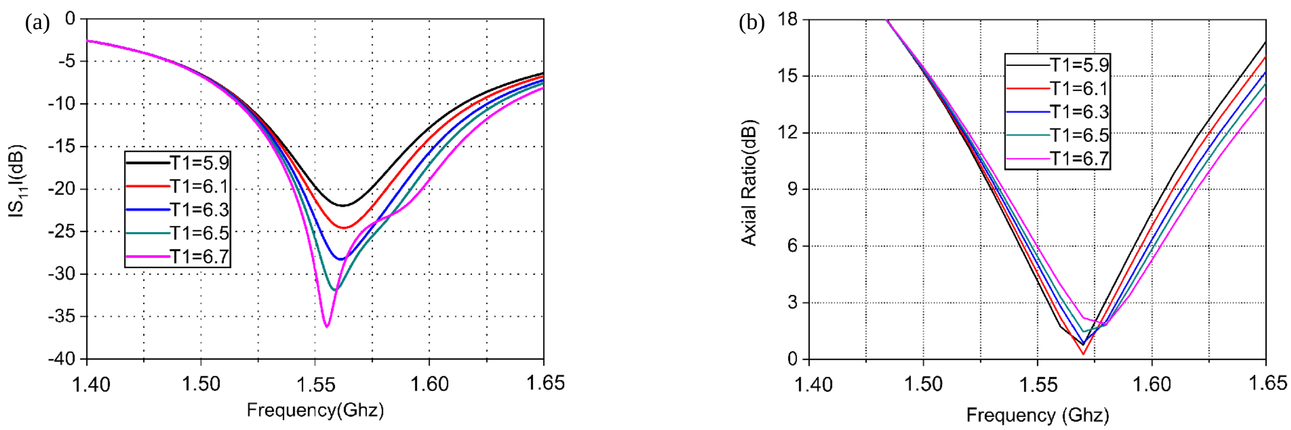

FIGURE 4. Parametric study: Effect of the corner truncation length ($T1$) on (a) reflection coefficient (S_{11}) and (b) axial ratio (AR).

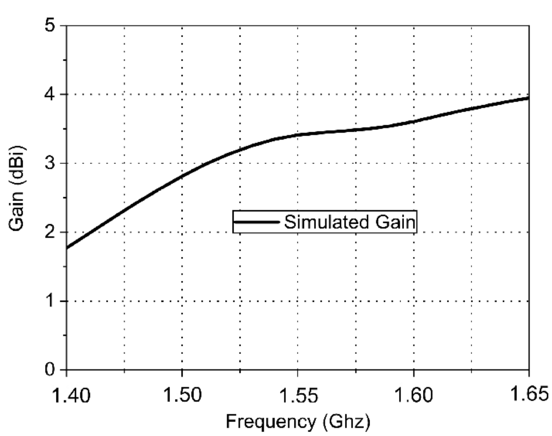

FIGURE 5. Simulated boresight gain vs. frequency.

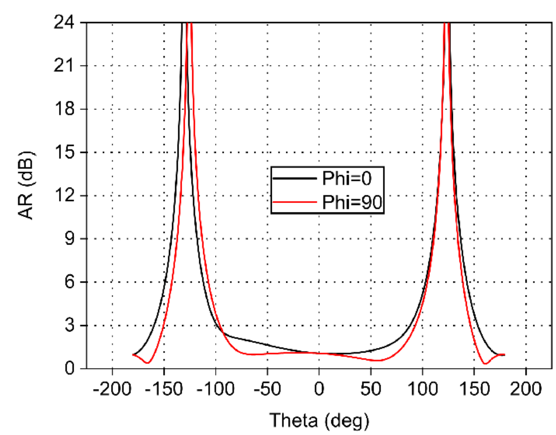

FIGURE 6. Simulated axial ratio (AR) vs. polar angle at 1.575 GHz in the E-plane ($\varphi = 0°$) and H-plane ($\varphi = 90°$), showing the 3-dB AR beamwidth.

can be seen that the phase center deviation is about 1.35 mm at the frequency 1.575 GHz and about 1.4 mm over the band from 1.563 to 1.587 GHz. Fig 10 shows the simulated and the measured reflection coefficients $|S_{11}|$, and the measured results agree reasonably with the simulated ones.

Figure 11 presents a photograph of the fabricated antenna prototype for experimental validation.

Compared with other antennas, the proposed antenna has a compact size, wide beamwidth, and zero phase center as it is figured in Table 2. The shifting in measured $|S_{11}|$ refers to the manufacturing errors process and the unavoidable air gap be-

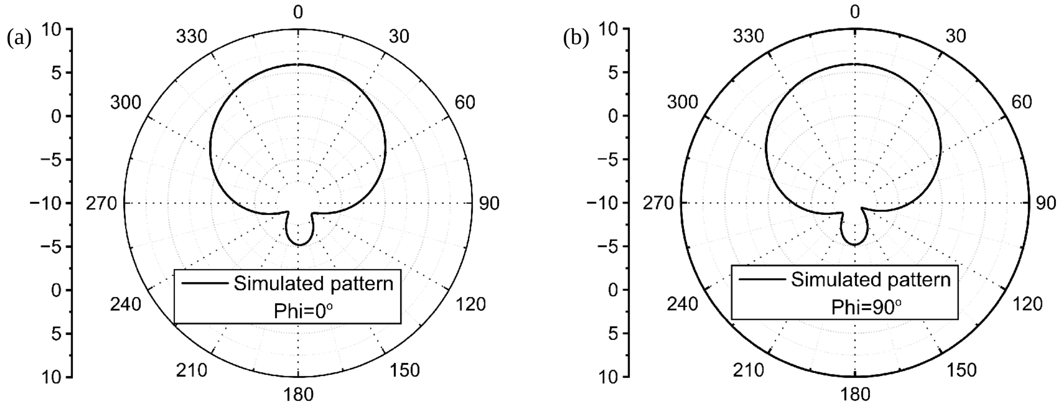

FIGURE 7. Simulated 2D radiation patterns at 1.575 GHz for (a) E-plane ($\varphi = 0^\circ$) and (b) H-plane ($\varphi = 90^\circ$).

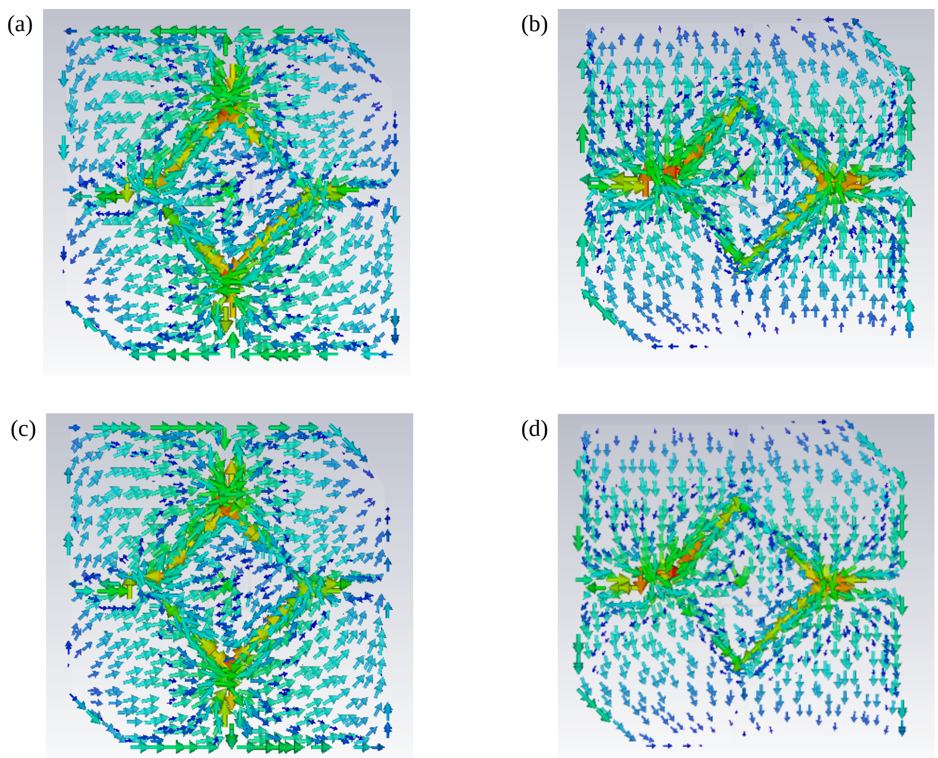

FIGURE 8. Simulated surface current distribution at 1.575 GHz for phase increments of 90°, illustrating the rotating current for circular polarization.

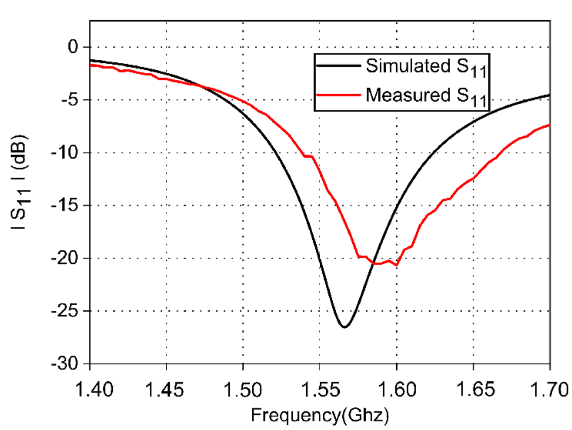

FIGURE 9. Comparison of simulated and measured reflection coefficient (S_{11}).

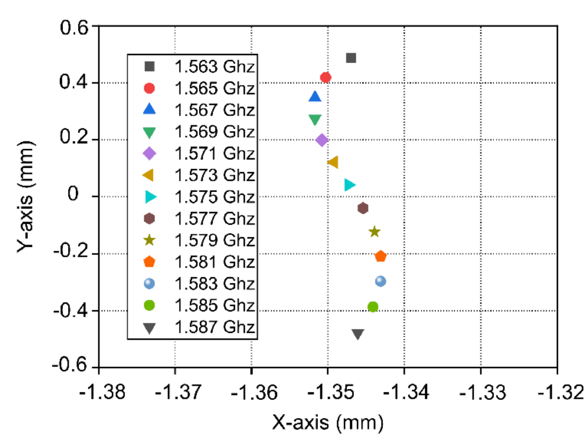

FIGURE 10. Simulated phase center location (x, y) across the GPS L1 frequency band (1.563–1.587 GHz).

TABLE 2. Comparison of the proposed antenna with previous works.

Structure	-10 dB S_{11} (GHz)	3-dB AR Beamwidth ($^\circ$)	Max mean PCD values	Total Volume (λ_0^3)
This work	1.52–1.62	190	0.05	$0.39 \times 0.39 \times 0.025$
[6]	1.51–1.62	210	0.16	$0.42 \times 0.42 \times 0.026$
[12]	1.55–1.61	180	Not given	$0.37 \times 0.37 \times 0.02$
[14]	0.903–0.909	100	Not given	$0.29 \times 0.29 \times 0.02$
[18]	1.5–1.61	195.8	0.3	$0.42 \times 0.42 \times 0.026$

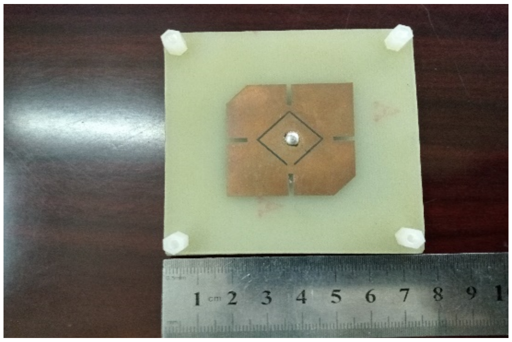

FIGURE 11. Photograph of the fabricated antenna prototype.

tween the substrate layers. Table 2 depicts the outstanding performances and results of the proposed architecture as compared to the literature.

5. CONCLUSION

We have successfully designed, fabricated, and tested truncated corners patch antennas for GPS L1 applications. The final design obtained performances meet the targeted application specifications, demonstrating a good CP radiation (axial ratio < 3 dB over the L1 frequency range), a stable phase center (1.35 mm PCD at the central frequency and 1.4 mm over the L1 frequency range), and a compact physical footprint ($0.39 \times 0.39 \times 0.025\,\lambda_0^3$). At its central operating frequency of 1.575 GHz, the antenna provides a gain of 3.49 dBi and maintains a wide 190° axial ratio beamwidth, making it suitable for receiving satellite signals from various angles. Compared to existing designs, the proposed antenna represents a robust and practical solution for modern high-precision navigation systems. The proposed structure offers a competitive combination of wide beamwidth (190°) and compact volume, as validated by both simulation and measurement. The slight discrepancies observed between the simulated and measured results are likely attributed to fabrication tolerances and unavoidable air gaps in the multi-layered substrate. As a future work, efforts will be oriented to focus on further miniaturization and gain enhancement without compromising phase center stability.

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