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Dual-Band Circular Polarized Stacked Patch Array Antenna for GPS Application

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Abstract

A dual-band circularly polarized antenna, for applications of a global navigation satellite system (GNSS), is designed. The proposed antenna can generate two frequency bands, covering L_1 [1.563 - 1.587] GHz and L_2 [1.215 - 1.2396] GHz GPS bands with a Right-Hand Circular Polarization (RHCP). To achieve a resonance at two distinct frequency bands, we have used the concept of a stacked antenna combined with a single feed. The S_{11} of the proposed antenna is less than −10 dB at the upper and lower bands. The gain is 7.6 dB at 1.227 GHz and 9.4 dB at 1.575 GHz. Circular polarization is obtained by using the truncated corner technique. We have obtained an axial ratio of less than 1 dB at 1.227 GHz and 1.575 GHz. For the design and optimization of antenna, we use CST MWS software.

Keywords

Stacked Patch Array Antenna, Dual-Band, RHCP, Gain, Axial Ratio, GNSS, GPS

1. Introduction

Global Navigation Satellite Systems (GNSS), including GPS, GLONASS, Galileo, and BeiDou, have become indispensable for a wide range of applications such as navigation, surveying, and timing synchronization. Among these, GPS remains the most widely adopted system, transmitting signals primarily in the L_1 (1.575 GHz) and L_2 (1.227 GHz) bands. To ensure robust signal reception under varying satellite orientations and environmental conditions, circular polarized (CP) antennas are preferred due to their ability to mitigate multipath effects and polarization mismatch.

Recent advancements in antenna design have focused on achieving dual-band operation with circular polarization to enhance positioning accuracy and reduce system complexity [1]-[4]. In [1], a dual-band transparent antenna with circular polarization for GNSS applications aiming to cover the L_5 and L_1 radio bands is proposed. Transparency is achieved by using a metal meshed structure with appreciable radiation efficiency. A quad-band circularly polarized antenna that can cover almost all global navigation frequency bands is proposed [2]. The antenna is formed by an L-shaped radiator, a rectangular frame ground with an L-shaped stub, and a rectangular strip at the corner. A novel technique is introduced in [3] to design a simple and novel reconfigurable dual-band dual circularly polarized (CP) cavity backed high-gain antenna for vehicle global navigation satellite system (GNSS). In [4], the proposed antenna is designed to be compact and suitable for GNSS and 5G NR applications.

The letter [5] presents an innovative design of dual-band printed dipole antenna with parasitic element for compensation of frequency space attenuation.

Despite these developments, challenges remain in optimizing gain [6] [7], axial ratio, and mutual coupling in array configurations [8]-[12], especially for compact GPS receivers. This paper presents the design of a dual-band circular polarized stacked patch array antenna for GPS applications. The proposed architecture aims to achieve high gain, and stable RHCP radiation across both L_1 and L_2 bands, contributing to improved signal reliability and positioning precision. The concept of a stacked antenna combined with a single feed is used to achieve the two frequency bands (L_1 & L_2). Circular polarization is obtained by using the truncated corner technique.

Following this introduction, the rest of the paper is organized as follows: the next section explains the design process of the proposed antenna. In section III, we show the simulated results. Finally, a conclusion is presented in the last section.

2. Antenna Design

The antenna design implements a double-layer substrate with two radiators, at the top layer of the first substrate (top patch) and the top layer of the second substrate (mid patch), with the ground at the bottom layer (**Figure 1**). To generate two orthogonal near-degenerate resonant modes for RHCP radiation [13], each square patch with size a1 = 48.75 mm and a2 = 61.34 mm has a pair of truncated corners with size b1 = 4.5 mm and b2 = 5.4 mm respectively (**Figure 2**). The feed is connected directly to the top patch through every substrate stack. The feed is not connected to the mid patch so that it can create an electromagnetic coupling effect (**Figure 1**). To increase the gain of the proposed antenna, a stacked array method is applied (**Figure 3**). The antenna (top and mid patches) is simulated on a Rogers RO4350B substrate with a permittivity value of 3.66 and a depth of 1.524 mm. PEC is used as a conducting material with a depth of 0.035 mm. Feed network is printed back to the antenna ground plane, onto a 0.508 mm thick Duroïd 4003C substrate ($\varepsilon r = 3.38$, $tg\delta = 0.0027$). The focus of this study is to produce array antenna with circular polarization with axial ratio < 3 dB, return loss < −10 dB and gain ≤ 9 dB which works at L_1 [1.563 - 1.587] GHz and L_2 [1.215 - 1.239] GHz GPS bands.

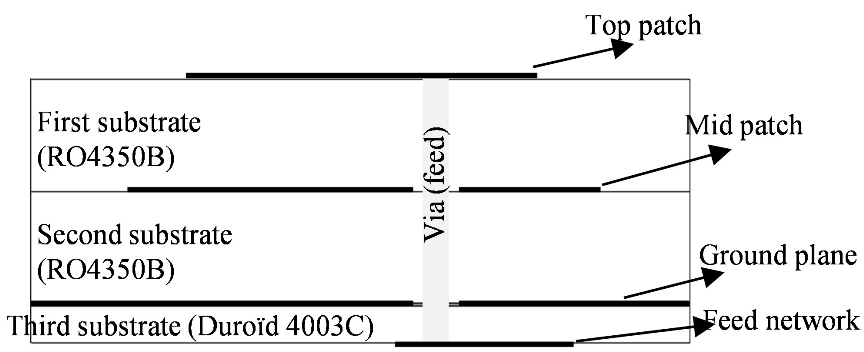


Figure 1. Side view of the antenna layers.

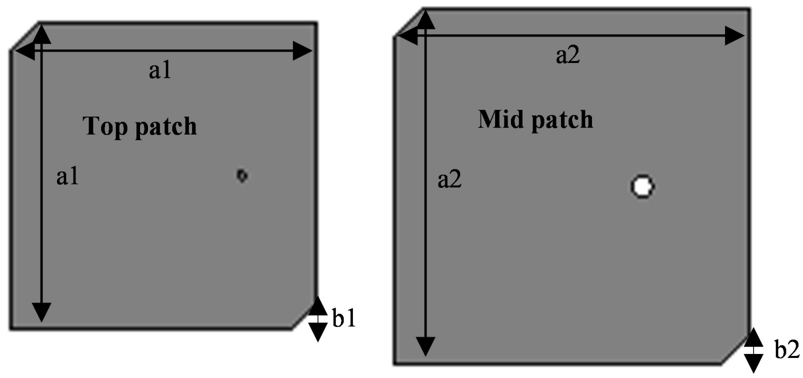


Figure 2. Top and mid antenna radiators.

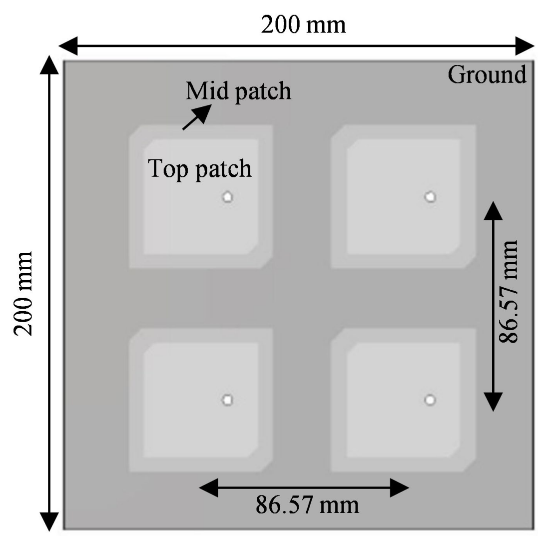


Figure 3. Design of the proposed stacked array antenna.

3. Simulated Results

3.1. Design of Single Stacked Patch Antenna with Truncated Corner

The antenna is modelled, simulated and optimized numerically using CST

MWS software. The antenna performance is analyzed in terms of reflection coefficient, axial ratio and radiation patterns at the operating frequencies. Figure 4 shows a single stacked patch antenna developed with the truncated corner technique.

Figure 4. Design of the single stacked patch antenna.

The simulated reflection coefficient of the single stacked patch antenna is presented in Figure 5. The simulated resonance frequencies are 1.227 GHz and 1.575 GHz, with return losses of −17 dB, respectively.

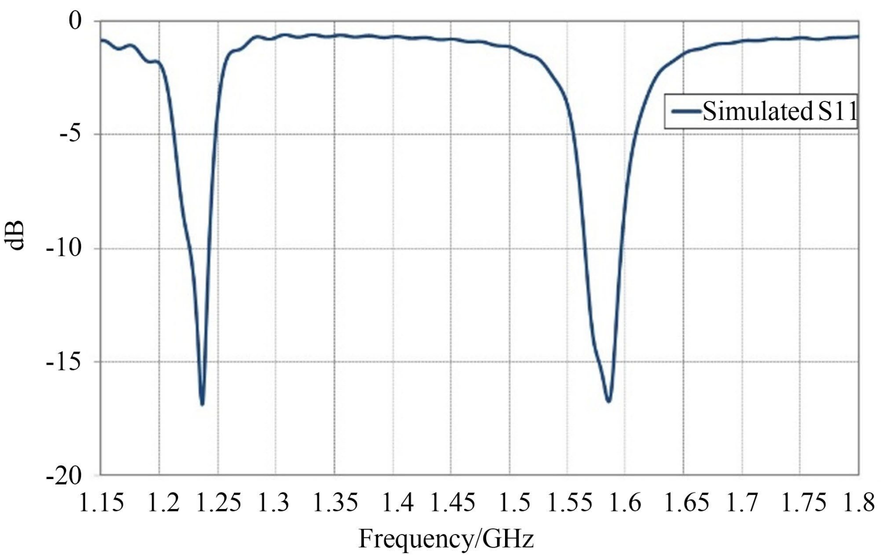


Figure 5. Simulated reflection coefficient S11.

The 3D radiation patterns at 1.227 GHz and 1.575 GHz are shown in Figure 6. The proposed antenna has a peak realized gain of 4.2 dB at 1.227 GHz (Mid patch) and 5.3 dB at 1.575 GHz (Top patch). The axial ratio is shown in Figure 7 as a function of the theta angle at 1.227 GHz and 1.575 GHz. It is less than 3 dB with a beamwidth of about 130˚ for good CP performance.

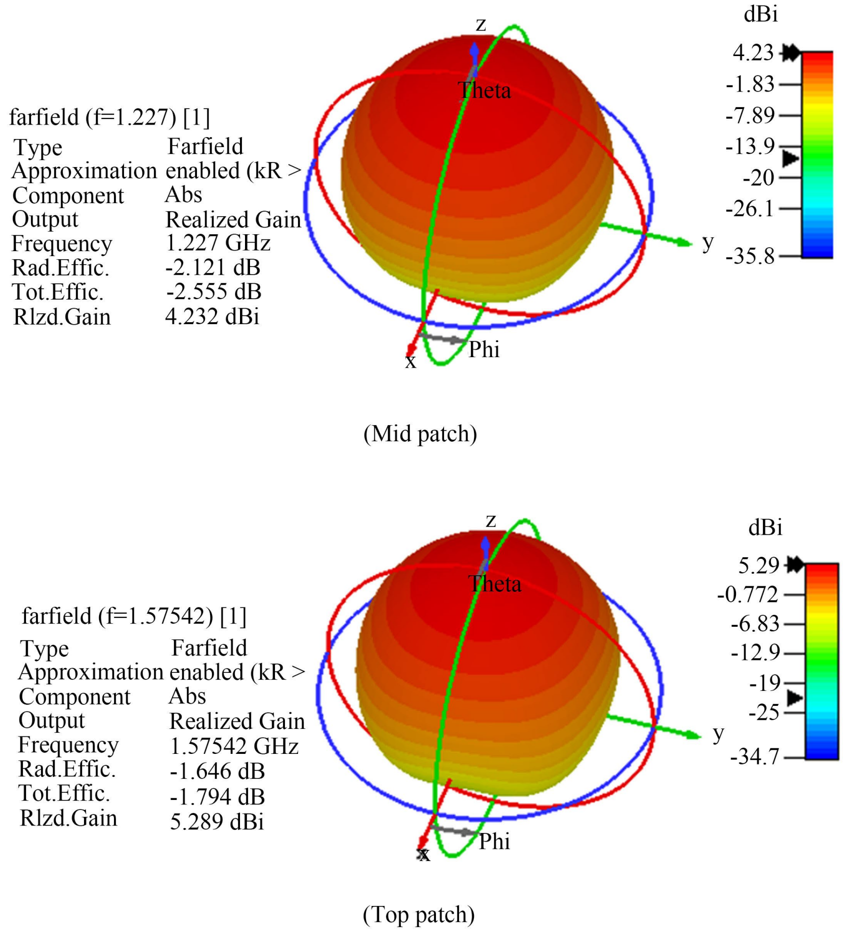


Figure 6. Simulated 3D radiation pattern (realized gain) at 1.227 GHz (Mid patch) and 1.575 GHz (Top patch).

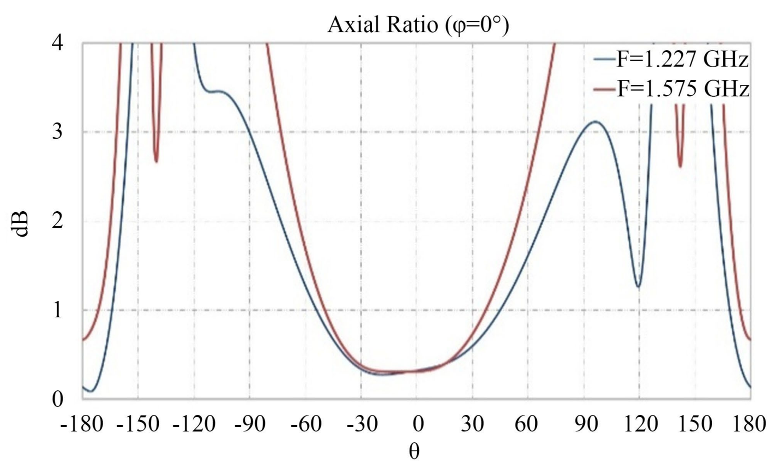
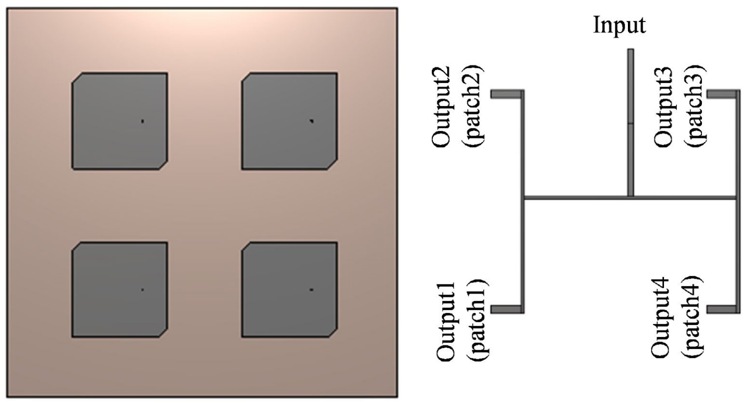


Figure 7. Simulated axial ratio at 1.227 GHz and 1.575 GHz.

3.2. Design of Stacked Array Antenna with Truncated Corner

A high-gain, dual-band GPS antenna with right-hand circular polarization (RHCP) is designed through the integration of a truncated corner patch, a stacked patch configuration, and a 2 × 2 array structure. The truncated corner technique facilitates the RHCP by inducing the orthogonal mode excitation with a 90˚ phase shift, while the stacked patch structure enables simultaneous operation at the L_1 (1.575 GHz) and L_2 (1.227 GHz) GPS frequency bands by vertically layering resonant patches separated by a dielectric substrate. To enhance the antenna's gain and directivity, a four-element array is employed (**Figure 8(a)**). This combined approach yields a compact, high-performance antenna suitable for precision navigation systems, offering improved axial ratio, bandwidth, directivity, high gain and robustness against multipath interference.



(a) (b)

Figure 8. Design of the proposed stacked array antenna (a) with the feed network (b).

The feed network (**Figure 8(b)**) for the patch array antenna radiating in the broadside direction is designed to deliver uniform phase and amplitude to each patch element. This ensures that all patches radiate coherently, producing a strong beam in the broadside direction with minimal side lobes. The central vertical line represents the main input transmission line, where the RF signal enters the network. This signal is then split into two equal parts at the first junction (a T-junction or power divider). Each of these two branches is further split again, resulting in four output lines, each carrying equal amplitude and identical phase. This symmetrical H-shaped layout ensures that all four outputs are equidistant from the input and follow identical electrical paths, which is crucial for maintaining phase coherence.

The simulated reflection coefficient of the array antenna is presented in **Figure 9**. The simulated resonance frequencies are 1.227 GHz and 1.575 GHz, with return losses of −30 dB and −18 dB, respectively. The bandwidth is 2.36% and 2.28% in the lower and upper frequency bands respectively.

The 3D radiation patterns of the proposed array at 1.227 GHz and 1.575 GHz are shown in **Figure 10**. The array has a peak realized gain of 7.6 dB at 1.227 GHz (Mid patch array) and 9.4 dB at 1.575 GHz (Top patch array). The axial ratio of the proposed array antenna is shown in **Figure 11** as a function of the theta angle at 1.227 GHz and 1.575 GHz. It is less than 3 dB with a beamwidth of about 130˚

for good CP performance.

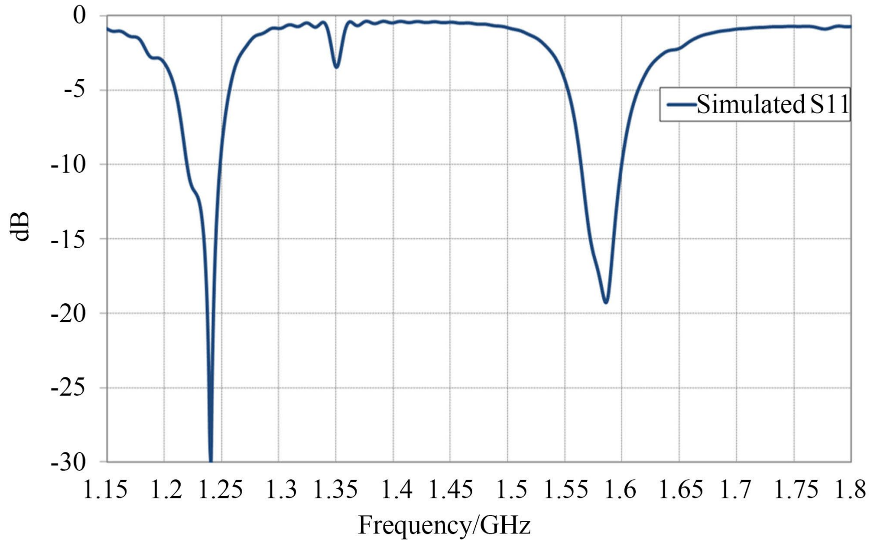


Figure 9. Simulated reflection coefficient S11 of array antenna.

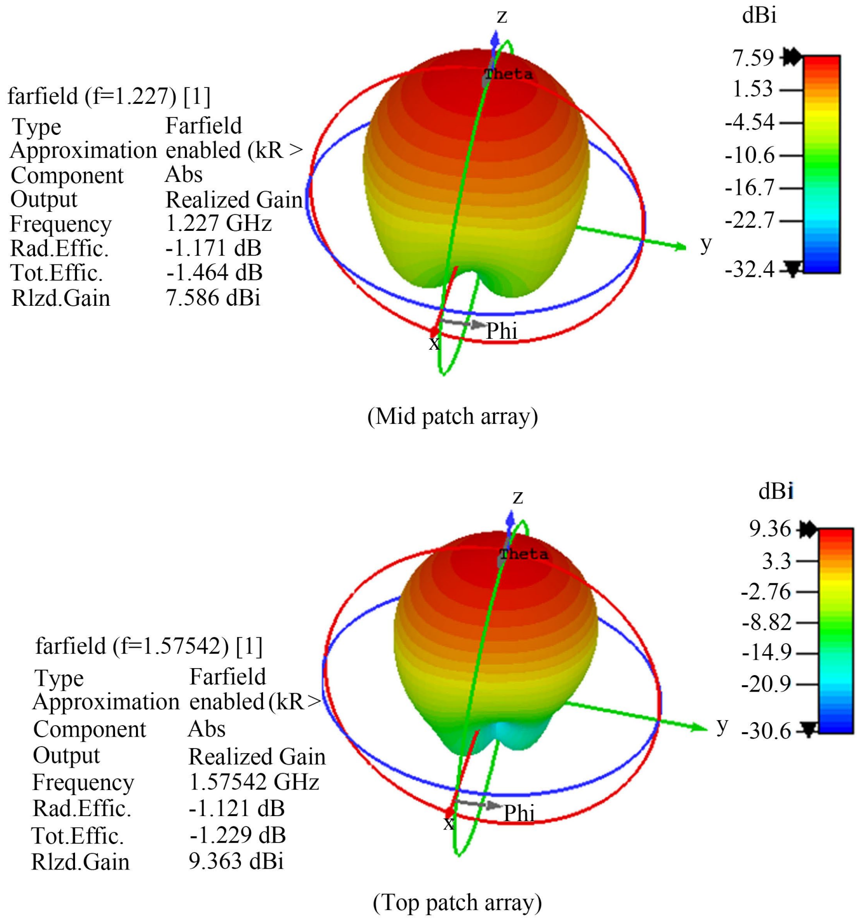


Figure 10. Simulated 3D radiation pattern (realized gain) at 1.227 GHz (Mid patch array) and 1.575 GHz (Top patch array).

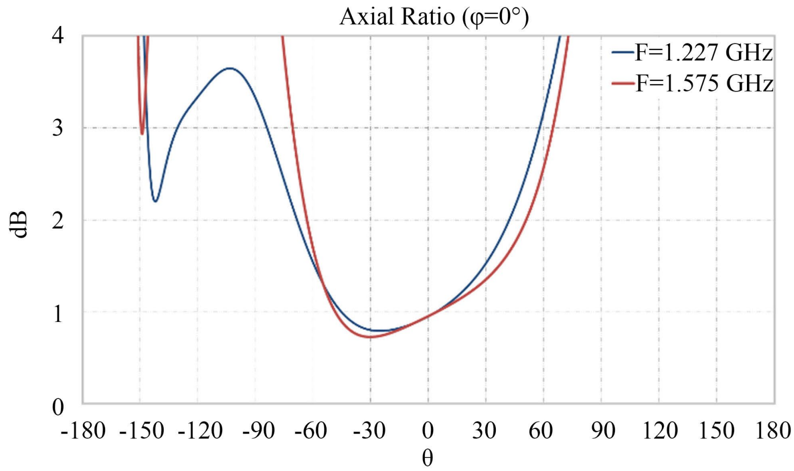


Figure 11. Simulated axial ratio at 1.227 GHz and 1.575 GHz of array antenna.

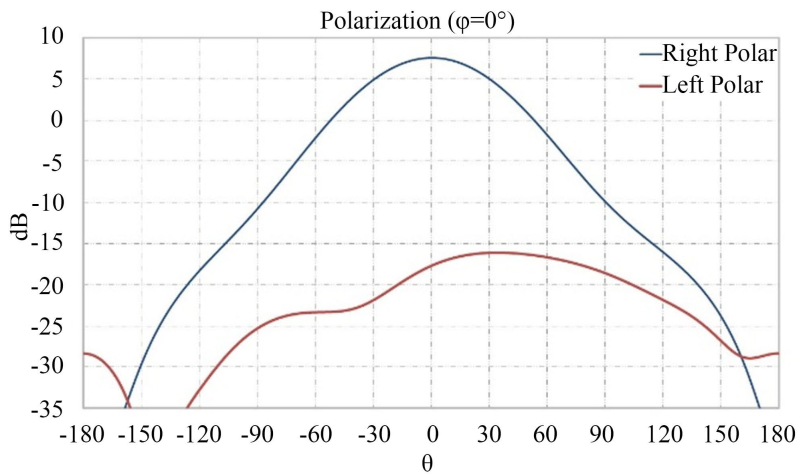


Figure 12. Simulated realized gain (right and left polarization) of the Mid patch array at 1.227 GHz.

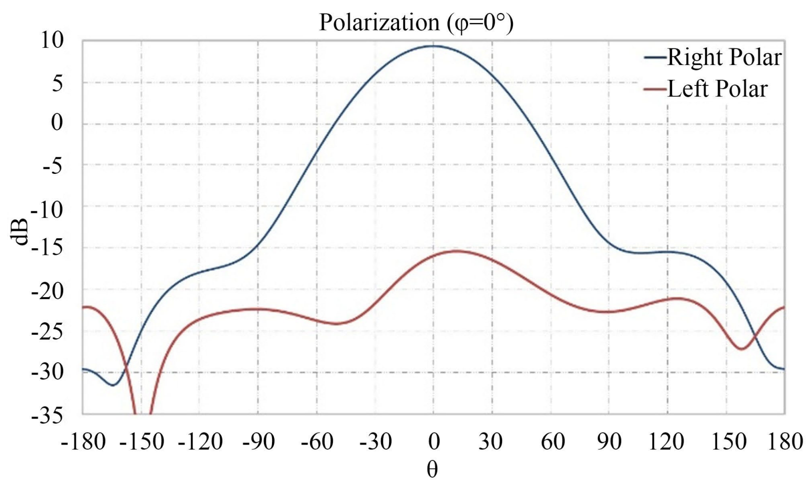


Figure 13. Simulated realized gain (right and left polarization) of the Top patch array at 1.575 GHz.

Figure 12 and **Figure 13** show that the antenna array propagates Right Hand Circular Polarization (RHCP) at 1.227 GHz and 1.575 GHz to identify the type of circular polarization. It can be observed that the Right-Hand Circular Polarization (RHCP) gain is approximately 25 dB higher than the Left-Hand Circular Polarization (LHCP) gain at broadside direction at 1.227 GHz and 1.575 GHz.

The polarization characteristics of the proposed antenna were evaluated through surface current analysis at multiple phase angles. **Figure 14** presents the surface current distributions at 45˚, 135˚, 225˚, and 315˚ for the Mid patch array antenna (1.227 GHz), corresponding to quarter-period intervals of the RF excitation. These subplots reveal a consistent clockwise rotation of the current vectors, confirming the generation of right-hand circular polarization (RHCP). This rotational behavior indicates that the radiated electric field maintains a constant magnitude while rotating in phase, a defining feature of RHCP. In **Figure 15**, the subplots correspond to the current distribution when the phase is 0˚, 90˚, 180˚ and 270˚. It's shown the Top patch array (1.575 GHz) generates RHCP mode. Such polarization is particularly beneficial for GNSS applications, as it matches the polarization of satellite signals, thereby improving signal reception and minimizing polarization mismatch losses.

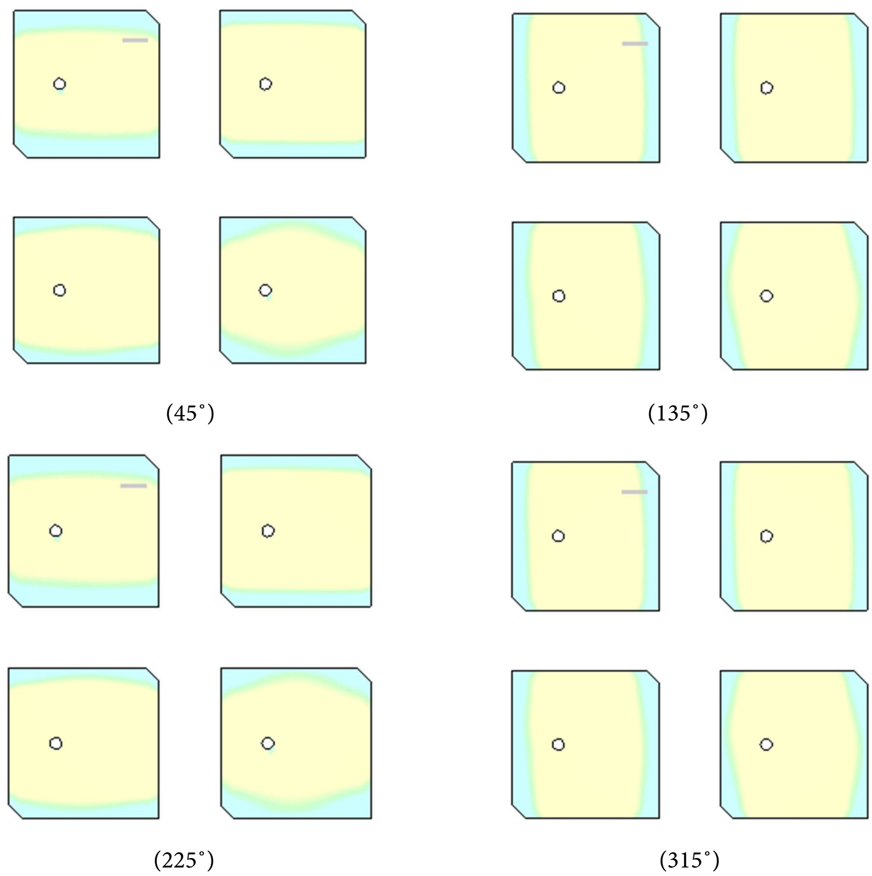
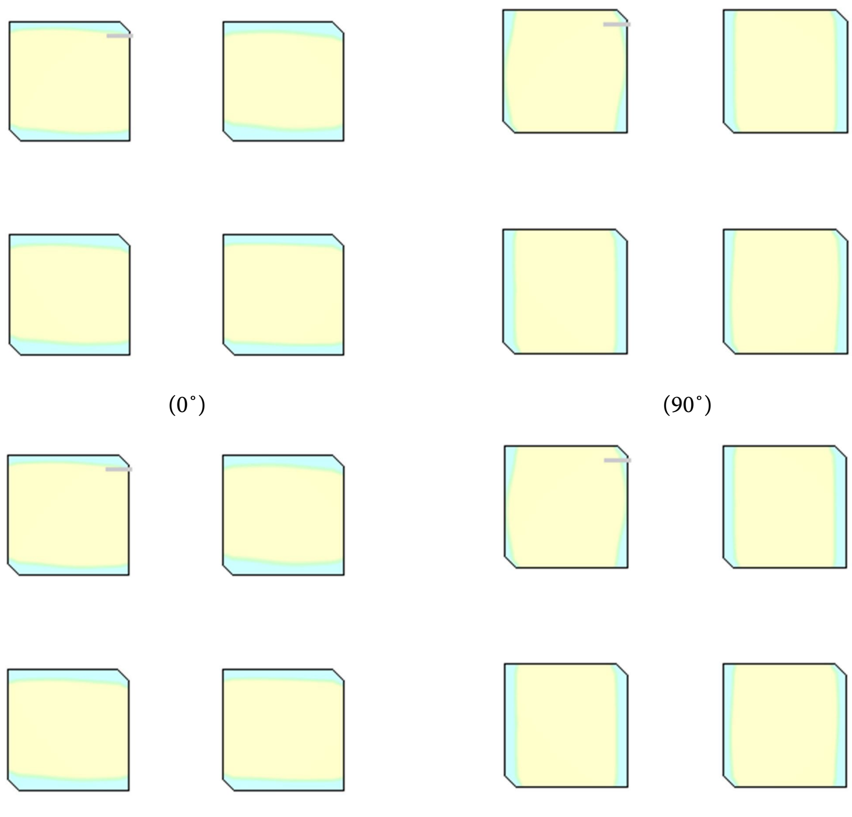


Figure 14. Simulated surface current distribution of the Mid patch array at 1.227 GHz.



(0˚) (90˚)

(180˚) (270˚)

Figure 15. Simulated surface current distribution of the Top patch array at 1.575 GHz.

4. Conclusion

A dual-band circular polarized stacked patch array antenna has been presented in this paper. The parameters of return loss, axial ratio, gain and bandwidth of the proposed antenna have been analyzed and simulated. For the patch array, the feed network has been designed and optimized. From the results obtained (S_{11}, axial ratio, gain), the proposed antenna has been successfully designed and worked on the GPS working frequencies (L_1 & L_2). This antenna can be used to receive GPS signals in GNSS receiver. The future of this research is to fabricate the antenna to validate the concept by an experimental device.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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