EHB 456E - Antennas
Term Project Report

Investigated Paper:

Dual-Band Circularly Polarized Annular Ring Patch Antenna for GPS-Aided GEO-Augmented Navigation Receivers [1]

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1 Introduction

Antennas are devices that "radiating or receiving radio waves" according to the IEEE Standards [2]. Antennas should effectively send and receive electromagnetic waves thus, antennas are essential components in various applications such as wireless communication and radar systems [3].

1.1 Application area of the proposed antenna

The antenna proposed in the article [1] is designed for GPS-Aided GEO-Augmented Navigation (GAGAN). Even though this system was firstly used in the aviation industry, specifically the Indian satellite-based augmentation system, its application areas have expanded to include railways, security, and the telecom industry.

1.2 Requirements for the antenna design

The antenna is specifically engineered for portable navigation applications thus, it should be compact and easy to design. An annular ring microstrip patch antenna is preferred over a conventional microstrip patch antenna since it offers a smaller antenna size in the operating frequency.

It is intended to be used in communication systems where circular polarization (CP) is crucial to overcome the problem of polarization mismatch. CP antennas are essential for maintaining a stable and reliable communication link in scenarios where linear polarization may not be sufficient. Furthermore, CP enhances signal stability and reduces interference which are important factors to maintain a strong and consistent communication. It should be underlined that, the antenna should produce CP without the necessity for a complicated feed design. Excitation in the antenna is achieved through a single coaxial feed and this is simplifying the overall setup and reducing complexity.

Another design factor to be considered while designing the antenna is that it should operate at dual-band frequencies corresponding to L1 (1575.42 MHz) and L5 (1176.45 MHz) for suitability with GAGAN receivers. Additionally, the antenna should exhibit good performance metrics such as impedance bandwidth (IBW) and axial ratio bandwidth (ARBW) at both operating frequencies to ensure reliable communication and navigation capabilities.

One of the most important design metrics to be considered while designing an antenna is the gain of the antenna. Especially in satellite communication, gain is an important design metric because enhancing gain allows the antenna to achieve better coverage and longer communication ranges, which are essential for GAGAN applications. Also, enhancing gain helps mitigate signal losses and this leads to better signal reception and transmission quality. Gain enhancement is achieved through the configuration of two annular rings connected by small strips and a ground plane coupled with crossed aperture.

2 Antenna Design

Ansys HFSS is a software tool for simulating high-frequency electromagnetic fields and it is used to simulate the antenna designed in the project [4]. HFSS uses the Finite Element Method (FEM) to accurately simulate the behavior of antennas. FEM is a frequency domain technique based on the minimization of integro-differential equations in place of Maxwell's equations [5]. Since FEM is suitable for arbitrary geometry (multi-level) problems, HFSS is the most suitable software to design the proposed antenna.

The proposed antenna is designed for satellite communication for GAGAN receivers. This application has its own requirements and the proposed antenna's electrical and geometrical parameters are determined to fulfill the given necessities of the application.

2.1 Electrical parameters

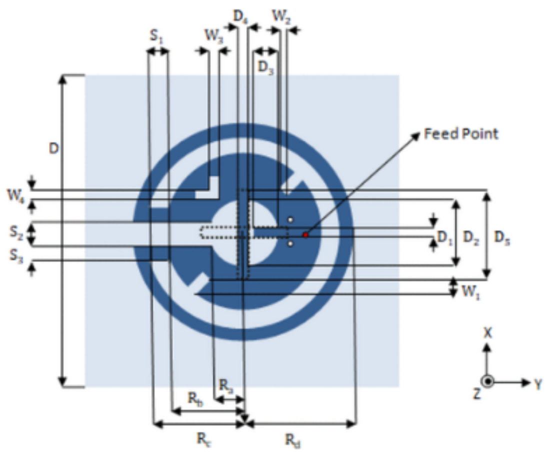
The proposed antenna is operating at dual-band frequencies of 1575.42 MHz and 1176.45 MHz, which are produced by the inner and outer rings, respectively. Rogers RT/Duroid 6002 substrate is used in the antenna, which has a relative permittivity of $\epsilon_r = 2.94$ and a loss tangent of $\tan\delta = 0.0012$. The antenna is excited by a single coaxial feed with an impedance of 50 Ω.

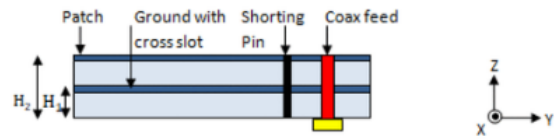
2.2 Geometrical parameters

The geometrical parameters of the antenna are shown in Fig. 1. Although the locations of the coaxial feed point and shorting pins are not explicitly specified thus in HFSS simulations, they are placed in estimated locations based on visual observation. In the simulations coaxial feed inner conductor and outer conductor diameters are used as 0.54 mm and 2 mm respectively. Feed offset from the origin is determined as 16 mm. Also, diameter of the shorting pins are decided as 1 mm. The purpose of the shorting pins is to achieve high impedance matching. In order to achieve that, pins should be located near to the coaxial feed. Thus, in the simulations, this fact is also considered.

In the article, the proposed antenna's geometrical parameters are initially determined by Eq. 1 and 2. Afterwards, the determined parameters are optimized using HFSS. In the equations, $f_{r_{\mathrm{nm}}}$ is the resonant frequency, χ_{nm} is the first-order Bessel function, c is the speed of light, and a and b are the inner and outer radii of the annular ring, respectively. The proposed antenna operates at TM_{11} mode thus the value of $\chi_{\mathrm{nm}} = 3.83$.

$$f_{r_{\mathrm{nm}}} = \frac{\chi_{\mathrm{nm}} c}{2\pi a\sqrt{\varepsilon_r}} \tag{1}$$





Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
R_a	8.5	D_3	16.88	S_1	3
R_b	24	D_4	2	S_2	5
R_c	27.2	D_5	9	S_3	3
R_d	31.5	W_1	7	H_1	1.6
D	86	W_2	3	H_2	3.2
D_1	2	W_3	2		
D_2	6.44	W_4	5		

Figure 1: Geometrical parameters of the proposed antenna.

$$\frac{b-a}{b+a} < 0.35 \tag{2}$$

Circular polarization can be represented using cosine phase as a combination of two orthogonal linearly polarized waves with a phase difference of $\pm\frac{\pi}{2}$ radians. Let E_x and E_y represent the electric field components of the linearly polarized waves along the x and y axes, respectively. Then, the electric field of the circularly polarized wave can be expressed as in the Eq. 3.

$$E_{\text{circ}} = E_x \cos(\omega t) + E_y \cos\left(\omega t + \frac{\pi}{2}\right) \tag{3}$$

With the help of the geometrical parameter adjustments such as changing the distance between two orthogonal strips, $\pm\frac{\pi}{2}$ phase difference can be obtained. Thus CP at both frequencies is achieved.

3 Simulation Results

In order to examine the antenna parameters such as return loss, radiation pattern and gain, the proposed antenna in the article is modeled and simulated through HFSS. Simulated

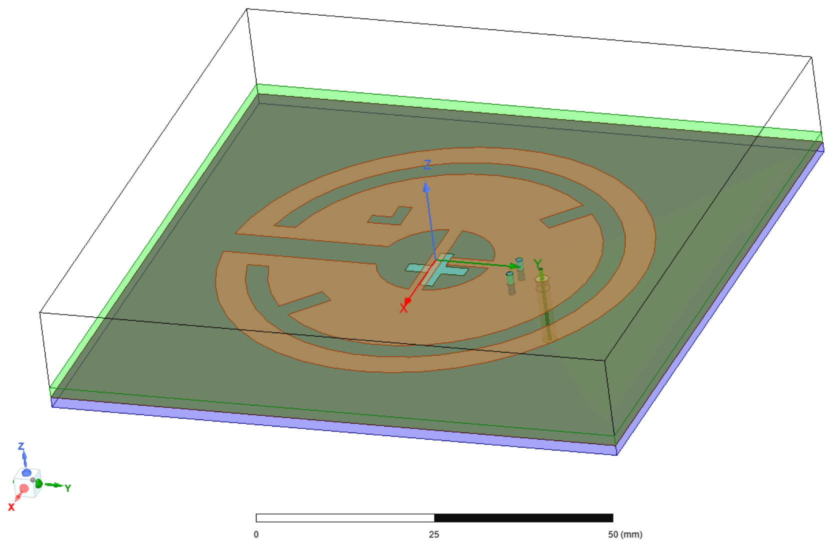


Figure 2: The proposed antenna simulated in HFSS.

antenna can be seen in Fig. 2.

3.1 Simulated Antenna Parameters

3.1.1 Return Loss (S_{11})

Return loss is a mesure of amount of power reflected back to the source due to impedance mismatches in the antenna. Higher return loss value is an indicator of a lower amount of reflected power which signifies better impedance matching between the antenna and the transmission line. Operating frequencies can be deduced from the return loss (S_{11}) graph. Peak values of the return loss graph indicates operating frequencies of the proposed antenna. Return loss of the simulated antenna can be observed in Fig. 3.

3.1.2 Radiation Pattern

Radiation pattern is a graphical representation of the relative strength of electromagnetic radiation emitted by an antenna in different directions. It indicates how the antenna radiates or receives energy in various directions. The shape and characteristics of the radiation pattern provide valuable insights into the antenna's performance, directivity and gain. Radiation pattern helps designers to understand how an antenna focuses or spreads energy through the presence of lobes, beamwidth. Radiation plot of the simulated antenna can be observed in Fig. 4.

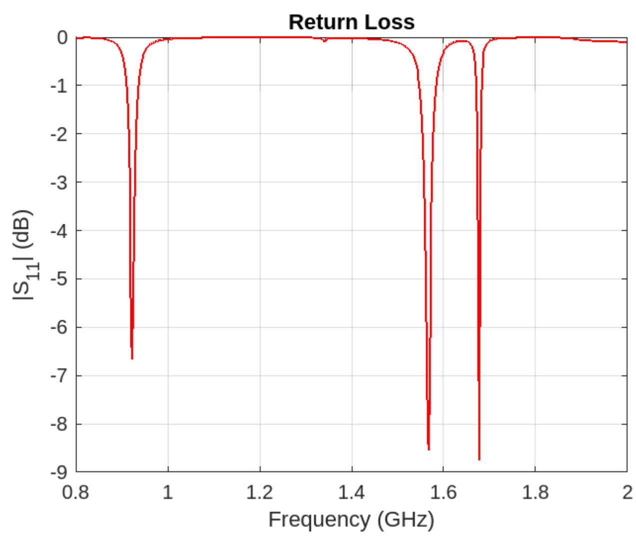


Figure 3: Return loss of the simulated antenna in dB. As it can be observed antenna operates at 0.92, 1.55 and 1.67 GHz.

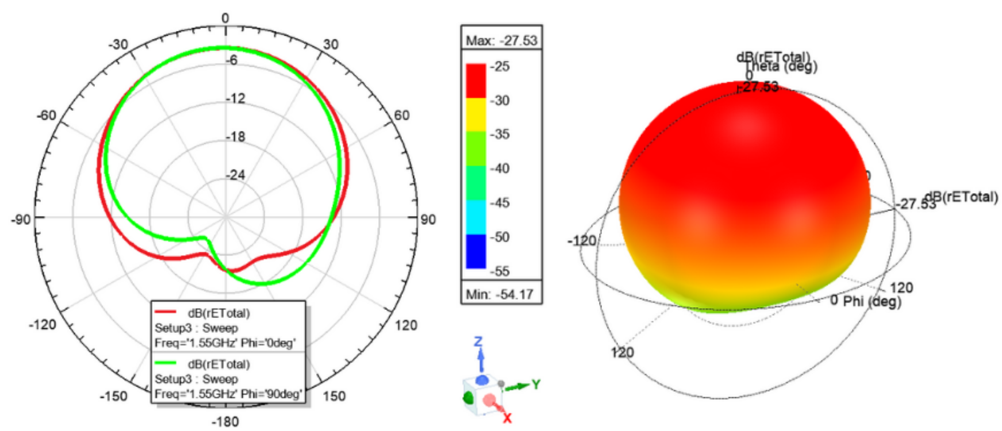


Figure 4: 2D and 3D radiation plots of the simulated antenna at $\phi = 0$ and $\phi = 90°$ for the operating frequency of 1.55 GHz in dB.

3.1.3 Realized Gain

Realized gain is the actual gain achieved by an antenna which accounts losses due to impedance mismatches, radiation inefficiencies and environmental factors. As it was mentioned before gain of the antenna is an indicator of coverage, communication range and ability to reduce signal losses. Difference between gain and relized gain is that, gain of an antenna depends on the material selection however realized gain of an antenna depends on both material selection and design choices. Formula of the realized gain is given in Eq. 4.

$$G_{re} = \frac{4\pi \cdot U(\theta, \phi)}{P_{\text{rad}}} \tag{4}$$

Here $U(\theta, \phi)$ represents radiation intensity, and P_{rad} is total radiated power. Realized gain of the simulated antenna is given in the Fig. 5.

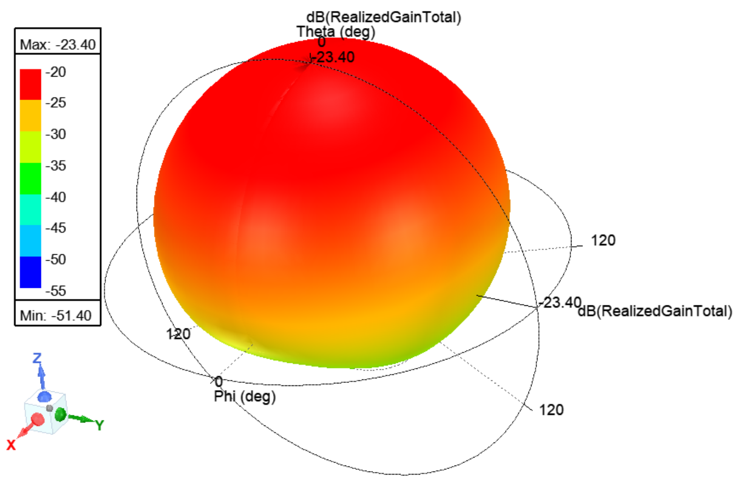


Figure 5: Realized gain of the simulated antenna in dB.

3.1.4 Directivity

Directivity is a measure of how well an antenna focuses its radiation in a particular direction compared to an isotrpoic radiator. Higher directivity implies that the antenna can transmit or receive signals more efficiently in a particular direction. Formula of the directivity is given in the Eq. 5.

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}} \tag{5}$$

Here, U represents the radiation intensity, U_0 is the radiation intensity of an isotropic source, and P_{rad} is the total radiated power. Directivity of the simulated antenna is given in the Fig. 6.

The simulated antenna is not as directive due to its design characteristics and operational principles. The use of two annular rings leads to a broader radiation pattern, thus reducing the directivity of the antenna. Furthermore for GAGAN receiver applications circular polarization is prioritized, which compromises directivity.

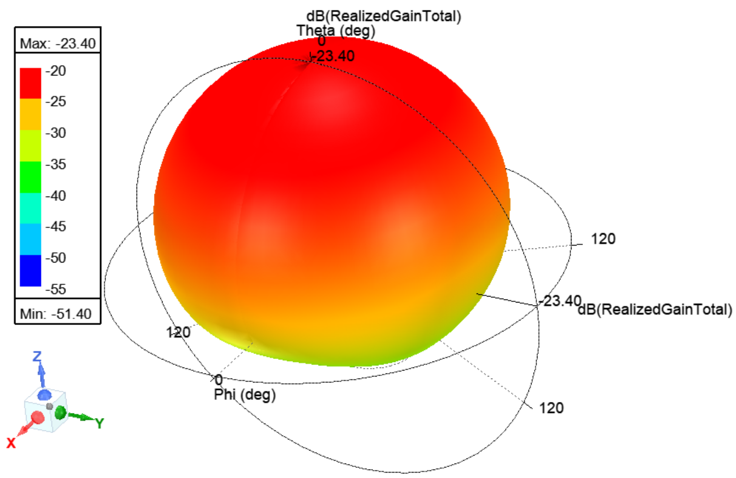


Figure 6: Directivity of the simulated antenna in dB.

3.2 Parameters for Tuning Radiation Characteristics

In the proposed antenna, there are critical parameters that are important for tuning the radiation characteristics. Firstly inner and outer radius of the annular ring patch play an important role in determining the resonant frequency and radiation pattern of the antenna. Secondly, adjusting the aperture sizes in the ground plane and arranging distance between shorting pins is essential to obtain 90 degree phase difference which results in CP. Thirdly, mode of operation (TM_{11} in the proposed antenna) influences the radiation and polarization characteristics. The excitation of the TM_{11} mode causes the surface current to rotate in a clockwise direction for different values of theta. This leads to left-hand circularly polarized radiation. Additionally, TM_{11} mode ensures consistency in achieving circular polarization across the desired frequency bands which is essential for GAGAN receiver applications.

3.3 Comparison

In the simulated antenna it can be observed from the return loss graph that, there are three operating frequencies of 0.92, 1.55 and 1.67 GHz. However in the proposed antenna in the journal paper there are two operating frequencies which are approximately 1.18 and 1.57 GHz. It can be said that in the simulations 1.57 GHz operating frequency is satisfied. The comparison of the S_{11} results can be observed in the Fig. 7.

If we compare radiation patterns of the proposed antenna and the simulated antenna, it can be observed in the Fig. 8, left-handed circular polarization (LHCP) of the proposed antenna is quite similar to the radiation pattern of the simulated antenna as oppose to the right-handed circular polarization (RHCP). The main reason is the TM_{11} mode when excited

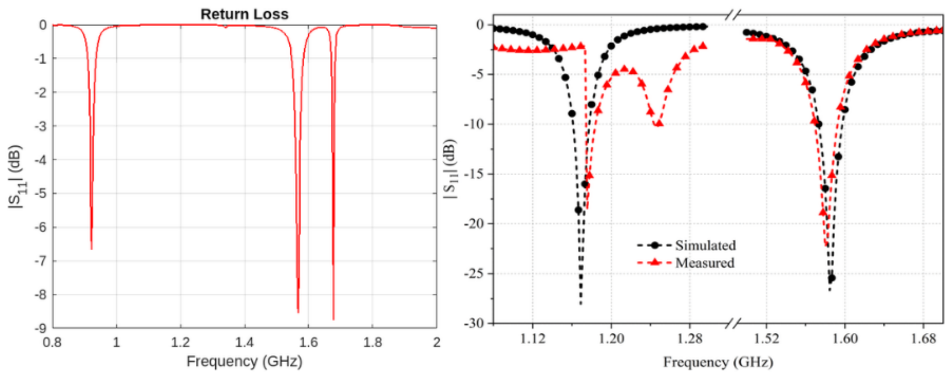


Figure 7: Comparison of S_{11} results of the proposed antenna and the simulated antenna. S_{11} results of the proposed antenna in the left and S_{11} results of the simulated antenna on the right.

in the annular ring antenna is associated with LHCP.

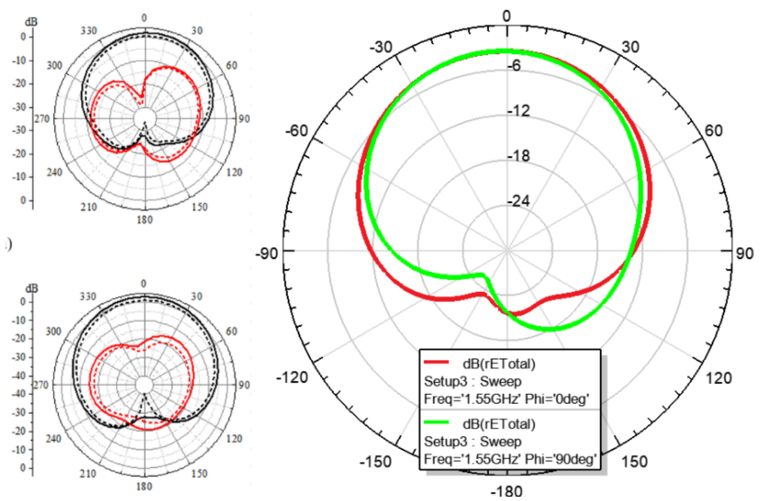


Figure 8: Comparison of radiation patterns of the proposed antenna and the simulated antenna in the operation frequency of 1.55 GHz. On the left top and bottom there are radiation patterns of the proposed antenna with $\phi = 0$ and $\phi = 90°$ respectively. Black lines indicate LHCP and red lines indicate RHCP. On the right there is the radiadion pattern of the simulated antenna.

Several factors can account for the difference between the results of the antenna in the paper and my simulation results. In the journal, some characteristics are not explicitly specified such as dimensions of the coaxial cable, feed offset location of the coaxial cable, dimensions of the shorting pins and location of the shorting pin. Additionally, possible impedance mismatch caused by the coaxial cable could affect the results. Moreover, the journal paper might make certain assumptions or simplifications that are not explicitly stated. These could impact the results.

4 Conclusion

In conclusion, the proposed antenna designed for GPS-Aided GEO-Augmented Navigation (GAGAN) demonstrates promising characteristics for portable navigation applications. The proposed antenna is engineered to operate at dual-band frequencies corresponding to L1 and L5 for compatibility with GAGAN receivers. The antenna showcases compactness and ease of design which are critical for its given application. Antenna is employing an annular ring microstrip patch antenna configuration and it achieves circular polarization crucial for overcoming polarization mismatch. This ensures stable and reliable communication links essential in various sectors including aviation, railways, security and telecom.

Simulation results conducted through Ansys HFSS highlight the antenna's performance parameters such as return loss, radiation pattern, realized gain, and directivity. While the simulated antenna closely matches the expected operating frequencies and demonstrates left-handed circular polarization consistent with the proposed design, some discrepancies exist potentially due to unspecified parameters and assumptions in the original article as well as practical variations inherent in antenna design and simulation processes.

A significant disadvantage can be noted in the presented model is the broader radiation pattern resulting from the use of two annular rings, which reduces directivity. For applications prioritizing high directivity, this could be a limitation. Additionally, the dependency on precise geometrical parameters and placement of components like the coaxial feed and shorting pins means that any deviations can significantly impact performance.

Overall, the proposed antenna shows promise in meeting the requirements of GAGAN applications. This offers reliable navigation and communication capabilities across multiple sectors.

References

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