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Design of a Compact Multi-Band Circularly Polarized Antenna for Tracking and Localization Applications

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ABSTRACT

This project is about designing a compact multi-band circularly polarized antenna for tracking and localization applications which is receiver type of antenna. Existing commercial GPS antenna uses 2 frequency bands which have linear polarization (LP), less robust to the future GPS receiver system. Thus, in this project, a multi-band circularly polarized antenna will be designed. The antenna is a multi-band type antenna since it is radiating at three GPS frequency bands. The antenna development starts with creating three different size of patch which is known as L1, L2 and L5. L5 (1.164GHz -1.189GHz) is the smallest frequency among those three, L2 (1.215GHz - 1.240GHz) is the middle range frequency and the biggest frequency is L1 (1.563GHz -1.588GHz). The size of the antenna will be approximately 100mm by 50mm because it is a handheld receiver antenna hence it is required to be small in size. This antenna uses Rogers and FR-4 as the substrate and copper as the ground plane and patch of the radiating element. All the design and simulation results are conducted using CST Studio Suite 2016 software. Based on the result, it is shows that the antenna producing 3 different frequency band with all the return loss value is under -10 dB. It is also producing an omnidirectional radiation pattern with axial ratio less than 3dB. For polarization, the antenna is right hand circular polarization (RHCP) and producing a reasonable gain for GPS application.

1. INTRODUCTION

global navigation satellite systems (GNSS), particularly the Global Positioning System (GPS), have become indispensable in modern society, supporting applications such as navigation, surveying, autonomous systems, disaster management, and location-based services. The rapid evolution of GNSS signals and services has significantly increased the demand for advanced receiver antennas that are compact, reliable, and capable of operating across multiple frequency bands. As a result, antenna design has emerged as a critical factor in determining the overall performance and robustness of GPS receiver systems
[1], [2].

Most commercially available GPS antennas are traditionally designed to operate at a single frequency band, typically the L1 band. While such antennas are adequate for basic positioning applications, they are increasingly insufficient for modern and future GNSS receivers that require multi-band capability to improve accuracy, integrity, and resistance to interference. Recent studies emphasize that multi-band reception, particularly across L1, L2, and L5 bands, enhances positioning performance by enabling ionospheric error correction and improved signal reliability [3], [4].

Microstrip patch antennas continue to be widely adopted in GPS receiver applications due to their low profile, lightweight structure, ease of fabrication, and compatibility with compact electronic devices. However, conventional single-patch designs inherently support narrow bandwidth and single-frequency operation. To address this limitation, recent research has explored various multi-band antenna design techniques, including stacked configurations, slot-loaded patches, parasitic elements, and multi-resonant patch geometries [5], [6], [7] . Among these methods, the use of multiple rectangular patches with different dimensions has proven to be an effective and straightforward approach for achieving stable multi-band operation without significantly increasing antenna complexity.

Another essential requirement for GPS receiver antennas is circular polarization, specifically right-hand circular polarization (RHCP). Since GPS satellites transmit RHCP signals, receiver antennas must maintain circular polarization to minimize polarization mismatch losses and mitigate multipath effects caused by reflections from surrounding structures. Recent works highlight that maintaining an axial ratio below 3 dB across all operating bands is crucial for reliable signal reception, particularly in handheld and mobile environments where antenna orientation continuously changes [8], [9].

In addition to polarization performance, antenna miniaturization remains a key challenge for handheld GPS receivers. Compact antennas must achieve acceptable impedance matching, radiation characteristics, and gain while occupying minimal physical space. Several recent studies report that careful optimization of patch geometry and substrate selection is necessary to balance size reduction with electrical performance [6], [10]. Substrate materials such as Rogers laminates are commonly used for their low dielectric loss, while FR-4 remains attractive for cost-effective and practical implementations despite its higher loss characteristics [11].

Motivated by these challenges, this work presents the design and simulation of a compact multi-band rectangular patch antenna for GPS receiver applications. The proposed antenna is designed to operate across three GPS frequency bands L5 (1.164GHz-1.189GHz), L2 (1.215GHz-1.240GHz) and L1 (1.563GHz-1.588GHz) by employing three rectangular patches of different dimensions within a compact form factor suitable for handheld devices. The antenna achieves RHCP radiation with an axial ratio below 3 dB, omnidirectional radiation characteristics, and satisfactory gain across all operating bands. Full-wave electromagnetic simulations are performed using CST Studio Suite to evaluate impedance matching, radiation patterns, axial ratio, and overall antenna performance. The results demonstrate that the proposed design is a promising candidate for next-generation multi-band GPS receiver systems.

2. DESIGN LAYOUT

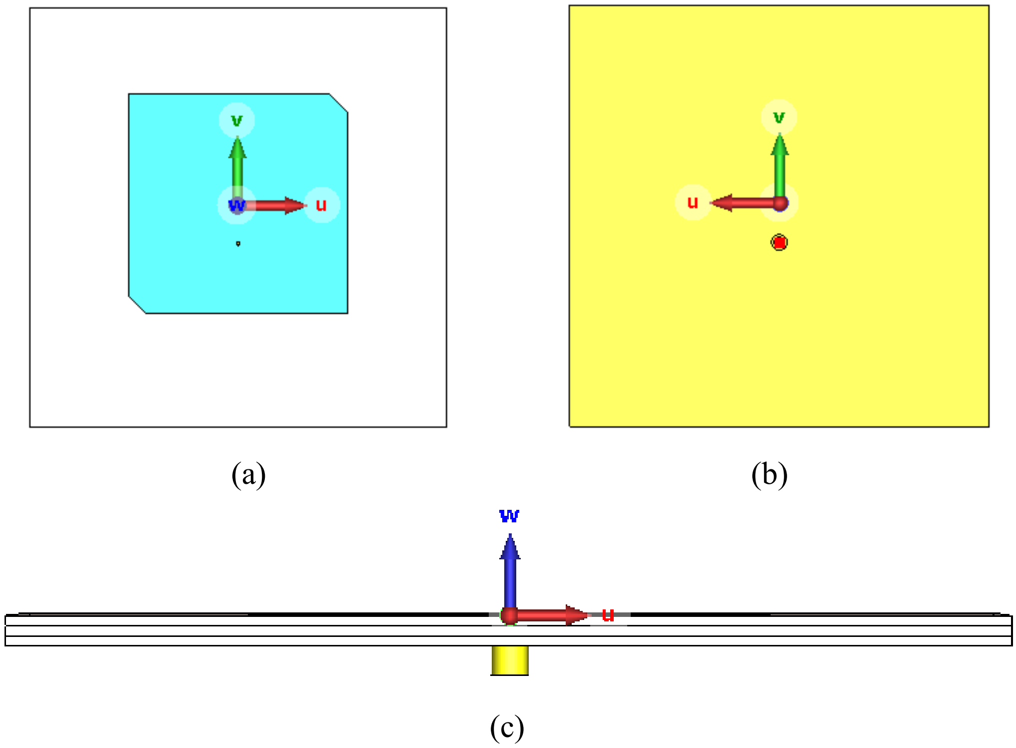


Figure 1. (a) Front, (b) Back view, (c) Bottom view of simulated design

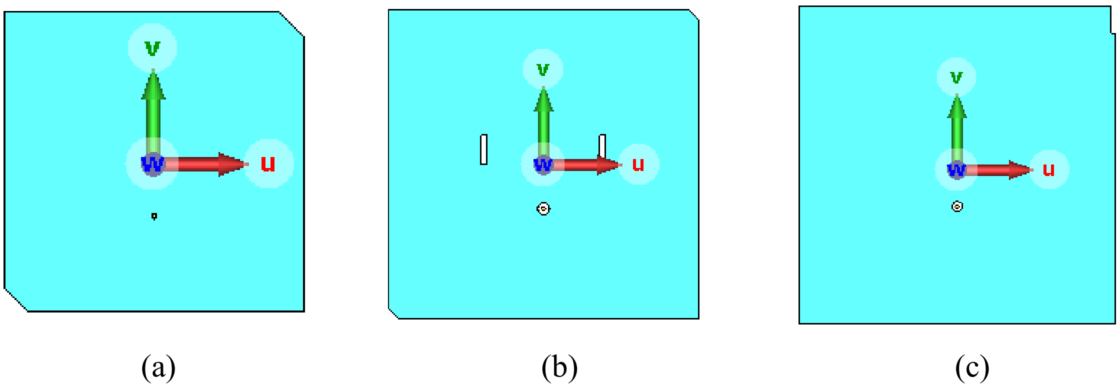


Figure 2. Simulated patch view of (a) L1, (b) L2, (c) L5

This is the final simulated design of multi-band rectangular patch Antenna as in Fig.1. The Fig 2. shows patch design on each layer. L1 is the top layer of the design, L2 is the middle layer of the design and L5 is the bottom layer of the design. Truncation technique used in layer 1 and layer 5 at corner of rectangular patch antenna so that it helps to generate circular polarization. Slot technique used in layer 2 is for creating multiband in patch antenna. The antenna is designed for receiving the GPS frequency bands of L5 (1.164GHz-1.189GHz), L2 (1.215GHz-1.240GHz) and L1 (1.563GHz-1.588GHz). S11 bandwidth has to be below -10dB and axial ratio (AR) below 3dB for the said three frequency bands. The antenna is also required to have sufficient gain more than 0 dB and good radiation pattern for RHCP while minimizing the LHCP.

Table 1. Antenna specifications

S11 bandwidth	Less than -10db
Axial ratio (AR)	Less than 3db
Radiation pattern	Right hand circular polarization
Gain	More than 0db
Center frequency	1.176GHz, 1.227GHz, 1.575GHz

3. RESULTS AND DISCUSSION

3.1. REFLECTION COEFFICIENT

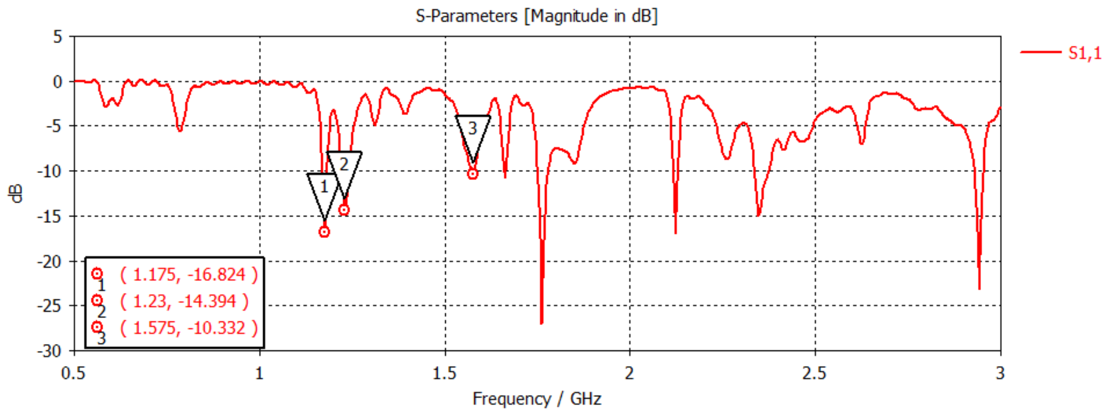


Figure 3. S11 result

Table 2. Summarization of Reflection Coefficient

Resonant Frequency	1.175GHz	1.234GHz	1.575GHz
Bandwidth Range	1.1GHz-1.2GHz	1.2GHz-1.3GHz	1.5GHz-1.6GHz

Return loss	-16.824dB	-14.394dB	-10.332dB

3.2. AXIAL RATIO VS FREQUENCY GRAPH

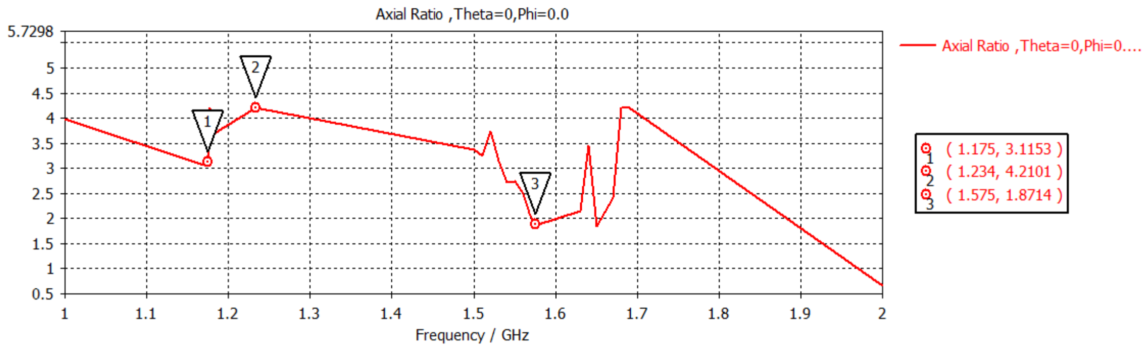
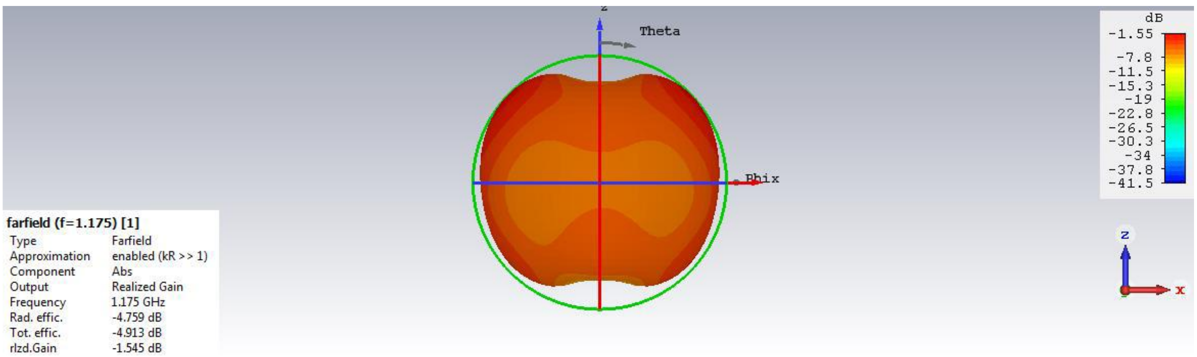


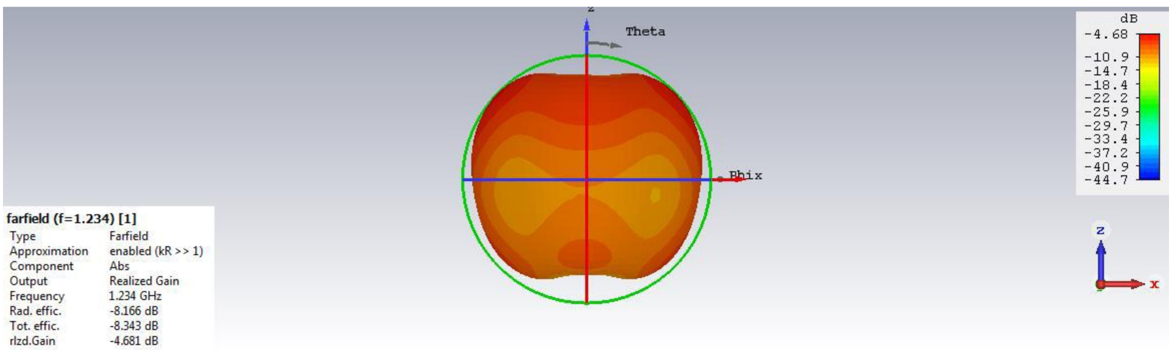
Figure 4. Axial Ratio result

Fig. 4 shows axial Ratio for frequency 1.575GHz is 1.8714dB achieved below 3dB while for frequency 1.175GHz and 1.234GHz is 3.1153dB and 4.2101dB respectively. Axial ratio is important for circularly polarized antennas. The value for the circular polarized is axial ratio less than 3dB.

3.3. 3D RADIATION PATTERN



(a)



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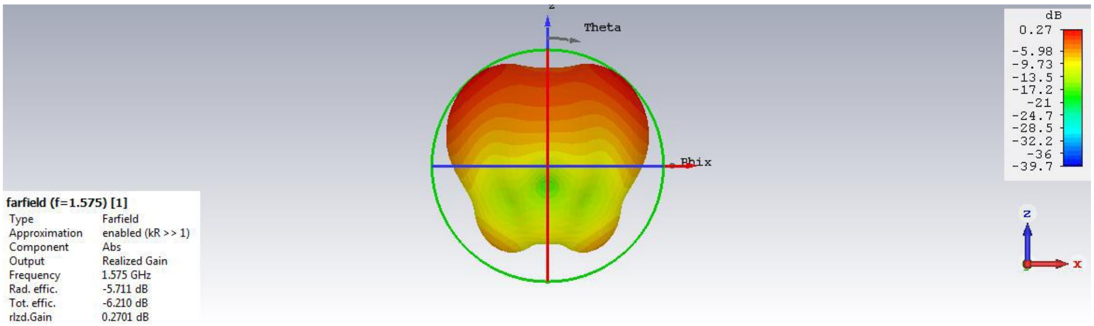
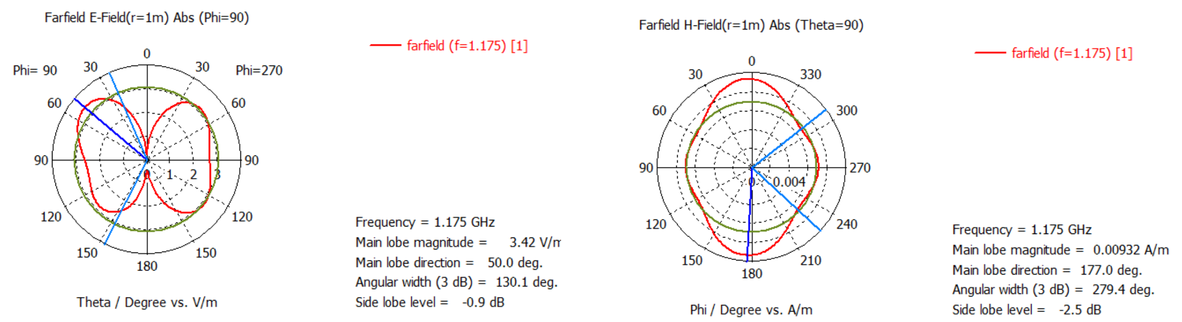


(c)

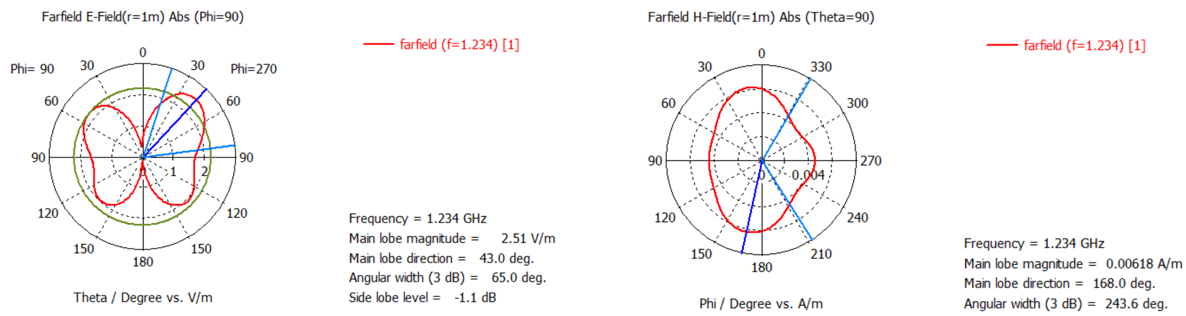
Figure 5. 3D result (a) 1.175GHz, (b) 1.234GHz, (c) 1.575GHz

Fig. 5(a) shows that frequency 1.175GHz excited by patch L5. It has radiation efficiency of -4.759dB and total efficiency of -4.913dB. The realized gain is -1.545dB. Fig. 5(b) shows that frequency 1.234GHz excited by patch L2. It has radiation efficiency of -8.166dB and total efficiency of -8.343dB. The realized gain is -4.681dB. Fig(c) shows that frequency 1.575GHz excited by patch L1. It has radiation efficiency of -5.711dB and total efficiency of -6.210dB. The realized gain is 0.2701dB.

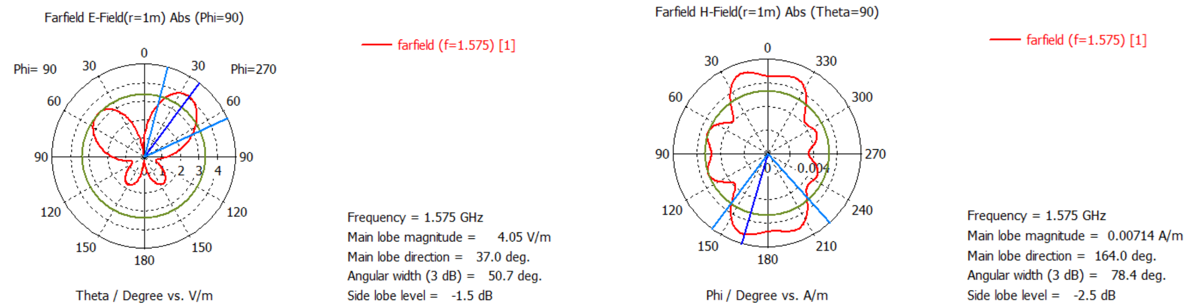
3.4. E-FIELD AND H-FIELD



(a)



(b)

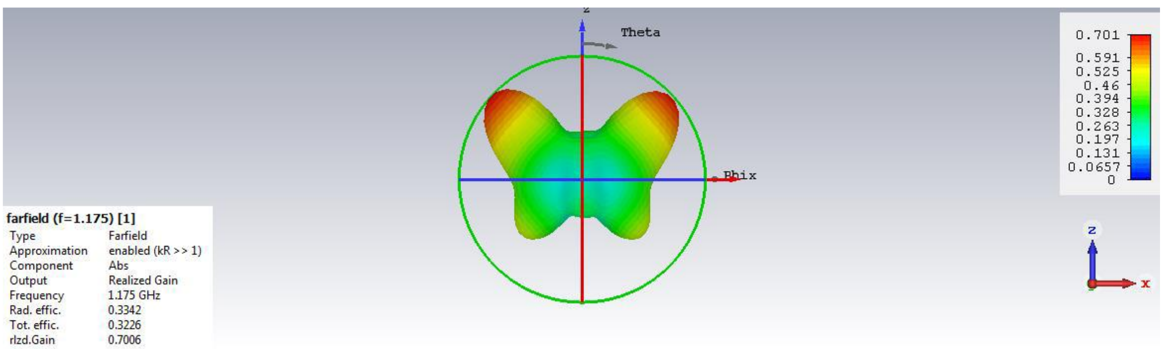


(c)

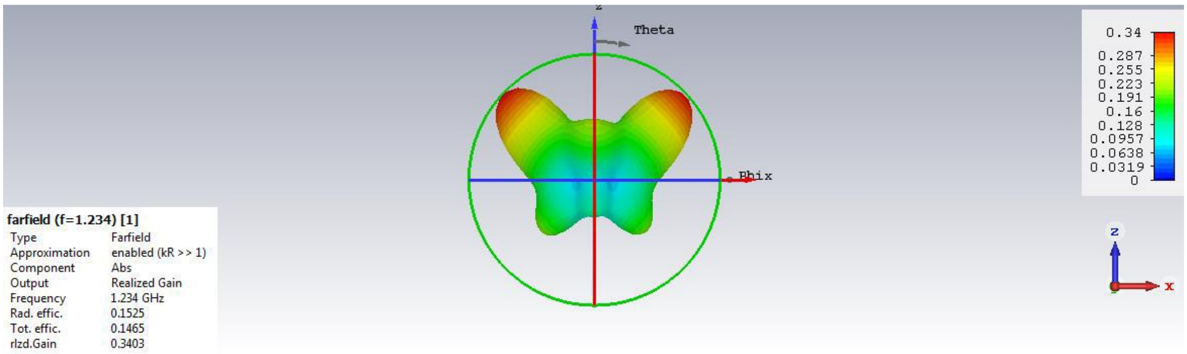
Figure 6. Farfield E-Field and H-Field (a) 1.175GHz, (b) 1.234GHz, (c) 1.575GHz

Fig. 6(a) shows that E-plane for frequency 1.175GHz phi equal to 90 power radiated from the main lobe is 3.42 V/m in the direction of 50 degree. It is omnidirectional radiation pattern because it is clearly visible from the polar form. The antenna showing like number 8 design is identical for an omnidirectional for an e-plane. H-plane for frequency 1.175GHz Theta equal to 90 power radiated from the main lobe is 0.00932 A/m in the direction of 177 degree. It is omnidirectional radiation pattern because it is clearly visible from the polar form. The radiation pattern shape looks approximately a round shape at h-plane which indicates an Omni directional.Fig. 6(b) shows that E-plane for frequency 1.234GHz Phi equal to 90 power radiated from the main lobe is 2.51 V/m in the direction of 43 degree. It is omnidirectional radiation pattern because it is clearly visible from the polar form. The antenna showing like number 8 design is identical for an omnidirectional for an e-plane. H-plane for frequency 1.234GHz Theta equal to 90 power radiated from the main lobe is 0.00618 A/m in the direction of 168 degree. It is omnidirectional radiation pattern because it is clearly visible from the polar form. The radiation pattern shape looks approximately a round shape at h-plane which indicates an Omni directional. Fig 6(c) shows that E-plane for frequency 1.575GHz Phi equal to 90 power radiated from the main lobe is 4.05 V/m in the direction of 37 degree. It is omnidirectional radiation pattern because it is clearly visible from the polar form. The antenna showing like number 8 design is identical for an omnidirectional for an e-plane. H-plane for frequency 1.575GHz Theta equal to 90 power radiated from the main lobe is 0.00714 A/m in the direction of 164 degree. It is omnidirectional radiation pattern because it is clearly visible from the polar form. The radiation pattern shape looks approximately a round shape at h-plane which indicates an Omni directional.

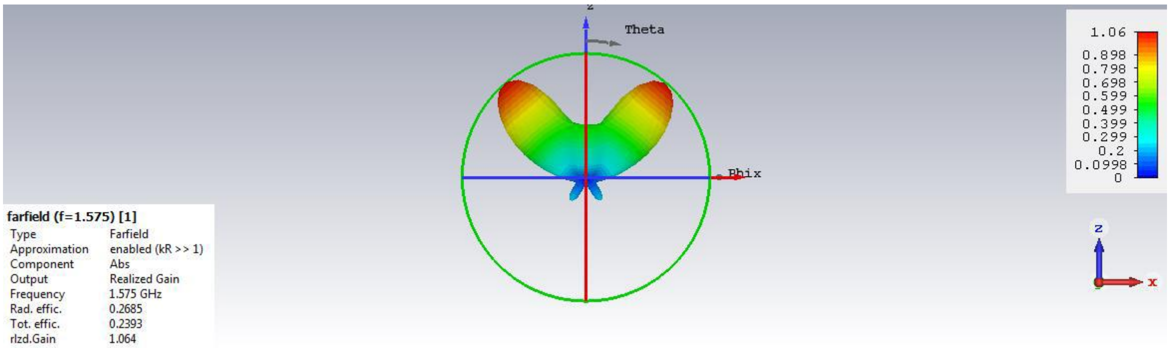
3.5. RHCP



(a)



(b)



(c)

Figure 7. RHCP (a) 1.175GHz, (b) 1.234GHz, (c) 1.575GHz

Fig.7(a) shows the RHCP is higher than LHCP but still it is not clearly visible. Therefore, the circular polarization is not fully achieved. Fig.7(b) shows RHCP is higher than LHCP but still it is not clearly visible. Therefore, the circular polarization is not fully achieved. Fig7(c) shows RHCP is higher than LHCP and it is clearly visible. Therefore, the circular polarization is fully achieved.

Table 3. Summary of three frequencies

Frequency	1.175GHz	1.234GHz	1.575GHz
S11	-16.824dB	-14.394dB	-10.332dB
Axial Ratio	3.1153	4.2101	1.8714
Radiation Pattern	Omnidirectional radiation	Omnidirectional radiation	Omnidirectional radiation
Gain	-1.545dB	-4.681dB	0.2701dB
RHCP	Not clearly visible, CP is not fully achieved	Not clearly visible, CP is not fully achieved	Clearly visible, CP is fully achieved

4. CONCLUSION

The Compact Multi-Band Circularly Polarized Antenna has been shown throughout this project. The main purpose of this project is to design Compact Multiband antenna with circular polarization characteristic which is proposed for GNSS applications. The proposed antenna element has three patches with slit, corner truncation or slots on it. The antenna element can cover over GPS L1(1.575 GHz), L2(1.234 GHz) and L5(1.175 GHz) frequencies. The lower patch has slit on it for the circular polarization while the middle patch has corner truncation for the circular polarization and 2 I-slots for getting better axial ratio. The upper patch has corner truncation on it for its circular polarization. The design and simulation were designed and simulated using CST Studio Suite 2016 but unfortunately the fabrication process of antenna could not be done due to Covid-19 outbreak. The performance of the antenna has also been measured based on the analysis of the simulation design in CST.

The first specification of getting S11 bandwidth under -10dB for all the frequencies is achieved. The second specification is to obtain Axial ratio less than 3dB for all the frequencies but is not achieved for all the frequencies. It is only achieved for frequency L1(1.575GHz). Third specification is to obtain gain more than 0dB for all the frequencies but it is not achieved for all the frequencies. It is only achieved for frequency L1(1.575GHz). The fourth specification is to get good radiation pattern for RHCP while minimizing the LHCP. It has been achieved for all the frequencies. The first objective of designing and simulating Multi-band Rectangular Patch Antenna for bands of L5 (1.164GHz-1.189GHz), L2 (1.215GHz-1.240GHz), L1 (1.163GHz-1.588GHz) using CST Studio Suite is achieved. The second objective of designing a circular polarization antenna with Right-hand circular polarization is not achieved for all the frequencies. It is achieved only for frequency L1(1.575GHz). This is designed to be operating as circular polarization design. However, only 1 frequency L1(1.575GHz) is operating as circular polarization. This is because, the configuration of the design is not suitable for the circular polarization. It is also found out that the position of the feed antenna also affects the circular polarization radiation pattern.

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