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Triple-band circularly polarized conformal antenna for vehicular communication applications

N. V. K Maha Lakshmi[1,2] | **A. Mallikarjuna Prasad**[1]

[1]Department of Electronics and Communication Engineering, Jawaharlal Nehru Technological University Kakinada, Kakinada, India

[2]Department of ECE, Malla Reddy Engineering College, Hyderabad, India

Correspondence
N. V. K Maha Lakshmi, Department of Electronics and Communication Engineering, Jawaharlal Nehru Technological University Kakinada, Kakinada, Andhra Pradesh 533003, India.
Email: mahalakshminvk.nvk@gmail.com

Abstract

Vehicular communication presents a compact wideband implantable antenna for the best wireless transmission of information. The key role of the antenna is handled by the thickness of the substrate present in that antenna. Also, the shape of the antenna causes the performance characteristics. Now, vehicle-to-vehicle communication is the interesting task for designers to create successful and organized vehicular communication systems. This article presents a triple-band circularly polarized conformal antenna for vehicular communication. An antenna is introduced as a triple-band circular polarized conformal antenna and preserved a suitable mount on the vehicle surface for greater gain to provide well-maintained operational performance characteristics. For getting circular polarization, circular cuttings are provided in the design of the proposed antenna. The radiation gives a fixed direction by providing 0.3 mm thickness. Here, use a circularly polarized antenna to rectify the signal absorption due to the contact material used in the antenna. A polyamide material is used as a substrate to get a probable successful link and improve the flexibility of the antenna. The triple-band circularly polarized antenna is designed to operate in vehicular communication bands such as 2.4 GHz Wi-Fi, 3.5 GHz WiMAX, and 5.9 GHz dedicated short range communication. The antenna is designed to resonate in a triple band to improve the antenna parameters like frequency response characteristics, gain, return loss, voltage standing wave ratio, left hand circularly polarization, right hand circularly polarization, axial ratio, fidelity factor, directivity, radiated power, and input impedance. Under the operating frequency bands of 2.4, 3.4, and 5.9 GHz, the efficiency of the proposed antenna is 98.48%, 97.31%, and 97.90%, respectively. The triple-band circularly polarized conformal antenna is implemented in the high-frequency structure simulator platform. The proposed tri-band antenna is applicable in vehicular communication systems and healthcare for efficient wireless transmission.

1 | INTRODUCTION

Nowadays, technology has built everything to become efficient and dense, mainly in vehicular applications.[1] Antennas are a necessary thing in any wireless communication system. Due to the emerging technologies, it is not easy to evaluate antenna systems.[2] The vehicular application's update of wireless communication techniques makes the traffic system efficient.[3] This technology notes important information about the awareness about traffic and the internal state of the vehicle. Vehicle-to-vehicle communication extends the state of wireless communication by adding on-road communication architecture.[4] Antennas play a main part in automobile communication.[5] In the current automobile, larger transmission systems are being added for various applications.[6] In vehicle to vehicle communication, there are lots of elements that will be affecting the antenna working, for example, the position change of the antenna on the vehicle, the vehicle's high amount of metallic things and frequency of antenna is working jointly with the vehicle's design, and the mobility of the vehicles.[7] Growing amount of antennas and the minimum space on the vehicle because of aesthetic aspects need the evolution and the use of more than one band antennas added in a sole module.[8] These multiband antennas causes mutual coupling or finite ground plane size.[9] Assuming the vehicles large mobility, the traditional technique for calculating the antennas may not be sufficient.[10]

The conformal antenna has a place in a state of an array for the phase. It includes a range of miniature flat antennas like dipoles and pads.[11–13] The conformal antennas are utilized in a number of applications in ordering antennas.[14] The insertion of an antenna for large integration, in the automobile system, the special mix due to load-bearing implementation of the senders, added for portable automobile networks in the device fabric antenna.[15–17] The antenna device must work on different applications with increasingly suitable beamforming capacity, achieve radiation success, constructional strength, and a cost-effective RF device. An antenna should initially face all environmental, automatic, and operational things for earthly and airborne applications.[18] In the few years, transmitters are invented for vehicle applications have been researched and noted.[19] However, the analyzed antennas are nonavailability of explained design architecture, co-simulation performance and actual positioning test.[20] Here a triple-band circular polarized conformal antenna is designed for different vehicular applications.

Motivation: The development of antenna design is extended to new departments such as automotive design to study the increasing conditions. The proposed method not only provides details about the traffic but also determine the minimum distance that has to be covered in order to reach the destination. Compared to linear polarization, circular polarization has certain advantages. Circular polarization has a strong penetration capability compared to linear polarization and can provide a stable signal link regardless of the device's antenna orientation. In light of this, circular polarization offers improved connection for both fixed and mobile devices. It is quite difficult to meet the circularly polarized radiation requirements at three separate bands since the orthogonal field components must be of identical size and have a phase difference of 90°. In the vehicular communication system antenna is the main fragment. Many antennas are used inside and outside the vehicles for various communication systems.

A solid traffic management strategy now places a high priority on vehicular communication. Researchers have worked to develop circularly polarized (CP) patch antennas with outstanding radiation properties, such as broad angle axial ratio bandwidth and better cross polarization isolation. In addition to patch antennas, CP antennas may also be constructed using helical antennas, spiral antennas, magneto electric dipoles, or slot antennas. The antenna that conforms to an ordered structure is called a conformal antenna. The empirical problems of any antenna consist of its physical size. Planar antennas are also used for fast-moving vehicles, but their radar cross section is larger than conformal antennas. The addition of a conformal antenna in a vehicle makes it minimum disturbance and lowers the range of vision to the human eye. Another property of the conformal antenna added in the vehicle is the streamlined pull that influences the radiation attribute. The antennas described in literature have complex structures. Therefore, the small and conformal antennas are required by modern communication and navigation systems. The antenna used in vehicular communication has some problems such as less efficiency and high return loss. The frequency response present in the existing methods should not give sufficient data for selecting a better band. To avoid this kind of issue and improve the performance by selecting a better frequency band, here a triple-band circularly polarized conformal antenna is designed.

Contribution:

1. A triple-band circularly polarized conformal antenna is introduced to get well-maintained operating performance characteristics.
2. To provide a suitable mount on the vehicular surface and keep the system's gain, a conformal antenna is introduced into this system to increase the radiation through a fixed direction by providing 0.3 mm thickness.
3. To avoid signal absorption due to the contact material used in the antenna, use a circularly polarized antenna for getting a highly probable successful link and improve the flexibility of the antenna; a polyamide material is used as a substrate.
4. The antenna resonates in a triple band to improve antenna parameters like frequency response characteristics, gain, return loss, voltage standing wave ratio (VSWR), LHCP, RHCP, axial ratio, and fidelity factor.

The article is organized as related work in Section 2. Section 3 includes the proposed methodology of triple-band circular polarized conformal antenna. Section 4 describes the result and discussion, and Section 5 concludes the article.

2 | RELATED WORK

Researchers have worked to develop circularly polarized conformal patch antennas with outstanding radiation properties, such as broad angle axial ratio bandwidth and better cross polarization isolation. The conformal antennas are utilized in a number of applications. Some of the recent related works regarding conformal antenna design is given as follow.

Wei et al.[21] proposed a vertical polarized conformal antenna based vehicle communication system. Here antenna is designed by combining different carrier structures. Invasive wed optimization is the technique used to reduce antenna installation space. The conformal antenna is saved and understand the omnidirectional circular polarized beam. The technique is applied to the unmanned aircraft carrier, which is designed as a low-profile vertical polarization unit. Due to the use of the electric fields integral equation (EFIE) and electric/magnetic current combined-field integral equation (JMCFIE) and multilevel fast multiple algorithms (MLFMA), it examines the contrasting performance, which is the main advantage and along with that, the result shows the antenna scanning angle as the corresponding beam direction. But in the lab, the integrator and the phase shifter are not able to work in the k-band.

Zhong et al.[22] proposed a dual-band circularly polarized antenna for vehicles with GPS navigation applications. This is a compact circular polarized antenna with large axial ratio bandwidth. Two stacked patches antennas are used in this concept for the notable dimension reduction. The antennas are backed with a metallic cavity to modify the beam width response. It has the advantage that it gets wide bands. But the frequency response goes up with some ripples, and the profile is only satisfactory when considering the low profile characteristics.

Safaron et al.[23] introduced a directional cloverleaf antenna for automobiles. A reflector is used in conjunction with the antennas to achieve a directional radiation pattern and a high gain. A 3-blade omni-directional cloverleaf antenna and a 4-blade omni-directional cloverleaf antenna are used here. After that, the indicated antennas are integrated with a reflector to get a large gain and directional radiation pattern. The system corrected the fixed beam switching angle and problems using embedded switching devices. The average gain of this antenna is 2.37 dB. It has a very low measured and simulated loss. However, the antenna's frequency has been changed to the high-frequency range.

Xu et al.[24] proposed a vehicle-based reconfigurable dual band circulatory polarize antenna. The antenna is a simple four branch planar monopole and uses a 4 pin diode to adjust the branch length. This antenna is capable of resonating in both directions. Unidirectional radiation may be found using an oval hole with a metal step. The calculated bandwidths of the impedance (|S11|-10 dB) are 22.69% (1.055–1.325 GHz) and 5.68% (1.54–1.63 GHz) with only 1.261 centre frequency-ratio, and the 3-dB AR, bandwidths are 7.4% (1.211–1.304 GHz) and 3.91% (1.554–1.616 GHz) with 1.261 center frequency-ratio (CFR). The suggested antenna offers the following merits: a simple construction, higher gain, and reduced CFR. However, compared to the old system, the benefit of the system is minimal.

Balderas et al.[25] a low-profile conformal antenna design was proposed for Ultra-wide band (UWB) communications. The aerodynamic form for quadcopter drones, low profile, and UWB performance are all advantages of this recommended antenna. The drag issue can be mitigated during flights by changing the appearance. Due to the presence of four antennas on the aircraft, the antenna is an excellent device for UWB systems with drones. This reduces the chance of developing interference with the circuitry of the entire system. The developed technology was installed in a real plane and produced a similar display of the stimulated antenna. However, implementing a UWB system while a UAV is in flight is not addressed in the system, and the antenna cannot find the center of the vehicle.

Abishek et al.,[26] a circularly polarized conformal micro strip patch antenna in a traffic related system for the application like SATCOM in Ku band is planned and simulated using both high-frequency structure simulator (HFSS) and Feldberechnung für Körper mit beliebiger Oberfläche tools. Differentiated research with linearly polarized conformal and planar antennas for automobiles' communication application is completed. One of the greatest ways for this task is to match the antenna to the vehicle design. The antenna's radiation framework is analyzed with the vehicle platform by following the steps to produce a better outcome for the issue above. Still, this stepwise approach requires a time delay to get the output.

Virothu et al.[27] suggested a flexible circularly polarized antenna study for roads from 3.40 to 3.80 GHz frequency bands based on attached cars. The selected spectrum provide large-connectivity around the area while minimizing the impact of transmission at 5.90 GHz, which is responsible for short-range communication. Keeping up with media growth such as streaming technologies. The services in the 5G network must be available in authorized frequency band of 3.4 to 3.8 GHz.

The purpose of this project was to create circularly polarized two CPW-fed flexible antennas that could function in the 2 to 5 GHz frequency range and cover the 3.4 to 3.8 GHz and LTE 2600 MHz. According to the findings, the circularly polarized antennas attain appropriate gain in the 2.5–2.57, 2.62–2.69, and 3.4–3.8 GHz bands (more than 3.2 dB).

Gopi et al.[28] proposed a conformal elliptical-shaped patch (ESP) antenna is used for vehicle systems. The measurement of an antenna is 40600.1 mm^3 and is designed to be mounted on a polyimide substrate. To increase bandwidth, a coplanar waveguide (CPW) is being considered. With a bandwidth of 4360 MHz, the antenna was duplicated at 4.26 and 6.61 GHz frequencies (3.35–7.71 GHz). For the two resonant frequencies, the 3D-gains are 4 and 4.2 dBi, respectively. Semi-omnidirectional and directional radiation characteristics are found. To check similarities on the vehicle surface here, use bending analysis. Because of its flexibility, low profile and simple structure, the antenna is best suited for the application in automobile communication.

Babu et al.[29] proposed a flexible transparent circularly polarized antenna for use in vehicles. The conductive layer is made of canopy mesh, and the substrate is made of Polydimethylsiloxane, with a 2.66 dielectric constant value and 0.023 tangent loss. The suggested antenna's total dimensions are $20 \times 20 \times 1\ mm^3$. The suggested antenna has a bandwidth of 5.3–6.87 GHz, the bandwidth related to the axial ratio 5.7–6.14 GHz, and the antenna has a 404 MHz resonant frequency.

Albagory et al.[30] presented unmanned aerial vehicles (UAVs) and space vehicles, a novel array of conformal construction and beamforming technology is presented to enable better characteristics performance. The suggested array is made up of conical, cylindrical, and concentric circular (CSC4) arrays which are arranged in the form of co-axial with the conforming body's axis and have consistent inter-element spacing. The array components are then supplied by a tapered adaptive cosine profile weighting vector with the amplitude coefficient with the highest value-orientated with the main lobe way to increase the array's capability of scanning and increase the effective area of the array. Moreover, a frontal main lobe-oriented partial CSC4 array beamforming approach to all big, space, for example, is a conforming bodily structure. Spacecraft is presented to use the vast array efficiently.

The antenna used in vehicular communication has some problems such as less efficiency and high return loss. The frequency response present in the existing methods should not give sufficient data for selecting a better band. To avoid this kind of issue and improve the performance by selecting a better frequency band, here propose a triple-band circular polarized conformal antenna. The comparative study of existing work is given in Table 1.

3 | PROPOSED METHODOLOGY

In vehicular communication, the information is transmitted and received through the antennas present in the vehicles. The antenna should be placed conformal safely on the vehicle's surface for effective data communication. Frequency selection of the antenna is very important for the effective selection of the radio frequency signal. This research focuses on designing a triple-band (Wi-Fi- 2.4 GHz, WiMAX-3.5 GHz, and dedicated short range communication (DSRC)-5.9 vehicular bands) circularly polarized conformal antenna for vehicular communication application. The layout of the proposed conformal antenna is shown in Figure 1. The designed antenna has a thickness of 0.3 mm and 3.5 dielectric constant to improve the antenna's radiation in a specific direction. The substrate selected for the fabrication of antenna model is polyamide and it is placed between the top and ground layers. The suggested antenna's electromagnetic study is performed in the HFSS simulation platform, which employs the finite element technique (FEM) to analyze the antenna shape and determine essential properties including reflection coefficient and radiation patterns. The top layer consists of a conformal antenna, and the ground layer has two rings and seven slotted arms for providing triple frequency band. The ground layer has four circular cuttings for providing better circular polarization.

3.1 | Antenna design

The geometry of the proposed antenna architecture is illustrated in Figure 1. The designed antenna has a thickness of 0.3 mm to improve the antenna's radiation in a specific direction. The antenna has two layers top layer and the ground layer. A polyamide substrate is used between the top and ground layers. The top layer consists of a conformal antenna, and the ground layer has two rings and seven slotted arms for providing triple frequency band. The ground layer has four circular cuttings for providing better circular polarization.

TABLE 1 Comparative study

Authors	Antenna design	Application	Overall parameters	Merits	Demerits
Wei et al.[21]	Vertical polarized conformal antenna	Vehicle communication system	Size = 240 mm × 155 mm Media loss = 0.02	The array scanning angle can reach the corresponding beam direction	The integrator and the phase shifter are not able to work for k-band in lab
Zhong et al.[22]	Compact circular polarized antenna	Vehicles with GPS navigation applications	Axial ratio bandwidth of lower band 3 dB = 133° and upper band 3 dB = 120°.	It gets wide bands	Frequency response goes up with some ripples
Safaron et al.[23]	Cloverleaf antenna design	Unmanned aerial vehicle	Average gain = 2.37 dBi, reflector average gain = 6.38 dBi	High antenna gain is attained	Antenna's frequency has been changed to the high-frequency range
Xu et al.[24]	Reconfigurable dual band circulatory polarize antenna	Vehicular applications	Axial ratio = 2 dB, centre frequency = 1.261 ratio	Simple construction, higher gain, and reduced CFR	The benefit of the system is minimal
Balderas et al.[25]	Low-profile conformal antenna design	Ultra wide band application	Return loss = 2.9 to 15.9 GHz, radiation pattern = 10.1 GHz	Simple to design	Antenna cannot find the center of the vehicle
Abishek et al.[26]	Circularly polarized conformal micro strip patch antenna	Vehicular communication	Resonating frequency = 12.2 GHz	Antenna's radiation produce a better outcome	Stepwise approach requires a time delay to get the output
Virothu et al.[27]	Flexible circularly polarized antenna	Vehicular application	Frequency band = 3.4 GHz to 3.8 GHz, LTE = 2600 MHz, gain = 2.5–2.57, 2.62–2.69, and 3.4 –3.8 GHz bands	It attain high gain and bandwidth	Design complexity is too high
Gopi et al.[28]	Conformal elliptical-shaped patch	Vehicular communication	Bandwidth of 4360 MHz, 3D-gains = 4 and 4.2 dBi	Flexibility, low profile, and simple structure	High power consumption
Babu et al.[29]	Flexible transparent circularly polarized antenna	Vehicular communication	Bandwidth of 5.3–6.87 GHz, bandwidth related to the axial ratio 5.7 to 6.14 GHz, resonant frequency = 404 MHz	Transparent nature, compact, and flexibility	High complexity of design
Albagory et al.[30]	Array of conformal construction and beamforming technology	Unmanned aerial vehicles (UAVs) and space vehicles	Side lobe level = −45 dB Back lobe level = −10 dB	It reduce the processing requirements and provide very low side lobe levels with reduced back lobe levels	Low amplitude coefficient

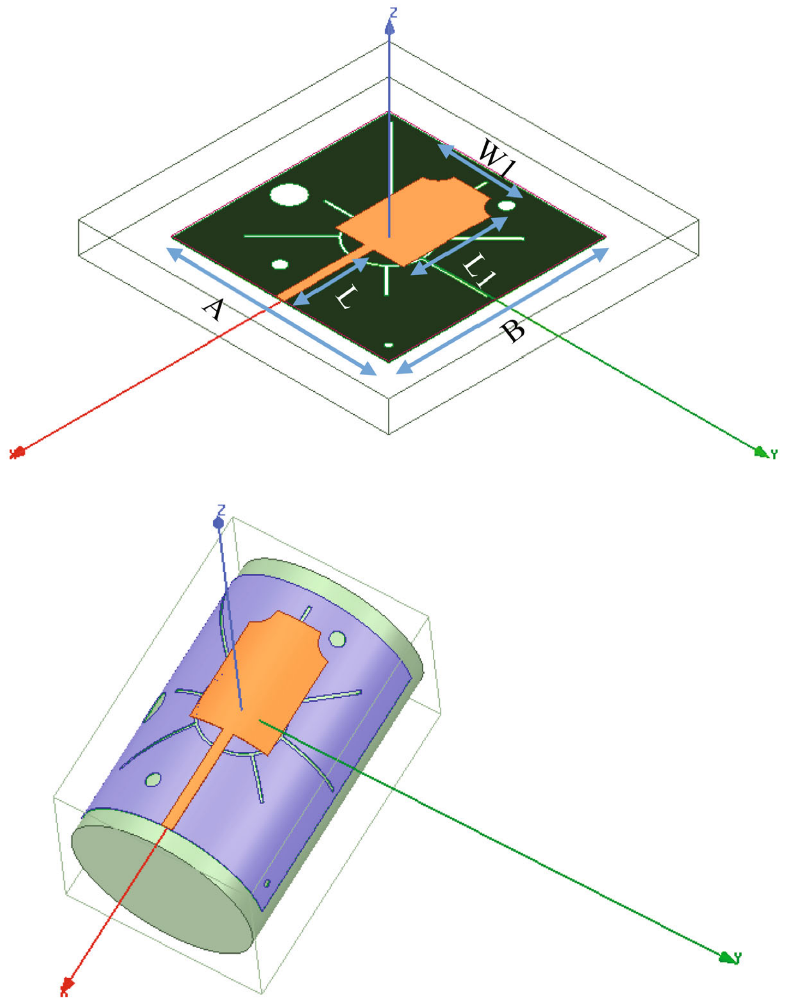

FIGURE 1 Proposed conformal antenna design

3.2 | Mathematical formulation

The antenna parameters are determined with the use of several prefixed design formulae, which are provided below. To attain an optimum results the parameters are adjusted while performing simulation.

Width: The patch width is minimum at the time of the radiation pattern and resonant frequency. The equation of width W is given as

$$W = \frac{1}{2F_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_D + 1}}, \tag{1}$$

where μ_0 is the permeability in the free space, ε_D is the dielectric constant of the substrate used, ε_0 is the permittivity in free space, and F_r is the resonant frequency.

Length: Patch length is used to find the resonant frequency. The equation for length is given below

$$\text{Length}\, L_1 = l_{\text{Eff}} - l_{\text{Ext}}, \tag{2}$$

where L_{Ext} and L_{Eff} is the patch extension length and patch effective length. The equation for length is given below

$$L_{\text{Eff}} = \frac{c_F}{2F_r\sqrt{\varepsilon_{\text{Eff}}}}, \tag{3}$$

where ε_{Eff} represent an effective dielectric constant of the substrate and free space light velocity is given as c_F.

$$\varepsilon_{\text{Eff}} = \frac{\varepsilon_D + 1}{2} + \frac{\varepsilon_D - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}}. \tag{4}$$

The expression for extension length is

$$L_{\text{Ext}} = 0.412h\frac{(\varepsilon_{\text{Eff}} + 0.3)\left(\frac{w}{h} + 0.2664\right)}{(\varepsilon_{\text{Eff}} - 0.258)\left(\frac{w}{h} + 0.8\right)}. \tag{5}$$

The above equations are utilized to design the antenna. The antenna characteristics are simulated for various bending angle iterations for the clear substrate material after selecting the final design that fulfills the coverage of necessary vehicle bands. For this experiment, the nominal bending angles of 30°, 60°, 90°, and 120° are primarily taken into consideration. The bending radius required to make the substrate flexible is calculated using the mathematical formula (6).

$$\text{Bending radius } (B_r) = 0.5\left(L_s - L_f\right) \times \left({}^{360}/_{\pi\theta}\right). \tag{6}$$

Here, L_s and L_f specifies the length of the substrate and feed line section. θ specifies the bending angle.

3.3 | Structure and design

The choice of length and width is critical for designing the antenna. The top layer is emphasized with feed line and at the center of the substrate it is employed with rectangular strips with arc shaped cuts at the top part for the circular polarization. Therefore, the length and width of the feed line and the loaded rectangular strips are represented as L, W and L_1, W_1. The height of the conformal antenna is 38.5 mm. In between the top and ground layers, a polyamide substrate is used to get a highly flexible conformal antenna. The substrate has a length and width of 70 and 70 mm. The intermediate steps of the antenna design is illustrated in Figure 2. Initially, the rectangular patch is created. In the second stage the feed lines are added. Figure 2A describes the design procedure of ground plane. Initially, the plane ground structure is fixed. In the second stage, the circular cut takes place in the center of the ground. Then from step 4 to 9, the rectangular seven slotted arms are introduced to generate circular polarization. In step 10, the parasitic circle is added and then the slot has been created in the center of the parasitic circle in step 11. In step 12, the parasitic circle is defined. Form steps 13 to 15, several the circle slots had been created in the ground plane. In step 16, a small connection between ground and parasitic circle outer layer takes place. Figure 2B describes the design procedure of antenna design. Initially, the rectangular patch is created. In the second stage the feed lines are added. In steps 3 and 4, an arc slot has been created on the top left and right corner of the antenna.

The ground layer in the conformal antenna consists of a circle with a center of radius R surrounded by seven slotted arms. There are two radii present in the ground layer: inner radius and outer radius. The inner radius has a magnitude of R_1 and the outer radius has a magnitude of R_2. The seven slotted arms have a length of L_2, L_3, L_4, L_5, L_6, L_7, and L_8, respectively. The representation of the ground layer is shown in Figure 3. The ground layer consists of four circular cuttings to generate circular polarization in the conformal antenna. The circular cuttings are C_1, C_2, C_3, and C_4 with radius 4, 2, 2, and 1 mm, respectively. The circles added slotted lines with an angle of 135°, 315°, 255°, 45°, 180°, 270° and 90°, respectively for L_2, L_3, L_4, L_5, L_6, L_7, and L_8, respectively. The arrangement of slotted lines are illustrated in Figure 4. The triple resonant frequency can be found by using the annular slotted dimensions. The upper, middle and lower resonant frequency can be determined according to each arm's length, the conductor ring's width, and the conductor ring dimension used in the design. The first resonant frequency can be found by the annular slot dimension and the longest arm present in the ground layer. Also, the second frequency band can be determined by calculating the shortest arm present in the ground layer and the conductor width. The third frequency band is obtained by providing rings into the ground layer. The third frequency can be determined according to the dimension of this conductor. Also, the dimension of the designed antenna are shown in Table 2.

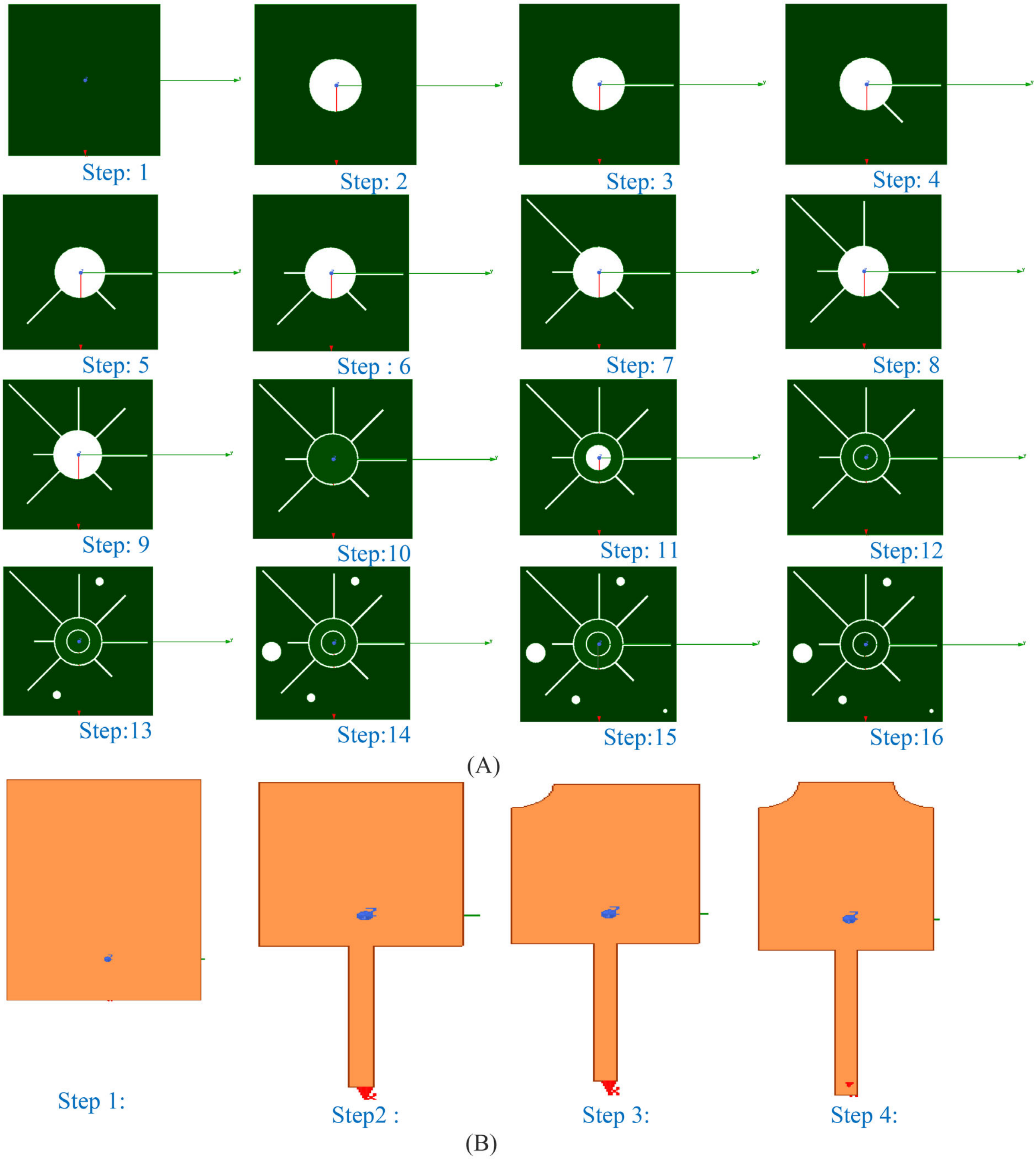

FIGURE 2 Evolution of proposed design. (A) Step by step procedure of ground plane and (B) step by step procedure of antenna design

4 | RESULTS AND DISCUSSIONS

The proposed antenna is designed in HFSS platform. The conformal antenna is designed in polyamide substrate material with 0.3 mm thickness. By using VNA, the measurements have been performed. The proposed triple-band circularly polarized antenna attains a bands of 2.4, 3.5, and 5.9 GHz and it is suitable for Wi-Fi, WiMAX, and DSRC vehicular bands. The antenna is designed in HFSS platform and the parametric analysis such as gain, radiation efficiency, radiation pattern, return loss, return loss by varying the substrate height, VSWR, axial ratio, surface current distribution, and fidelity factor. In addition to this, the bending analysis also performed for several parameters with the conformal structures of 30°, 60°, 90°, and 120°, respectively.

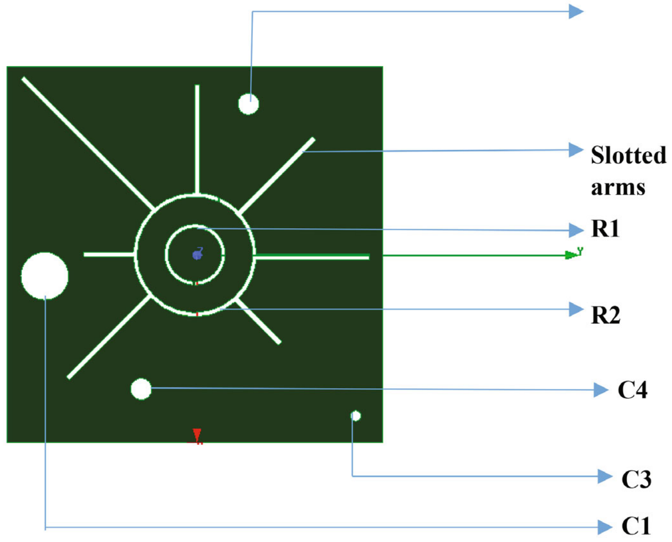

FIGURE 3 Ground layer structure

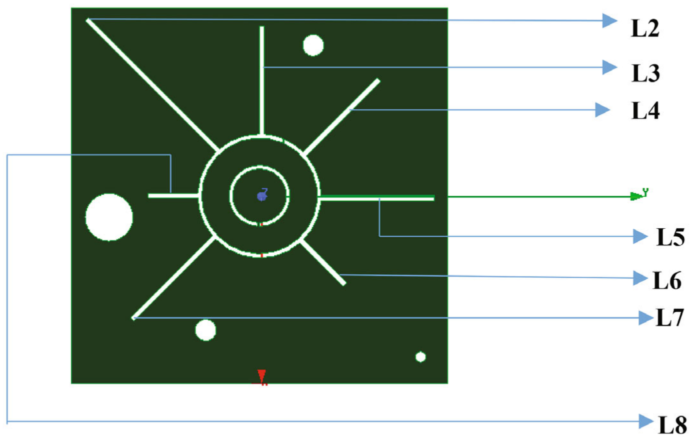

FIGURE 4 Arrangement of slotted lines

4.1 | Parametric analysis of the proposed design

4.1.1 | Analysis of gain and radiation efficiency

The normal gain and the gain analysis for the conformal structure plot of designed antenna is shown in Figures 5 and 6. The parameter gain is measured for both the measured and simulated scenario and it shows that the measures results matched with the simulated outcome to validate the design performance. To verify the design of the proposed antenna, the antenna fabrication takes place and the measured and simulated results are validated and it shows that both are close to each other. The operating bands of the proposed design is 2.4, 3.4, and 5.9 GHz and it is shown in Figure 5. Under the frequency range of 2.4, 3.4, and 5.9 GHz, the attained gain is 1.6, 5.09, and 5.45 dB. The measured analysis of return loss under different bending analysis of 30°, 60°, 90°, and 120° is illustrated in Figure 6.

A radiated efficiency measures the difference between the power given to its terminals and the power it radiates as an electro-magnetic wave. If the antenna were created as a perfect electrical component, it would be able to transform all of the power supplied to its terminal into electromagnetic energy that could be transmitted into space. This is only theoretically possible since in reality, some of the power transmitted via the antenna terminals is frequently lost. For instance, a mismatch between the antenna element and the feeding network results in power losses. In addition, the antenna material itself naturally loses energy and produces unwanted heat. The result of all these losses is that the antenna's actual

TABLE 2 Dimensions of parameters

Parameter	Description	Dimension (mm)
L	Feed length	28.7
W	Feed width	2.87
A	Substrate width	70
B	Substrate length	70
L_1	Length of the rectangular patch	28.3
W_1	Width of the rectangular patch	22
R_1	Radius of the inner most circle	4.58
R_2	Radius of the inner circle	10.26
L_2	Slotted arm 1	34.53
L_3	Slotted arm 2	20.035
L_4	Slotted arm 3	19.53
L_5	Slotted arm 4	21.31
L_6	Slotted arm 5	8.024
L_7	Slotted arm 6	21.53
L_8	Slotted arm 7	9.2
C_1	Diameter of circular slot 1	8.9
C_2	Diameter of circular slot 2	4
C_3	Diameter of circular slot 3	2
C_4	Diameter of circular slot 4	4

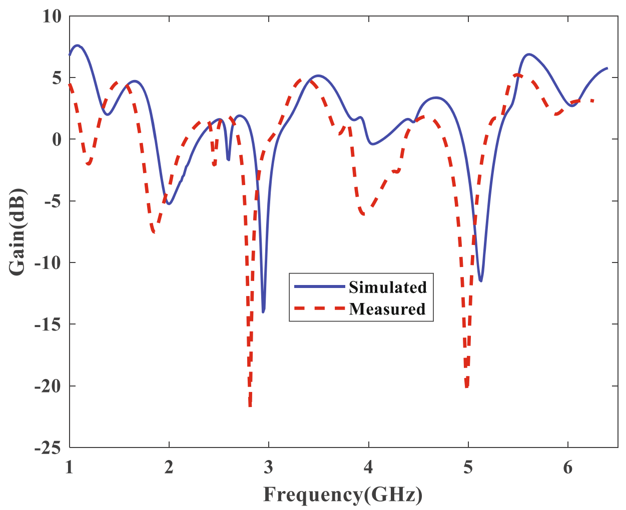

FIGURE 5 Analysis of gain versus frequency

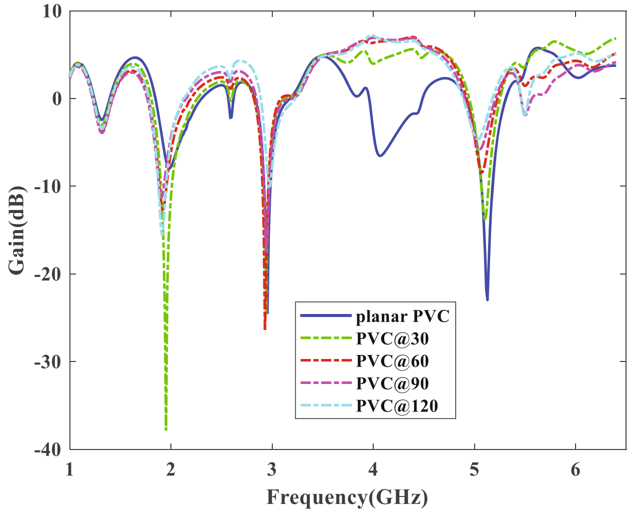

FIGURE 6 Gain analysis of conformal structures of 30°, 60°, 90°, and 120°

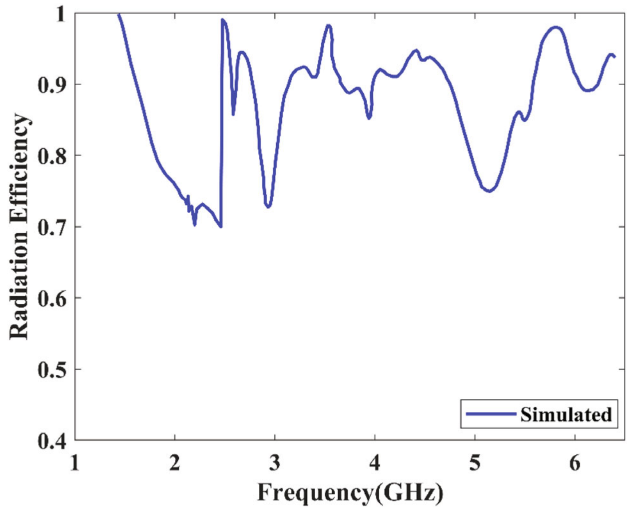

FIGURE 7 Radiation efficiency versus frequency

radiated efficiency is never more than 100%. Antenna efficiency is assessed in an anechoic chamber by applying some power to the antenna feed pads and measuring the intensity of the emitted electromagnetic field in the surrounding area. The radiation efficiency of the proposed design with respect to frequency is illustrated in Figure 7. Under the frequency range of 2 to 6 GHz, the radiation efficiency of the proposed design ranges from 97.3% to 98.4%, respectively.

4.1.2 | Analysis of radiation pattern

The amount of radiated antenna power is expressed in radiated power and is defined by the antenna's radiation pattern. The graphical representation of the directional angular helplessness of the power of the radio wave in the field of the antenna architecture or other source defines the radiation pattern. Antenna radiation pattern in E-plane[31] is represented as

$$E_\theta = \frac{\sin\left(\frac{ZW\sin\theta\sin\varphi}{2}\right)}{\frac{ZW\sin\theta\sin\varphi}{2}}\cos\left(\frac{ZW}{2}\sin\theta\cos\varphi\right)\cos\varphi, \tag{7}$$

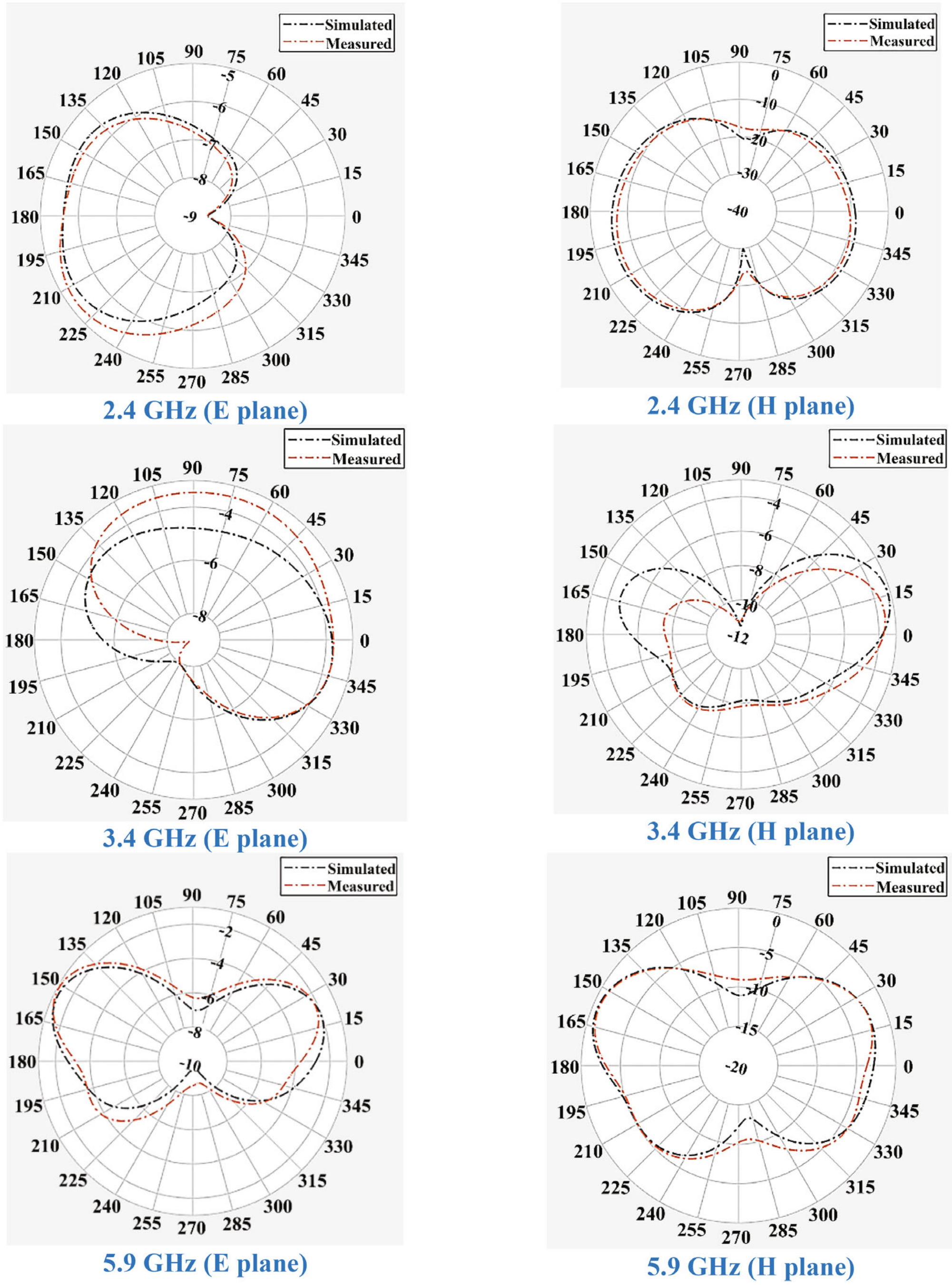

FIGURE 8 Radiation pattern analysis of simulated and measured under the frequency range of 2.4, 3.4, and 5.9 GHz

$$E_\varphi = -\frac{\sin\left(\frac{ZW\sin\theta\sin\varphi}{2}\right)}{\frac{ZW\sin\theta\sin\varphi}{2}}\cos\left(\frac{ZW}{2}\sin\theta\cos\varphi\right)\cos\theta\sin\varphi, \tag{8}$$

where Z gives the free space wavenumber. The radiation pattern analysis of the measured and simulated outcome under the frequency range of 2.4, 3.4, and 5.9 GHz is illustrated in Figure 8.

The impact of co and cross polarization is demonstrated using the two main planes, the E plane (y-z) and the H plane (x-z). The proposed antenna modifies a portion of the ground plane to get bidirectional circular polarization (CP) radiation with right hand circular polarization (RHCP) in one direction and left hand circular polarization (LHCP) in the opposite direction. Significant back lobe is also produced by this ground plane. The RHCP and LHCP radiation pattern of

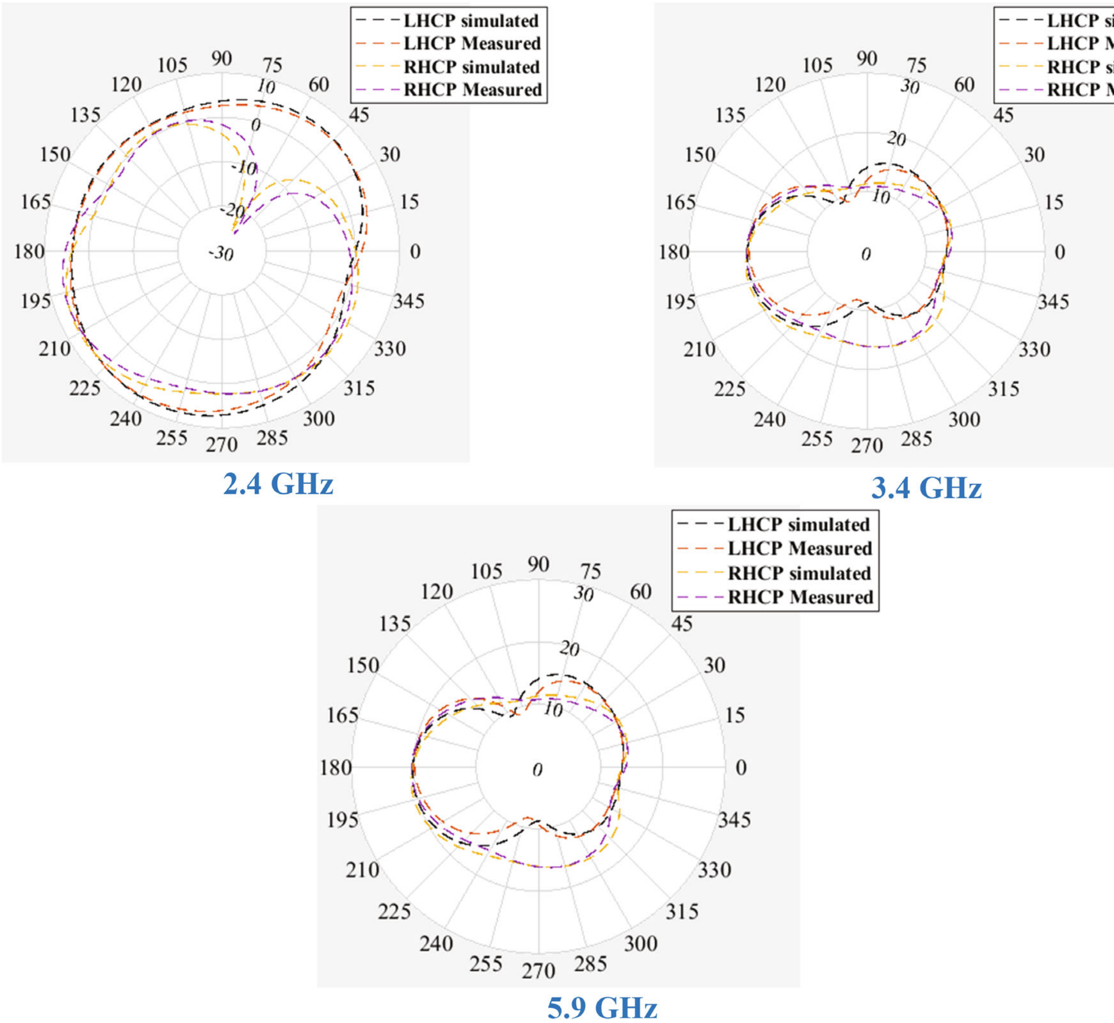

FIGURE 9 RHCP and LHCP radiation pattern (x-z and y-z plane) of the proposed antenna under the frequency range of 2.4, 3.4, and 5.9 GHz

the simulated and measured antenna under all the frequency bands are illustrated in Figure 9. The analysis of radiation pattern for various bending conformal structures under the triple frequency band are illustrated in Figure 10.

4.1.3 | Analysis of return loss of the proposed antenna

The analysis of return loss of the proposed antenna under measured and simulated outcome for desired frequency is illustrated in Figure 11. Both the findings from simulation and measurement have almost the same resonance frequency. Due to a few small manufacturing or material mistakes, the observed return loss marginally varies in comparison to the findings of the simulation. The loss of signal power is returned/reflected by a break in an optical fiber or transmission line. Return loss is usually conveyed in decibels. The expression for return loss is expressed[31] as follows

$$R = 10\log_{10}\left(\frac{P_i}{P_r}\right). \tag{9}$$

In the case of an electric system, the input and output mapping between terminals is explained by S-parameters. The polarization of the triple-band antenna gives a circular shaped polarization. Figure 11 shows the operational band and resonant frequency of the designed antenna. The proposed design attains a three frequencies and the corresponding

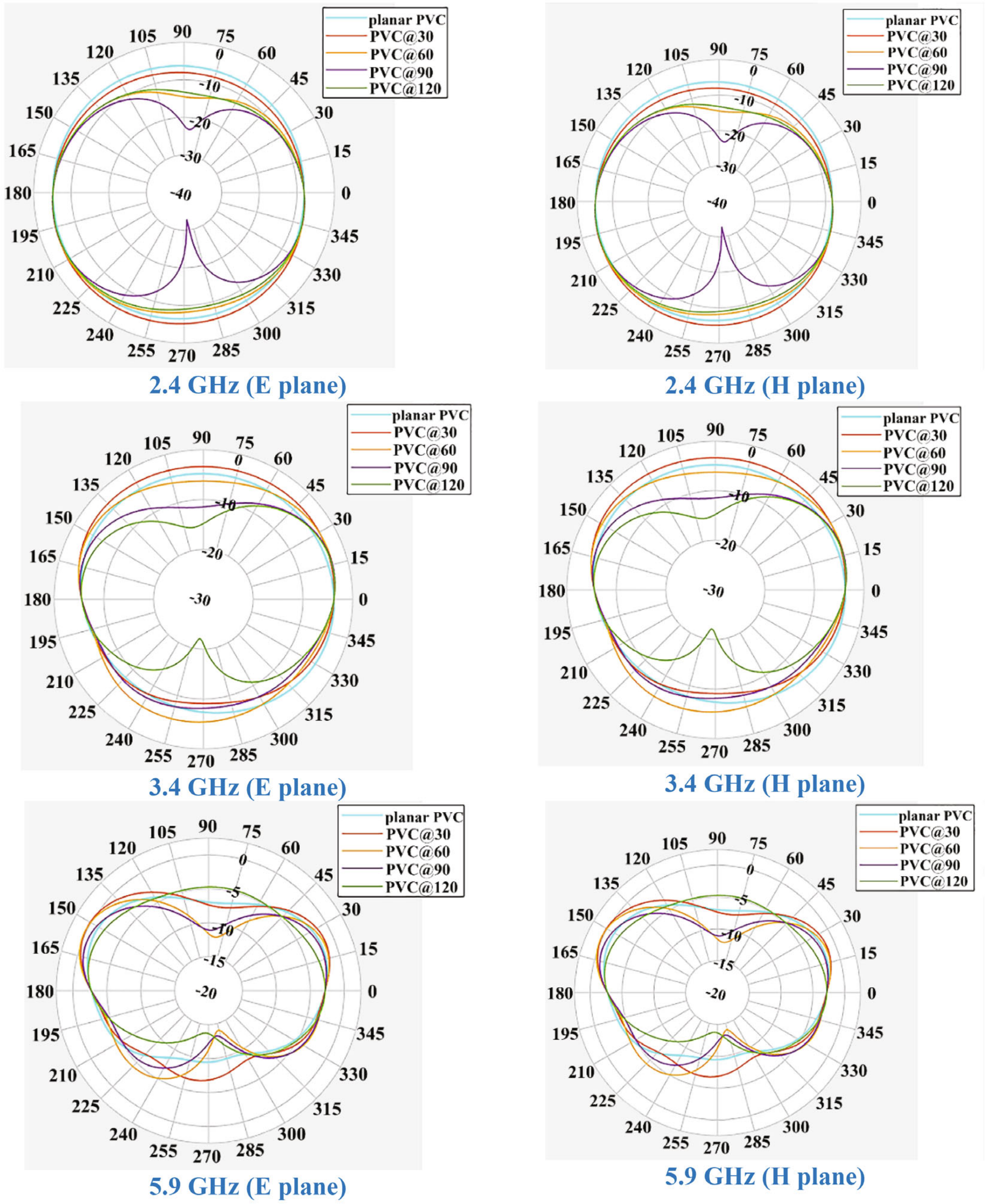

FIGURE 10 Bending analysis of radiation pattern under the frequency range of 2.4, 3.4, and 5.9 GHz

frequencies are 2.4, 3.4, and 5.9 GHz, respectively. The return loss attained for 2.4 GHz is 16 dB, 3.4 GHz is 21 dB, and 5.9 GHz is 18 dB consecutively.

The height of the substrate antenna is very important in the antenna to provide proper attachment to the vehicle surface and maintain the gain of the system. Here, the return loss for a triple-band circular polarized conformal antenna for three different substrate heights are analyzed. Figure 12 shows the comparison graph of return loss by varying the substrate height such as 0.28, 0.29, and 0.3 mm of the antenna. Also, the gain analysis of the conformal structures under triple frequency bands are shown in Figure 13.

4.1.4 | Analysis of VSWR and axial ratio

The VSWR explains the proportion of minimum voltage to the maximum voltage in a shading wave. There will be no efficient power radiation until it matches the communication line, circuitry and antenna impedance. The VSWR is also

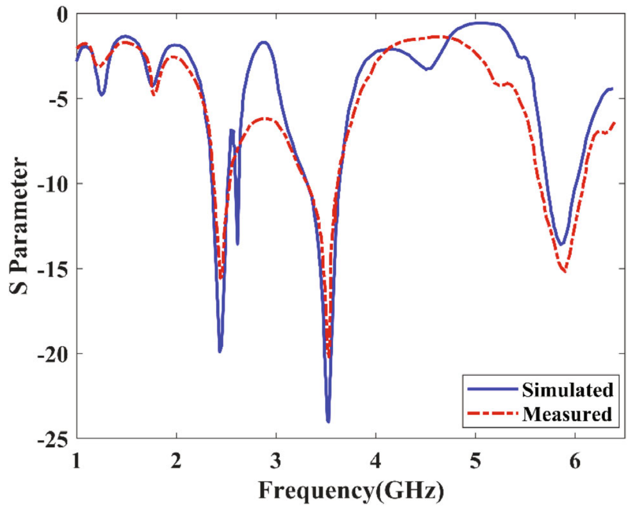

FIGURE 11 Simulated and measured return loss versus frequency

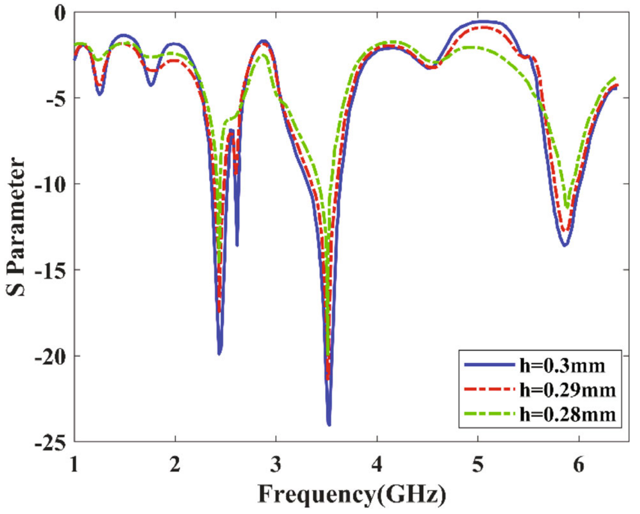

FIGURE 12 Analysis of return loss by varying substrate height

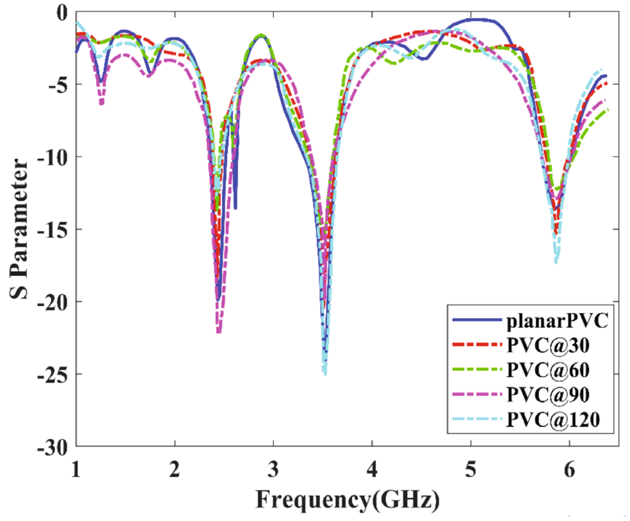

FIGURE 13 Gain analysis of conformal structures of 30°, 60°, 90°, and 120°

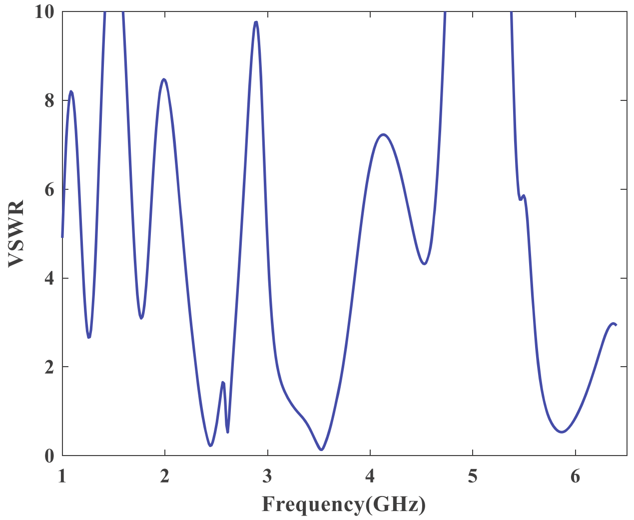

FIGURE 14 VSWR versus frequency

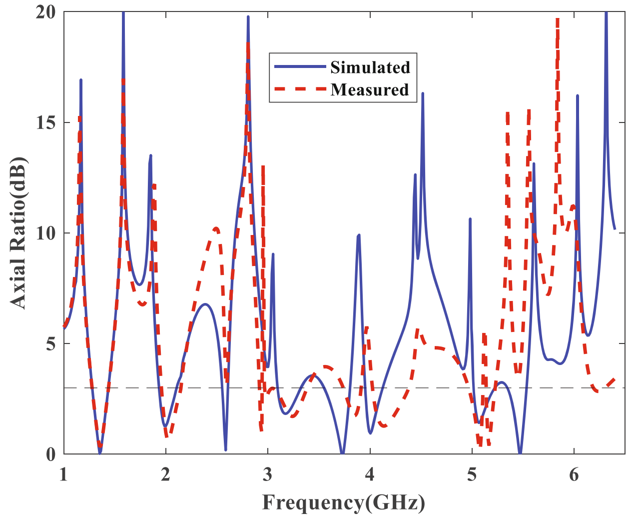

FIGURE 15 Axial ratio versus frequency

named as standing wave ratio. Figure 14 shows the VSWR for the three frequency bands. For successful radiation, the perfect value of VSWR should be 1:1. For the proposed triple-band circularly polarized antenna, the quantitative values of the VSWR are 0.2, 0.1, and 0.5 under the frequency range of 2.4, 3.4, and 5.9 G Hz respectively. The mathematical expression of VSWR[31] is shown below:

$$\text{VSWR} = \frac{V_{Max}}{V_{Min}}. \tag{10}$$

The axial ratio plot of the proposed antenna in terms of simulated and measured outcome is illustrated in Figure 15. The polarization characteristics of circularly polarized antennas are described by the parameter which is named as axial ratio. If the value of axial ratio is less than 3 dB then the antenna presumed as circularly polarized antenna. Due to the incisions made at the corners of the square patches, the suggested antenna is circularly polarized. Here, the axial ratio had been examined with respect to frequency. Form the Figure 15 it is observed that the measured values are in concurrence with simulated values.

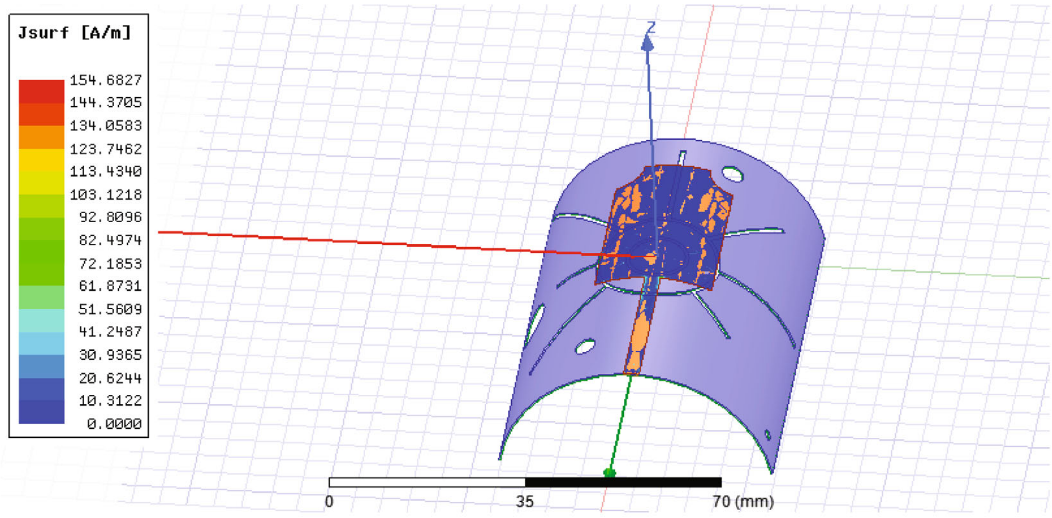

FIGURE 16 Surface current distribution for phi = 0

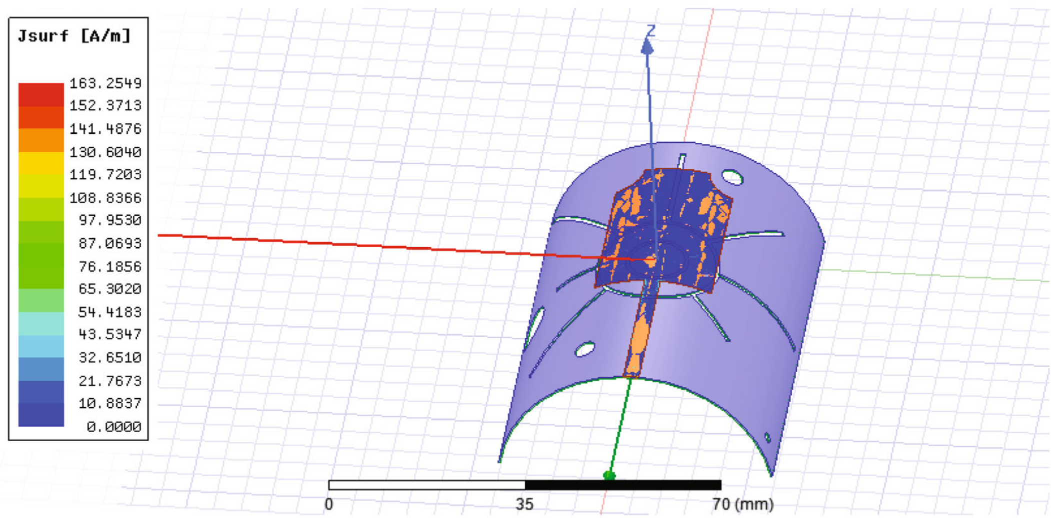

FIGURE 17 Surface current distribution for phi = 90

4.1.5 | Determination of surface current distribution

The surface currents flowed in the direction of phi = 0° at time $t = 0$, but at $t = T/4$, the surface currents' direction altered to flow upward in the direction of phi = 90°. At times $t = T/2$ and $3T/4$, the vector currents' directions shifted to phi = 180° and phi = 270°. The surface vector current graph demonstrates that the current vector's directions at $t = T/2$ and $t = T/4$ were just the opposite of those at $t = 0$ and $t = T/4$, respectively. However, the magnitude of the current flows is maximum when the antenna is operating at the required frequency. Therefore, the surface current distribution at different frequencies for the triple-band conformal antenna is illustrated in Figures 16, 17, 18, and 19, respectively. The fabricated antenna design is shown in Figure 20.

4.1.6 | Fidelity factor

The antenna fidelity factor is defined as the ability of an antenna to maintain its original shape. The fidelity measurement is used in the exact antenna. Figure 21 represents the fidelity factor of the proposed by comparing the existing antennas.

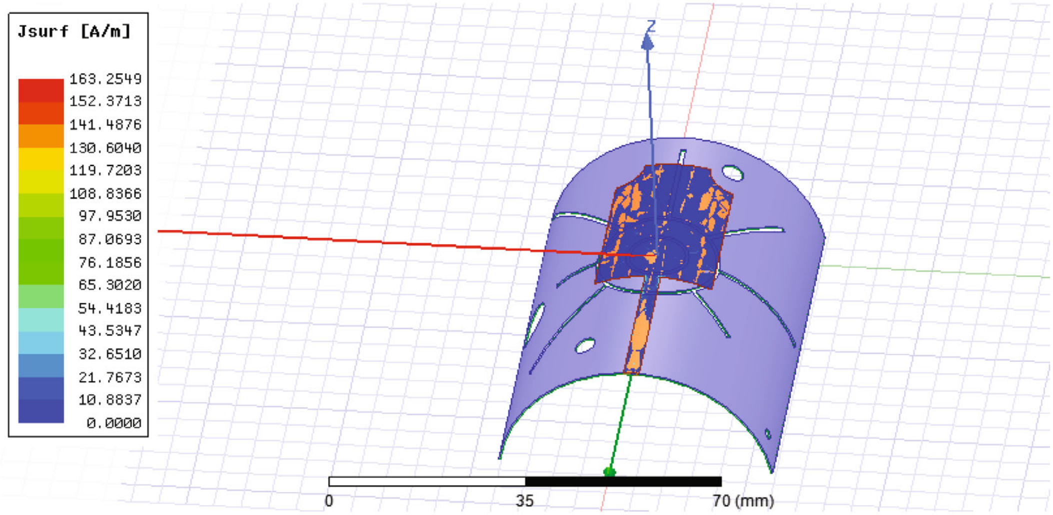

FIGURE 18 Surface current distribution for phi = 180

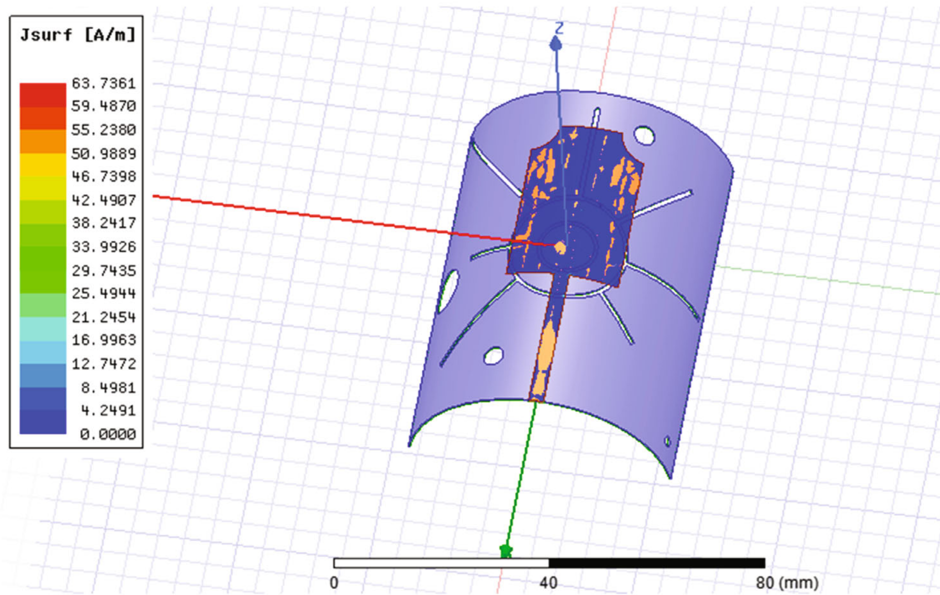

FIGURE 19 Surface current distribution for phi = 270

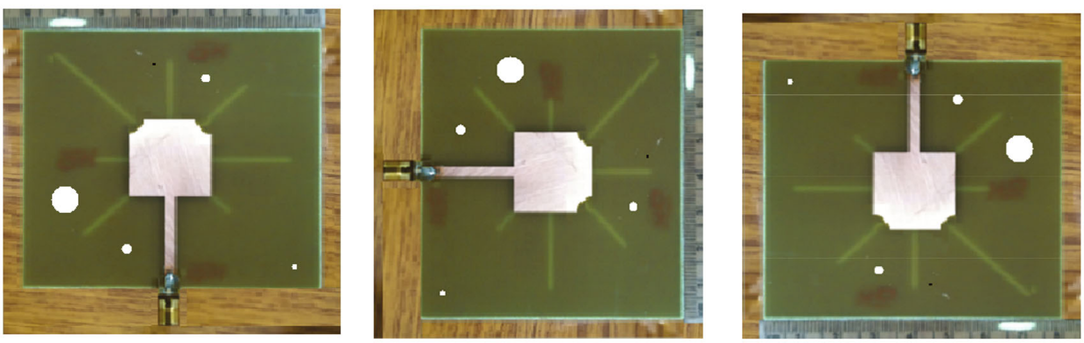

FIGURE 20 Fabricated prototype

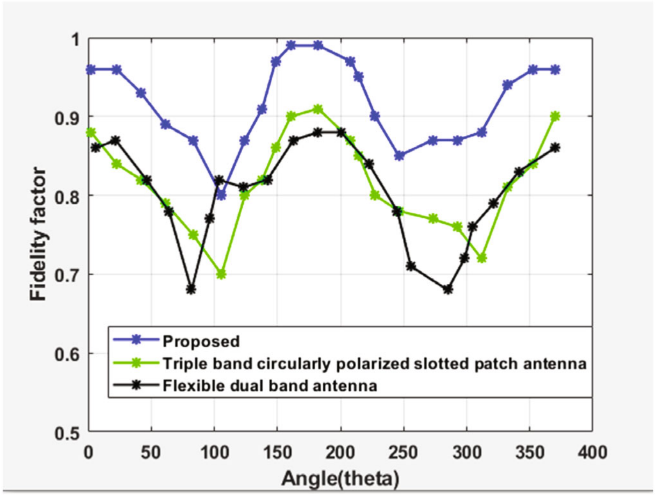

FIGURE 21 Fidelity factor

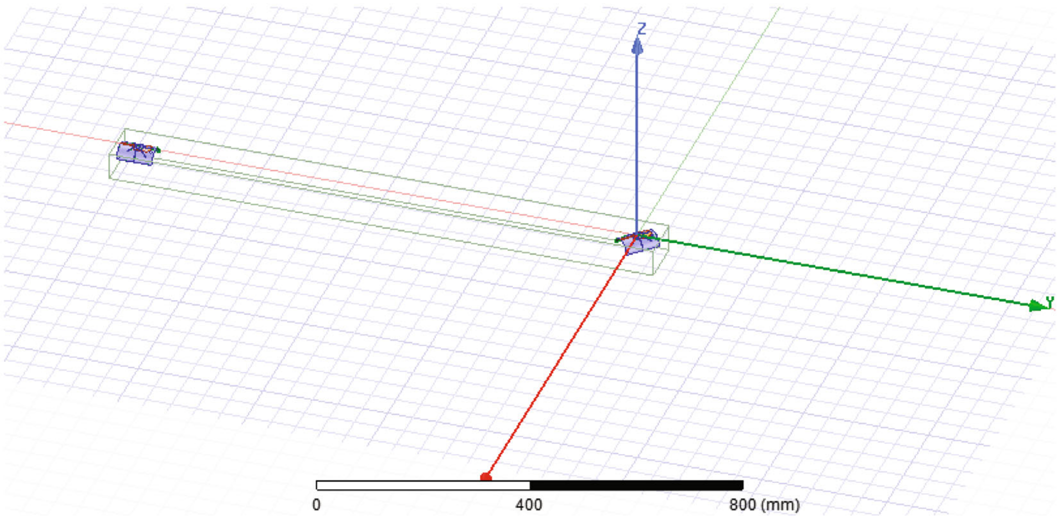

FIGURE 22 Arrangement of transmitter and receiver

The figure shows that the fidelity factor of the proposed antenna is greater than that of the existing designs. The fidelity factor value of the proposed antenna is 0.98. Figure 22 shows the arrangement of the transmitter and receiver of the antenna.

The proposed antenna is the antenna-parameters like frequency response characteristics, gain, return loss, VSWR, LHCP, RHCP, axial ratio, fidelity factor, directivity, radiated power, and input impedance. Table 3 gives the performance comparison of the frequency range, thickness, return loss, VSWR, directivity, and fidelity factor. The value shows that the proposed triple-band circular polarized conformal antenna gives better performance than the other existing antenna designs. The existing antenna designs are triple-band circularly polarized slotted patch antenna,[32] flexible dual band antenna,[33] poly-imide dual band antenna,[34] and flexible bow-tie antenna.[35]

The designed antenna is small in size and offers a number of excellent characteristics, including impedance bandwidth, high gain, and high radiation efficiency. A triple-band circularly polarized low profile antenna with simple design is suggested in this study for 2.4 GHz Wi-Fi, 3.5 GHz WiMAX, and 5.9 GHz (DSRC) vehicular communication. Vehicular communication can reduce traffic accidents, Wi-Fi and WiMAX is suited for high-speed internet access in vehicles. CP antennas are beneficial for vehicular communications because they are resistant to multipath propagation and fading. The simulated and measured results closely match each other, demonstrating that the designed antenna is applicable

TABLE 3 Performance metrics comparison

Antenna design	Frequency range (GHz)	Thickness (mm)	Return loss (dB)	VSWR	Directivity	Input impedance (Ω)	Fidelity factor
Proposed method	2.9/6.4	0.3	−21.8	1.002	high	60	0.98
Triple-band circularly polarized slotted patch antenna[32]	2.4	0.5	−18.9	1.15	High	54	0.89
Flexible dual band antenna[33]	5.4	0.7	−17.5	1.18	Low	56	0.86
Poly-imide dual band antenna[34]	2.5/5.2	0.6	−17.95	1.19	Low	41	-
Flexible bow-tie antenna[35]	4.9	0.5	−16.45	1.21	Low	52	-
Reconfigurable dual-band dual-circularly polarized[24]	1.1	1.0	−18.5	-	Low	22.69	-
Circularly polarized wideband antenna[27]	2.5/3.4	0.8	−19.23	-	Low	62.69	-
Monopole antenna[29]	5.85	-	−16.5	-	Low	-	-

for Wi-Fi, WiMAX, and DSRC-band for vehicular communication applications. To further understand the benefits of the designed antenna, the comparative analysis was conducted the over traditional circularly polarized antennas. Form the comparison it is clearly observed that the proposed design yield a better parametric performance. The designed antenna had an ability to cover the whole DSRC band for vehicular communication application. The proposed design is a feasible contender for the DSRC-band application, especially for the vehicular communication, because the measured and simulated results show good agreement. Utilizing rectangular strips with arc-shaped cuts at the top portion of the design and seven slotted arms at the ground plane of the design, a triple-band design achieves circular polarization operation.

5 | CONCLUSION

In vehicular communication, the wireless transmission of information increases day by day. The radio communication technologies are integrated into the traffic systems for the safety of drivers and people. The data transmission is done by using the antennas placed in the vehicles. The transmission parameters depend on the design and substrate of the antenna. This article presents a triple-band circular polarized conformal antenna to improve the antenna characteristics. The conformal antenna provides a suitable and comfortable placing on the vehicular surface. The 0.3 mm thickness of the antenna provides fixed radiation with high efficiency. The system provides efficient circular polarization by providing the circular cuttings and the attained triple bands are 2.4 GHz, 3.5 GHz and 5.9 GHz, respectively. In an anechoic chamber, the radiation patterns of the designed antenna is measured at frequencies of 2.4, 3.5, and 5.9 GHz, respectively. Above this, a suitable frequency can be selected for the application. The proposed antenna provides −21.8 dB return loss, a better axial ratio of 1.001 dB, a high fidelity factor of 0.98, a better VSWR of 1.002, high directivity, and a better input impedance of 60 Ω. Also, the radiation efficiency was examined and it yield an outcome of %, %, and % for 2.4, 3.5, and 5.9 GHz, respectively. The proposed antenna design is implemented in the HFSS platform. In future work, the compact and transparent antenna can be integrated.

CONFLICT OF INTEREST STATEMENT

Authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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