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Design and Analysis of Printed Conformal Antenna System for Inter and Intra Vehicular (V2V) Communication Utilizations

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ABSTRACT: A multiple antenna placement system analysis for the improvement of efficiency and capacity for inter and intra vehicular communication is proposed in this article. Four antennas are placed in the four locations of the vehicular body which includes roof, side mirror, rear screen, and dashboard. The constituted antenna occupying the dimension of $40 \times 38.5 \times 0.2\,\text{mm}^3$ on flexible substrate material of photo paper and the bending analysis of the model as per the conformal nature on vehicular body is also analyzed and presented in this work. The received power from each receiving antenna response with respect to the transmitter has been analyzed. The channel capacity with respect to the antenna position for V2V communication is analyzed in different areas and in different environmental conditions.

1. INTRODUCTION

The aspect of road safety is gaining more importance to avoid accidents and for providing proper communication to save the valuable lives. Intelligent transport systems and advanced traffic management systems are using highly efficient simulation tools for analyzing different scenarios and to predict the various possible solutions for collision avoidance. The effects of buildings, trees, and other infrastructure in the electromagnetic wave propagation and signal transmission conditions can be analyzed with the help of EM-simulation with high performance computing. Figure 1 shows the vehicular communication scenarios and the possible signal interference with various objects. Precise designing of antennas is highly required for the successful establishment of vehicular communications. Several antenna models have been designed by the researchers for vehicular communication applications.

A printed automotive antenna was designed on a glass window, and the model was verified at 100 MHz. Those glass windows affect the impedance matching which cause the signal scattering [1]. Madhav et al. [2] proposed a low cost and conformal wheel shaped antenna by applying the concept of fractal geometry to work in vehicular communication band. An average gain of 5.9 dB obtained confirmed that the proposed antenna had suitable vehicular integration on top or on side locations. He et al. [3] designed an antenna to enhance directivity, which was used in wireless local area networks (WLAN) at vehicular IEEE 802.11a ($4900 \sim 5935$ MHz) band. It is also applied in different vehicular communication systems and has a capability to oppose the distortion in polarization attained from the car top roof. Ref. [4] studied a microstrip antenna with FERN fractal shape and aperture coupled feed for the detection of blind spot in smart vehicles. The bandwidth of almost 410 MHz was obtained from 3.49 GHz to 3.9 GHz, and the axial ratio was found below 3 dB and acquired from 3.62 GHz to 3.71 GHz. Artner et al. [5] proposed a concealed antenna cavity to integrate onto the vehicle chassis. Feasibility for future vehicles with CFRP chassis is illustrated by building a prototype. Kim et al. [6] designed a conformal meta-resonator vehicular antenna with high impedance surface (HIS) structure in the ground plane. Khan et al. [7] designed an antenna with the peak gain of 11.84 dBi and bandwidth of 17.6 which can be used in different applications of wideband and multimedia applications. Lopez et al. [8] studied an inverted-F tri-band antenna for vehicle-based applications. The first band of the designed antenna was above 1% and the second band near 0.4%, and the proposed antenna is suitable for various communication purposes of flying vehicles, toys, etc. Nguyen-Trong et al. [9] studied a compact dimension wideband monopolar design which was integrated in helmet. Initially, four symmetrical tapered slots were added to reduce the size of the antenna for vehicular installation applications. Later, a helmet material was included in the design to integrate onto a helmet with a finite-curved ground plane. Abbas et al. [10] studied the complementary antenna effect with placement on vehicles and impact of diversity in vehicle-to-vehicle communications based on measurement analysis. Navarro-Mendez et al. [11] designed a three-dimensional antenna for vehicular applications.

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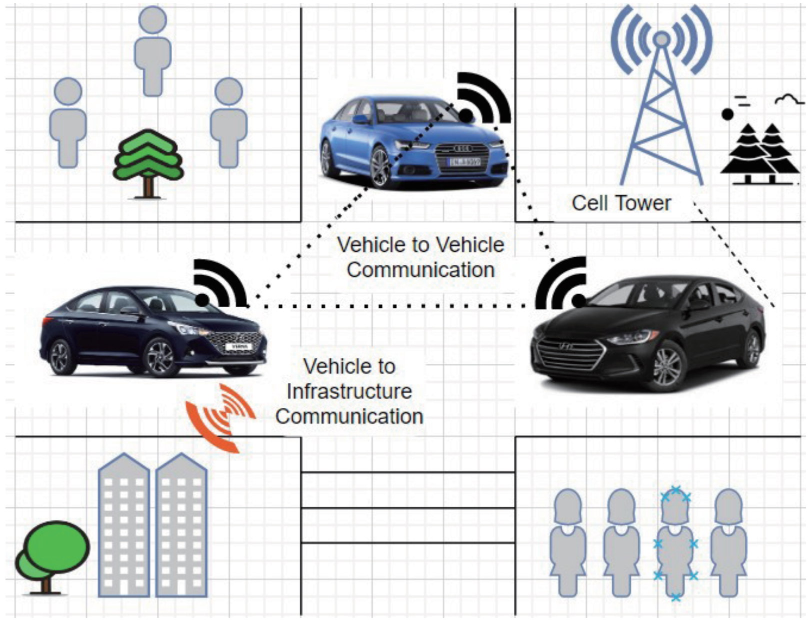

FIGURE 1. Inter and intra vehicular communication scenario.

It is a shark-fin shaped antenna located inside the plastic cover. It is covered by two monopoles, i.e., double shorted monopole that covers the LTE 700, GSM 850, and GSM 900 bands and drop shaped monopole that operates in the 1.7–2.7 GHz which covers DCS 1800, PCS 1900, WCDMA 2100, WLAN 2400, LTE 2600, WiMAX 2350, and 5.1 to 6 GHz which covers Wi-Fi and Car-to-Car (C2C) bands. Tseng [12] designed an LTE system to support V2X service and ProSe service for direct information exchange between two entities with/without the support of E-UTRAN. Alsath et al. [13] studied the make use of folded microstrip line concept to achieve a compressed quad-band antenna. The designed asymmetric coplanar strip line antenna covers some of the IEEE Standards, DCS 1800, and Wi-Max and V2X communications. Dzagbletey et al. [14] proposed a dual C-V2X Vivaldi antenna to improve the low frequency input impedance matching with two stage balun in test antenna. The proposed antenna provides 560 MHz to 7.7 GHz, i.e., 173% of fractional bandwidth, which covers the existing V2X communication frequencies. It also provides better isolation of -28 dB, 17.2 dB cross polarization and the gain up to 9.2 dB. Sakthi Abirami et al. [15] designed and developed a conformal self-balanced two arm L1 band [1.575 GHz] antenna for automotive applications. The optimized antenna was fabricated on a wind shield substrate, and the two arms were curtailed asymmetrically to attain circular polarization. Wong et al. [16] presented a monopolar patch antenna with V-shaped slots for vehicle-to-vehicle (V2V) and WLAN communications. Shorting pins and V-shaped slots were applied on an equilateral based triangle-shaped patch to widen the impedance bandwidth. Wu et al. [17] introduced an L-sleeve L-monopole (LLM) antenna fitted with shark fin for vehicular applications. To fix various shark fin modules, the effect of ground plane and its placement with position and bending of the LLM is examined. The proposed antenna was prototyped on printed circuit board (PCB) which covers the frequency range 5–6 MHz. It can be placed on the shark fin module to provide services for WLAN and C2C communications. Bactavatchalame and Rajakani [18] studied the design of model, preparation and testing of a broad band slot antenna along with its applications. The designed multiple-input multiple-output (MIMO) antenna consisted of a slot structure antenna which was fed by a modified microstrip line feed, and it was connected with a suitable impedance transformer and in association with a square patch. The designed slot antenna covered the communications applications in between 3–6.75 GHz range bandwidth centered around 4.8 GHz with the gain enhancement of 2.45 dBi at 5 GHz. A monopole antenna with double circular rings and dual operating bands was proposed by the authors in [19]. A monopole antenna with planar circular slots operating for ultra-wideband was proposed by the authors in [20]. It achieved a gain of 4.2 decibels, and the maximum radiation efficiency was 97%.

On the basis of literature study, the authors of this current article are motivated to design and prescribe a multipurpose antenna with flexible nature for vehicular communication utilizations. Furthermore, the analysis of the propounded printed antenna has been presented for Inter vehicular and Intra vehicular communication. The designed antenna holds an attractive compact size of $40 \times 38.5 \times 0.2\,\text{mm}^3$ on the flexible substrate material of photo paper, and it operates at multiple bands satisfying the conditions of impedance matching.

2. ANTENNA DESIGN

The designed antenna is constructed on a polyethylene terephthalate (PET) substrate, and the modelling has been studied with electromagnetic tool.

The basic design equations of a coplanar waveguide (CPW) fed microstrip patch antenna are as represented in Equations (1)

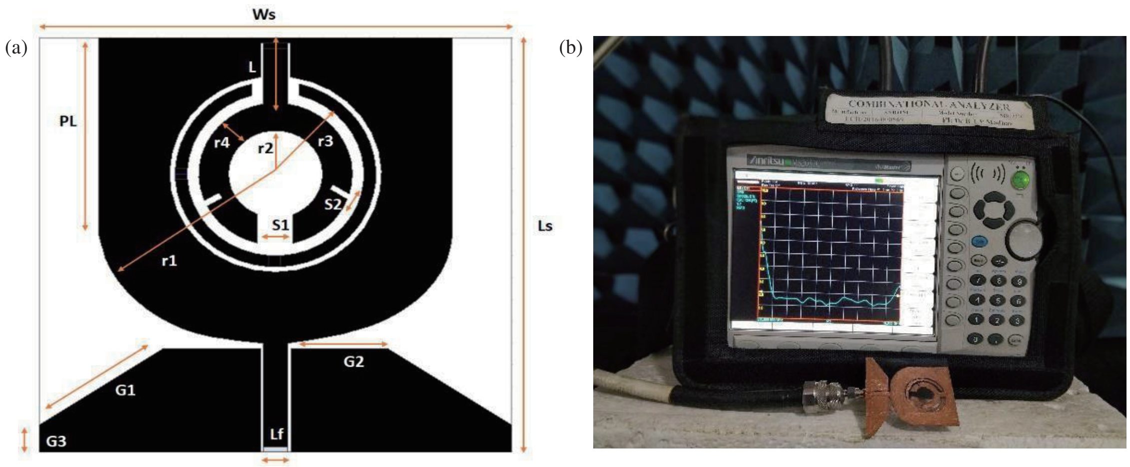

FIGURE 2. Proposed antenna. (a) Design. (b) Prototype measurement.

TABLE 1. Antenna dimensions.

Parameter	Ws	Ls	PL	R1	R2	R3	R4	G1	G2
In mm	40	38.5	18	12	7.5	8.5	6.5	10.5	10.5
Parameter	G3	S1	S2	Lf	L1	L2	h	L3	W2
In mm	3	3	1.5	2	28	6	0.2	3	8.5

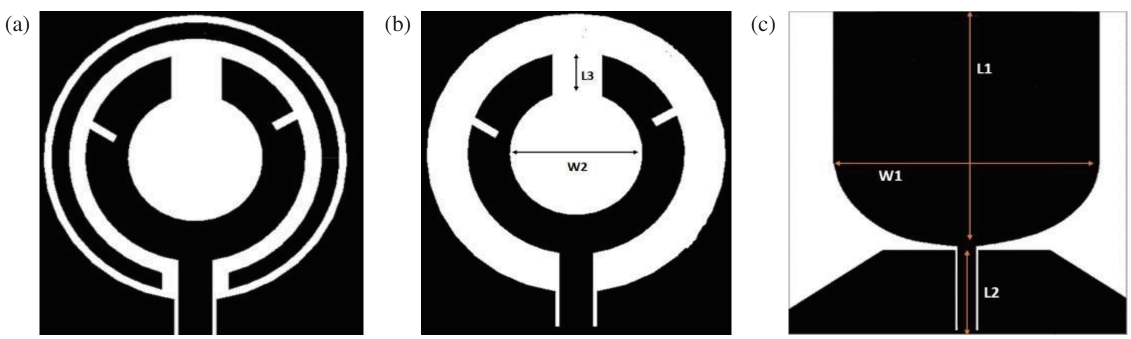

FIGURE 3. Antenna model iterations, (a) CPW fed antenna, (b) SRR, (c) CSRR.

and (2).

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2}\Big\{\tanh\left[0.775\ln\left(h/g\right) + 1.75\right] + \frac{kg}{h}\left[0.004 - 0.7k + 0.01\left(1 - 0.1\epsilon_r\right)\left(0.25 + k\right)\right]\Big\} \quad (1)$$

Where,

$$k = \frac{W}{W + 2g} \quad (2)$$

W is the width of the centre conductor, h the thickness of substrate, and g the gap between signal conductor and the ground.

The modelled antenna is studied for validation with combinational analyzer in chamber. The optimized parameters are given in Table 1. The submitted antenna structure and real time measurement are shown in Figure 2, and the iteration wise process is shown in Figure 3. The designed antenna can be excited with dual feeding and resonant bands, radiation characteristics, and the vehicle placement analysis has been presented in the subsequent sections.

3. RESULTS AND DISCUSSION

Figure 4 shows the reflection coefficient parameters of the designed antenna model. The voltage standing wave ratio (VSWR) of the proposed antenna is depicted in Figure 5. The simulated results are precisely verified through the measurement results. The antenna resonates at triple bands considering $S_{11} \leq -10$ dB and VSWR ≤ 2. Reflection coefficient (S_{11}) shows the triple band characteristics with resonating frequencies at 3, 5.8, and 8 GHz, respectively. As per observations in Figure 5, the suggested antenna shows perfect impedance

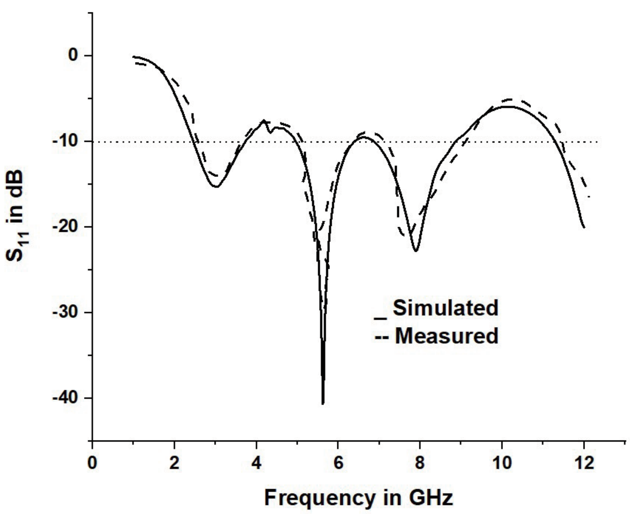

FIGURE 4. S_{11} parameter of proposed antenna.

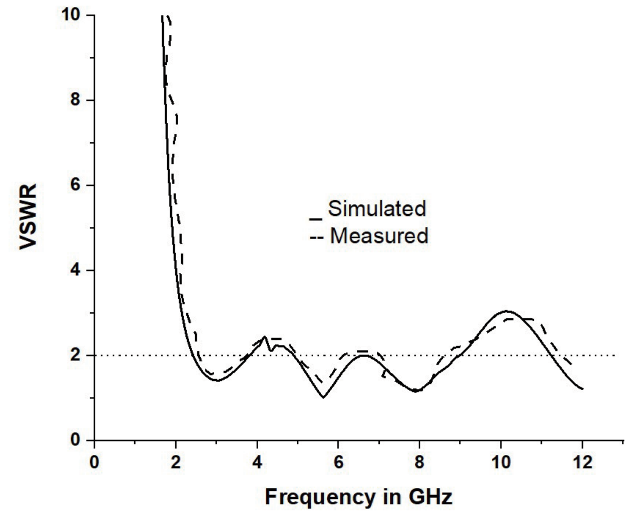

FIGURE 5. VSWR plot of proposed antenna.

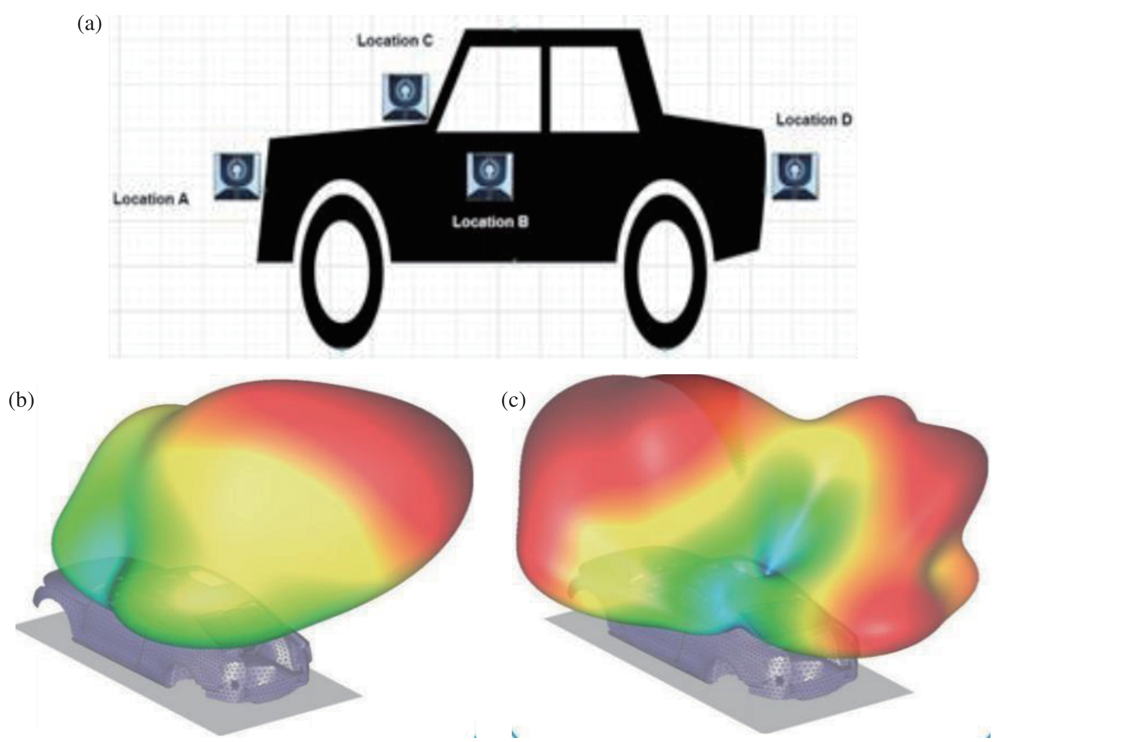

FIGURE 6. Antenna placement and radiation. (a) Antenna placement on vehicle. (b) Radiation at 3.1 GHz. (c) Radiation at 5.8 GHz.

matching at triple bands by offering VSWR within 2 at the acquired bands. As per measurements, the designed antenna resonates at triple bands with 10 dB bandwidth extending from 2.40 to 3.85 GHz; 5 to 6.15 GHz, and 7.15 to 9.02 GHz. The designed antenna covers the commercial communication bands of Bluetooth, LTE, Wi-Fi, WLAN, and Satellite communications.

4. INTER VEHICULAR COMMUNICATION

The designed antenna performance characteristics are analyzed by placing it on a vehicular structure. A 3D-Vehicular structure has been imported to EM-tool, and the antenna is placed at four locations as shown in Figure 6(a). The locations are selected in planar configuration, and the radiation analysis is given in Figures 6(b) and 6(c) for top loading of the antenna.

The coupling analysis of the antenna at two operating bands of 3.1 and 5.8 GHz has been performed and presented in Tables 2 and 3. The receiving antenna locations at A, B, C, D with respect to transmitting antenna locations are presented here, and good isolation is found between the antennas.

The signal transmission to its reception in the presence of various infrastructures is analyzed and presented in this work.

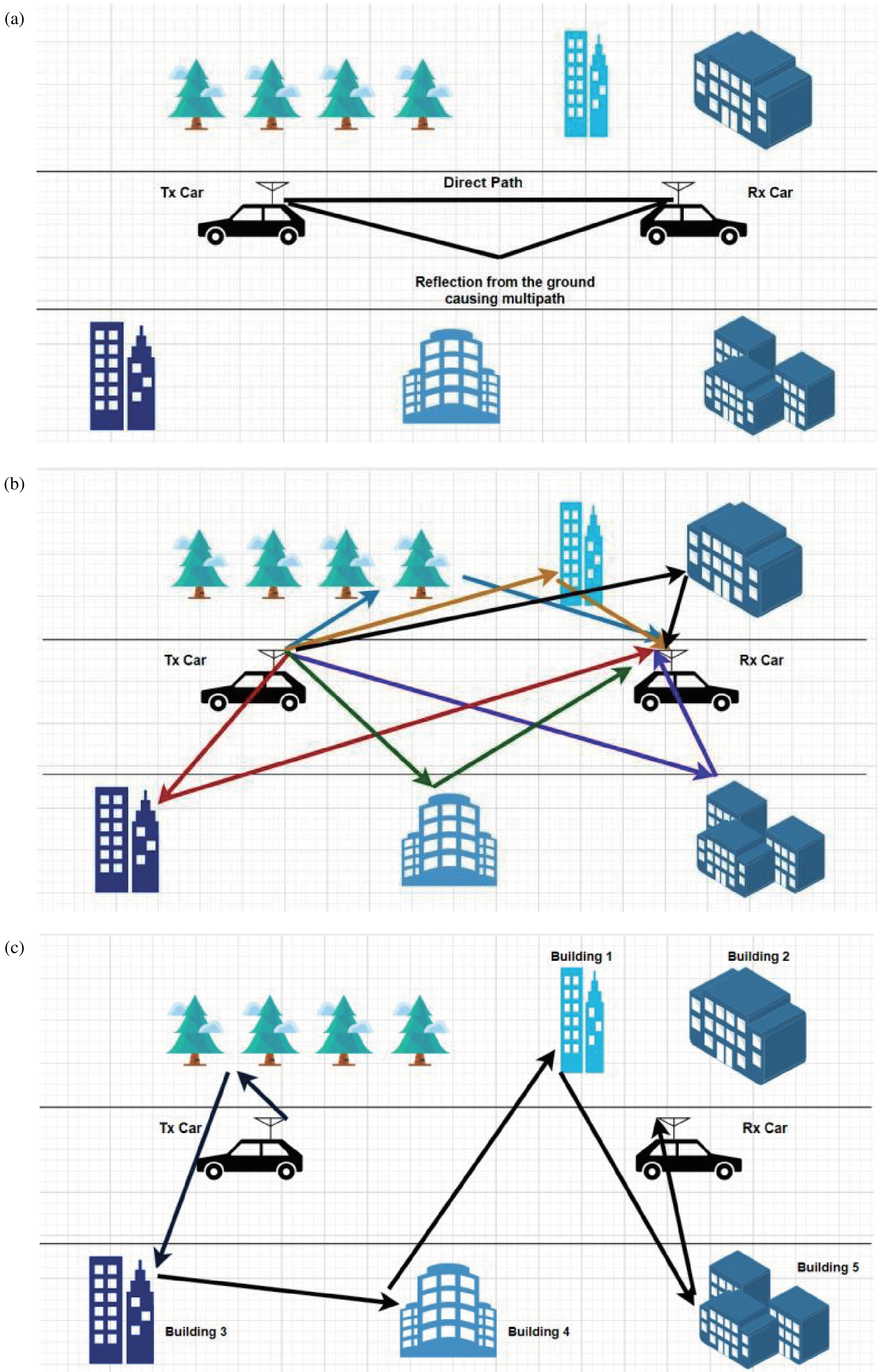

FIGURE 7. Different ways of signal transmission, (a) Direct Path, (b) Multipath 1, (c) Multipath 2.

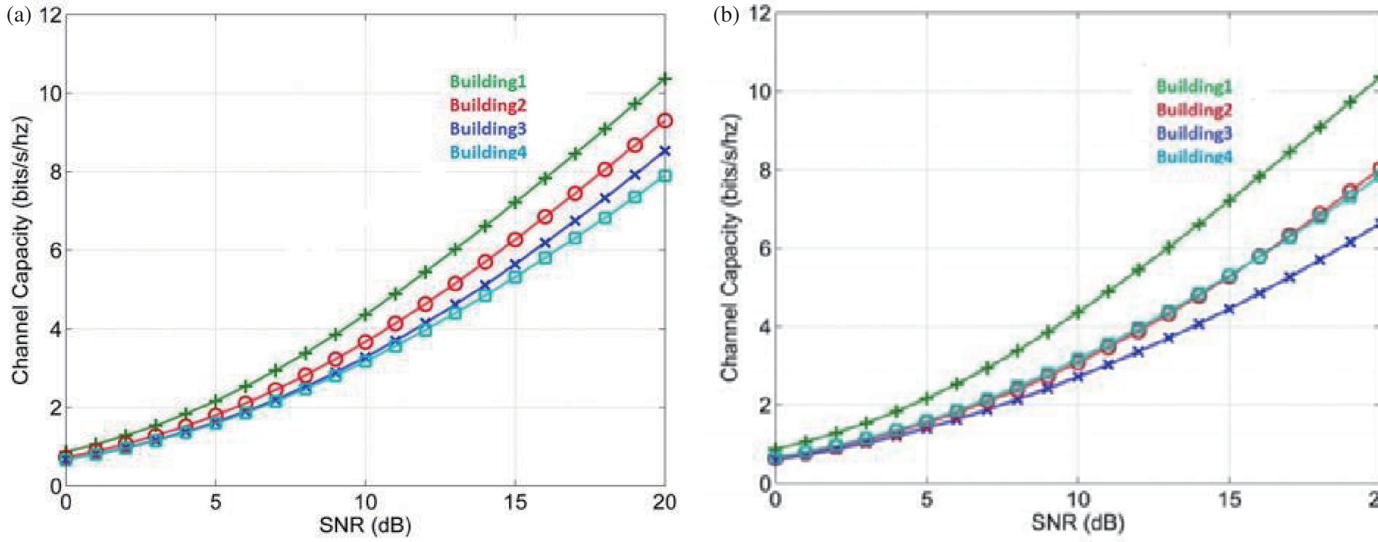

FIGURE 8. SNR Vs Channel Capacity (a) Case 1, (b) Case 2.

TABLE 2. Coupling analysis of antenna at 3.1 GHz.

	Tx Antenna			
Rx Antenna	A	B	C	D
A	NA	-84.86	-56.83	-71.38
B	-73.48	NA	-71.64	-66.50
C	-58.66	-60.04	NA	-71.23
D	-67.90	-73.93	-75.84	NA

TABLE 3. Coupling analysis of antenna at 5.8 GHz.

	Tx Antenna			
Rx Antenna	A	B	C	D
A	NA	-73.90	-55.99	-76.93
B	-77.84	NA	-66.94	-75.01
C	-60.46	-72.94	NA	-77.88
D	-71.62	-73.73	-63.60	NA

TABLE 4. Comparative analysis.

References	Antenna dimensions (mm × mm × mm)	Operating bands (GHz)	Gain (dB)	Efficiency (%)
[11]	$40 \times 36.5 \times 1.5$	698 MHz to 960 MHz; 1.7 to 2.7 GHz; 5.1 to 6 GHz	3.8	70
[17]	120×52	698–2700 MHz; 1.575 GHz; 5–6 GHz	5.5	74
[19]	$50 \times 100 \times 1.6$	0.82–1.25 GHz; 1.65–2.79 GHz	3.7	68
[20]	$49 \times 35 \times 1.6$	1.51–12.5 GHz	4.2	77
Proposed	$40 \times 38.5 \times 0.2$	2.40–3.85 GHz; 5–6.15 GHz; 7.15–9.02 GHz	5.8	82

Figure 7 shows the direct path and multipath in two scenarios. The inter vehicular communication cases are presented in Figure 8. In Case 1, multipath effect 1 has been analyzed, and signal-to-noise ratio (SNR) vs channel capacity is presented for signal reception from Tx car antenna to Rx car antenna through building reflection. In Case 2, multipath effect 1 has been analyzed and presented for signal reception from Tx car antenna to Rx car antenna through multiple building reflections.

5. INTRA VEHICULAR COMMUNICATION

The intra vehicular communication scenario has been presented in Figure 9 with respect to the radiation characteristics. The proposed antenna has been placed near the driver, and using electromagnetic simulation, the radiation analysis in XY and YZ planes is presented. The antenna has been placed on the seat cover. It has been observed that the field distribution in-

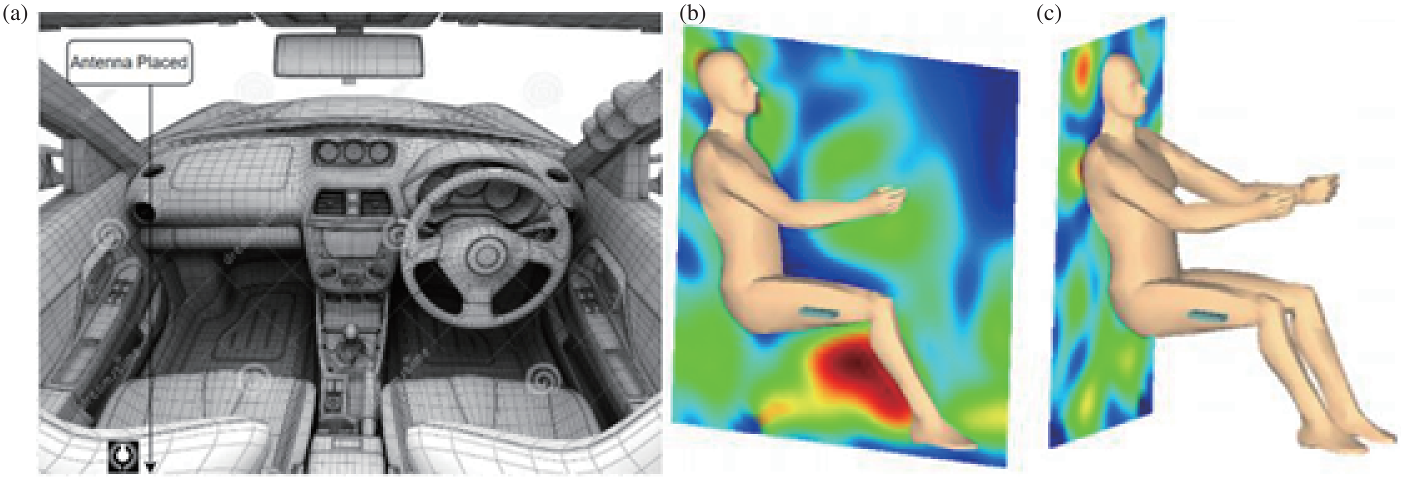

FIGURE 9. Intra vehicular analysis. (a) Antenna in vehicle. (b) Radiation in XY-plane. (c) Radiation in YZ-plane.

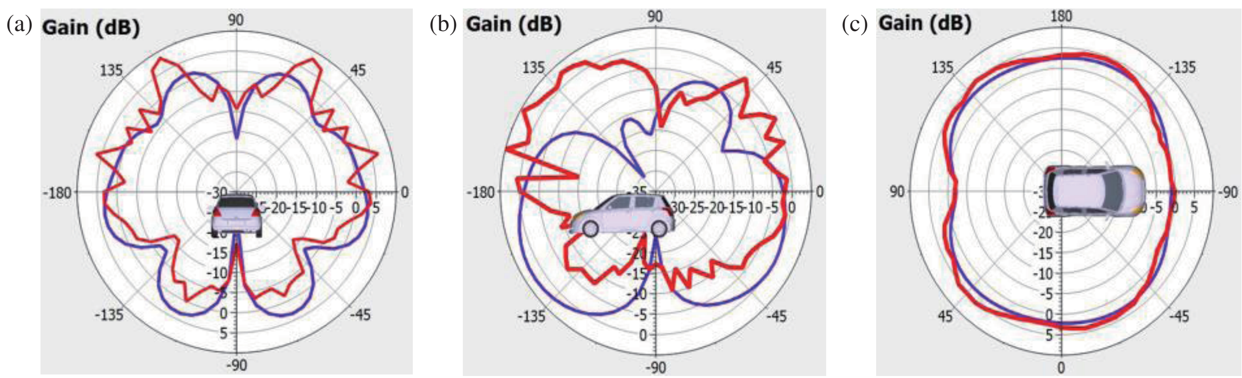

FIGURE 10. Radiation patterns analysis at 5.8 GHz for various planes, (a) XY-plane, (b) YZ-plane, (c) ZX-plane [Red colour indicates measurement results and Blue colour indicates simulation results].

tensity is near the knee (within acceptable range), and in other locations it is very less. In intra vehicular communication, the antenna placement in the vehicle will play a crucial role. The designed antenna is conformal and flexible to meet the requirements of the vehicular body placement. The antenna can be placed on any location, and the signal reception is quite acceptable as per the analysis.

6. RADIATION PATTERN ANALYSIS

The proposed antenna is analyzed for its radiation characteristics in XY, YZ, and ZX directions, and the simulated and measured results are presented at 5.8 GHz. Figure 10 shows the radiation pattern results of the proposed antenna at WLAN/DSRC communication applications. The red colour indicates the measurement results, and blue colour indicates the simulated results. Harmonics are observed in the measured radiation characteristics due to the vehicle metal body effect in the placement. The simulated and measured results are in good matching with each other at the analyzed frequency band.

A comparison with literature is performed, and it is found that the performance characteristics of the proposed antenna show superior results with respect to gain and efficiency. It can be summarized from the contribution of this article and the comparison table that the geometry of the proposed antenna is novel; the structure of the proposed antenna is very thin; and it occupies less volume for implementation than the state-of-the-art mentioned in the table. The antenna offers maximum gain and efficiency as compared to other referred articles [11, 17, 19, 20]. The designed antenna is suitable for Inter and Intra Vehicular (V2V) Communication, which has been justified through analysis of the antenna by placing the radiator at various positions on the vehicle. Furthermore, the analysis of mutual coupling, radiations patterns for different vehicle directions, and channel capacity loss vs SNR is presented in the article.

7. CONCLUSIONS

A PET substrate material-based monopole antenna is designed, and the analysis with inter and intra vehicular communication is submitted in this study. The proposed antenna is very thin and compact in size. The modelled antenna operates at multiple bands which cover Bluetooth, LTE, Wi-Fi, WLAN, and satellite communication applications. Coupling analysis of the antenna with placement on a vehicular structure at different locations is performed, and low mutual coupling is found between the antennas. Radiation patterns are analyzed and discussed for movement of the antenna mounted vehicle in different directions. Signal reception analysis is also performed and discussed for intra vehicular communication.

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