Transparent Circular Monopole Antenna for Automotive Communication

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Abstract ─ A novel fractal shaped antenna on transparent material is communicated in this article. The proposed antenna is flexible and conformal on the automotive surface to serve at vehicular communication applications. Polyvinyl chloride substrate material of ε_r=3 and loss tangent 0.02 is used in the antenna design with overall dimension of 55 x 40 x 3 mm. The virtual placement of the antenna on vehicular surface is simulated with the combination of ANSYS HFSS and Savant tools. Far-field radiation and the Electric-field distribution with respect to the antenna placement on vehicular structure is analyzed and presented in this work. The prototyped antenna measurements are in good agreement with the simulation.

Index Terms ─ Conformal antenna, flexible, Polyvinyl Chloride (PVC), vehicular communication.

I. INTRODUCTION

The advanced wireless modules with modern antenna elements are needed to access the condition of various parts of the automotive system and to timely report the data to a common control system in which the vehicle condition can be notified to the driver. Even a large family of antennas exists till date, but the compact and conformal antennas with good radiation performance and with attractive look is mostly preferred.

There are many antennas existing in the literature, and some are designed for different wireless and vehicular applications. The modelling of vehicular antenna at 100 MHz is discussed in [1]. A meta-resonator-based high impedance ground antenna is presented for vehicular applications in [2] and some interesting works on transparent glasses and materials like corning glass and IZTO/Ag/IZTO are reported in [3,4]. In vehicular technology WLAN, WiMAX and DSRC (dedicated short-range communication) applications-based antennas are discussed in [7-10].

In this letter, a novel fractal design is employed as the radiating structure, which is prototyped on conformal and transparent PVC substrate material. The radiation performance of the conformal antenna after placement on the vehicle is also discussed along with the effective electric-field distribution regions.

II. ANTENNA CONFIGURATION

Nowadays several modern vehicles are introduced with stylish body and with some of their metallic cabinets such as side view mirrors are being replaced with rigid and durable materials like plastic/fiber/polymer composites etc. Antennas which are designed on transparent substrates will make minimal presence on the vehicle rather than it appears as some beautiful design on the vehicle. Keeping view of this scenario, the transparent PVC material is considered for design of the antenna in an attractive manner. The proposed antenna structure on transparent PVC substrate is shown in Fig. 1. The radiating element of the proposed design is formed by taking the circular patch of radius 'R_1' then annular ring of width 'W' is formed by cutting a circle of radius 'R_2'. The effective permittivity 'ε_{eff}' is given by equation (1) as described in [5]:

$$\varepsilon_{eff} = 0.5(\varepsilon_r + 1) + 0.5(\varepsilon_r - 1)\sqrt{(1 + 10t / W)}, \quad (1)$$

where

$$W = (R_1 - R_2). \quad (2)$$

Later, circular slots are introduced in the radiating structure. These slots are iteratively made and merged together with the slots etched in previous iteration, and this process continued up to three levels and then terminated due to the limitation of fabrication of the antenna as shown in Fig. 1 (b). The scale factor 'sf' is considered to compute the radii of next iteration slots. The scaling factor 'sf' is determined through the parameters 'a_n', 'a_{n-1}' by equation (3):

$$sf = a_n / a_{n-1}, \quad (3)$$

where 'a_n', 'a_{n-1}' are n^{th} and $(n-1)^{th}$ circular cuts radii respectively. The scale factor is considered as 0.54. The overall shape of the patch obtained based on fractal concept, resembles like a wheel-shaped structure. The

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coplanar waveguide feeding is used in the design with 50-ohm impedance at feed point. The feed line of width 'W_f' and two ground conductors on either side of the feed line with a gap 'g' are soldered to a 50-ohm SMA connector through which the antenna can be excited. The structural parameters are optimized to obtain the desired pass band performance under vehicular bands.

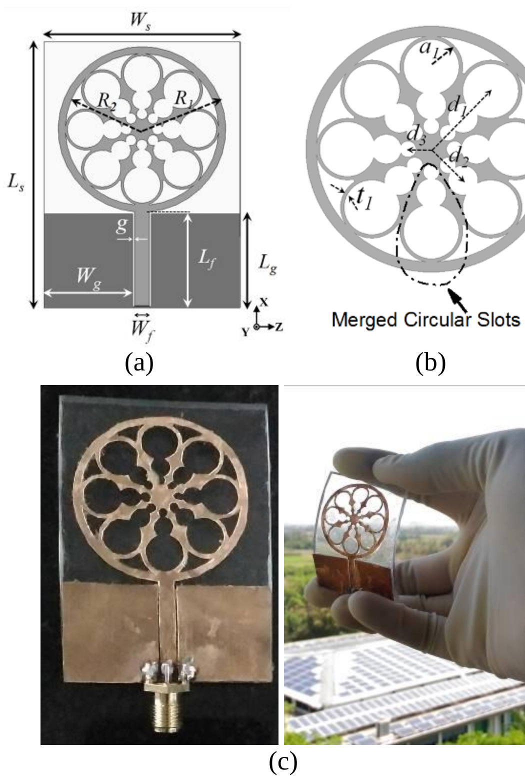


Fig. 1. Geometry of the proposed wheel-shaped fractal antenna: (a) front view, (b) structure of radiating element, and (c) prototype of the fabricated antenna with SMA connector. (L_s=55, W_s=40, L_g=19.4, W_g=18.155, L_f=19.87, W_f=3, g=0.345, R_1=17.1, R_2=15.72, a_1=4.35, d_1=11.44, d_2=6.82, d_3=4.46, t_1=0.475, h=3) (unit: millimeter).

III. SIMULATION AND MEASUREMENT CHARACTERISTICS

The proposed transparent antenna is simulated by bending the substrate at different bending angles mainly, 30^0, 45^0, 60^0, 90^0 and 120^0 respectively. The equation (4) is used to calculate the bending radius of the substrate:

$$\text{Bending radius,} \quad b_r = 0.5\left(L_s - f_b\right) \times (360 / \pi\theta), \quad (4)$$

where 'L_s' is length of the substrate, 'f_b' is the length of the feed line section on the flexible substrate and 'θ' is the bending angle which are indicated pictorially in Fig. 2 (a) for the conformal antenna configuration. The corresponding VSWR characteristics for the mentioned bending angles are presented in Fig. 2 (b). It witnesses the frequency shift towards the higher frequencies with the increase in bending angle.

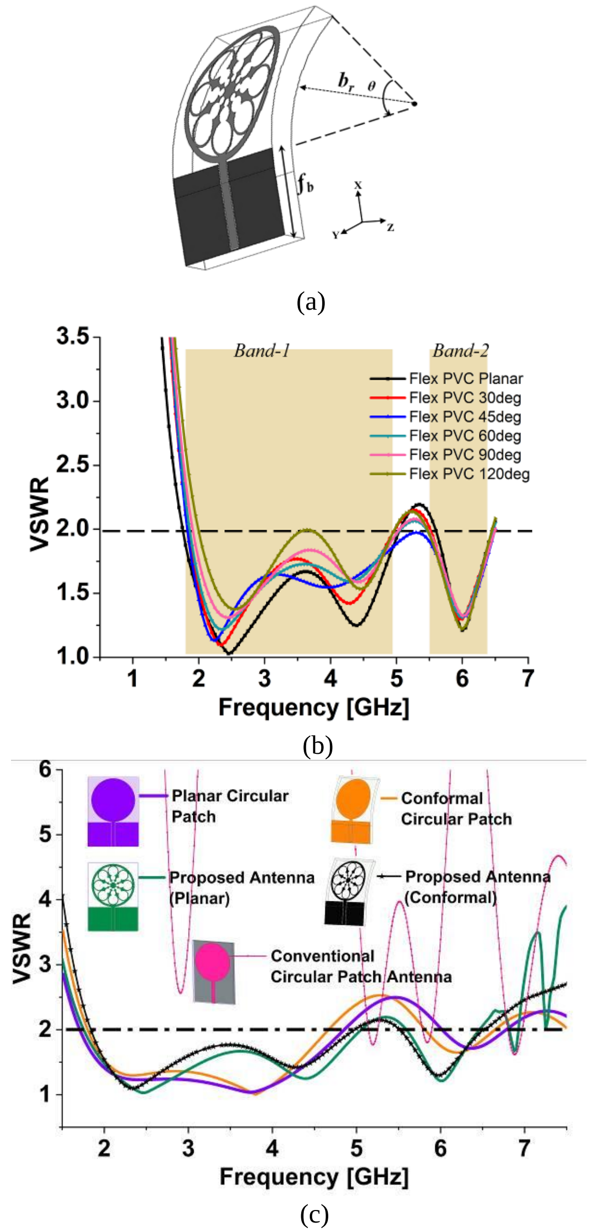
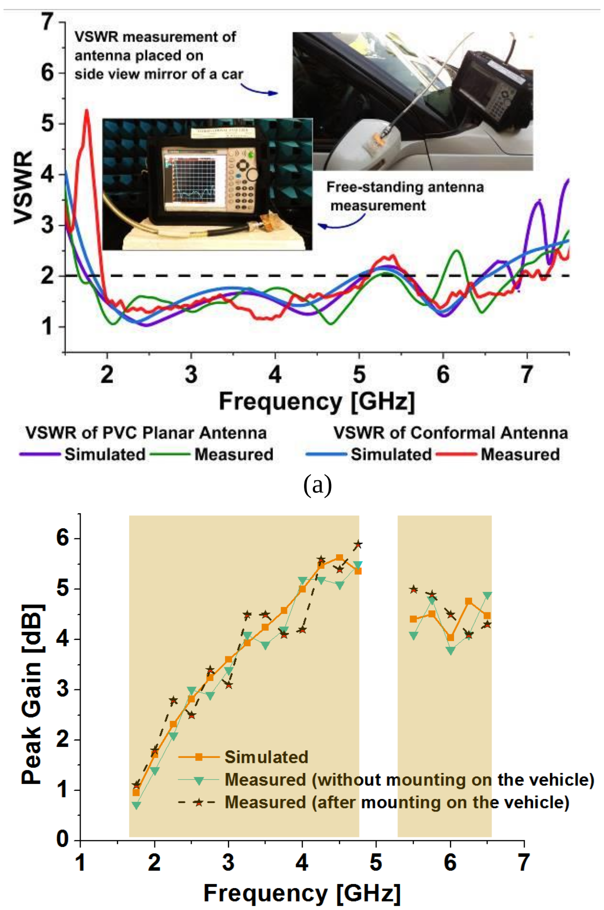


Fig. 2. Bending characteristics of the proposed antenna: (a) geometrical configuration, (b) simulated VSWR vs frequency characteristics of the antenna at different bending angles, and (c) VSWR comparison with respect to basic circular patch.

The proposed flexible fractal antenna on transparent material is compared with that of the circular monopole without any slots in planar and flexible versions. The level of transparency is increased because of the modified ground plane from the conventional patch to the proposed structure and also due to the etched circular slots in the final structure. The variations in their operating bands are presented in terms of VSWR performance as shown in Fig. 2 (c) and characteristics are tabulated in Table 1. The proposed antenna geometry is fabricated on transparent PVC material and its VSWR is measured with MS2037C combinational analyzer, for both planar and conformal versions of the antenna. The simulated and measured VSWR characteristics of the planar antenna are presented in Fig. 3 (a) and the corresponding observations are tabulated in Table 1. The peak gain of the proposed antenna when mounted on side view mirror of the vehicle is measured by comparison method. The standard gain PowerLOG70180 series horn antennas are used as transmitting antennas and Keysight-EXG-X-Series Microwave Signal Generator is used as source to the antenna. The Friis transmission formula [5] is used to compute the peak gain of the antenna.



(a)

(b)

Fig. 3. Simulated and measured characteristics of the proposed transparent fractal antenna: (a) VSWR vs frequency characteristics, and (b) peak gain vs frequency characteristics.

In Fig. 3 (b), the variation of peak gain characteristics of the antenna is shown, and it has been observed that the antenna radiates with a maximum gain of 5.9 dB in its conformal mode of operation at a bending angle of 30^0.

Table 1: Operating band characteristics of proposed antenna

Antenna Type		Operating Bands [GHz]
Conventional Circular Patch Antenna	Planar	5.14-5.25/5.79-5.90/6.80-6.97
CPW fed Circular Patch Antenna	Planar	1.71-4.85/6.02-6.78
	Conformal	1.80-4.67/5.82-6.65
Proposed Fractal Antenna	Planar	1.75-5.1/5.55-6.5 (Simulated)
		1.66-5.1/5.43-6 (Measured)
	Conformal (30^0-bending angle)	1.85-5.0/5.5-6.54 (Simulated)
		1.95-5.1/5.55-6.9 (Measured)

IV. VEHICULAR MOUNTING CHARACTERISTICS OF THE ANTENNA

The features of vehicle-to-vehicle (V2V) safety communication usually operate by mutual exchange of vehicular-traffic information among the nearby vehicles. The antennas for these V2V systems can be mounted on various places on the body of the vehicle. Side view mirrors of most of the sport utility vehicles (SUV) and light trucks have the good scope of accommodating conformal antennas on or inside their shells. This kind of facility is useful in scenarios such as cross roads, intersections and blind-spots to detect other vehicles/ infrastructure for avoiding major fatalities. To study the radiation performance of the antenna, the proposed antenna is mounted on the shell of the side view mirror by bending the antenna with a bending angle of 30^0. This angle allows better conformal adherence on the side view mirror.

The far-field radiation characteristics of the proposed transparent antenna are shown in Fig. 4. The radiation patterns are observed at 2.4 GHz, 3.5 GHz and 5.9 GHz, where the applications of the vehicular communication are mainly concentrated.

The patterns are plotted according to the azimuth plane of the antenna mounted on vehicle with reference to the coordinate location of car body. The co-polarized radiation is better than cross-polarized radiation which is evident from Fig. 4, at a cost of ripple like behavior in the radiation performance. Antenna covers the all-around radiation, but some of its radiation is found to be blocked in the side directions. Similar kind of nature is observed as frequency is increased. Some ripples are observed in the patterns which could be due to the increased scattering of the signal from the vehicular body. The computational aspects regarding the simulation using the shooting and bouncing rays (SBR) method employed by the simulation tool are presented in Table 2. It can be observed that the total number of rays launched are increased with frequency of excitation also, the total number of rays that contribute to the generation of far-field is in proportion with frequency. With increase in frequency, one can notice the blocked rays increased for a particular vehicular body.

Table 2: Computational statistics of SBR for calculating the far-field characteristics when antenna mounted on vehicular platform

Specification→ **Frequency** *(below)*	No. of Rays Launched	No. of Rays Blocked	No. of Rays Split	No. of Rays Exceed Max Bounce (A)	No. of Rays Escaped (B)	No. of Rays Contributed (A-B)	Total Simulation Time (CPU) in Seconds
2.4 GHz	10,363	3,19,294	52,822	44,726	36,104	80,830	7,276.0
3.5 GHz	12,581	4,44,479	54,214	46,652	38,476	85,128	10,459.0
5.9 GHz	18,388	8,04,833	57,498	51,164	44,687	95,851	10,600.0

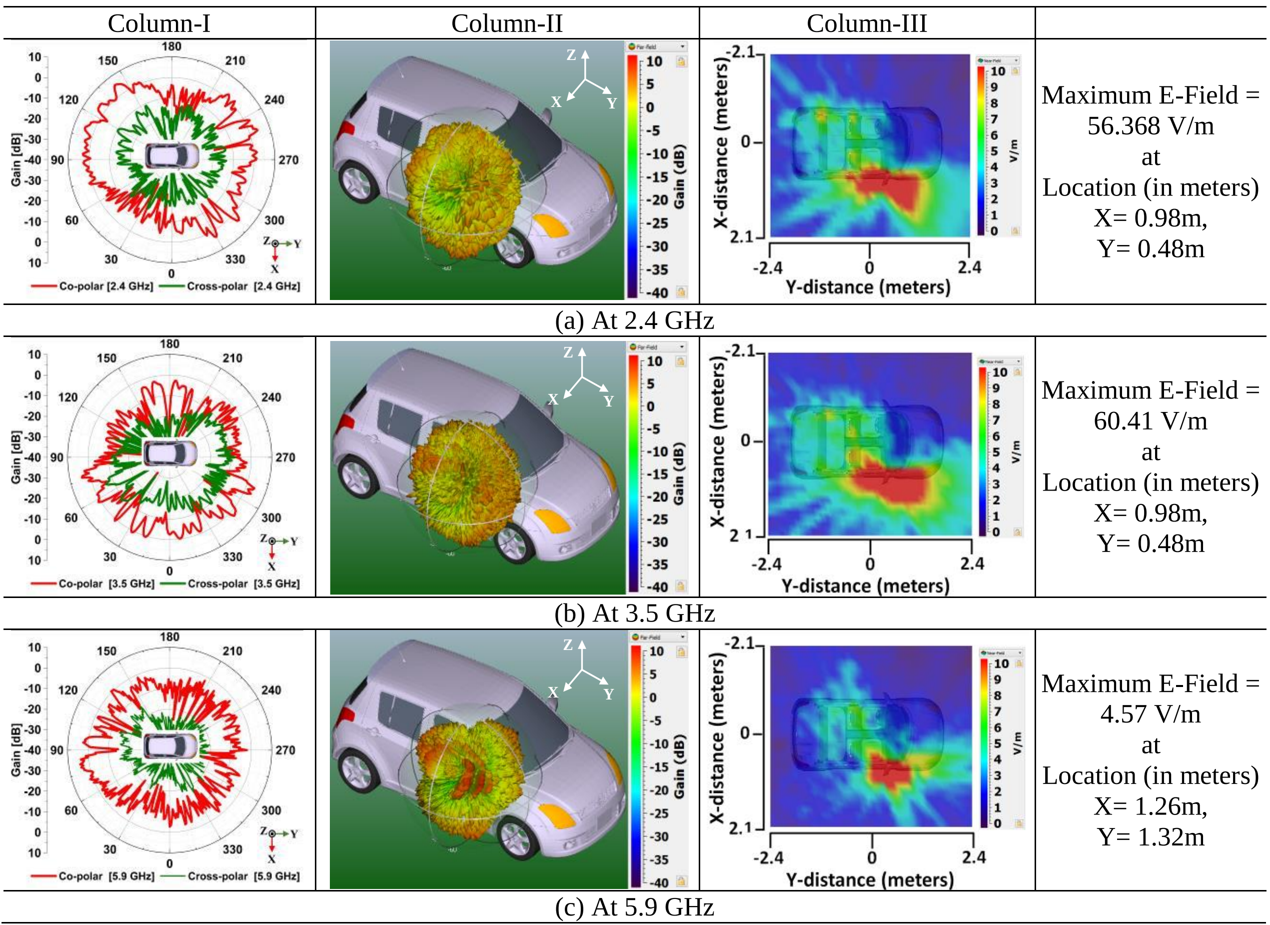


Fig. 4. Simulated field patterns of the proposed antenna when mounted on side view mirror of the vehicle: co-polar and cross-polarized patterns (*Column-1*), 3D far-field (*Column-II*), and Electric-field strength (V/m) near the vehicle (*Column-III*).

The electric-field strength within the vehicular surroundings is presented in Fig. 4 (*figures on the right)* for the frequencies at 2.4 GHz, 3.5 GHz and 5.9 GHz. The azimuth region of 4.8 meters in Y-direction (along the length of the car) and 4.2 meters (along the width of the car) is considered and shown graphically in Fig. 4. Here, the origin of the coordinate system is assumed to be co-located with the center of the footprint of the car.

Table 3: Performance comparison of proposed antenna with earlier literature

Ref.	Dimension of the Antenna (*L* x *W* x *h*)	Substrate Used	Operating Band (GHz)	Percentage Bandwidth (%)	Max Gain (dB)
This work	50 x 40 x 3 $0.45\lambda_g$ x $0.33\lambda_g$ x $0.025\lambda_g$	Transparent PVC	1.95-5.1/ 5.55-6.9	89.3/ 21.6	5.9
[2]	$0.51\lambda_g$ x $0.41\lambda_g$ x $0.05\lambda_g$	LTCC, Dupont	1.83/2.18	23	7
[3]	$1.98\lambda_g$ x $1.98\lambda_g$ x $0.0072\lambda_g$	1737 Corning glass	1.83-2.23	19.7	5
[4]	$0.199\lambda_g$ x $0.13\lambda_g$ x $0.0004\lambda_g$	IZTO/Ag/IZTO, FR4	1.1-1.65	40	1.84
[6]	$0.26\lambda_g$ x $0.24\lambda_g$ x $0.008\lambda_g$	FR4	2.57-3.29/3.95-4.73/ 6.55-12.31	22.52/17.9/61.0	~5.8
[7]	35 x 4 x 0.8 $0.29\lambda_g$ x $0.033\lambda_g$ x $0.006\lambda_g$	FR4	2.35-2.51/ 4.82-6.22	6/ 25	2.63/ 3.22
[8]	$0.5\lambda_g$ x $0.375\lambda_g$ x $0.0133\lambda_g$	FR4	2.17-2.5/ 4.98-6.31	14.13/ 23.56	3.65

VI. CONCLUSION

In this article, a transparent and conformal antenna is presented with wheel-shaped fractal structure for vehicular communication applications. The fabricated antenna is tested in planar and conformal mode with placement on the vehicle. The experimentally taken VSWR results of the conformal antenna after placing on the side-view mirror of the vehicle shows its operating band from 1.85-5 GHz and 5.55-6.5 GHz in simulation and 1.95-5.1 GHz, 5.55-6.9 GHz in measurements, which supports the WLAN, Bluetooth, WiMAX, DSRC, V2X vehicular applications. The measured radiation characteristics and the obtained gain of 5.9 dB makes the antenna as a good candidate for using in automotive applications.

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