High Gain Circularly Polarized Wire Antenna for DSRC Applications

Mohammad J. Almalkawi

***Abstract*—** In this communication, a low-cost circularly polarized wire antenna exhibiting improved gain performance for Dedicated Short Range Communications (DSRC), vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications is presented. The proposed antenna comprises a Y-shaped quarter-wavelength monopole antenna surrounded by two iterations of eight conductive arched walls acting as parasitic elements to enhance the overall antenna gain and to shape the radiation pattern in the H-plane. A hemispherical radome shell is added to protect the antenna structure and its effect on the antenna performance is discussed. The designed antenna demonstrates antenna gain of 8.2 dB with omnidirectional far-field radiation pattern in the H-plane. The gain of the proposed antenna is also compared with the characteristic of the stand-alone Y-shaped monopole to highlight the advantages of the proposed approach.

***Keywords*—**Circularly polarized, dedicated short-range communication, omnidirectional pattern, vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), Y-shaped wire monopole antenna.

I. Introduction

In July 2010, IEEE amended the 802.11 standard with 802.11p, and regulated the frequency band of 5.85-5.925 GHz for Wireless Access in Vehicle Environments (WAVE) and Dedicated Short Range Communications (DSRC) [1] allowing high-speed communications up to 27 Mbps between vehicles and roadside, as also between vehicles. Since 2010, researchers across the globe started investigating potential benefits of communication-based vehicle safety applications and defining their communications requirements, ensuring that proposed DSRC communications protocols meet the needs of vehicle safety applications, investigating specific technical issues that may affect the ability of DSRC to support deployment of vehicle safety applications. A key element in such mobile communication systems that can significantly impact the state of the art of transponder modules used in V2V/V2I communications is the DSRC antenna. DSRC antennas are becoming the genesis for more than seventy DSRC applications for public safety and traffic management [2]. For example, V2V applications include but are not limited to post-crash warning; vehicle-based road condition warning; and blind spot warning, whereas V2I applications include highway/rail collision warning; curve speed warning; left turn assistant; and traffic signal violation warning. In essence, advances in DSRC antennas are of significant interest to automotive industries and their suppliers including members in the Vehicle Safety Communication (VSC) Consortium. Considering more than 87 million new cars enter the market every year [3], it is therefore possible to conclude that high performance DSRC antenna designs are highly desirable.

Generally, gain and radiation pattern enhancement in co-linear antennas can be established by introducing a certain number of iterations of beam-forming elements. In [4], parasitic antennas were built on the top of a skirted conductive sleeve to steer the direction of vertical radiation into 6.34 dB directive gain in the azimuth plane. Here, a monopole antenna is used as the driven element over a finite ground plane; however, for automobile applications the metal surface of a car roof is normally treated as an infinite ground plane for the vehicle antenna [5]. Additionally, Yagi-Uda antennas can be tuned to obtain a high directive gain by including a number of parasitic elements in line with the driven element along with a reflector on the opposite side of the driven element [6]. The directivity of a Yagi-Uda antenna is proportional to the number of the parasitic elements at the expense of the antenna's physical size. Similarly, it was demonstrated in [7] that a wire monopole surrounded by a ring of parasitic elements can achieve an omni-directional pattern with an improved antenna gain performance of 6.5 dB. Increasing the number of elements and arranging them symmetrically is necessary to obtain the desired omni-directional pattern with some sacrifice of the peak gain. Moreover, it was found that eight elements are sufficient to generate a uniform omnidirectional pattern.

The objective of this work is to introduce a circularly polarized wire antenna configuration that exhibits low profile, low cost features with enhanced electrical performance when compared with conventional monopole antennas. The proposed configuration is inspired from the conventional Yagi-Uda antenna, where the reflective and directive nature of the parasitic elements is utilized to shape the antenna radiation pattern and to achieve high antenna gain. The reflector element of a Yagi-Uda however is removed in proposed design to enable the generation of omnidirectional radiation pattern in a fashion similar to those used in roadside base stations. Circularly polarized wire antenna is made possible by using a single-fed Y-shaped monopole antenna having two unequal monopole arms, each tilted 45^{o} from the antenna z-axis [8]. Such configuration eliminates the need for a complex

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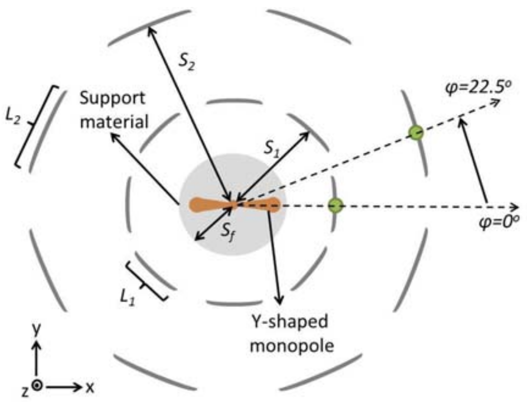
feed network required to provide orthogonal E-field vectors of an antenna with same magnitude but out-of-phase phase by 90°.

II. Antenna Configuration

DSRC is a short to medium range (i.e., 1000 meters) communication service operates at a center frequency of 5.9 GHz with a 75 MHz bandwidth. A quarter-wavelength monopole antenna at that frequency is around 10 mm long, which would meet the low profile requirements. Fig. 1 shows a Y-shaped monopole wire antenna, surrounded by two sets of parasitic elements, each with eight conductive arched walls touching a perfectly conducting ground plane and forming two circles of radius S1 and S2, respectively around the driven element (i.e., the monopole) which is placed at the circle's center. The parasitic elements are equally spaced from each other by 45°. For a maximum realizable gain, the angular offset between the two sets of parasitic elements is set to 22.5° (as illustrated by the two green dots in Fig. 1). It will be shown that this arrangement of parasitic walls is capable of generating 8.2 dB omnidirectional average gain allowing waves to travel in all directions in the azimuth plane and provide freedom in terms of the transmitter/receiver position, a feature critical to V2V/V2I DSRC communications.

In order for the antenna to operate properly in a practical vehicle environment, a hemispherical shaped radome is used to protect the antenna surface from the environment and to preserve the cosmetics of the vehicle. Ideal radomes are constructed of materials that are electrically transparent in the antenna's operating frequency band. In the proposed design, plastic material has been selected to construct the radome with low dielectric constant of 2.7 and loss tangent of 0.01 [9]. Additionally, cylindrical shape of high-density polystyrene foam [10], [11] is adopted as a dielectric support to the antenna arms. The used foam material is light-weight, low-loss, and has a dielectric constant of 1.06 [10].



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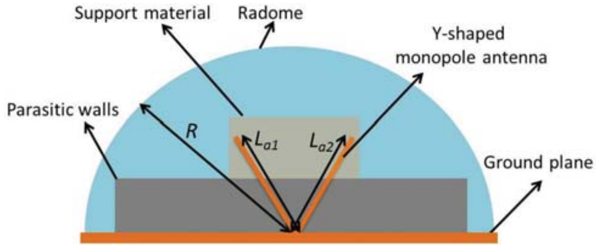

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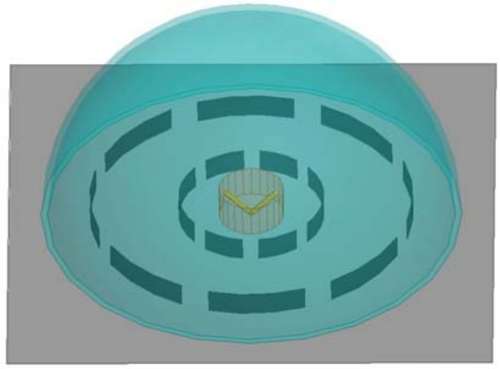

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Fig. 1. (a) Top view of the proposed antenna configuration with two iterations of eight conductive arched walls that is touching the ground plane; (b) Side view showing the added hemispherical radome shell and the foam supporting material; and (c) 3D view of the assembled antenna.

III. Results and Discussions

Full-wave EM simulations have been accomplished using ANSYS-HFSS [12] that is based on the Finite Element Method (FEM) for evaluating the antenna performance and finding the optimal geometrical parameters listed in Table I. The design is simple and has no critical dimensions which can be manufactured by standard fabrication equipment, an important feature for industrial mass production.

Fig. 2 shows the change of the far-field radiation pattern in the H-plane corresponding to the parasitic elements' spacing. By examining Fig. 2, it is evident that the spacing between the driven element and parasitic elements plays a vital role in obtaining a high gain and a uniform omnidirectional radiation pattern.

Fig. 3 shows the results of the proposed circularly polarized Y-shaped monopole antenna with radome and high-density polystyrene foam as support dielectric material. Fig. 3(a) illustrates the return loss and the evaluated axial ratio (AR) frequency responses with $S_{11} < 10$ dB and AR < 2.7 dB, respectively over the DSRC frequency band from 5.85 GHz to 5.925 GHz. Generally, a circularly polarized antenna has an AR of less than 3 dB. Fig. 3(b) demonstrates the frequency dependence of the antenna input impedance. The real part of the input impedance is nearly 50-Ω (i.e., matched to the port's impedance), while the reactive component is very low at the antenna resonant frequency (5.9 GHz).

TABLE I
DESIGN PARAMETERS OF THE PROPOSED ANTENNA IN FIG. 1

Parameter	Value (mm)
Diameter of the Y-shaped radiator	1.6
Radome thickness	2
Parasitic elements height	7.2
Support material height (Foam)	10.0
L_1	12.5
L_2	27.2
L_{a1}	11.0
L_{a2}	10.7
S_1	22.5
S_2	50.0
R	65
S_f	10

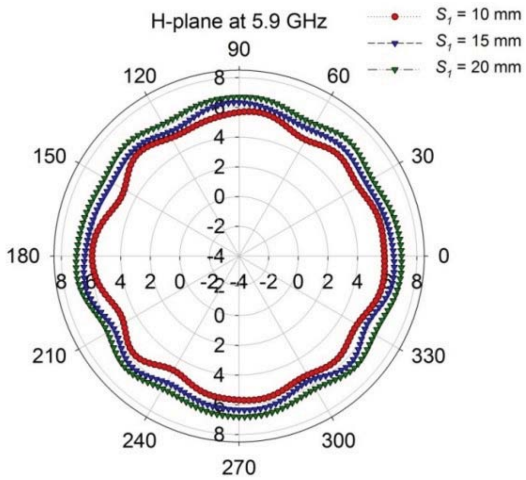
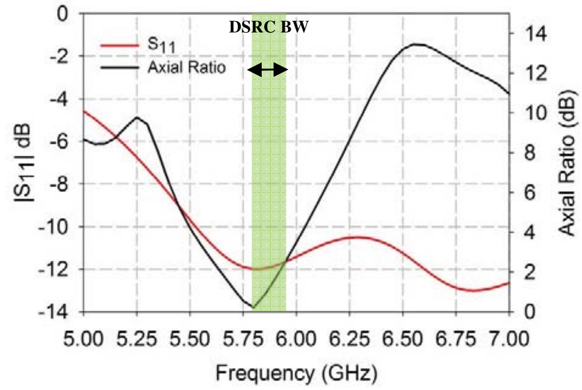


Fig. 2. (a) Effect of spacing between the Y-shaped monopole and the first iteration of the conductive arched walls on antenna gain level and radiation pattern.

Fig. 3(b) clearly shows that the Y-shaped monopole behaves as a parallel resonant RLC circuit, where below the resonant frequency the monopole impedance looks inductive and above the resonant frequency the impedance appears capacitive. Therefore, an equivalent circuit model of the proposed antenna can be derived from a degenerated Foster canonical form depicted in Fig. 3(c) for modeling electric antennas (e.g., dipoles and monopoles) [13]. Here, C_o is the quasi-static input capacitance, and L_o is an inductance that takes into account the feeding effects. C_n, L_n, and R_n are the capacitance, inductance, and resistance, respectively, describing the resonance of the antenna structure.



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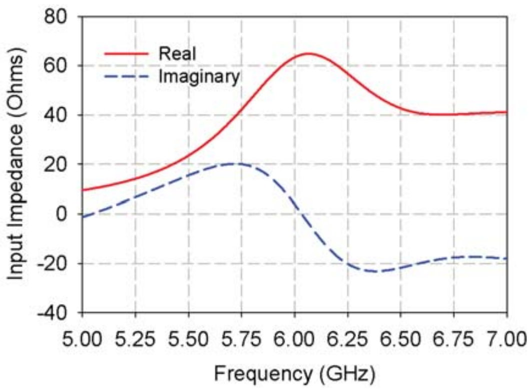

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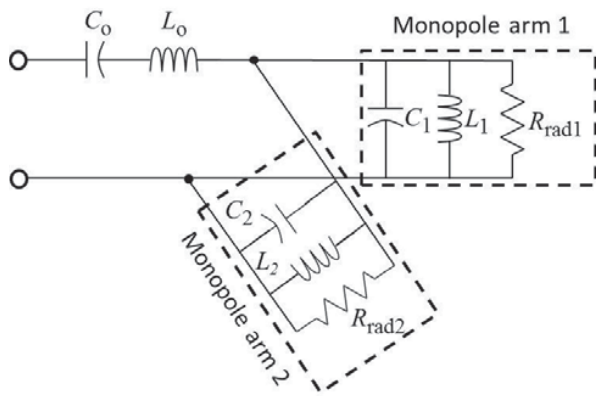

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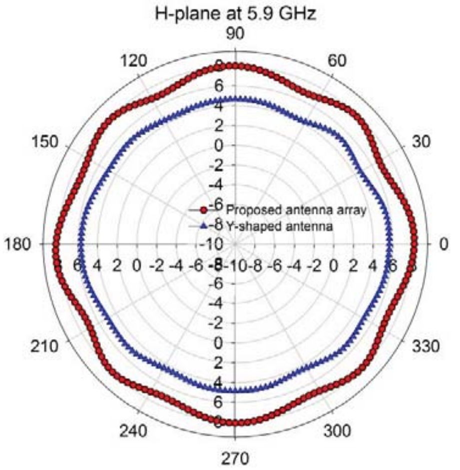
Fig. 3. (a) Simulated return loss and axial ratio versus frequency of the proposed DSRC antenna. (b) Real and imaginary parts of the antenna input impedance. (c) Equivalent circuit model of the proposed Y-shaped antenna comprised of two tilted monopoles.



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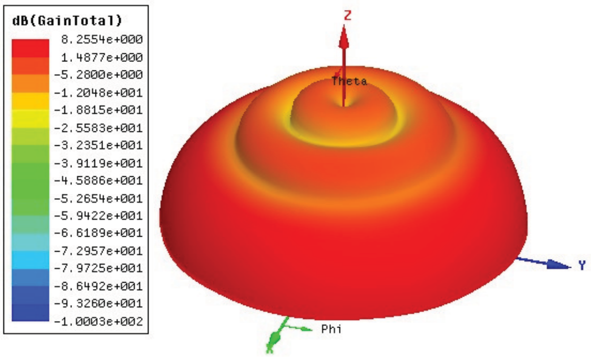

(b)

Fig. 4. (a) Evaluated far-field radiation pattern in the azimuthal plane (xy-plane) at 5.9 GHz showing improved omni-directional gain when compared with the stand-alone Y-shaped monopole. (b) 3D radiation pattern of the antenna.

The H-plane pattern in Fig. 4(a) shows an omni-directional radiation pattern similar to those of conventional monopole antennas. In the proposed antenna, the optimal successive spacing between the antenna radiator and the parasitic elements are found to be 0.44λ and 0.47λ, respectively. This is slightly larger than the 0.3λ to 0.4λ range specified for Yagi-Uda design in [14]. Antenna gain of 8.2 dB is achieved at 5.9 GHz with the hemispheric shaped radome, while 8.0 dB is available without. The added radome has no significant distortion on the radiation pattern except slight increase (i.e., 0.2 dB) on the antenna overall gain. Fig. 4(b) depicts the 3D far-field radiation pattern at the same resonant frequency.

IV. Conclusion

In this contribution, a circularly polarized monopole antenna with improved omnidirectional gain performance for DSRC V2V/V2I communications has been presented. Gain improvement has been accomplished by introducing two sets of conductive arched walls acting as parasitic elements arranged along circumferences of two circles having different diameters. The arched walls are touching the ground plane and employed to steer the antenna radiation in all directions in the azimuthal plane. The evaluated antenna performance shows excellent impedance matching at the DSRC center frequency (5.9 GHz) and axial ratio less than 2.7 dB. Compared to conventional monopole antenna, the proposed antenna has an improved omni-directional gain of 8.2 dB. The proposed antenna structure meets the low cost, low profile requirements and enables aftermarket retrofit with flexible installation at different positions of a vehicle.

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