MODELING AND CHARACTERIZATION OF FIBONACCI HEXAGON BASED PRINTED FRACTAL ANTENNA FOR VEHICULAR COMMUNICATIONS

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Abstract—

This article presents a concept for using a printed array of hexagonal radiators in vehicle-to-vehicle applications. The IEEE 802.11p standard designates the frequency range of 5.85 to 5.925 GHz for dedicated short-range communication specifically tailored for vehicle applications. The singular radiator has been developed from regular hexagonal structures based on the Fibonacci sequence. The suggested construction has five hexagons, each with a length scaled down by a factor of 0.625. To provide connectivity between the hexagons, a vertical slit has been introduced, followed by the addition of a horizontal slit on the acquired structure. The Wilkinson power divider is employed in the configuration of the feed network of an array in order to achieve a substantial level of isolation. Implementing antennas in CST Microwave Studio entails using a single-layer printed circuit board (PCB) composed of FR-4 laminate material with a relative permittivity of 4.40. The antenna and the array have gains of 6.96 and 10.20 dBi, respectively, and possess a bandwidth coverage that exceeds 100%. Both antennas demonstrate a minimal level of cross-polarization in the principal beam direction. Both antennas have notable radiation efficiency and acceptable aperture efficiency, respectively. Due to its minimal correction factor values, the antenna shows a reduced electromagnetic interference (EMI) and electromagnetic compatibility (EMC) effect. Both antennas are suitable choices for applications in vehicles.

Keywords—
Antenna, DSRC, microstrip, V2V, Wilkinson.

I. INTRODUCTION

In recent times, there have been notable improvements in intelligent transportation systems (ITS), including cutting-edge technologies. The current state of technical progress allows for the effective exchange of information between motor vehicles, fixed infrastructures, and other pertinent organizations. The Dedicated Short-Range Communication (DSRC) service spectrum has been allocated with the specific objective of facilitating continuous and uninterrupted communication. On the other hand, the 5.90 GHz frequency in the Dedicated Short-Range Communications (DSRC) band is specifically allocated to enhance the exchange of information between cars and base stations. The primary purpose of this communication channel is to detect and address areas of limited visibility that may arise under inclement weather conditions. Additionally, it facilitates the functioning of collision avoidance systems. The microstrip antenna is commonly preferred for Dedicated Short-Range Communications (DSRC) services due to its favourable attributes, such as its ability to be easily moved, its lightweight construction, its cost-effective manufacturing process, its uncomplicated matching network, its seamless integration with microwave equipment, and its convenient installation on the roof of a vehicle. Nevertheless, the adequate bandwidth of conventional patch antennas is limited by a high-quality factor (Qn).

The rapid advancements in Intelligent Transportation Systems (ITS), Vehicle-to-Vehicle (V2V) communication has emerged as a critical technology for enhancing road safety and enabling efficient traffic management. The development of efficient antennas that can sustain high-performance wireless transmission is a crucial part of vehicle-to-vehicle (V2V) communication systems. This paper covers an in-depth analysis and design process for V2V communication antennas used for secure and dependable wireless communication between vehicles. The goal is to design an antenna to maintain an effective signal throughout extended distances. To facilitate communication between vehicles using the DSRC service band, this project will focus on designing and developing an antenna array. Initially, we will focus on developing a new fractal-printed radiator that conforms to the requirements of C-band V2V communication.

II.LITERATURE SURVEY

In 2017, Daniel Jiang, Vikas Taliwal, Andreas Meier, And Wieland Holfelder [1] propose the improvement of automotive safety in the United States over the last two decades, with a focus on active safety systems and communication-based active safety as the next step in proactive safety systems. It mentions the allocation of Dedicated Short-Range Communication (DSRC) spectrum for vehicle-to-vehicle and infrastructure-to-vehicle communications, and the ongoing development of DSRC technologies and applications by the Department of Transportation and the automotive industry. The paper also highlights the challenges of channel congestion control, broadcast performance enhancement, and concurrent multichannel operation in vehicular-safety communication, and proposes a set of protocols to address these challenges.

In 2018, y John B. Kenney [2] provides a detailed description of the Dedicated Short-Range Communications (DSRC) standards in the United States, specifically focusing on the Wireless Access in Vehicular Environments (WAVE) standards. It discusses the DSRC protocol stack, including the LLC PDU format for DSRC and the various layers of the protocol stack. The paper also mentions SAE J2735, which defines data elements and data frames in DSRC using Abstract Syntax Notation One (ASN.1) and Distinguished Encoding Rules (DER) for over-the-air encoding. It highlights the division of time into CCH (Control Channel) and SCH (Service Channel) intervals in DSRC and the performance analysis of channel switching safety paradigm. Additionally, the paper mentions the sublayers of the Data Link layer in DSRC, including the medium access control (MAC) sublayer and the logical link control (LLC) sublayer.

In 2018, Yuan Yao, Lei Rao, Xue Liu [3] proposed a primary technique for the 802.11MAC is the distributed coordination function (DCF). Previous works on VANET broadcast performance analysis are based on the 802. 11DCF.Li et al. proposed an analytic model to predict the optimal range for maximizing the one-hop broadcast coverage in dense ad hoc wireless networks. Vinel et al. leveraged a periodic broadcast model to compute the successful reception probability and the mean transmission delay in the WAVE. MA et al. proposed a 1-D Markov chain model for the backoff procedure of the 802.11a broadcast and evaluated the PRR and PD of V2V safety-related broadcast services. Moreno et al. analysed and improved the performance and reliability of the 802.11EDCA broadcast for safety-related IVC applications. Burguillo-Rial et al. presented a multiagent model to analyse the characteristics and performance of V2V communications in urban environments. Eichler gave an overview of the capabilities, including throughput and delay, of the standard 802.11p with EDCA in VANETs.

In 2019, Lin Cheng, Benjamin E. Henty, Daniel D. Stancil [4] presents narrow-band measurements of the mobile vehicle-to-vehicle propagation channel at 5.9 GHz, under realistic suburban driving conditions in Pittsburgh, Pennsylvania. The study includes the use of Differential Global Positioning System (DGPS) receivers to enable dynamic measurements of path loss, Doppler spectrum, and coherence time based on vehicle location and separation. The authors introduce the Speed-Separation diagram as a new tool for analyzing and understanding the vehicle-to-vehicle propagation environment, which can be used to model and predict channel Doppler spread and coherence time using vehicle speed and separation. The Nakagami distribution is used to describe the fading statistics of the channel. The paper also discusses the procedure for Nakagami analysis, including smoothing the raw signal strength data and modifying the equation for different numbers of packet transmissions between vehicles.

III. ANTENNA DESIGN

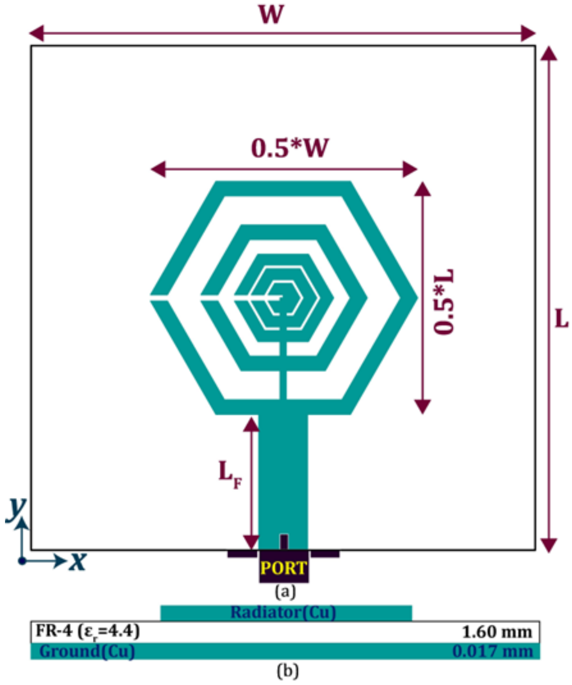

Fig. 1. Proposed sole antenna: (a) horizontal and (b) vertical-view (W = L = 30, LF = 8.25; unit: mm).

The structure denoted as K, which is shown in Fig.1. is affixed to a single side of the printed circuit board (PCB) made of FR-4 material with a dielectric constant of 4.40. An additional stratum of the substrate functions as the grounding component. The feedline, denoted as LF, directly stimulates the complete structure through the outer ring using a 50Ω source. The antenna was developed using the SONNET electromagnetic simulator and its design was cross-verified using the CST Microwave Studio (v2019). The above antenna has the following characteristics. They are, the sole radiator is derived from Fibonacci series based hexagonal geometries. It gives 100% bandwidth coverage for vehicular applications. The Wilkinson divider reduced the physical size of the array. The array provides enhanced gain and good isolation.

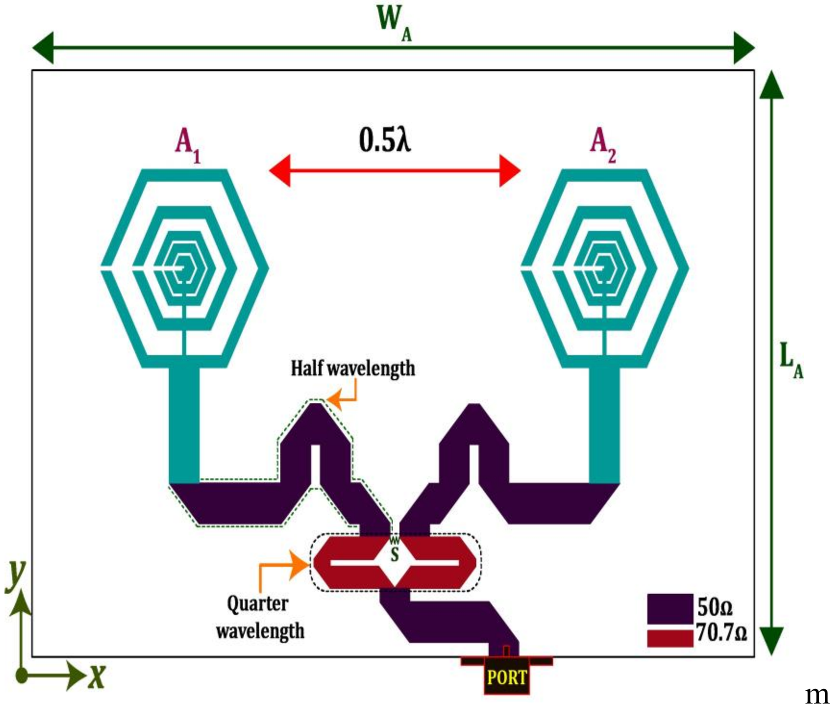

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FIG.2. Constructed array antenna (WA = 7.10, LA = 4.26; unit: mm)).

The two-element linear array has been developed using the CST Software shown in Fig.2**.**To lessen the mutual-coupling effect, it is necessary to maintain a consistent spacing of 0.5λ between the two identical radiators, denoted as A1 and A2. The feed network for the array is constructed using a transmission-line technique and a customized Wilkinson power divider. The line length of 50Ω and the length of the quarter-wave transmission line are kept at integer multiples of λ/2 and λ/4, respectively. A chip-resistor (S) with a resistance of 100Ω is positioned at the junction of a 70.7Ω line to achieve high isolation.

IV. SIMULATION RESULTS AND DISCUSSION

The solo radiator under consideration has been developed using CST Microwave Studio (v2019), and its simulation results are shown in Fig. 3. The resonant frequency of the antenna was measured to be 5.90 GHz, and the return loss was found to be 27.65 dB, as shown in Fig. 3(a). The impedance bandwidth of the antenna spans a range of 0.21 GHz, essentially covering the whole Dedicated Short-range Communications (DSRC) band. The curve illustrating the gain characteristics of the antenna is shown in Fig. 3(b). The antenna exhibits a significant gain of 6.96 dBi. The graphical representation of the co- and cross-polarization properties of the antenna is depicted in Fig. 3(c). The cross-polarization discrimination (XPD) for both the plane (E & H) is less than −32.50 dB, which is considered desirable and commonly accepted for vehicle communications. The radiation patterns of the antenna in the xz-plane (with $\varphi = 0^\circ$) and yz-plane (with $\varphi = 90^\circ$) are shown in Fig. 3(d). The antenna demonstrates a substantial decrease of back-lobe radiation, with a measurement exceeding −34 dB. The three-dimensional radiation pattern of the antenna is presented in Fig. 3(e). The antenna's radiation pattern demonstrates symmetry in the desired direction, as shown in Fig. 3(e).

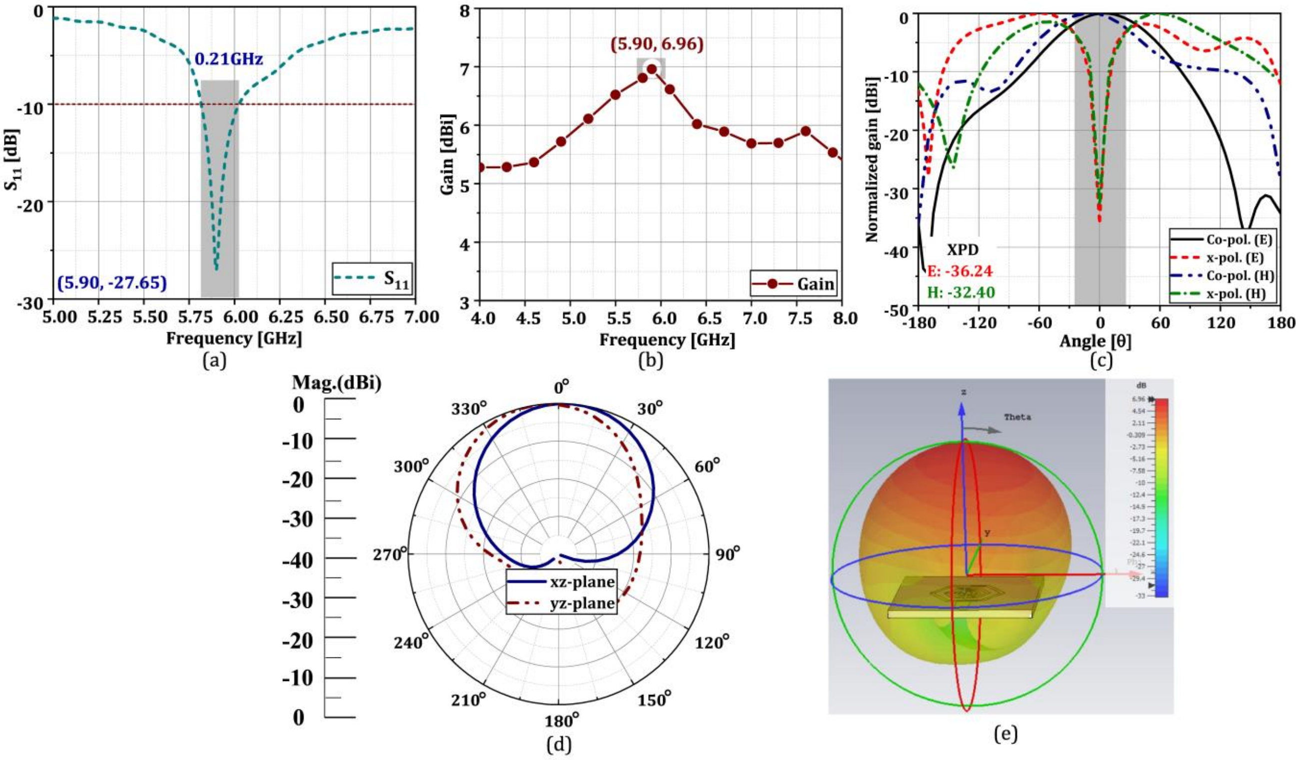
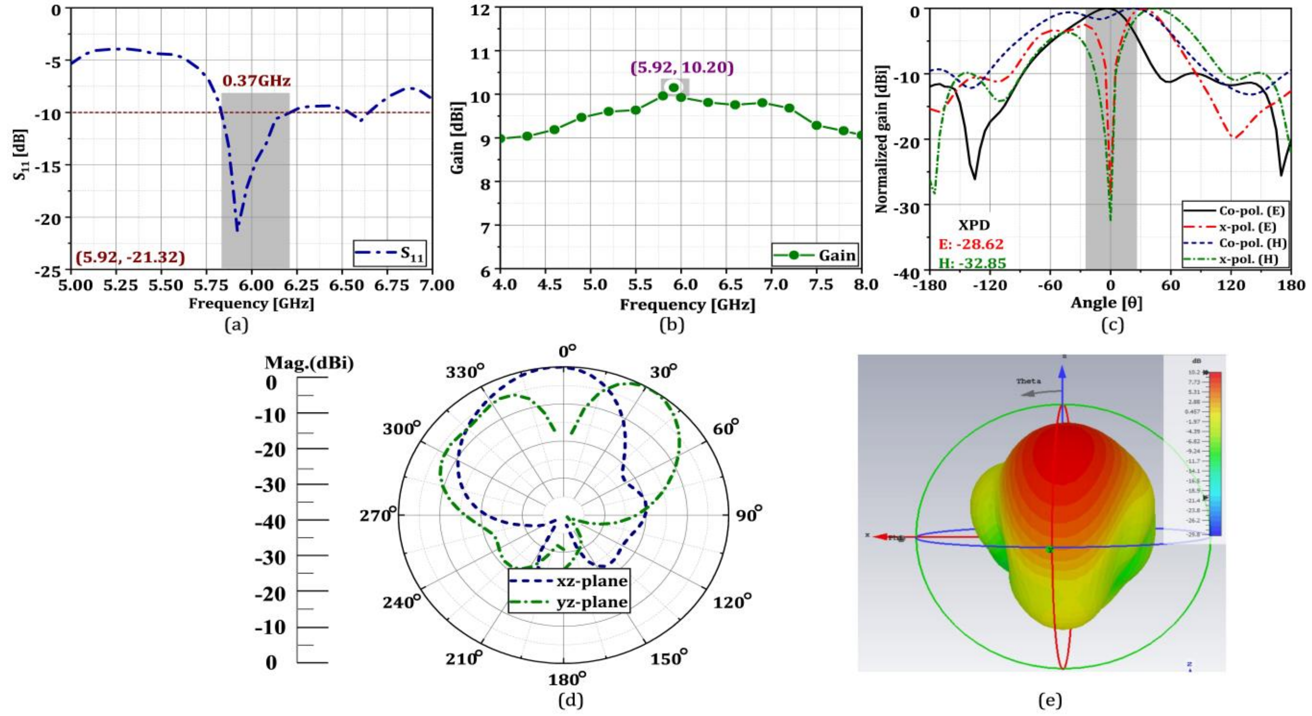


Fig. 3. Simulated outcome of sole radiator: (a)S11 (b) gain (c) E & H-field (d) xz-yz (e) 3D radiation patterns.

A two-element array has been developed with FR-4 epoxy substrate material to enhance parametric results. The simulated results are shown in Fig. 4. The linear array exhibited resonance at a frequency of 5.96 GHz and demonstrated a return-loss of 21.32 dB, as seen in Fig. 4(a). Additionally, it has an impedance bandwidth of 0.37 GHz at the resonant frequency. The array gain has significantly improved around 46%, resulting in a value of 10.20 dBi, as shown in Fig. 4(b). The array also demonstrates cross polarization discrimination (XPD) of less than −28 dB along the desired direction of the main beam, as seen in Fig. 4(c). The radiation pattern of the array in the xz- and yz-planes is shown in Fig. 4(d). The figure demonstrates that the array displays back-lobe radiation with a magnitude lower than −25 dB. Much like the single radiator, the array demonstrates a symmetrical radiation pattern in the desired direction, as shown in Fig. 4(e).

Moreover, the array exhibits a radiation efficiency of 93% at the designated resonance frequency. The array's dimensions are given as 7.10 × 4.26 cm2, and its directivity is reported as 11.57 dBi. Therefore, the calculated aperture efficiency of the array is 79%. The determined array correction factor is 36 dB/m, signifying a significant decrease in the array's electromagnetic interference and compatibility impacts. The parametric outputs of the array are shown in TABLE I. TABLE I is a comprehensive compilation of the simulated results obtained from the lone radiator. A two-element array has been developed with FR-4 epoxy substrate material to enhance parametric results.



(a) (b) (c)

(d) (e)

Fig. 4. Simulated outcome of array: (a)S11 (b) gain (c) E & H-field (d) xz-yz (e) 3D radiation patterns.

TABLE.1. PERFORMANCE PARAMETERS OF ANTENNA AND ARRAY.

Parameter(s)	Single Antenna	Antenna Array
fr [GHz]	5.90	5.92
S11 [dB]	-27.65	-21.32
VSWR	1.09	1.19
BW [GHz]	0.21	0.37
Gain [dBi]	6.96	10.20
Directivity [dBi]	8.24	11.57
x-pol. [dB]	-32.56	-28.62
η [%]	95	93
ηap [%]	83	79
CF [dB/m]	35	36

V. CONCLUSION

A specially designed linear arrangement of printed antennas has been developed to enhance the functionality of Dedicated Short-Range Communications (DSRC) applications. The sole radiator consists of five scaled hexagon structures where the hexagon length follows the Fibonacci series. The solitary radiator exhibits a gain of 6.96 dBi, minimal cross-polarization, extensive coverage throughout the frequency spectrum, and notable radiation efficiency. The present study provides a comprehensive analysis of the circuit-equivalent model of the antenna, which is then followed by an examination of the array. The Wilkinson divider provides enhanced isolation within the array configuration. The approach described above has many noteworthy benefits, such as improved radiation efficiency, substantial gain, and reduced cross-polarization along the primary beam axis. Both antennas provide extensive coverage of bandwidth for vehicle communication.

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