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RESEARCH ARTICLE

THE DESIGN OF A PRINTED 5G MONOPOLE ANTENNA FOR VEHICULAR COMMUNICATIONS

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ABSTRACT

This paper presents the design of a compact printed 5G monopole antenna for vehicular communication applications. The monopole antenna is placed directly on the laminated glass of vehicle for eliminating additional mounting space. The proposed antenna operates within the sub-6 GHz frequency range, covering the 5G bands from 26 GHz to 30 GHz. The antenna features a simple and compact design, making it suitable for integration into vehicles. The design utilizes a monopole resonator, magnetic line, and co- planar waveguide (CPW) to achieve improved performance. The antenna is designed on the vehicle's windshield. The simulated results show a reflection coefficient of -10 dB and a gain of 8.5 dBi across the operating frequency range. The proposed antenna is a promising candidate for vehicular 5G communication systems, enabling reliable and high-speed data transmission for various applications, including vehicle- to-everything (V2X) communication and autonomous vehicles.

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INTRODUCTION

Over the present years, the necessity for vehicles to gather large amounts of data about their environment—such as information on nearby vehicles and road conditions has increased, especially with the push for higher levels of autonomous driving. However, traditional communication technologies face limitations like low data throughput and high latency, leading to a growing interest in utilizing fifth-generation (5G) networks in vehicles. One major challenge observed was that any antenna for vehicles needs extra space for mounting. Generally, vehicles use shark-fin antennas on the roof, chosen for their aerodynamic design and low wind resistance. We prefer millimeter-wave (mmWave) antennas so that it is small enough to fit in such spaces, but to achieve efficient 5G communication, an array system is required. Space limitations in the shark-fin housing can still make it hard to obtain optimal performance. A different method involves using window glass as an antenna substrate, with the antenna pattern printed directly onto the glass. It offers many advantages. One major advantage is that it does not require additional mounting space, maintaining the vehicle's original design and appearance. Traditional antennas often need separate installation, which can affect the vehicle's appearance. With a glass antenna, this issue is eliminated. Another advantage is that it reduces interference, both physically and electrically. Since the antenna is integrated into the glass, there is no risk of its being physically obstructed or causing mutual coupling issues with other antennas on the vehicle. This improves signal performance and ensures stable wireless communication. Additionally, glass antennas can be manufactured conveniently because they can be integrated into the vehicle's window glass at the time of the production process. This reduces space complexity. Due to these advantages, glass antennas are considered a strong element for vehicle communication. However, a major con we observed was that thick glass with high dielectric loss is not ideal for 5G antennas. We have identified through some studies that there were mmWave antennas on vehicle glass, but they mainly used very narrow glass. This is a major challenge because usually, vehicle windshields are made of laminated glass, which is electrically thick and causes significant signal drop in the 5Gfrequency band. Hence, we further researched to make effective 5G antennas for vehicle window glass. In this paper, we suggested a new pattern for a 5G monopole antenna which is placed directly on a vehicle's windshield by adjusting glass dielectric constant and tangent loss parameters. The suggested antenna composed of three main components: a mono pole resonator, an magnetic line, and a CPW. The magnetic line plays a crucial role in adjusting the phase of the current in every resonator, ensuring that they remain nearly in phase. This improves the overall antenna gain, making it suitable for vehicle 5G communications despite the intense dielectric loss of vehicle windshield. By verifying the required characteristics of this antenna design, the results confirmed that the suggested 5G monopole design is well-suited for vehicular wireless communication.

Design Approach: The structure of the suggested 5G monopole antenna for vehicle windshield is shown in Fig ure . The antenna is directly printed to the side of the vehicle's windshield. This glass substrate has a intense dielectric loss ($\varepsilon r = 6.95$, $\tan\delta = 0.05$) and a thickness of3.2 mm. Due to this, a standard quarter-wavelength printed antenna cannot provide the required gain. To overcome this challenge and enhance antenna performance while considering the high-loss nature of vehicle windshield, the suggested design having a 4 × 1 array of monopole resonators, each with dimensions 2.8 mm × 1.8 mm × 0.035 mm, connected through an inductive line with dimensions 0.7 mm × 0.4 mm × 0.035 mm. This inductive line adjusts the phase of each resonator, ensuring in- phase surface current distribution. As a result, despite the high dielectric loss, the antenna achieves suitable gain for 5G communication. The 4 X 1 array of mono pole resonators was placed on a glass substrate with the dimensions of 50 mm × 50 mm × 3.2 mm, where 50 mm × 50 mm represents the length and width, and 3.2 mm represents the thickness. The substrate is a Glass material. The dimensions of each ground plane are 24.62 mm × 3 mm × 0.035 mm, where 24.62 mm is the length, 3 mm is the width, and 0.035 mm is the thickness. The dimensions of the CPW feed line are 0.5 mm × 3 mm × 0.035 mm. The presence of two symmetrical ground planes in the CPW structure enhances impedance matching, Since vehicle windows have smooth surfaces, directly depositing a copper layer on the glass is difficult.

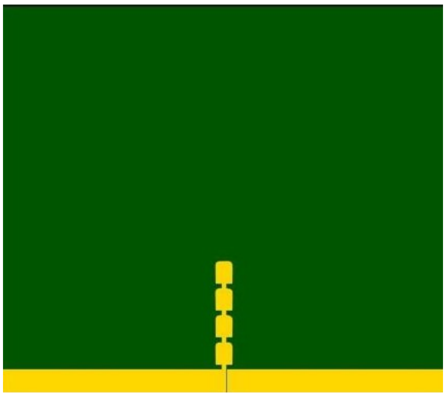

Fig . 1. Design of the proposed antenna

Conventional printed antenna fabrication methods, like silk screening, have poor manufacturing tolerance and are unsuitable for small 5G antenna patterns. To overcome this, a Thermosetting sealant is preferred to add a copper sheet to the vehicle windshield. This fixative maintains grip when the antenna is heated for soldering. After attachment, the etched copper film forms the antenna pattern, even on the smooth glass surface. The Co- planar Wave-guide line is connected to a k-type (2.92 mm) port, which ensures low insertion loss at the 5GmmWave band. band. For validating the antenna's performance, Reflection Coefficient and Radiation Pattern were measured.

RESULTS

To validate the suggested design effectiveness, various parameters like gain, VSWR, and Radiation Pattern were analyzed.

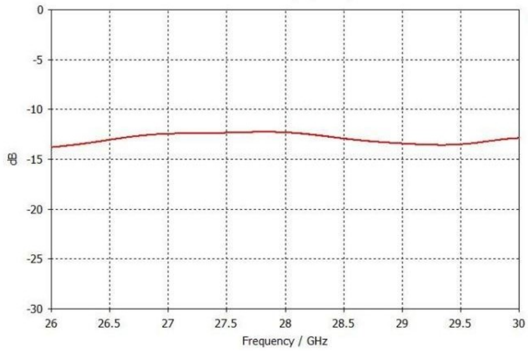

Fig . 2. Return Loss

From Fig .2, the simulation results were obtained using CST Studio Suite 2024, and the observed S-parameter characteristics align well with the expected performance. This implies that significant segment of the input power was being radiated rather than reflected back into the source, which is a crucial factor for ensuring efficient Antenna properties.

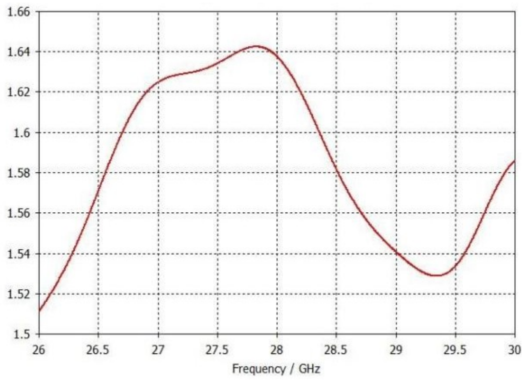

Fig . 3. Voltage Standing Wave Ratio

From Fig .3, the VSWR plot indicates how well the antenna is impedance-matched to the transmission line. In this case, VSWR values remain within a reasonable range across the frequency band of interest, staying close to 1.5 - 1.66, which suggests minimal signal reflection and good impedance matching. A lower VSWR value ensures that more power is transmitted effectively rather than being reflected back,which is crucial for efficient antenna operation.

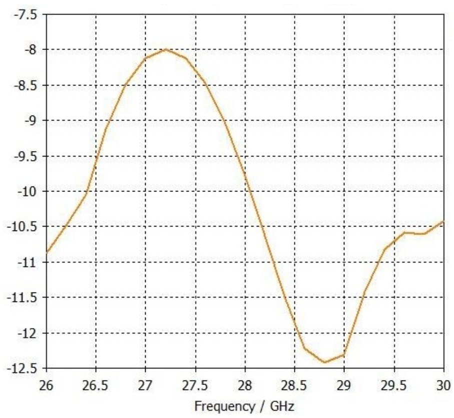

Fig . 4. Gain

From Fig .4, the gain analysis of the antenna provides insights into its directivity and efficiency. The plotted gain values across different frequencies show variations, with a peak gain reaching approximately -8 dBi at 27 GHz. This relatively low gain suggests that the antenna has noticeable efficiency losses, which could be due to factors such as substrate material properties, conductor losses, or an inadequate ground plane. The drop in gain around 28.5 GHz highlights a point of reduced radiation performance.

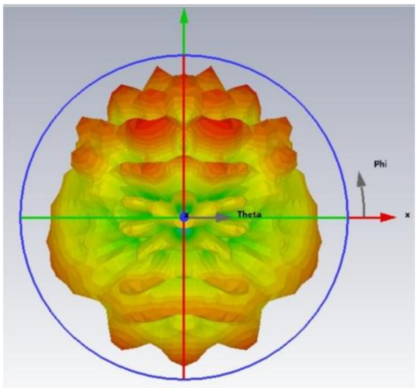

Fig . 5. Radiation Pattern

From Fig .5, the 3D far-field radiation pattern of the antenna is another critical aspect of its performance. The observed pattern exhibits an omnidirectional radiation characteristic, which is typical for monopole antennas. This means that the antenna radiates energy relatively uniformly in all directions, making it suitable for applications where a broad coverage area is required.

Fig. 6. Fabricated Antenna

The picture in Fig .6, shows the fabricated prototype of the proposed mono pole antenna intended for 5G vehicular communication. The antenna is implemented on a transparent glass substrate, which reduces the additional mounting space on vehicle window glass. This physical prototype validates the simulation results and provides an essential step towards further optimization and practical deployment in intelligent transportation systems and 5G vehicular networks.

CONCLUSION

We designed a 5G monopole antenna that can be mounted on vehicle window glass. The antenna includes a monopole resonator, an magnetic line, and a CPW feed. The magnetic line helps control the phase of the current in every resonator, ensuring that currents remain nearly in Phase. This design helps achieve good antenna gain, even though vehicle windshield is having high Dielectric loss. To validate antenna's performance, we measured its reflection coefficient, VSWR, gain and radiation pattern. The results showed that reflection coefficient stayed below -10dB within 5Gmmwave band, and it indicates good impedance matching. Additionally, in a 4 × 1 array setup, the measured gain reached 8 dBi. The Voltage Standing Wave Ratio (VSWR) of the antenna ranges from 1.5 to 1.64, indicating a relatively good impedance match with minimal signal reflection and efficient power transfer. We also studied the surface current distribution with and without magnetic line. These findings confirmed that magnetic line is necessary for enhancing gain by properly aligning the current phase across the resonators. Although the suggested design is compact, it is not optically transparent. Future improvements can explore using transparent conductive materials or mesh structures to make the antenna less visible while maintaining its performance.

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