Orthogonally Integrated Hybrid Antenna for Intelligent Transportation Systems

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Abstract **─** The aim of this paper is to design an orthogonally integrated hybrid antenna to address 5G/Wi-Fi/C-V2X communication simultaneously in one device. The proposed antenna consists of three planar monopoles and a defected ground plane with a dimension of 55x30x1.2mm^3. High Frequency Structure Simulator (HFSS) is employed to design the proposed antenna, which resonates at three distinct frequencies 2.45 GHz (Wi-Fi), 3.5 GHz (5G), and 5.9 GHz. Further, the prototype antenna is fabricated and experimentally validated in comparing with simulation results. The excellent agreement among the simulation and measured results shows that the designed antenna operates simultaneously at 5G/Wi-Fi/C-V2X frequency bands and the isolation effects between the elements is less than 15dB.

Index Terms **─** C-V2X, defective ground, DGS, ECC, hybrid antenna, vehicular communication.

I. INTRODUCTION

Wireless communication is integral to life of common man that involves the necessity for public safety communication. Intelligent Transportation Systems (ITS) are a combination of cutting-edge information and communication technologies used in transportation and traffic management systems for safety improvement, efficiency, and sustainability of transportation networks; to minimize traffic congestion; and to enhance drivers' experiences. Intelligent Transport Systems (ITS) addresses these safety and environmental related issues by incorporating government bodies, universities, research organizations, and automotive industries [1]. Recent development in the vehicles are connected to each other through on-board-unit (OBU) and also with the road-side-unit (RSU) to communicate the information regarding the traffic for ITS. Cellular and transportation networks, in partnership, can deliver efficient smart transportation solutions through the way of providing safer pedestrians and bicycling conditions, reducing cut-through traffic, contribute to city-level traffic planning, pre-trip information and multi-modal choices Greening opportunities. Additionally, it ensures the safety during land travel. Figure 1 shows the different portfolios of communication in vehicular communication services.

Many researchers have addressed different types of antennas for vehicular communication which are surveyed and analyzed. Numerous solutions are proposed in the survey which addresses slot antennas, inverted F antennas, and printed monopole antennas with multiband operations for various vehicular applications. Stacked antennas are developed to operate in multiple frequencies and different structures of monopole were addressed [2-6]. Many multi-band frequency operating antennas and embedded antennas were evolved for mobile communication [7-12], it also impinges the challenges occur in the integrating multiband antennas in a smaller volume. In [13], planar inverted F antenna (PIFA) is integrated with "Y" shaped monopole antenna to obtain the multiband operation. In [14], author designed an antenna to address LTE and C-V2X. A three-dimensional antenna addressing GPS, LTE, WLAN, and DSRC is presented in [15-16]. In [17] integrated monopole antenna is proposed to operate at GPS and DSRC frequencies.

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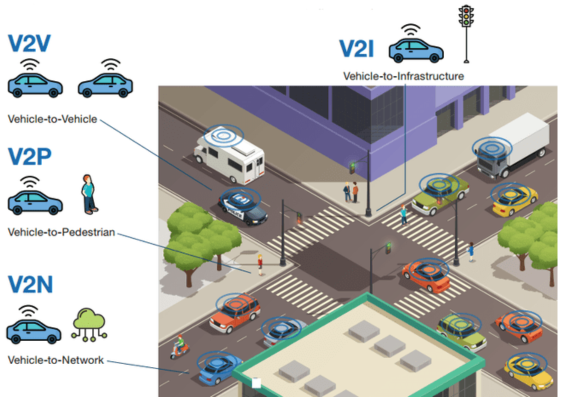

Fig. 1. Different types of V2X.

Many other multi-band antennas have been proposed for automotive applications including unmanned automotive vehicle [18-24] by that a good intelligent transportation system is evolved. Our innovative technology enables the connected transportation experience today. To be at the forefront of pioneering technologies from vehicle communications to precise positioning for the always connected.

For perfect intelligent transportation system, we have proposed an integrated planar monopole hybrid antenna which resonates at triple-bands addressing 5G/Wi-Fi/C-V2X communication simultaneously in a single device. Initially, the planar monopole antenna resonates at 2.4 GHz. Further, other antennas were integrated to operate on 5.9 GHz and 3.5 GHz. When each antenna element is placed closely located, another challenge nurtures the researcher is the isolation effect among elements. Various methods like defected ground structure (DGS), EBG structure, stubs, parasitic elements and novel 3D meta-material structures [12,25-28] to improve the isolation and capacity enhancement of vehicular antennas are found in the literature. In this proposed work, the monopole antennas are integrated orthogonally by that without incorporating any special methods to have better isolation among the antennas.

This research article is divided into multiple sections for clear explanation. Section I deals with a general introduction to this research work, Section II explains the design methodology, and Section III explains the result analysis of the proposed work followed by the conclusion.

II. DESIGN METHODLOGY

This work proposes a three port hybrid antenna with an overall dimensions of 30x55, which operates at three different frequencies to address 5G/Wi-Fi/C-V2X. The design of the antenna is evolved from a fundamental micro strip antenna substrate dimensions. A monopole antenna with λ/4 dimension inspired with meander line antenna is designed to operate at the lowest desired operating frequency. The single band (2.45 GHz) antenna is shown in Fig. 2.

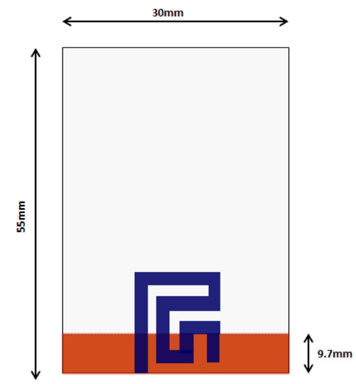

Fig. 2. Structure of single band antenna.

The ground plane length is chosen based on the parametric study and it is shown in Fig. 3. The designed antenna operates at 2.45 GHz. This band is aimed for Wi-Fi/V2I/Intra-vehicular applications. Another monopole antenna with λ/4 dimension is added to operate at the highest desired operating frequency. Figure 4 shows the structure of the antenna resonates at two bands simultaneously.

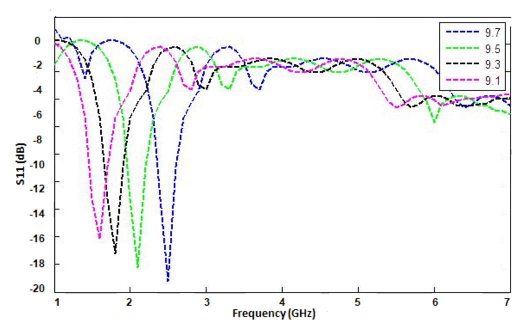

Fig. 3. Parametric analysis of single band antenna.

The antenna is placed orthogonal to the earlier one to achieve better isolation. This frequency is suitable for C-V2X applications. Figure 5 shows the performance of dual band antenna with the parametric analysis of second structure.

Furthermore, the monopole antenna with λ/4 dimension is added to operate at the 3.5 GHz operating frequency. This configuration provides tri-bands (2.45 GHz/3.5 GHZ/5.9 GHz) operation. The location of the three different monopole antenna in a same substrate, which comes under hybrid antennas. The antenna dimensions are optimized to provide a better impedance match at the desired tri-bands. Figure 6 shows the structure of the proposed hybrid antenna and Fig. 7 shows its return loss characteristics of hybrid antenna along with the parametric analysis of third antenna.

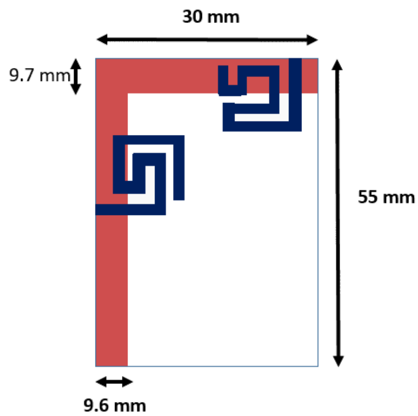

Fig. 4. Structure of dual band antenna.

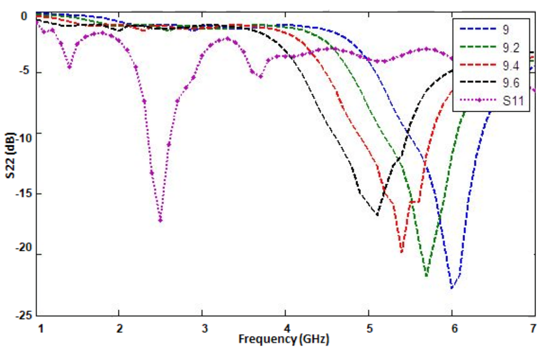

Fig. 5. S-Parameter of dual band antenna.

III. RESULTS AND DISCUSSION

The designed antenna is printed on 1.2 mm thickness FR4 substrate with the permittivity of 4.4, and loss tangent (d)=0.0009. Field Fox Vector Network Analyzer (N9952A) is been used to do near field measurements. Figure 8 and Fig. 9 shows the prototype of the designed antenna and measurement set-up.

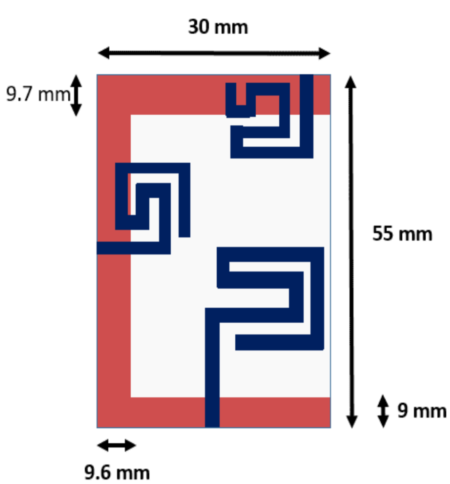

Fig. 6. Structure of Hybrid antenna.

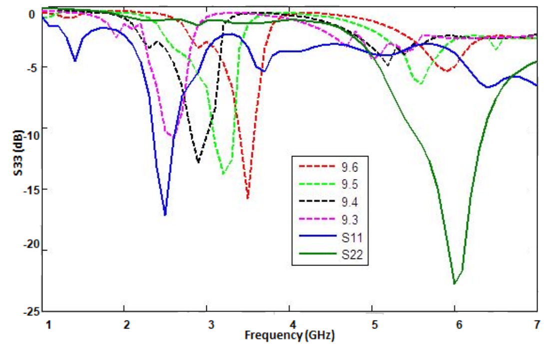

Fig. 7. Simulated and measured S-parameter of hybrid antenna.

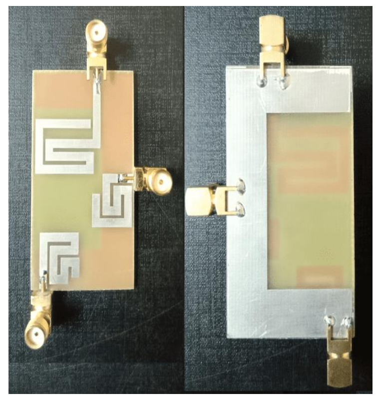

Fig. 8. Designed prototype.

A. S-parameters

Figure 9 shows the experimental setup of the measurement of S-parameter. Figure 10 shows the comparison of simulated and measured S-parameter characteristics of the proposed Tri-band integrated antenna. The graph reflects the excellent agreement between simulated and measured results.

Fig. 9. Measurement setup.

The Fig. 10 clearly specifies the inference that the proposed antenna has impedance bandwidth of 2.15 GHz to 3.05 GHz, 3.35 GHz to 3.75 GHz and 5.3 GHz to 6.8 GHz. There is a variation between the simulated and measured impedance bandwidth. This may be due to prototyping error

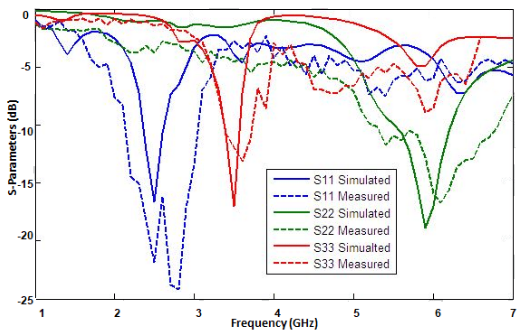

Fig. 10. Simulated and measured S-parameter results.

B. Isolation characteristics

Figure 11 shows the isolation characteristics comparison of the proposed antenna. The results show that isolation is greater than 15 dB at all desired bands. It conveys that there is a considerable amount of isolation among the ports, and the possibility of interference between the antennas are less.

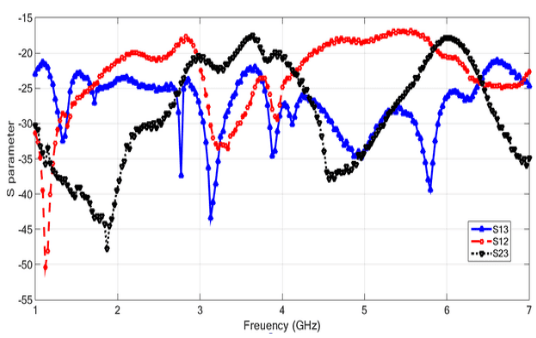

Fig. 11. Measured isolation effects of hybrid antenna.

C. Radiation pattern

Figure 12, shows the far field measurement setup of the tri-band antenna in the anechoic chamber. E field and H Field patterns of the proposed antenna are shown in the Fig. 13. It shows that the antenna has Omni-directional radiation pattern at the desired frequencies. It is observed that maximum of gain of 2.77 dB, 3.75 dB and 4.183 dB at 2.45 GHz, 3.5 GHz, and 5.9 GHz respectively.

The comparison between various antennas with proposed work is discussed in Table 1. It shows that the proposed work gives better gain with smaller dimension and proves the proposed work can be a better candidate as integrated antenna for vehicular communication.

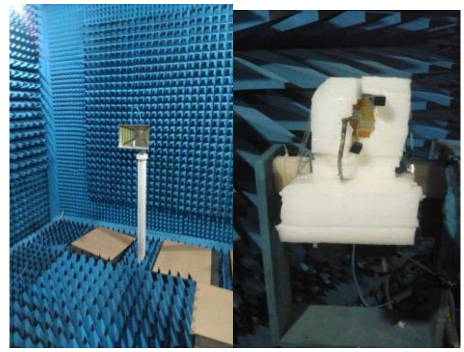

Fig. 12. Far field measurement setup.

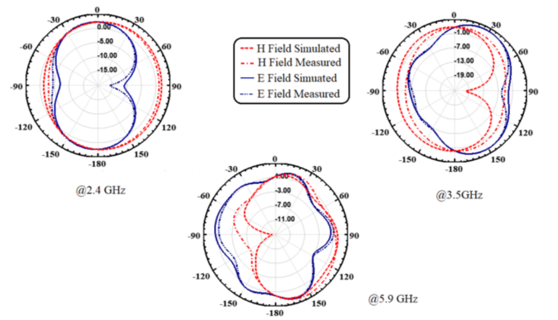

Fig. 13. Simulated and measured radiation pattern at tri-bands.

Table 1: Comparison among the different antennas and its performance

Reference Paper	Operating Frequency (GHz)	Dimensions (mm^2)	Gain (dB)
[5]	1.5, 2.4, 5.9	59.5x44.3	0.5 – 2.5
[6]	2.54, 3.5, 5.8	90 x 90	5
[7]	5.1 & 6.7	35 x 52.2	2.45
[15]	2.5, 3.5, 4.5, 5.5	50x50	0.75 – 4.15
Proposed work	2.45, 3.5, 5.9	55 x 30	2.77 3.75 4.18

D. Envelope correlation co-efficient

The envelope correlation co-efficient is essential parameter to analysis the different ports of the hybrid antenna. This parameter explains the correlation among the different antennas at various ports and lower the ECC means better performance of antenna. The value of ECC<0.5 is a desirable standard value for the hybrid system. The ECC is given by equation (1):

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{\left(1-|S_{11}|^2-|S_{12}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)}. \quad (1)$$

Table 2: ECC between different antennas

Freq (GHz)	Envelope Correlation Coefficient			
	Antenna 1,2	Antenna 2,3	Antenna 3,1	S_{11}
2.4	0.0374	0.00068	0.0319	-35dB
3.5	0.057	0.065	0.027	-18dB
5.9	0.0067	0.028	0.0026	-21dB

Table 2 explains the correlation between the various antennas. The ECC value is less than 0.1 over the different frequency ranges.

IV. CONCLUSION

The MIMO antenna is designed to address 5G/Wi-Fi/C-V2X for vehicular Communication is presented in this paper. The significant feature of the design approach is its compactness of total substrate dimension of 55 mm x 30 mm. There is good agreement between simulated and measured results on S-parameters, radiation patterns, gain and ECC Values. Further, it is observed that the inter port isolation is achieved below 15 dB among antenna elements in the hybrid structure. Thus, the proposed design is a suitable candidate for vehicular applications.

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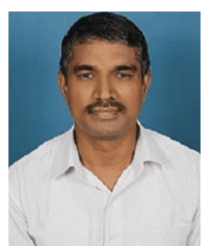

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