Design of a Compact Size Bridge Connected Multiband MIMO Antenna for Automotive 5G and DSRC Communications System

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***Abstract*—This paper presents a compact six-element dual-band multiple-input and multiple-output (MIMO) antenna system for automotive 5G technology and Dedicated Short Range Communication (DSRC). The MIMO antenna was designed and optimized to cover the dual-frequency bands (center frequency of 5.85 GHz and 28 GHz). The designed antenna works well at both frequency bands showing a very high -10 dB bandwidth, i.e., 4.1 GHz bandwidth for Band 1 (5.85GHz), and a bandwidth of 3.4 GHz for band 2 (28 GHz). The proposed structure comprises six antenna elements and is designed on Rogers RO3003 substrate. The overall electrical size of the whole dual-band MIMO antenna system is 15 mm x 15 mm. The antenna is designed and simulated using HFSS software. The electrical performance results of the proposed design and its MIMO characteristics are discussed and presented in terms of Voltage Standing Wave Ratio (VSWR), radiation patterns, radiation efficiency, gain, Diversity Gain (DG), reflection coefficient (S11). The measured VSWR is better than 3.5:1 at the desired frequencies (28 GHz and 5.9 GHz) across the operating bands. It can be seen that good impedance matching makes this proposed antenna suitable for automotive as well as 5G applications.**

Keywords*— *MIMO, Patch Antenna, Automotive, mmWave, 5G, V2X.

I. Introduction

Automotive industry is moving fast towards self-driving or autonomous applications. Significant feature development has been made in the communication systems to improve safety features like driver alert system (DAS), forwarding collision alert, adaptive cruise control (ACC), front- and rear-object detection for collision avoidance, headway alert, and blind-spot monitoring (BSM) [1-4]. Short distance communication especially vehicle to vehicle network establishment, vehicle-to-everything (V2X) communications via the dedicated short-range communications (DSRC) or the cellular or mobile vehicle-to-everything (C-V2X) protocols are upcoming hot feature. V2X allows vehicles within range of one another to exchange data for collision avoidance. Data such as GPS location, speed, the direction of travel, braking and turning status are communicated ten times a second to adjacent vehicles. Dedicated Short Range Communication (DSRC) and Cellular-V2X (C-V2X) are the two competing standards. DSRC is a variant of IEEE standard 802.11a, the first Wi-Fi standard to use orthogonal frequency-division multiplexing and the 5.85 GHz –5.925GHz band. The millimeter-wave (MMW) spectrum is already very attractive for vehicle-to-vehicle communication, vehicle-to-network, and collision avoidance systems due to its good performance, high capacity, and interference-preventive capabilities. In addition, higher-frequency bands provide better resolution and miniaturized sensor units [4]. The 5G network consists of two main frequency bands, a sub-6GHz band from 617MHz to 6 GHz, and a second band on the MMW from 28 GHz up to 60 GHz [5]. The MMW band not only helped us to get flexibility on frequency availability but also enabled us to reach data rates up to 10Gbps. The capacity of user nodes and performance are up to a hundred times better now. High-performance intelligent antennas are key technology enablers in meeting the ambitious goals of reliable and real-time wireless communication for advanced automotive systems, air-navigation systems, weather forecasting, massive MIMO systems for 5G communication, and vehicle-to-everything (V2X) connectivity. Capacity and reliability needed for 5G systems require high-gain, broadband, and beamforming antennas or antenna arrays that can handle propagation losses at higher frequencies as well as high throughputs and implementation of massive MIMO, moving the emphasis from antenna performance towards system performance. The concept of developing MIMO systems is to have many antenna elements placed at both the receiver and transmitter sides, which operate at the same frequency range band. As many antenna elements can be worked together, which will boost the number of channels across the radio frequency (RF) link [6].

There are many obstacles to designing a MIMO antenna in the automotive industry, such as location, weight, and, most importantly, grounding plays a crucial role in its performance. The packaging is very challenging if multiple elements are placed in a single housing, as physical dimensions, size limitations, and interference (coupling) between different

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antennas can ruin or destroy the overall performance. These challenges make it hard to meet the standards of MIMO performance such as radiation efficiency, gain, and diversity, especially when multiple applications are implemented in one single housing, such as radar detection, obstacle avoidance, AM/FM, Digital Audio Broadcast (DAB), cellular 5G, Telematic Box Module (TBM), 9-1-1 service or Emergency assistance service, Satellite Digital Audio Radio System (SDARS), Dedicated Short Range Communications (DSRC), Global Navigation Satellite System (GNSS). The United States (US) DSRC frequency band is allocated between 5850 MHz to 5925 MHz [7]. The reuse policy of DSRC frequency, as specified by the Department of Transport, provides a limited range with a maximum of 1000 meters, allowing spectrum to be used by different nodes. This also helps to restrict the interference between them. The bandwidth improvement helps transfer messages up to 6 megabytes per second, while vehicles run at high speed and are resilient to severe weather conditions such as rain, snow, or fog [4].

This paper proposes a bridge array connecting a 2x3 MIMO multiband patch antenna. The proposed MIMO antenna is a multi-band antenna and can operate at 5G band (28GHz) and DSRC band (5.9GHz). This antenna can be easily manufactured on standard ROGERS board using standard lithography and chemical etching, however only simulated results are presented in this paper.

II. ANTENNA DESIGN AND SIMULATION

The design of compact bridge array connecting 6 element (2 x 3) MIMO microstrip antenna geometry is shown in Fig. 1. To design this antenna, Rogers RO3003 substrate is selected ; with a dielectric constant (εr=3), loss tangent (δ=0.0013) and thickness of 0.5 mm. The final dimensions used are listed in Table 1. The basic antenna structure begins as rectangular-shaped, and then the antennas are created by cutting rectangular slots and putting them as arrays on both sides of the patch. The design has six antennas, and three antennas of each side are connected in a bridge. The different arm lengths of antenna slots (given by AL1, AL2, AL3, AL4 AL5, AL6) and widths (*AW*1, A*W2, AW3, AW4, AW5, AW6*) have been optimized to obtain desired results. The other two important parameters for the proposed antenna design are the length of the step feed (FL1, FL2, FL3, FL4) and the gaps between arrays and arrays to the bridge line (AG1, AG2, AG3). These parameters are optimized and adjusted to find the best matching impedance. The above-mentioned parameters control the number of operating bands and impedance matching. The four ports are defined as P1, P2, P3 and P4. These antenna parameters are very important and optimized carefully to get the best multi band characteristics. The proposed antenna operates in two different bands; the feed line length is carefully adjusted to achieve good impedance matching in working bands; FL3 and FL4 are comparatively larger than feedlines FL1 and FL2 because adjusting the length of these lines results in a trade-off between the impedance bandwidth and the initial frequency. Similarly, the gaps AG1, AG2, and AG3 are critical and must be appropriately selected to avoid disturbance in impedance matching for desired operational bands.

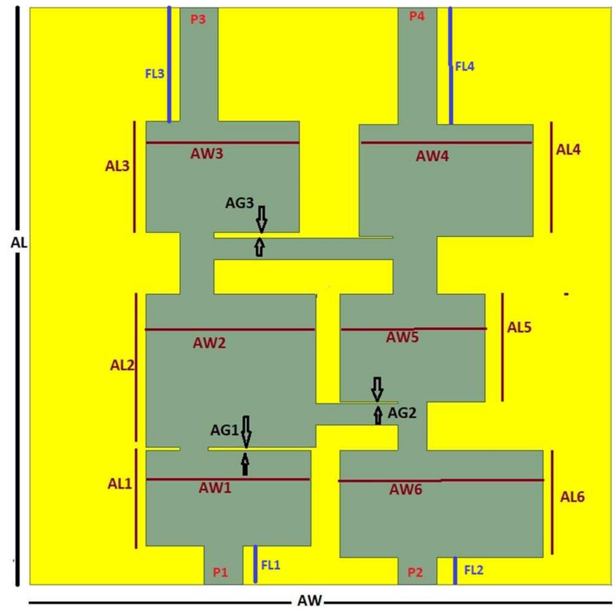

Fig: 1: Geometric of "Bridged" six element MIMO Antenna

TABLE 1: GEOMETRIC DIMENSION OF BRIDGED 2X3 MIMO ANTENNA FOR RO3003 SUBSTRATE

Substrate Materials	Design Parameter	Value (mm)	Design Parameter	Value (mm)
RO3003	AL1	2.8	AL4	2.6
	AW1	5.25	AW4	4.25
	AL2	2.5	AL5	3.9
	AW2	3.75	AW5	4.3
	AL3	2.9	AL6	2.9
	AW3	4.5	AW6	3.9
	AG1	0.07	AG2	0.05
	AG3	0.15	AG4	0.05
	FL1	1	FL4	3.05
	FL2	0.7	FL3	2.95

The overall dimension of the array is 15mm x 15mm making this antenna significantly smaller and compact in size. Due to its compact size, this bridge-shaped multiband MIMO antenna can be easily placed within an existing shark fin package or inside the driver assist system module (DASM).

III. RESULTS

This section presents the simulation modeling results and a few characteristics, including S-parameters (reflection coefficient), Gain, VSWR, and far-field radiation pattern. All the simulations shown in this paper were performed using a commercial finite element method solver, ANSYS High-Frequency Structural Simulator (HFSS).

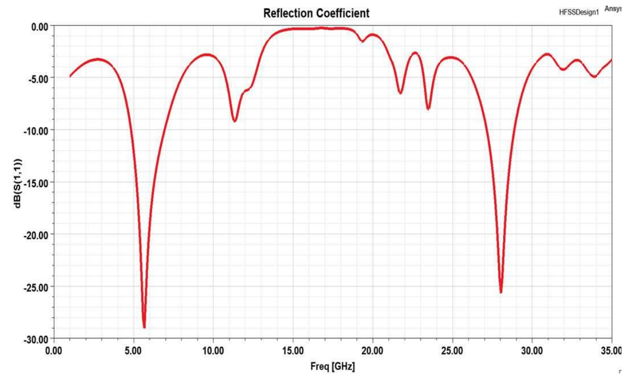

Fig 2: Simulated Return loss(S11) of antenna array

Fig 2 shows the simulated *S*-parameter (return loss) for the 2x3 MIMO Bridge connected antenna. The patch antenna shows multiple resonant frequencies at 5.85GHz and 28GHz, with a return loss of -29dB, -25.5dB, respectively. The designed antenna works well at both frequency bands showing a very high -10 dB bandwidth, i.e., 4.1 GHz bandwidth for Band 1 (5.85GHz), and a bandwidth of 3.4 GHz for band 2 (28 GHz). Table 2 represents the average gain and return loss observed from radiation patterns at different frequencies. The gain for antennas is ~4.65 dBi and 8.481dBi, at frequencies 5.85GHz and 28GHz, respectively.

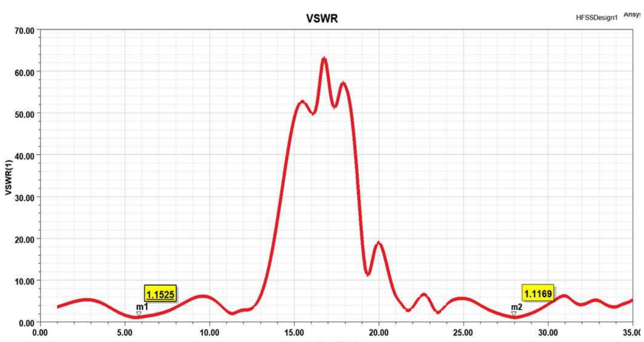

Figure 3: VSWR of antenna

TABLE 2: KEY PERFORMANCE PARAMETERS OF THE ANTENNAS DESIGNED ON RO3003

Substrate	***Center Frequency***	***~ Return Loss (dB)***	***Gain G (dBi)***
RO3003	5.85GHz	-29	4.65044
	28 GHz	-25.5	8.481

Figure 3 shows the simulated voltage standing wave ratio (VSWR) as a function of frequency. The VSWR is a very important parameter for any antenna, and this indicator gives us a good understanding of antenna behavior. Though VSWR 1:1 means perfect with different usages of antenna, VSWR can be varied differently. In some instances, A VSWR of less than 1.5:1 is ideal, while a VSWR of 2.2:1 is considered to be marginally acceptable in other applications where power loss is more critical, but sometimes it can go all the way to as high as 5.8:1. Due to large ground factor and multiple connection factor many automotive original equipment manufacturers (OEMs) specify 3.3:1 VSWR for 5G frequencies in the low band range and 2.5:1 VSWR across 5G high band range. It is noticed that the simulated VSWR is much better across the operating bands than 3.3:1 at the desired frequencies (5.85GHz and 28GHz) for RO3003 substrate; however, the lowest VSWR (1.11:1) is obtained at 28 GHz for the antennas.

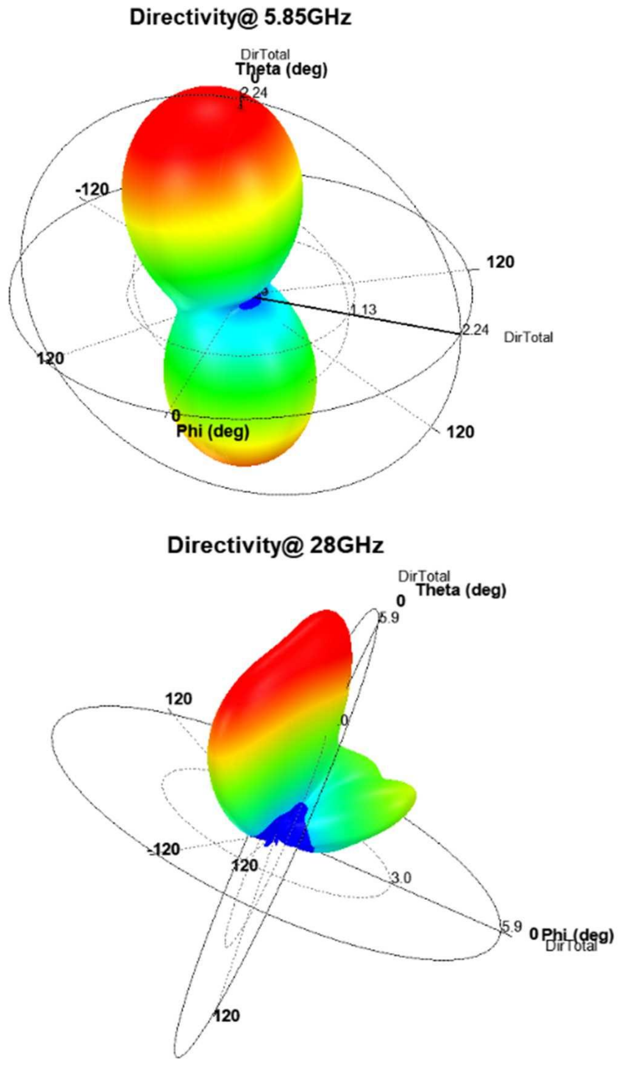

Figure 4: Directivity Radiation Pattern of 6 element MIMO antenna at different frequencies (a) 5.85 GHz, and (b) 28 GHz

Figure 4 shows the far-zone 3D radiation pattern for directivity at 5.85GHz and 28GHz, respectively. A good radiation pattern indicates the efficiency of the antenna and with this simulated radiation pattern, at the gain of 4.65dBi (5.85GHz) and 8.48dBi (28GHz) can radiate 74% and 88% of energy, respectively, which is well above the standard antenna radiation (55%). On the other hand, figure-5 shows the E-plane and H-plane radiation patterns. From simulated data, we identified that both planes are showing good results as there are no side lobes to waste power. The side lobes sometimes consume more power, so the directional power decreases. The DSRC band should avoid minimum values (nulls) as it directly impacts the coverage range at a certain azimuth. Figure 5 also shows the radiation pattern at 5.85 GHz has more angular coverage, which is required for V2X communication. On the other hand, 28GHz shows less angular coverage.

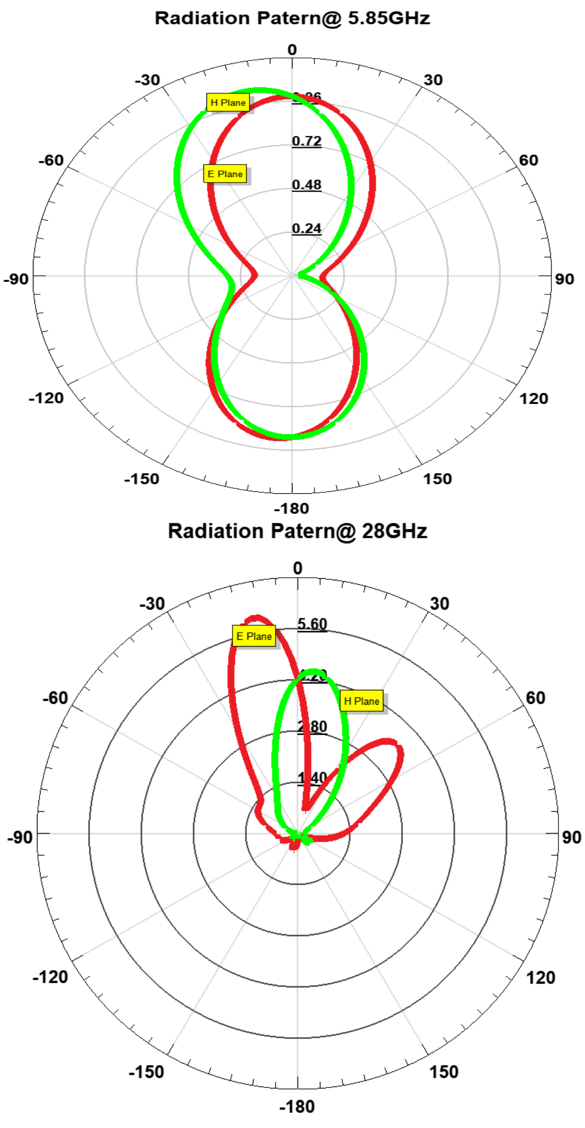

Figure 5. Radiation Patterns (E plane and H Plane) of antenna at different frequencies (a) 5.85 GHz and (b) 28 GHz

IV. DISCUSSION

This section summarizes some of the future directions of the work presented in this paper. With recent advancements in automobile communication, multiple-input-multiple-output (MIMO) technologies can be used in more higher band technology (6G) to improve link reliability, lower high data rates, and overcome multipath fading. The low-profile, compact-sized 2x3 MIMO array antenna element developed in this paper can be further formed into a 4x4 MIMO antenna configuration. First, six antenna elements are placed orthogonally on a single plane in a MIMO antenna structure to achieve polarization diversity. In addition to further improving each unit cell's performance (single array antenna), the length and width of the antenna element can be optimized further to improve bandwidth. Different impedance matching techniques can be implemented to try out the improvement of antenna performance. In this paper, only simulation results are shown, and in the future, the antennas will be fabricated using the standard manufacturing process and tested to get measured data. Both the data can be compared and adjusted accordingly. The unstable surface of the material brings one of the critical challenges in higher frequency antenna, especially in the automotive industry.

Moreover, the vast ground plane significantly impacts the antenna performance at higher frequencies. Therefore, the effect of this larger ground plan also needs to be tested. The components always face challenges in automotive due to their physical conditions and locations, and RF components face more challenges due to extreme heat, air flow, snow, rain, etc. Vehicles are driven at different speeds and in geographical areas, ranging from high summer heat to snow and ice. In addition, the external RF interface and interaction with other high-frequency components made them face significate challenges regarding their in-housing location, such as shark-fin rooftop aerials, rearview mirror, front-rear facia or engine compartments. Therefore, there is a need for detailed study on the behavior of this substrate and its location for automotive applications.

V. CONCLUSION

The paper presents a low profile 2x3 MIMO bridge array connected patch antenna for 5G and DSRC band for the vehicle to everything (V2X) applications. The design allows multiband technology 5G and DSRC operation over their permitted band. Based on the result, this highly performed, cheap, commercial substrate RO3003 provides excellent performance on a Bridge patch antenna. The designed and proposed 2x3 MIMO V2X patch antenna provides excellent simulation results at 5.85GHz and 28GHz band. The simpler design and compact size have very good cost and packaging advantages as it is easy to integrate with other components and is suitable for automotive applications. The antenna shows a return loss of -29 dB, gain of 8.48dBi at 28GHz (5G). This paper presents only simulation results; however, the antennas will be fabricated in the future, and the measurement results will be presented.

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