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Original Article

A Novel Design of Low Profile Two port MIMO Antenna for V2x Applications

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Abstract - *The proposed paper presents a Multiple-Input Multiple-Output (MIMO) antenna design for automotive applications that require two specifically designed elements: a low-profile UWB antenna and compact UWB monopole for sub-6 GHz network connectivity and Vehicle-to-Everything Vehicle communications over the frequency range. The suggested MIMO systems can be installed in a low profile or roof-of-the-vehicle container on top of the car. A two-element monopole MIMO system with the proper physical dimensions can work effectively throughout the entire range. Findings include measurements almost identical to those from the simulation and findings from putting the suggested antenna prototype on the top of an automobile. In light of the findings, VSWR, combined radiation patterns, ECC, DG, and passive isolation between elements are investigated.*

Keywords *- ECC, MIMO, Monopoleantenna, Vehicle.*

1. Introduction

In recent years, there has been a significant advancement in vehicle communication systems. Today's automobile communication systems are designed to deliver entertainment and information continuously. Regarding features and services, current car communication is more akin to a mobile phone on wheels, offering nearly all of the functionality seen in smartphones. The difficulties in antenna design will always arise as efforts to enhance this system's performance continue to grow [1-3]. This antenna is suitable for easy integration into the shark-fin housing and covers the 4G frequencies.

A three-dimensional antenna5 that can be fitted into the shark-fin housing is created by combining a double-shorted monopole antenna with a drop-shaped antenna. While the latter antenna supports WiMAX, WiFi, DCS, and PCS frequencies, the former covers LTE and GSM frequencies. There is a report on a conformal windscreen antenna for GPS use [4, 5]. Without adding intricate decoupling structures between antenna unit cells, the correlation between antenna components can be decreased by positioning the radiators in a horizontal and vertical orientation. To achieve polarization diversity, many MIMO/diversity antennas have been published recently without adding any intricate decoupling structure between antenna unit cells; the correlation between antenna components can be decreased by positioning the radiators in a horizontal and vertical Orientation. Many MIMO/diversity antennas have been published recently [5-8] to achieve polarization diversity. These antennas use different radiator arrangements. The cuboidal polystyrene block was encircled by radiating components of the MIMO antenna demonstrated in [7-9]. A proposed customizable MIMO antenna with a shared aperture in [10-12] had radiating parts arranged vertically and horizontally. Eight antenna elements of a 3-D array were shown, one of which was positioned vertically and the other four horizontally [13].

UWB-MIMO technology is created by combining UWB and MIMO technologies [14, 15]. Utilizing the benefits of both UWB and MIMO, UWB-MIMO technology efficiently increases data rates and channel capacitance while reducing multipath fading. Antennas are a crucial component of wireless communication systems, especially for UWB-MIMO systems [16-18].

A band-notched UWB-MIMO antenna is necessary. Various methods have been published recently to create band-notched features, such as loading filter structures [19, 20] etching slots, and others. Several researchers have suggested the MIMO slot antenna to overcome the restriction of shrinking antenna size. UWB-MIMO slot antenna with band-notched characteristics [21, 22], a T-shaped slot is etched on the ground to enhance the impedance matching characteristic and allow for the antenna's miniaturization [22, 24].

Proposed antenna designs and new developments in MIMO antenna architectures concentrate on creating integrated, small systems that can fit many antenna components in a constrained amount of space. Multi-layered substrates, metamaterials, and multi-functional designs are some of the sophisticated antenna miniaturization approaches used in this process.

New tiny MIMO antenna designs are currently used in wearables, smartphones, and Internet of Things devices without compromising functionality. For example, diversity antennas or patch antennas combined into a single small device can provide MIMO advantages without requiring a significant increase in size.

2. Proposed MIMO Antenna

The article examines several 2 × 2 MIMO antenna layouts for automobile applications in the V2X and 5G frequency bands. In the first arrangement, the vehicle's roof has two low-profile PIFA antennas spaced apart by a certain amount of space. The second arrangement features two PIFAs on the same printed circuit board at distinct rotational positions.

The ECC between the vertical current produced by the monopole and the horizontal current introduced by the PIFA is analyzed in the third configuration, which combines a PIFA and a tiny ultra-band monopole antenna on the identical PCB.

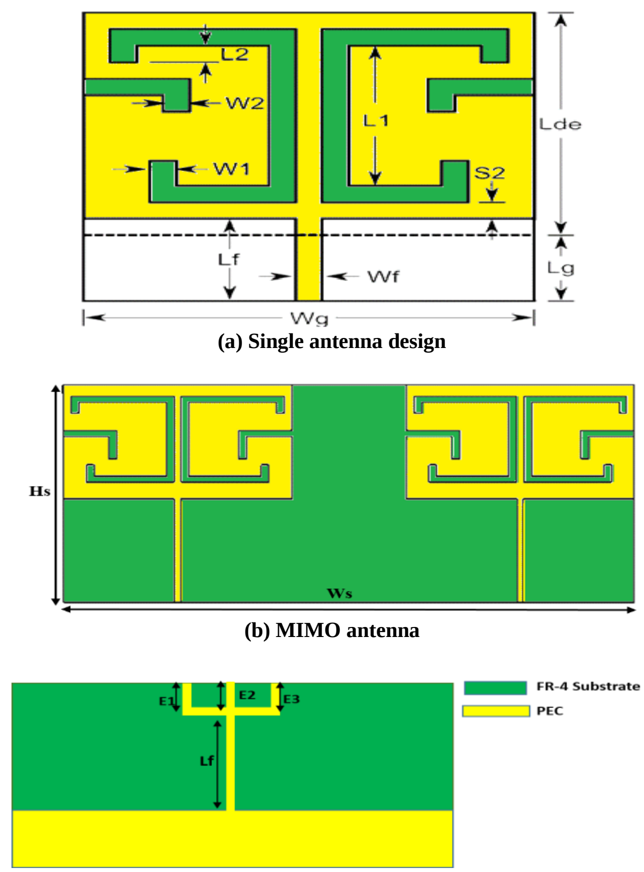
Both antennas work on 2 to 6 GHz and V2X frequency ranges (2.4 MHz–6 GHz) with appropriate rejection for using Groundside filtering stud and have appropriate physical dimensions, making the suggested MIMO system.

The proposed MIMO antenna designs have distinctive components. Each system uses orthogonal, rotational, or spatial variety in a different way to maximize MIMO performance. In contrast to previous research in the literature, the MIMO systems described in this study encompass the V2X spectrum at 5.2 GHz and the expanded sub-6 GHz communication bands from 2.4 GHz to 5 GHz. They also have suitable physical dimensions and distinctive features of the suggested antennas.

Additionally, the 5G/V2X MIMO systems include acceptable GNSS frequency filtering, allowing them to work with various navigation systems in the same housing.
MIMO implementation is shown in Figure 1.

The following novel, distinctive antenna contributions are included in the paper:

- In addition to the midband (about 3GHz), the antenna functions over the future communication bands in 1 GHz, sub-6GHz 5G NR, and Wi-Fi 6 G communication bands.
- The Characteristic Mode Analysis (CMA) is used to build the multi-band circular printed monopole antenna, and a design curve is provided to determine the appropriate dimensions.
- The use of stubs in the sub-1GHz band to increase this antenna's working bandwidth is described.
- The omnidirectional radiation pattern of the stub-loaded antenna provides a pattern variety appropriate for MIMO deployment.
- It has a co-surfaced ground plane and a 2-port antenna architecture, which might eventually lead to the creation of 3-D and conformal MIMO antennas.



(a) Single antenna design

(b) MIMO antenna

(c) Back side of the antenna

Fig. 1 The proposed UWB-MIMO antenna's shape and characteristics

Figure 1 shows the proposed UWB-MIMO antenna's shape and characteristics. The suggested antenna, 34x34 mm by 1.6 mm overall, is printed on an FR4 substrate with a relative dielectric constant of 4.4. A two-element L-shaped system is used to calculate the optimized design parameters. A CST microwave simulation studio, an electromagnetic simulation program, is used. The ideal parameters are listed in Table 1.

Table 1. Design parameters of the antenna

S.No	Parameter	Value	Parameter	Value
1	Wg	30.80mm	ws	45mm
2	Lg	10.41mm	Hs1	18.2mm
3	Wf	818.1μm	Wp1	1.016mm
4	Lf	18.47mm	E1	0.5mm
5	S2	2.061mm	L1	5.6mm
6	W1	1.016mm	L2	12.5mm
7	W2	1.016mm	Lde	20.5mm

Table 1 is the design parameter antenna design parameter that identifies two or more parameters. The two L-shaped element strip lines can be positioned perpendicular to increase isolation. However, the antenna is so compact that there is still a substantial mutual coupling between the parts. As seen in Figure 1, to further reduce the mutual coupling, an E-shaped device linked to the ground inserts a parasitic strip between the next microstrip-fed line. As a reflection plate, parasitic strips are frequently positioned on the ground to stop the antenna elements from interacting with one another. Since the antenna proposed in this study is a slot antenna, the impedance matching of the antenna will be greatly affected by the placement of parasitic strips on the ground, which will change the structure of the E-type slot.

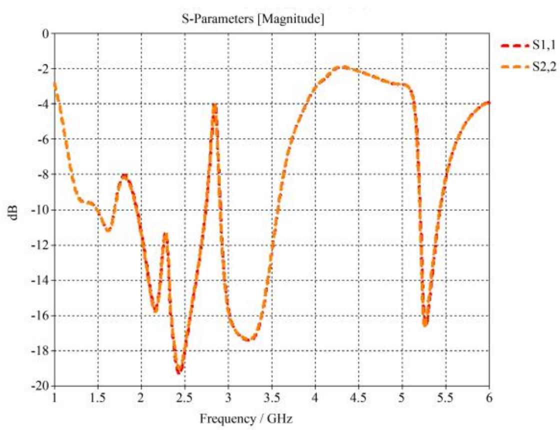


Fig. 2 Simulated S11 of the MIMO

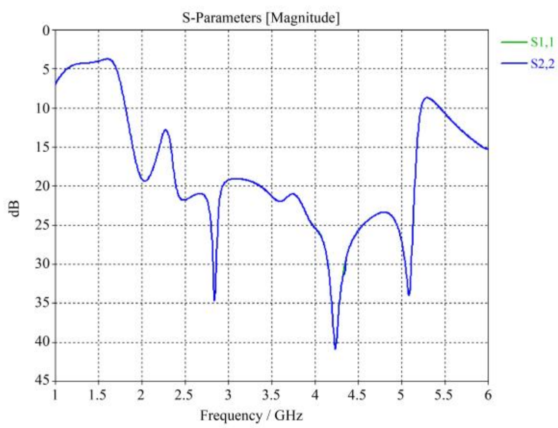


Fig. 3 Transmission coefficient S21&S12

Figure 3 shows that the positioning of decoupling structures affects antenna matching of resistivity in the low and high-frequency range transmission coefficients of antennae one and two. The ECC can be entirely ascertained from the antenna isolation for efficient antennas (say >90% or > -1dB). Thus, you can measure s12 and calculate the ECC without assessing the radiation patterns of the antennas.

Antenna 2 will "see" a radiation pattern transmitted by antenna one and receive energy proportionate to the degree of correlation between the radiation patterns of the two antennas since their transmit and receive characteristics are the same (owing to reciprocity).

Despite its simplicity, the reasoning proves to be accurate. To increase ECC, you may save a great deal of effort and concentrate on enhancing isolation. In terms of isolation (S12).

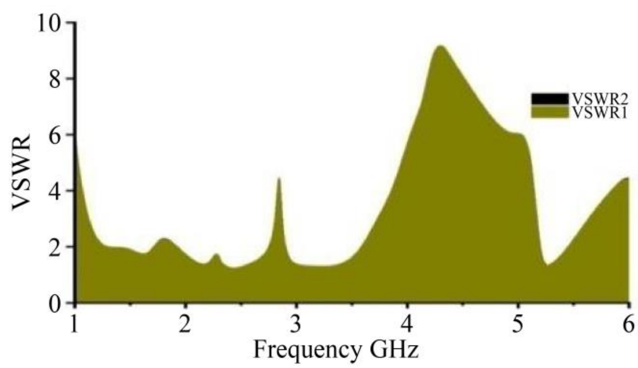


Fig. 4 VSWR of the antenna 1&2

3. Envelope Correlation and Diversity Gain

Multiple Input, Multiple Output (MIMO) systems are an excellent method to increase wireless throughput, or the quantity of data you can transfer per second. That implies you have a radio that can send and receive numerous streams of data at the same time.

Antenna Diversity describes the case in which more than one antenna is implemented in a device. The correlation of two antennas or the diversity gain is evaluated to specify the benefit of multiple antennas. In this template, both values are calculated from the Fairfield Pattern according to the formulas:

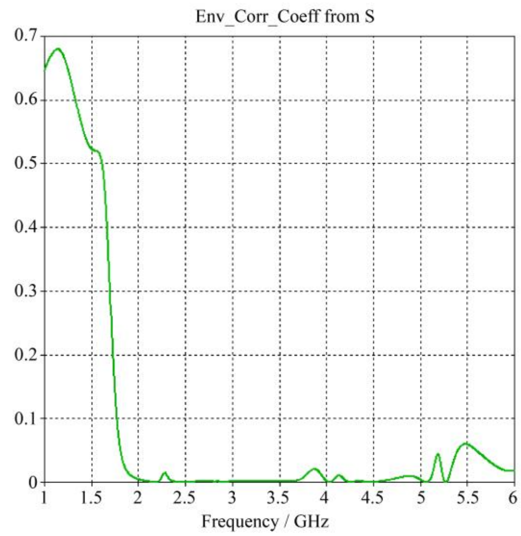


Fig. 5 Envelop the correlation coefficient

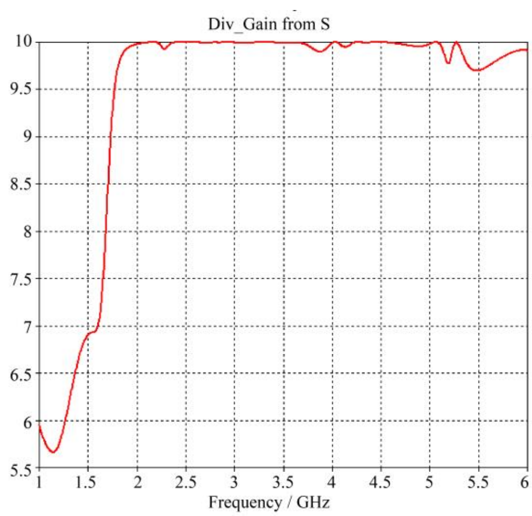


Fig. 6 Diversity gain of the antenna

Figure 5 shows ECC how independent two antennas' emission patterns are from one another. Consequently, if one antenna was vertically polarized and the other was fully horizontally polarized, they would not communicate.

3.1. Envelope Correlation

$$\rho_{eij} = \frac{[\oint G_{ij}(\Omega)d\Omega]^2}{\oint G_{ij}(\Omega)d\Omega \oint G_{ij}(\Omega)d\Omega} \quad (1)$$

$$G_{ij} = XPDG_{\theta i}(\Omega)G_{\theta j}(\Omega)p_{\theta} + G_{\phi i}(\Omega)G_{\phi j}(\Omega)p_{\Phi}(\Omega) \quad (2)$$

$$\rho_{eij} = \frac{\left|S_{ii}^{*}S_{ij} + S_{jj}^{*}S_{ji}\right|}{\left|\left(1-|S_{ii}|^2-\left|S_{ji}\right|^2\right)\left(1-\left|S_{ji}\right|^2-\left|S_{ij}\right|^2\right)\right|} \quad (3)$$

Pθ (Ω) and PΦ (Ω) describe the Gaussian distributions as shown above.

In the case of isotropic power distribution (Pθ (Ω)=PΦ (Ω)=1), no cross-polarization ratio (XPR = 0 dB), and a lossless structure, the Envelope correlation calculated from S-Parameters

3.2. Diversity Gain

$$DG = 10\sqrt{1-\rho_{eij}}$$

Innovation of the present antenna for future communication, higher isolation, and a lower antenna beam is needed. Monopole antennae arise in the lower bands with higher bandwidth. 90% reduce the radiation losses. The antenna is mainly compatible with vehicular applications.

4. Results and Discussion

After parametric analysis and optimization, the suggested antenna is designed and constructed using CST Microwave Studio Software. To measure the proposed MIMO/Diversity antenna, a VNA machine MS2703 V is used.

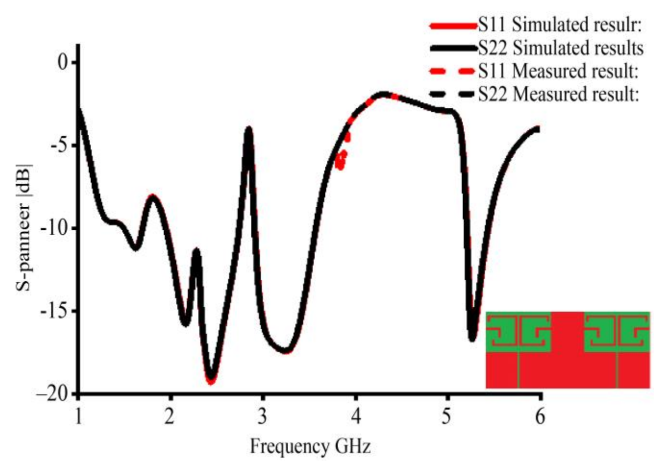


Fig. 7 Reflection coefficient of the antenna simulated and measured

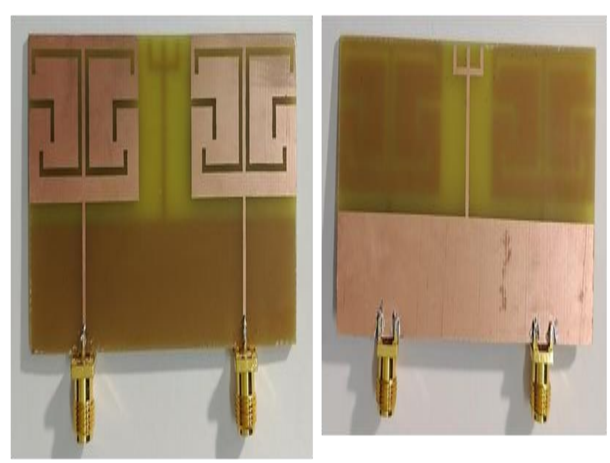
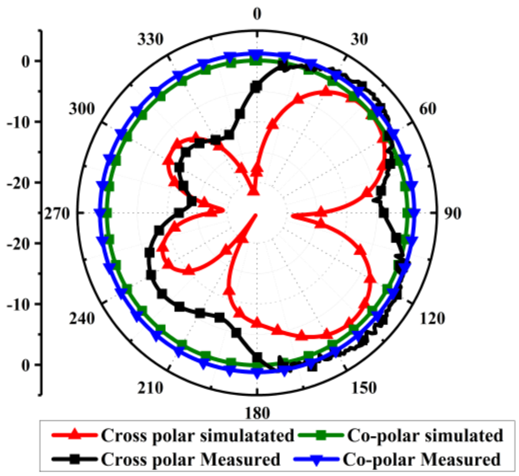
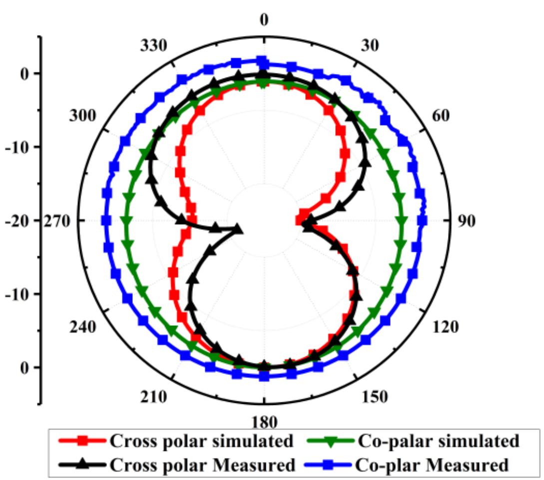


Fig. 8 Fabrication of the antenna

Fig. 9 Antenna connected to VNA machine



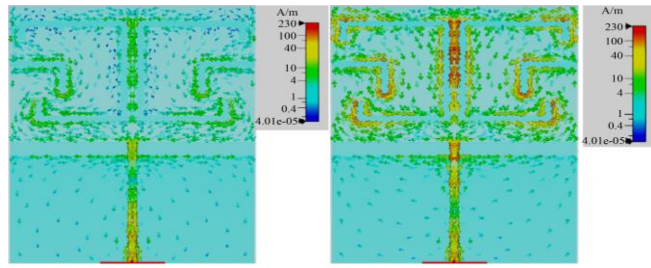
(a)



(b)
Fig. 10 Far-field results

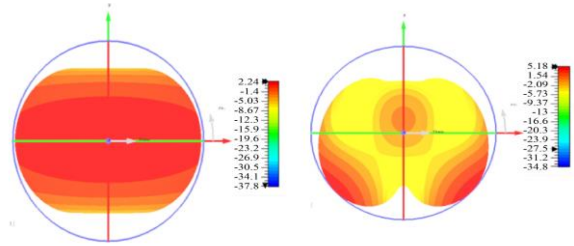
Far-field results Figures 10 (a) and (b) of the 2.4GHz 5.2GHz of antenna co-cross and co-polarized simulated and measured results.

The antenna prototype's gain and radiation patterns were assessed in a far-field anechoic chamber (Figure 10). Normalized radiation patterns at 2.4 and 5.2 GHz are displayed, respectively, and there is good agreement between the measured and simulated results.



(a) **(b)**
Fig. 11 Surface current distribution of antenna prot1&2 2.4 and 5.2GHz

Figure 11 shows the current distributions used to analyze the circular polarisation generation of the proposed antenna. The surface current distribution illustrates the mutual coupling performance analysis and other performance of the designed antenna over the desired frequency band and is further justified.



(a) (b)
Fig. 12 The 3D radiation pattern of the 2.4 & 5.2 GHz comparison

Table. 2 Isolation of the antenna

Ref	Frequency GHz	ECC	Isolation dB	Gain (dB)
[14]	1.8-5.5	<0.015	12	1.5
[15]	2.2-4.5	<0.008	14	2.5
[16]	1.8-5.2	<0.002	15	2.8
[17]	2.2-5.2	<0.004	18	2.9
[18]	2.5-5.5	<0.014	14	3.1
[19]	1.8-5.4	<0.002	16	3.5
[20]	2.2-5.5	<0.004	15	3.7
[21]	2.4-5.5	<0.002	18	4.1
[22]	2.4-3.5	<0.008	20	2.9
[23]	2.5.-5.8	<0.015	22	4.3
[24]	2.4-3.4	<0.002	22.3	4.1
[25-28]	2.5-5.98	<0.008	20	4.0
Present proposed work	2.4-5.2	<0.02	35	4.58

Comparison of other antennas UWB-MIMO antennas have a compact dimension. Achieving numerous notches and sound isolation in a tiny antenna can be challenging-a novel design structure with less thickness. The proposed 2-port UWB-MIMO antenna has petite dimensions, dual-band notching, improved isolation, and more significant gain than previous antennas.

However, improvements in polarization diversity and tiny, compact antennas make it possible to include the suggested design's high performance-primarily the newness of the MIMO antenna's design miniaturization. The antenna has a minimal thickness (0.5 mm) and superior isolation and radiation efficiency compared to other systems.

Multi-band MIMO antennas (2.4 GHz, 5.2 GHz) enable simultaneous communication in several frequency bands, making possible effective use of the available spectrum. This is especially helpful for systems like Wi-Fi, 5G, and IoT that must work with several standards. Adaptive beamforming techniques, where the antenna array dynamically adjusts to optimize signal strength in desired directions, are being integrated into UWB designs. This increases the system's robustness and efficiency, especially in multipath or interference-heavy environments.

5. Conclusion

This design of the two-port UWBMIMO antenna is (30.8x45) mm by 1.6 mm overall. With a high isolation of 25 dB, the suggested antenna can function in the whole UWB band. The MIMO antenna uses parasitic components, protruded ground, and polarization diversity to accomplish excellent isolation. The radiation pattern, isolation, and observed return loss are all consistent with the simulated ones. The antenna's gain is 4.5 dBi on average. The suggested antenna has a strong diversity performance, with a TARC of less than 25 dB, a DG greater than 9.9985 dB, and an ECC of less than 0.02. Overall, the suggested antenna shows promise for UWB-MIMO wireless applications.

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