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Dual-Port MIMO antenna design for IoT: Analysis and implementation

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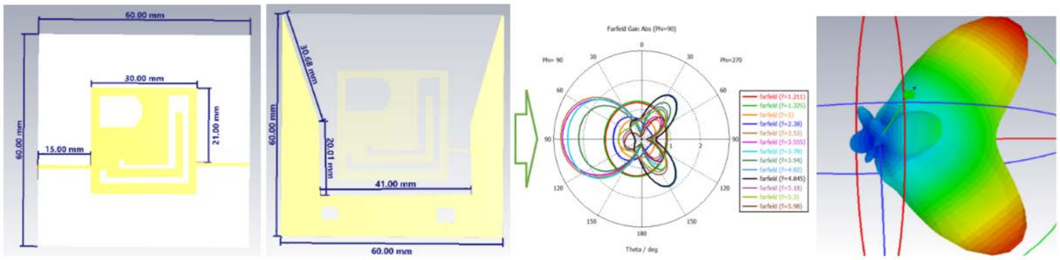
ABSTRACT



Two Port MIMO antenna 2D 3D radiation

The research presents a new type of antenna that makes use of MIMO technology, which employs multiple antennas for signal transmission and reception. This antenna also features a defective ground structure, a patterned ground plane that is frequently utilized to boost an antenna's performance. Adding or altering the ground plane patterns can enhance the antenna's performance. To improve antenna performance, a variety of designs, including rectangular and asymmetrical shapes, are being investigated, indicating a flexible method of antenna design optimization. The following features apply to the designed MIMO antenna: 60 x 60 mm2 in size, two ports are present. Operating Band: 1-6 GHz, Gain: 6.40 dBi, Return Loss (RL): -30.06 dB. The antenna is made to work in the 1-6 GHz frequency band, which includes a large variety of wireless communication frequencies. It specifically indicates appropriateness for WLAN frequencies such as 1.2 GHz, 2.4 GHz, 5.2 GHz, and 5.98 GHz that are used in IoT applications. A single radiating element with two slits and enhanced rectangular patches are features of the antenna's design. It can support sub-6 GHz WLAN bands as a result, making it appropriate for IoT applications that use these frequencies. In this research, a MIMO antenna with a DGS is shown. It has good performance characteristics, such as a broad operating band and applicability for IoT applications in different WLAN frequency bands. This antenna design might be useful for wireless communication systems needing multiport capabilities and increased performance.

Keywords: Antenna array; Defected Ground Structure (DGS), Gain, Internet of Things (IoT), Wireless Local Area Network (WLAN)

INTRODUCTION

Due to the increasing number of users and insatiable need for faster data rates, wireless communication technologies have advanced quickly and relentlessly in the modern period.[1] Notably, the interest in and acceptance of Internet of Things (IoT) technologies have increased at an unparalleled rate during the past ten years. IoT, an extension of the World Wide Web, easily connects a wide range of internet-connected devices, igniting a plethora of applications for vehicle and road traffic control, industry, and healthcare.[2-4,5-7,8-9] The growth of IoT applications has accelerated antenna researchers' efforts to develop wireless systems that can support this complex environment.[10] Signal quality, device compatibility, multifunctionality, and reliability are the top requirements in the IoT space. In this situation, Wireless Local Area Network is the go-to wireless technology since it gives consumers freedom and mobility.[11] IoT applications frequently use WLAN's operational bands, which include 2.4 GHz, 5.2 GHz, and 5.8 GHz, each having unique bandwidths[12] and coverage ranges. Due to their superiority in beam steering, data capacity augmentation, and diversity properties, Multiple-Input Multiple-Output systems herald the future of modern communication technology.[13-14] The integration of several radiating elements in constrained areas while guaranteeing strong isolation and minimal correlation between closely spaced antenna components provide tremendous obstacles in the creation of a state-of-the-art MIMO system. Additionally, supporting lower WLAN bands may have an influence on antenna size, necessitating wise design decisions, such as sufficient spacing between radiation elements to prevent reciprocal coupling.[15-18]

A broad variety of multi-band antennas have been studied in academic literature, including different types of dipoles, microstrip patches, monopoles, and dielectric resonators.[20-23] As wireless

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communication technologies have advanced, a wide variety of dual-band antenna structures have emerged, each designed to satisfy particular application requirements. In order to accommodate WLAN/WiMAX situations, notable designs include E-shaped structures, slotted triangular configurations, asymmetric T-shaped arrangements, half-mode substrate integrated cavities, and rectangular-shaped designs fed by CPW.[20-24] Additionally, the academic literature explores triple-band monopole antennas and introduces cutting-edge ideas like Y-shaped radiators with twin ring resonators, Y-shaped radiators with L-shaped slits etched into the ground plane, as well as L-shaped and T-shaped radiators, among others[24-31]. Quad-band monopole antennas have been thoroughly investigated for those seeking even more bandwidth[32-33]. Multiple-input-multiple-output (MIMO) antenna topologies have become very popular in IoT applications. As shown in the academic literature,[34-46] notable examples include a planar multi-band MIMO antenna, a split-ring resonator that is complementary to a triple-band MIMO antenna, and numerous more innovative designs. These cutting-edge MIMO architectures support a broad range of IoT requirements and frequencies, adding to the development of wireless communication technologies. Although these designs cover a wide range of frequencies and applications, it is important to note that particular antenna sizes make it difficult to integrate IoT modules onto printed circuit boards.[39-51]

The objectives of the work are:

- The novel double-sided (DS) MIMO antenna with dual ports described in this article is specifically designed for Internet of Things applications.
- To minimize mutual coupling, the antenna carefully places its radiators on either side of the dielectric substrate.
- The design offers extraordinary versatility, enabling four separate frequency bands covering GSM, Wi-Fi/WLAN, WiMAX, and 5G by the integration of numerous strips, each with various wavelengths harmoniously merged with the radiator.
- Notably, the suggested MIMO antenna maintains a surprisingly compact form factor, measuring just 60 mm x 60 mm^2.
- The adoption of a defective ground plane at the targeted frequencies adds to increased impedance matching.

METHODOLOGY

The use of MIMO antenna systems has become crucial in the quest for improved wireless communication performance. These systems, which use numerous antennas to broadcast and receive signals, are crucial to improving several communication-related functions. A good example is the 2-port MIMO system shown in this paper, which uses the capabilities of two antennas to improve signal quality, boost data throughput, and reduce interference, among other advantages. CST Microwave Studio, a well-known tool in this field, is used systematically to build and analyze electromagnetic structures for antennas. In the context of this work, Figure 1 shows a convincing use of a Defected Ground construction to depict the suggested MIMO antenna construction, successfully exhibiting its configuration on both the top and bottom sides for thorough understanding and analysis.

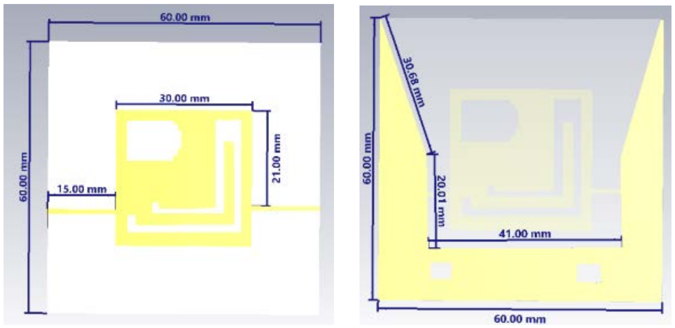


Figure 1: Designed Two port MIMO antenna

Our initial research focused on a two-port antenna configuration, as shown in Figure 1, to fully comprehend the performance of the antenna. Figure 3 illustrates the results of this investigation and gives light on the measured antenna response. We used formulae 1 through 4 to calculate important design characteristics such as the antenna's length and diameter, as described in the literature.[52] These formulas act as crucial calculators, enabling accurate characterization and performance optimization of the antenna's critical dimensions.

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L \tag{2}$$

$$\Delta L = 0.412h\,\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.258}\left[\frac{\frac{w}{h} + 0.264}{\frac{w}{h} + 0.8}\right] \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} - \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{4}$$

Important parameters are defined in the context of antenna design and characterization to ensure accurate performance analysis. These parameters include "h" for the height of the substrate, "Wp" and "Lp" for the width and length of the patch, and εeff and $\varepsilon relative$ for the effective and relative permittivity's of the substrate, respectively. To further evaluate the behavior and performance of the antenna, central parameters like the central frequency ('fc'), effective length ('L'), and light speed ('c') are important. The accurate determination and fine-tuning of antenna characteristics using these formulaic representations and parameter definitions are crucial to optimizing antenna design for particular operational needs.

Two MIMO components are deliberately positioned in the antenna system's layout to create a geometric framework above and below the radiating patch. The geographic coverage and overall performance of the antennas are enhanced by this creative design approach. Notably, to enhance antenna performance, this antenna design has an asymmetrical ground construction in the bottom layer. In particular, the ground structure incorporates rectangular gaps strategically to efficiently optimize the antenna's unique performance characteristics. The antenna construction is painstakingly built on an FR4 substrate with a relative permittivity (*ε*r) of 4.4, and a thickness of 1.6 mm. The electromagnetic wave propagation properties of an object are significantly influenced by the choice of permittivity. This study provides insightful information about the development of antenna design, from simple single-element antennas to the more intricate two-element MIMO arrangement. This evolution necessitates a thorough investigation of factors such as Gain, radiation patterns, and matching of impedance and how the addition of different components affects them. The designed MIMO antenna, which has a single radiating patch with numerous slits, measures 30 mm in length and 30 mm in width and shares a ground plane, is notable for its small design. Low mutual contact between the patches was found as a result of the initial insertion of slots for the 6 GHz operation of rectangular antenna elements. Due to the increase of current channels caused by these slots, mutual coupling at the required frequency was significantly reduced, demonstrating the antenna's improved performance characteristics.

RESULTS AND DISCUSSIONS

The close proximity of the antennas in MIMO (several-Input Multiple-Output) antenna systems, where several antennas are placed side by side on the transmitter and receiver, can cause mutual couplings between certain antenna elements. The performance of the MIMO antenna can be severely impacted by this phenomenon, also known as mutual coupling.[16,17] It usually causes the isolation between antenna elements to decrease, which could affect radiation patterns and general performance. The sub-6 GHz frequency spectrum is appealing due to its lower attenuation loss, broader coverage area, and relatively lower data speed given the constrained available bandwidth. Therefore, it is essential to build a MIMO antenna that can handle multiband operation for both FR-1 and FR-2. It becomes crucial to check that the antenna's emissions and bandwidth are appropriate for the specified frequency ranges. The detailed examination of a dual-element antenna included the reflection coefficient, radiation pattern, antenna gain, and numerous diversity parameters.[22,23] It tries to shed light on how the relative arrangement of antenna elements affects performance in a MIMO environment by examining two different instances.[19]

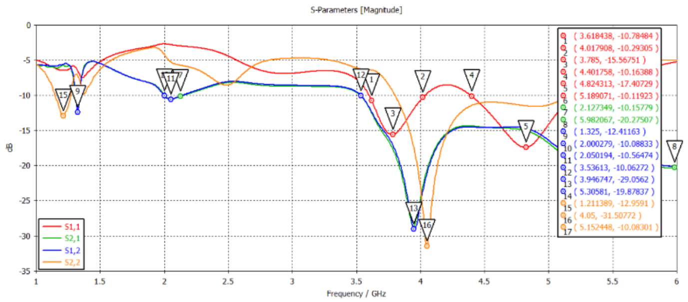
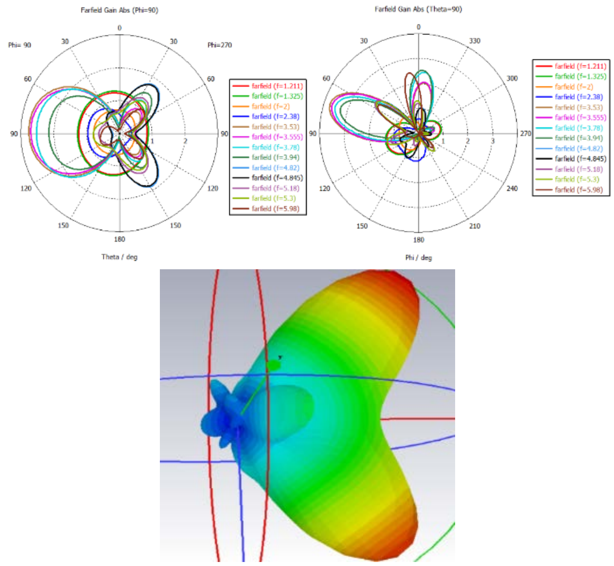
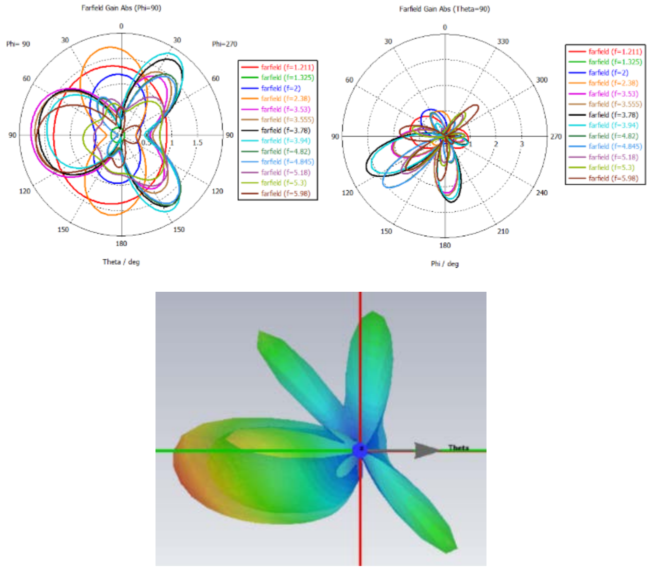


Figure 2: Return loss analysis of the Designed Antenna

The performance of the antenna system is mainly evaluated in Figure 3, with a focus on the S parameters, notably S11 and S12. In this situation, two MIMO antennas are used, with the elements oriented both horizontally and vertically. With a range of 3.5 to 6 GHz for case 1 and 3.785 to 4.94 GHz for case 2, the impedance bandwidth attained is impressive. Case 1 displays a resonant peak within this range at 3.785 GHz, with a remarkable |S11| value of -15.16 dB and an even more impressive isolation measured by |S12|, which is greater than -29.05 dB. Case 2 shows a resonant peak at 4.05 GHz, along with isolation |S12| larger than -17.40 dB and a |S11| value of -31.50 dB. These findings highlight both architectures' strong MIMO isolation capabilities. In contrast to instance 2, where it is linked to spatial diversity, case 1's higher isolation can be attributed to a unique ground profile. Importantly, the measured findings closely match the simulated values, supporting the correctness and dependability of the performance assessment of the antenna system.



a) Port 1 Radiation Pattern in 2D and 3D



b) Port 2 Radiation Pattern in 2D and 3D

Figure 3: Radiation pattern response of the designed antenna at Port 1 and Port 2

The co/cross-polarization 2D radiation patterns in the E and H planes, which were precisely measured in an anechoic laboratory, are shown in detail in Figure 4. The outcomes show a remarkable omnidirectional radiation pattern for the antenna, which is observable in both the E and H planes. The ORBIT/FR far-field measuring device was used to carefully evaluate 2D radiation patterns in an anechoic environment (Figure 4), providing in-depth knowledge about the antenna's radiation characteristics. This thorough analysis involved measurements made in the x, y, and theta planes across a range of -90 to 90 degrees. A horn antenna with a typical gain of 20 dBi was used for signal transmission. The suggested antenna's 6.40 dBi observed gain attests to its applicability and high potential as a MIMO antenna for a variety of applications and supports its positive performance features.[19]

CONCLUSIONS

MIMO technology is a significant improvement over older single-input single-output (SISO) wireless communication technologies. MIMO makes it possible to transmit several data streams at once across the same frequency band, which leads to noticeably faster data rates. The system's overall throughput rises as the number of MIMO layers does as well. This work offers a small 2 x 2 MIMO antenna with a shared ground plane designed for 5G communications. Slits were deliberately added to the radiators to improve current flow, reducing the antenna's footprint while keeping its simplicity. Slots were also added to the patches to ensure strong isolation between resonators. The MIMO antenna suggested in this work has the potential to be an attractive option for 5G applications, as shown by the return loss (S_{11}) simulation findings. Surprisingly, the simulated outcomes match the experimental outcomes very closely, displaying an outstanding level of agreement across multiple measures, including S-parameters, radiation patterns, and diversity gain. Notably, this antenna demonstrates its effectiveness and dependability in the context of next-generation wireless communication while being smaller than preceding sub-6 GHz working bands. These results confirm its adaptability to the challenging environment of 5G technology, emphasizing its strong performance and capability to meet the changing requirements of contemporary wireless networks.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest for the publication of this work.

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