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REGULAR ARTICLE

Design and Simulation of a Compact U-Shaped 4-Element MIMO Antenna for Secure Wi-Fi Applications

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The performance and capacity of wireless systems can be significantly increased by adding many antennas to the transmitter and receiver ends. An overwhelming number of users have spurred the growth of digital platforms, which in turn compels communication systems to provide information at an exceptional rate with high reliability and quality of transmission. The achievement of such parameters through wireless systems with single Antenna Elements is not feasible. As a result, advanced modern high-speed communication systems are increasingly utilizing multiple two-way antennas (MIMO). These antennas are now considered the most important component in modern wireless technology. Multiple Input Multiple Output (MIMO) technologies use several antennas to fulfill the demands of higher data throughput and reliability. This study recommends a compact, four-element MIMO antenna explicitly designed for Wi-Fi applications. The antenna comprises four U-shaped patch components with a maximum gain of 7.8 dB at 5 GHz. The HFSS simulation platform was used to design and simulate the suggested antenna. The MIMO antenna has a 50 MHz bandwidth with a 10 dB impedance to improve Wi-Fi security. Additionally, there is more than 15 dB of isolation between neighboring antenna ports. This lowers interference and improves optimal performance in small configurations.

Keywords: Return loss, MIMO antenna, Isolations, HFSS, Wi-Fi application.

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1. INTRODUCTION

MIMO (Multiple input–Multiple output) systems have become essential in addressing the increasing demands for high data rates in modern communication systems. These systems can simultaneously transmit and receive signals through parallel channels, enhancing channel capacity without additional bandwidth or transmission power. This capability has made MIMO systems a highly attractive solution for improving the performance and reliability of wireless mobile communications [1]. Write the reference.

MIMO technology is gaining popularity because it can significantly upgrade the reliability as well as efficiency of wireless communication networks. MIMO systems use both line-of-sight as well as non-line-of-sight propagation to expand channel capacity, improve coverage, and provide more exceptional dependability across a range of communication circumstances [2-5, 7]. Several factors must be carefully considered while configuring, including mutual coupling, gain, and efficiency [5-10]. The substrate material dramatically influences the total performance of the antenna. Low-cost FR-4 is commonly used substrate due to its ability to optimize impedance matching factors, gain, and isolation. dependability, and cost-effectiveness by utilizing cutting-edge simulation methods and material selections to optimize critical parameters. This study's primary objective is to design and evaluate a compact MIMO antenna system that meets the demanding requirements of modern Wi-Fi applications [5, 7]. The suggested design seeks to attain high performance,

2. DESIGN OF MIMO ANTENNA HAVING U SHAPE

Figure 1 shows the suggested MIMO antenna operating at 5 GHz. The antenna utilizes FR4 as the substrate material, characterized by a dielectric constant ($\varepsilon_r = 4.4$) and a loss tangent ($\delta = 0.02$), with a thickness of 1.6 mm. The design comprises four identical U-shaped antenna elements, each with dimensions of 19×4 mm^2.

The substrate and ground plane share the exact dimensions, measuring 76×58 mm^2. The patch and ground plane thickness are 0.05 and 0.0349 mm. The antenna's radiating elements are positioned on the top surface of the substrate (FR4), while copper is employed as the conductive material for both the patches and the ground plane.

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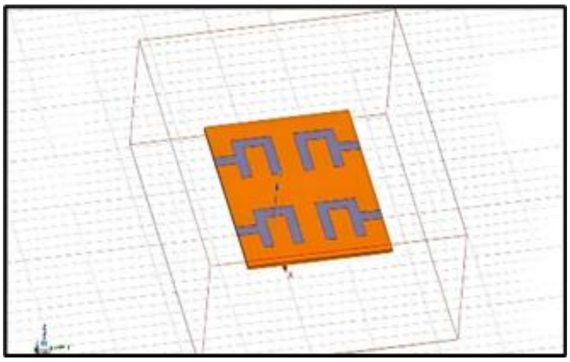

Fig. 1 – Design of proposed MIMO antenna using HFSS software

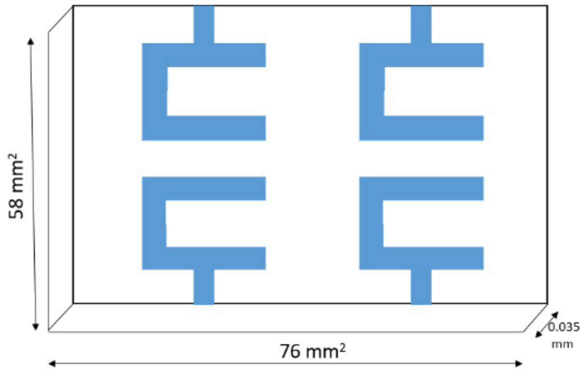

Fig. 1.1 – Design of MIMO antenna (having *U*-shape) with dimension

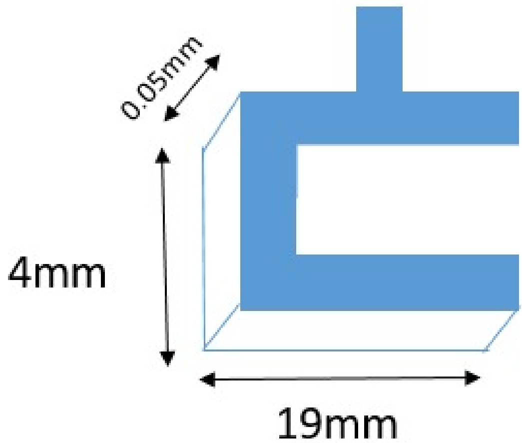

Fig. 1.2 – Design of MIMO antenna(having *U*-shape) one slot with dimension

3. RESULT AND OBSERVATION

Figure 2 shows the simulation results for S11 at 5 GHz, which validate a 50 MHz – 10 dB impedance bandwidth. At 5 GHz, the antenna's efficiency is 42.12 %, and its highest gain is 7.8 dBi. There is little interference because the distance between neighboring antenna ports is greater than 15 dB. The proposed antenna is designed to enhance security in Wi-Fi applications with a narrow bandwidth of 50 MHz.

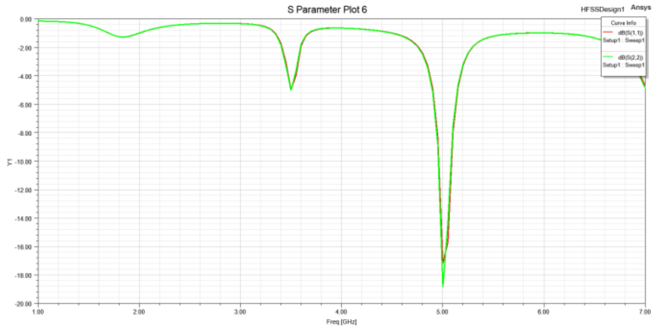

Fig. 2 – Return loss at 5 GHz

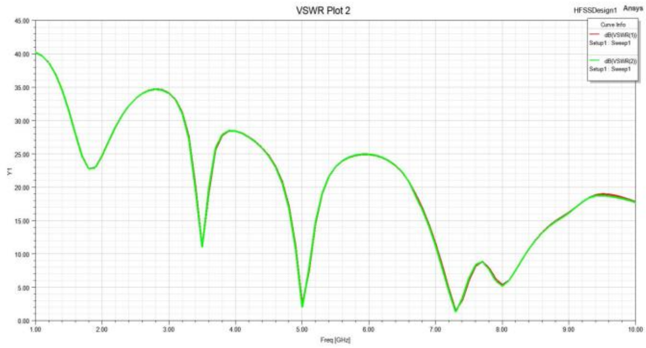

Fig. 3 – VSWR at 5GHz

E plane as well as *H* plane radiation pattern, as seen in Fig. 4, guarantees adequate coverage of the surrounding area.

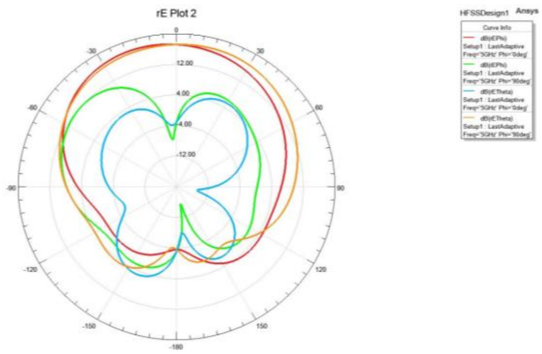

Fig. 4 – *E* and *H* plane pattern for 5 GHz

The performance of an antenna is evaluated based on various parameters, including gain, radiation pattern, efficiency, and bandwidth. Among these, gain, and radiation patterns are crucial in determining the antenna's effectiveness for a given application. In this discussion, We examine the suggested antenna's radiation pattern and 3D gain, shown in Figures 5 and 6, respectively.

An antenna's gain shows its ability to concentrate emitted power in a particular direction, unlike an isotropic radiator, which radiates uniformly in all directions. Decibels relative to an isotropic source (dBi) are commonly used to assess gain. The results show that the highest gain for the suggested antenna is 7.8 dBi, a substantial number that indicates efficient radiation and strong directivity.

An antenna with a high gain efficiently concentrates its energy in a desired direction for applications like satellite communication, radar systems, and wireless communication, where focused energy transfer is essential. Figure 5's 3D gain plot offers a thorough overview of the radiation properties of the antenna. The gain pattern's form aids in comprehending how power is distributed across various angles.

A smooth and consistent gain pattern in the intended direction indicates minimal distortion and ideal performance. High side or back lobes in the gain plot may cause inadvertent interference and decreased efficiency. The primary lobe of the suggested antenna is well-defined, guaranteeing that the most energy is emitted in the desired direction while maintaining manageable side lobe levels.

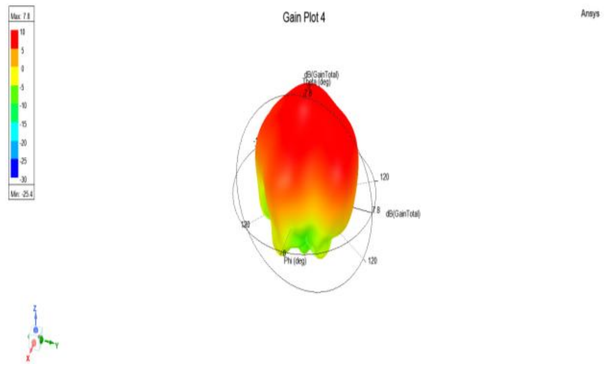

Fig. 5 – 3D gain pattern at 5GHz

An antenna's radiation pattern explains how the emitted power changes with direction. Two-dimensional (2D) or three-dimensional (3D) plots are frequently used to depict it. Figure 6's radiation pattern sheds light on the suggested antenna's spatial energy distribution.

A distinct main lobe with few side lobes is the ideal radiation pattern. While the side lobes are undesired emissions that may interfere with neighboring systems, the main lobe indicates the direction in which most power is concentrated. The back lobe – which indicates radiation in the opposite direction – should be reduced to increase the antenna's efficiency.

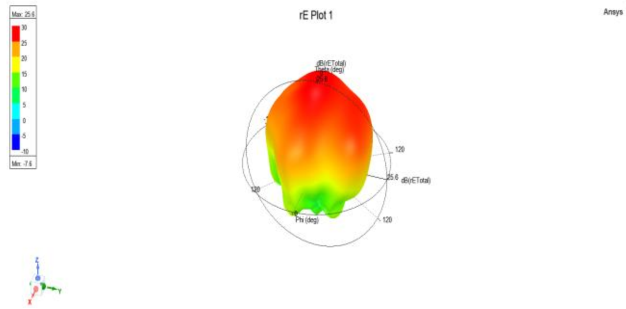

Fig. 6 – 3D radiation pattern at 5GHz

The ideal radiation pattern for an antenna with a maximum gain of 7.8 dBi is directional, meaning that the antenna focuses most of its energy in one direction rather than radiating evenly in all directions. Patch, horn, and some Yagi-Uda antennas – frequently utilized in radar and wireless communication applications – all exhibit this behavior.

Another crucial factor gleaned from the radiation pattern is the antenna's beamwidth or the angular width of the main lobe. High directivity, or the ability of the antenna to efficiently focus its radiation, is indicated by a narrow beam width. Conversely, a larger beamwidth indicates poorer directivity but more coverage.

4. CONCLUSION

This paper focuses on the MIMO antenna suitable for 5 GHz Wi-Fi applications [8-12]. MIMO antenna, which was built using FR4 substrate material, is thoroughly examined. The antenna geometry at 5 GHz is explained in depth. The results demonstrate that the proposed design offers the necessary frequency spectrum with sufficient efficiency and simulation performance. The antenna's physical architecture also makes integrating it with embedded electronics possible, making it appropriate for a range of wireless communication applications.

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Проектування та моделювання компактної U-подібної 4-елементної MIMO-антени для безпечних Wi-Fi-додатків

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Продуктивність та пропускну здатність бездротових систем можна значно збільшити, додавши багато антен до передавача та приймача. Переважна кількість користувачів стимулювала зростання цифрових платформ, що, у свою чергу, змушує системи зв'язку надавати інформацію з винятковою швидкістю, високою надійністю та якістю передачі. Досягнення таких параметрів за допомогою бездротових систем з одним антенним елементом є неможливим. Як результат, сучасні високошвидкісні системи зв'язку все частіше використовують кілька двосторонніх антен (MIMO). Ці антени зараз вважаються найважливішим компонентом сучасних бездротових технологій. Технології з кількома входами та множинними виходами (MIMO) використовують кілька антен для задоволення вимог щодо вищої пропускної здатності та надійності передачі даних. Це дослідження рекомендує компактну чотириелементну антену MIMO, спеціально розроблену для застосувань Wi-Fi. Антена складається з чотирьох U-подібних патч-компонентів з максимальним коефіцієнтом посилення 7,8 дБ на частоті 5 ГГц. Для проектування та моделювання запропонованої антени була використана платформа моделювання HFSS. Антена MIMO має смугу пропускання 50 МГц з імпедансом 10 дБ для покращення безпеки Wi-Fi. Крім того, між сусідніми портами антени існує ізоляція понад 15 дБ. Це зменшує перешкоди та покращує оптимальну продуктивність у невеликих конфігураціях.

Ключові слова: Втрати на відбиття, MIMO-антена, Ізоляція, HFSS, Застосування Wi-Fi.