Performance Analysis of a Swastika shaped MIMO Antenna for Wireless Communication Applications

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ABSTRACT

A novel wideband 4-port Multiple-Input Multiple-Output (MIMO) circular patch antenna is presented for operation in a resonant frequency band from 1.76 to 9.06 GHz used for PCs, Wireless Local Area Networks (WLANs) and satellite applications. The structure of the design consists of microstrip fed slot antenna considered on the four corners of the FR-4 substrate. To reduce mutual coupling and enhance the parameters of the MIMO antenna, a swastika-shaped ground is embedded. The simulated and experimental results show that the design achieves good performance, isolation >15 dB and radiation efficiency greater than 85%. The radiation patterns, surface currents, gain and channel capacity are also investigated. This circular shaped patch antenna is applicable to WLAN and satellite communication applications. Each circular patch on the four corners is connected to a 50 Ω microstrip feedline. A ring slot is etched on the circular patch and a small rectangular slot is embedded to the etched circular patch. The design provides good radiation patterns and the operating bands are obtained at 1.76 GHz, 2.4 GHz, 3.5 GHz and 9.06 GHz attaining reflection loss of -16 dB, -22 dB, -24 dB, -15 dB. The structure of the proposed design is simulated and evaluated in High-Frequency Structure Simulator (HFSS) software. The MIMO structure is fabricated on the FR-4 substrate. The minimum proximity between simulated and measured results is observed.

Keywords-Multiple-Input Multiple-Output (MIMO); Total Active Reflection Coefficient (TARC); Diversity Gain (DG)

I. INTRODUCTION

Wireless communication technology is rapidly evolving, requiring systems with higher data rates, greater security, and increased channel capacity [1-2]. By using multipath data communication, Multiple-Input Multiple-Output (MIMO) wireless technology can significantly increase data throughput, capacity and link security of wireless systems. By distributing power to multiple antennas at the transmitter and the receiver, MIMO systems can increase channel capacity without consuming additional bandwidth or power [3-5]. MIMO systems are an emerging technology for 5G handsets [6]. Additionally, today's handsets require multiband capabilities such as Bluetooth, Wi-Fi and Worldwide Interoperability for Microwave Access (WiMAX) and these capabilities are being combined into a single MIMO mechanism. that provides effective and compelling communications. MIMO systems use multiple antenna components to eliminate interference from other systems. They also use the diversity approach method to enhance communication security. Due to their potential to increase the channel capacity with the available frequency spectrum or transmitted power, MIMO systems are widely deployed [7, 8]. Wideband technology has become one of the most likely technologies to achieve fundamental improvements such as high-speed transmission rate, high reliability, low cost, and low power consumption. Wideband systems are severely affected by the signal fading issue in multipath environments [9, 10]. Since MIMO technology is designed to improve communication quality and capacity, it can be used as a viable solution to address the multipath fading problem in these systems. As per the literature review, there are several MIMO antennas for wireless applications. A 4-port MIMO antenna has been developed by the authors in [11]. It has a size of 72×72 mm2 and a frequency range of 2.34–2.56 GHz. A wideband 4-port MIMO antenna with a shared radiator and dimensions of 75×75 mm2 has been developed by the same authors in [12]. A circular common element 4-port MIMO antenna with a size of 72×72 mm2 has been designed by the authors in [13]. A 2-port MIMO antenna with an operating frequency of 1.71-2.69 GHz was built on a tablet-sized ground plane by the authors in [14]. In the example of an integrated antenna system by the authors in [15], a wideband modified monopole-based sensing antenna was paired with a frequency-agile slot-based four-element MIMO antenna. The antenna was mounted on a single 60×120×1.5 mm3 board. However, all of the aforementioned designs have various limitations, including their large size, low gain and low radiation efficiency. Unlike the antenna designs proposed in other research, the wideband MIMO antenna design presented in this study overcomes the limitations of gain, radiation efficiency and large size. A study on the reduction of mutual coupling using a defected isolation wall was presented by the authors in [16]. The isolation between the antenna elements is improved by about 15 dB using the decoupling technique employed by the authors in [17] in their MIMO antenna array. Authors in [18] proposed a MIMO design for the advanced 5G technology, and a revolutionary approach presented by the authors in [19] provides higher isolation between multiple antenna elements. Authors in [20] proposed a two-element MIMO antenna with improved isolation between the antenna components.

The isolation between the antenna elements is improved by about 20 dB using the decoupling technique utilized in the MIMO antenna array [19-22]. Authors in [21, 22] proposed an MIMO design for advanced 5G technology. A revolutionary approach is modified to provide higher isolation between several antenna elements Authors in [23, 24] designed small antennas in compact size.

A compact step slotted MIMO antenna for wideband applications is introduced. Starting from a single-element wideband antenna and concluding with a 4-port MIMO antenna, a complete step-by-step analysis is provided. The proposed antenna achieves high isolation by placing all antennas in orthogonal directions. It outperforms the antennas discussed in other works while being more compact and having a simpler structure.

II. 4-PORT MIMO ANTENNA DESIGN

The iterative design process and the final design are depicted in Figures 1 and 2. The 4-port symmetrical microstrip fed MIMO antenna is printed on FR-4 substrate The device parameters of the antenna are of Ls and Ws (40 mm × 40 mm) and with a height of 1.6 mm, with a dielectric constant of 4.4. The input impedance attained for the MIMO design is 50 Ω. The structure consists of concentric circular main slots integrated with small rectangular slits. To minimize mutual coupling and enhance the radiation properties of the design, a swastika-shaped ground is considered. The circular patch is etched to form a circular slot and presented over four corners of the substrate. Table I shows the parametric dimensions of the MIMO design which operates in the frequency range of 1.76 to 9.06 GHz. The dimensions of the antenna parameters such as slots and feedlines govern the impedance matching.

TABLE I. DIMENSIONS OF THE CIRCULAR SHAPED MIMO ANTENNA

Device parameters	Dimensions (mm)	Device parameters	Dimensions (mm)
W_1	40	p	2
W_2	5	q	0.5
W_3	14	r_1	5.4
L_1	40	r_2	4.4
L_2	14	Ports 1, 2	S1, S2
L_3	4	Ports 3, 4	S3, S4

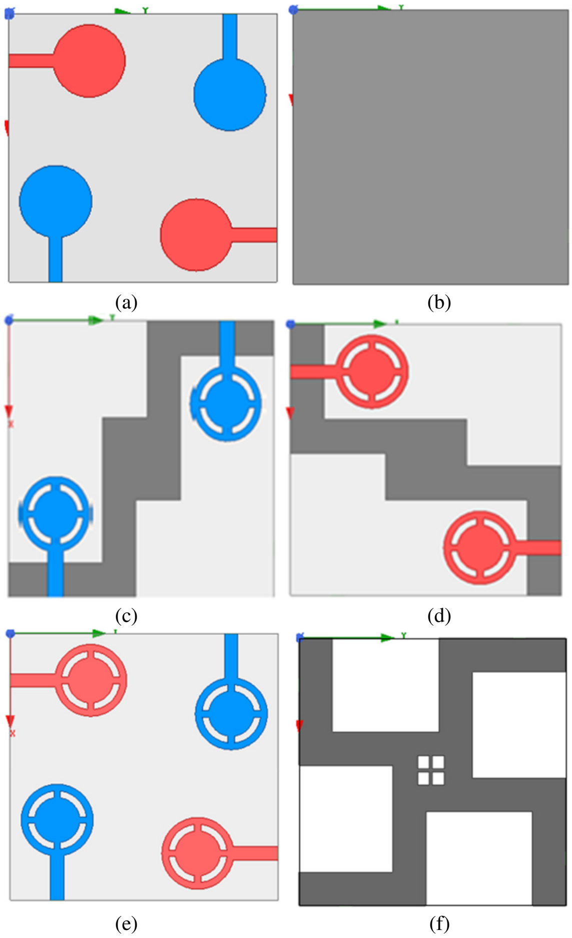


Fig. 1. The iterative structures of the 4-port MIMO antenna.

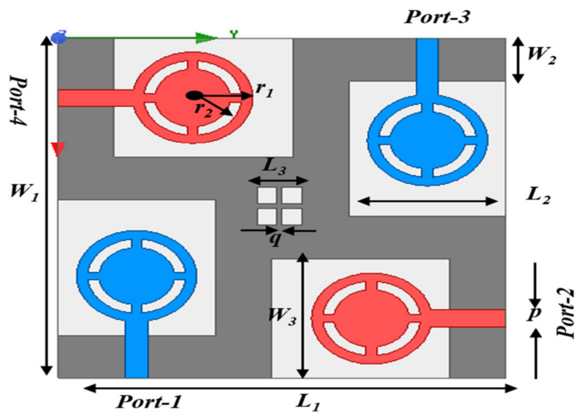
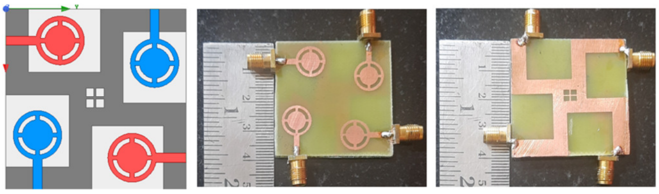


Fig. 2. Final design of the 4-port MIMO antenna.

The final structure of the design was proposed by considering the iterative analysis shown in Figure 1(a-f). In the first step of the iterative process, simple circular patches are shown along with circular slots loaded with slits on the four corners of the substrate. The ground is also etched accordingly to form a half designed swastika shape. Similarly, in the third iteration step, the remaining two ports are loaded on each side of the substrate and the ground is similarly etched to form the second part of the swastika shape. Finally, in the fourth iteration step, all pairs of circular slot patches are placed on the substrate, followed by iterative steps. The main ways in which a radiating patch influences an antenna's performance are by changing its patterns and surface current fields. The performance of the patch is enhanced by the variety of antenna sizes and shapes. These processes are used to identify the ideal answers for the finished design. The center of the ground is etched with two rectangular strips, ultimately forming four rectangular slots. A small gap is also maintained between the rectangular slots to achieve wideband coverage. Iterative comparisons are made to realize the most promising shape for the final antenna design. As the radius of the circular patch increases from 5.4 to 6.4, the frequencies increase and shift toward the lowest frequencies. Figure 3 shows the fabricated model of the proposed MIMO antenna.



(a) (b) (c)

Fig. 3. Proposed antenna fabricated model: (a) radiating patch view, (b) top view, (c) ground view.

III. RESULTS AND DISCUSSION

A. Scattering Parameters

The reflection coefficient of the design operates at 1.76 GHz, 2.4 GHz, 3.5 GHz, and 9.06 GHz with a reflection loss of -15 dB. The reflection loss of the MIMO antenna is below the reference level from 1.76 GHz to 9.06 GHz with isolation greater than 15 dB. The radiation efficiency performance parameters such as radiation pattern, gain and MIMO performance are also examined. Minimum discrepancy between simulated and experimental results is observed as shown in Figure 4. In addition, Figure 5 shows the voltage standing wave ratio (VSWR) of the MIMO antenna with a good reference value.

B. Isolation

The simulated and measured performance of the isolation shows the effectiveness of the MIMO structure, as shown in Figure 6. More than 15 dB of port-to-port isolation was measured between port 1 and the other ports. The antennas have low isolation without the decoupling structure, according to the simulated and measured results. However, the addition of a decoupling structure enhances antenna isolation, especially at low and medium frequencies. The isolation for the proposed MIMO antenna between the adjacent components is higher than 20 dB throughout the operating band. Table II and Figure 6 show the isolation performance between adjacent ports.

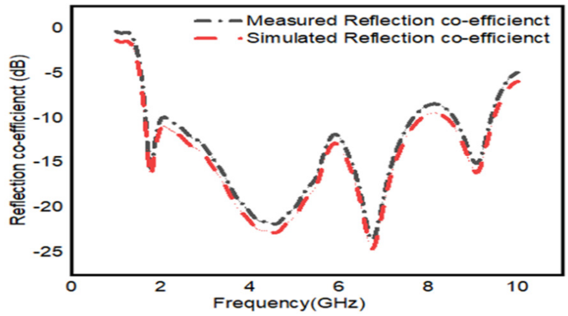


Fig. 4. The reflection coefficient of the proposed design.

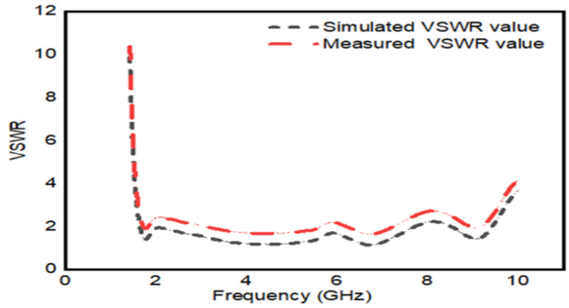


Fig. 5. The VSWR of the proposed design.

(a)

(b)

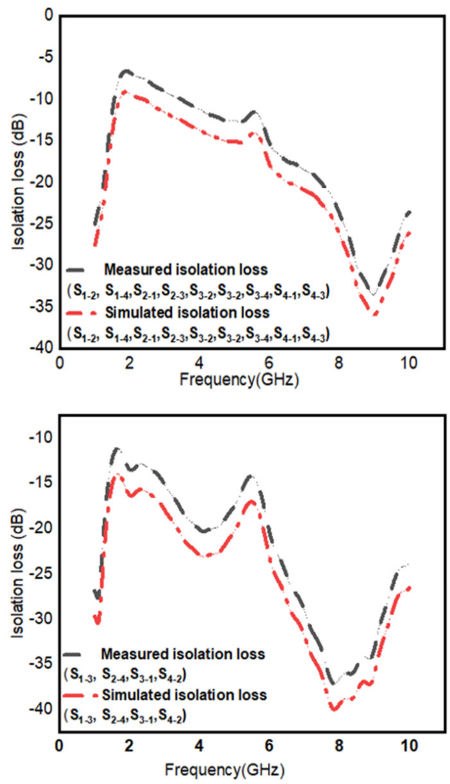


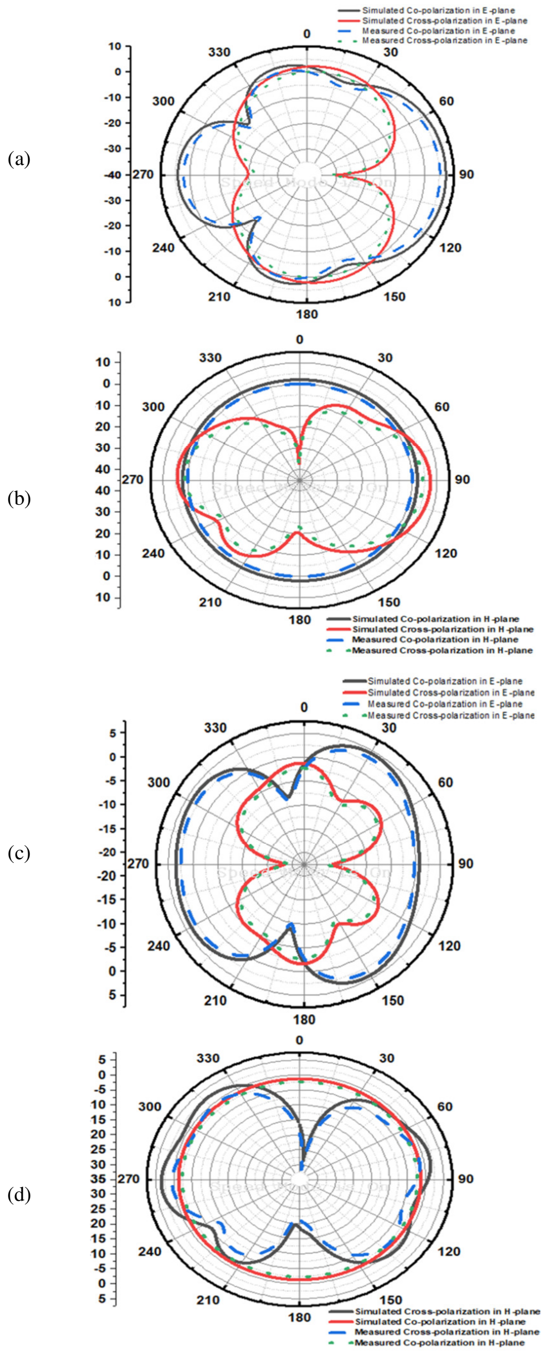
Fig. 6. Isolation characteristics with respect to different ports.

TABLE II. ISOLATION PERFORMANCE BETWEEN ADJACENT PORTS

Frequency (GHz)	Isolation-1 (dB)	Isolation-2 (dB)
1.76	-25.5	-30.2
2.4	-12.3	-16.2
3.5	-13.3	-18.2
9.06	-35.3	-37.2

C. Radiation Patterns

To understand the wideband characteristics, the E-field distributions are shown in Figure 7.



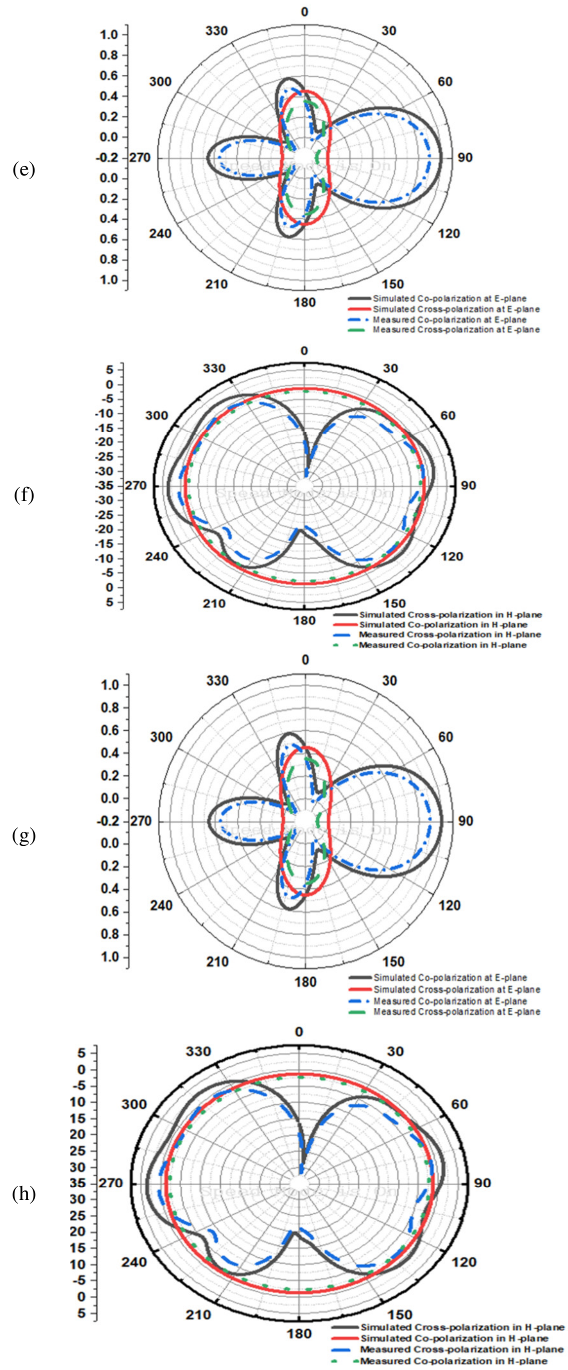


Fig. 7. 4-port MIMO design radiation patterns: (a-b) 1.76 GHz, (c-d) 2.4 GHz, (e-f) 3.5 GHz, (g-h) 9.06 GHz.

The far field patterns of the 4-port MIMO design are evaluated when one port is excited and other ports are connected to the load. The radiation patterns at each operating band considering the E and H-planes are shown in Figure 7. There is little discrepancy between the simulated and measured results. The effect of the test cables provides the minimum discrepancy. The simulated results are in agreement with the measured results, and the radiation patterns of the proposed device are stable.

IV. MIMO PERFORMANCE PARAMETERS

In this part, crucial performance measures such as Total Active Reflection Coefficient (TARC) and Diversity Gain (DG), are analyzed to ensure that the proposed antenna has high multi-channel performance.

A. Total Active Reflection Coefficient

To increase the bandwidth of the MIMO antenna, the TARC must be calculated. For the proposed 4-port design, TARC can be evaluated as the ratio of the square root of the total power divided by the total incident power as described in (1), and a reference value of <0 dB is desirable. The TARC analysis with respect to different ports is shown in Figure 8. The proposed design has a simple structure and flexible expandable characteristics, which improves the design for multiband applications.

$$TARC = \sqrt{\frac{(S_{mn}+S_{mn})^2+(S_{mn}+S_{mn})^2}{2}} \quad (1)$$

B. Diversity Gain

DG is the term used to describe the reduction in transmitted power that occurs when diversity schemes are applied to the MIMO module. The DG is calculated using (2) and Figure 9 shows that the DG is -10 dB over the entire band, demonstrating the antenna's successful operation.

$$DG = 10\sqrt{1-\left|\rho_{e_{ij}}\right|^2} \quad (2)$$

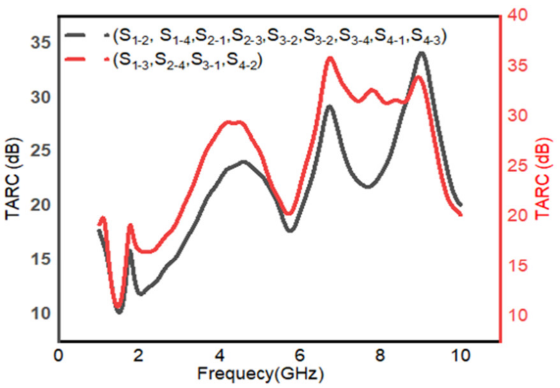
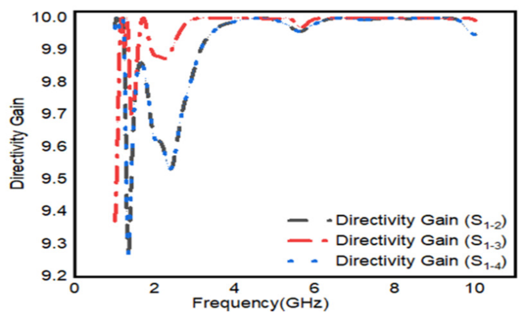


Fig. 8. TARC curves of proposed 4-port circular patch MIMO.

(a)



(b)

(c)

(d)

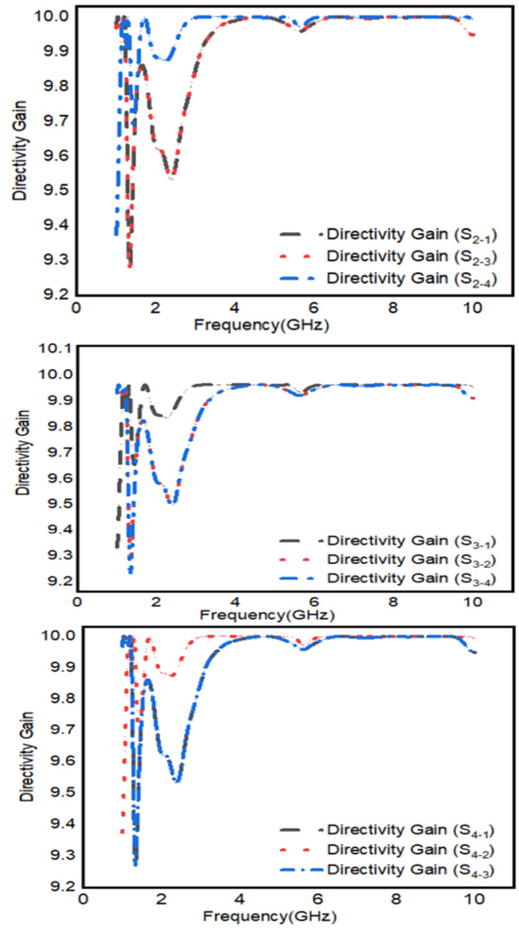


Fig. 9. DG of the proposed design altering all ports.

V. CONCLUSION AND FUTURE WORK

The proposed configuration of a 4-port Multiple-Input Multiple-Output (MIMO) antenna design consists of four circular patches on the FR-4 substrate. By placing the ports on the four sides of the geometry, they are fed by the microstrip feedline. A new 4-port wideband MIMO array has been studied for wireless and satellite applications covering the frequency range from 1.76 GHz to 9.06 GHz band. The design structure consists of 4 pairs of fed slot antennas on either side of the antenna on FR-4 substrate. Each pair of circular patches consists of a concentric circular slot that is etched and a small slot that is loaded on the patch antenna. The novelty of this structure increases the gain and diversity of the radiation patterns. To reduce mutual coupling, rectangular slits with feed lines are integrated on the circular patch. The wideband of the antenna is achieved by considering the swastika-shaped ground for the proposed structure. The simulated and experimental results prove that the new antenna design achieves the desired performance such as isolation of >15 dB and efficiency of >85%. Along with the above factors, the radiation patterns, Total Active Reflection Coefficient (TARC) and Diversity Gain (DG) are also investigated. Based on the obtained results, the new antenna design can be used for PCs, Wireless Local Area Networks (WLANs), and Worldwide Interoperability for Microwave Access (WiMAX) applications. Since metamaterials can significantly reduce the size of the antennas, new antenna design methodologies need to be explored to further reduce the size of antennas.

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