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Research Article

Design of a Novel Triple Band Monopole Antenna for WLAN/WiMAX MIMO Applications in the Laptop Computer

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This paper presents a triple band monopole antenna design with an overall size of 21×8 mm^2 for WLAN/WiMAX Multiple Input and Multiple Output (MIMO) applications in the laptop computer. It comprises of three monopole radiating elements, along with two rectangular open-ended tuning stubs. This structure excites 2.4/5.2/5.8 GHz WLAN and 2.3/3.3/5.5 GHz WiMAX bands. The prototype testing of proposed antenna array formed by using the same antenna design shows that, it has measured -10dB impedance bandwidth of 11.86% (2.22-2.50 GHz) in a lower band (f_l), 5% (3.25-3.42 GHz) in medium band (f_m) and 16.84% (5.00-5.92 GHz) in upper band (f_u). The measured gain and radiation efficiency are well above 3.65 dBi and 75%, respectively, throughout the operating bands. Also, the measured isolation between two antennas is better than -20dB and envelope correlation coefficient (ECC) is less than 0.004 across the three bands of interest. This confirms the applicability of the proposed antenna array for MIMO applications in the laptop computer.

1. Introduction

The MIMO technology has aroused interest in WLAN and WiMAX operating systems because of its possible applications, security, high-speed data transmission, and efficient utilization of spectrum. Practically, minimum two antennas occupying smaller area with high isolation are needed in order to get the high-speed signal transmission and reception in the laptop computer. Literature [1–10] reports many promising MIMO antenna array with multiband operations for the laptop computer.

Kin. Lu. Wong et al. have proposed high isolation MIMO antenna array for the laptop computer in [1, 2] and for the tablet computer in [3]. The proposed antennas occupy a large volume of $45 \times 14 \times 0.8$mm^3 [1], $55 \times 9 \times 0.8$mm^3[2] and $45 \times 10 \times 0.8$mm^3[3]. The MIMO antenna composed of a loop structure and a parasitic element is proposed in [4] and has a size of $38 \times 7 \times 0.8$mm^3 along with an additional ground plane of size 38×6mm^2 which is connected to the system ground. Also, the impedance bandwidth is measured at -6dB, which is generally not acceptable for wireless application in the laptop computer. The dual band antennas operating at 2.4/5.2/5.8 GHz are reported in [5–7]. The MIMO antenna array in [5] uses a decoupling structure as an isolating element between two antennas for the laptop computer and also occupies a large volume of $54 \times 9 \times 0.8$mm^3. It is also placed at the center of the system ground, which is generally reserved for embedding the digital camera lens. The uniplanar printed antenna in [6] uses protruded ground embedded with a T shaped slot, in order to reduce mutual coupling and has the dimension of $40 \times 9 \times 0.8$mm^3. The meandered isolation technique used in [7] reduces the mutual coupling lower than -20dB and has large dimensions of $45 \times 12 \times 0.4$mm^3. Two identical antennas presented in [8] have a size of $5 \times 42 \times 0.8$mm^3 and use a decoupling inductor, to reduce the mutual coupling in the 2.4GHz band. The use of inductor makes the hardware complex and also increases the power consumption of the antenna. The standalone monopole antenna used for MIMO array without any isolation element operates at 2.4/3.5/5.5 GHz and having dimensions of $12 \times 18 \times 0.8$mm^3 is reported in [9]. The planar inverted-F antenna along

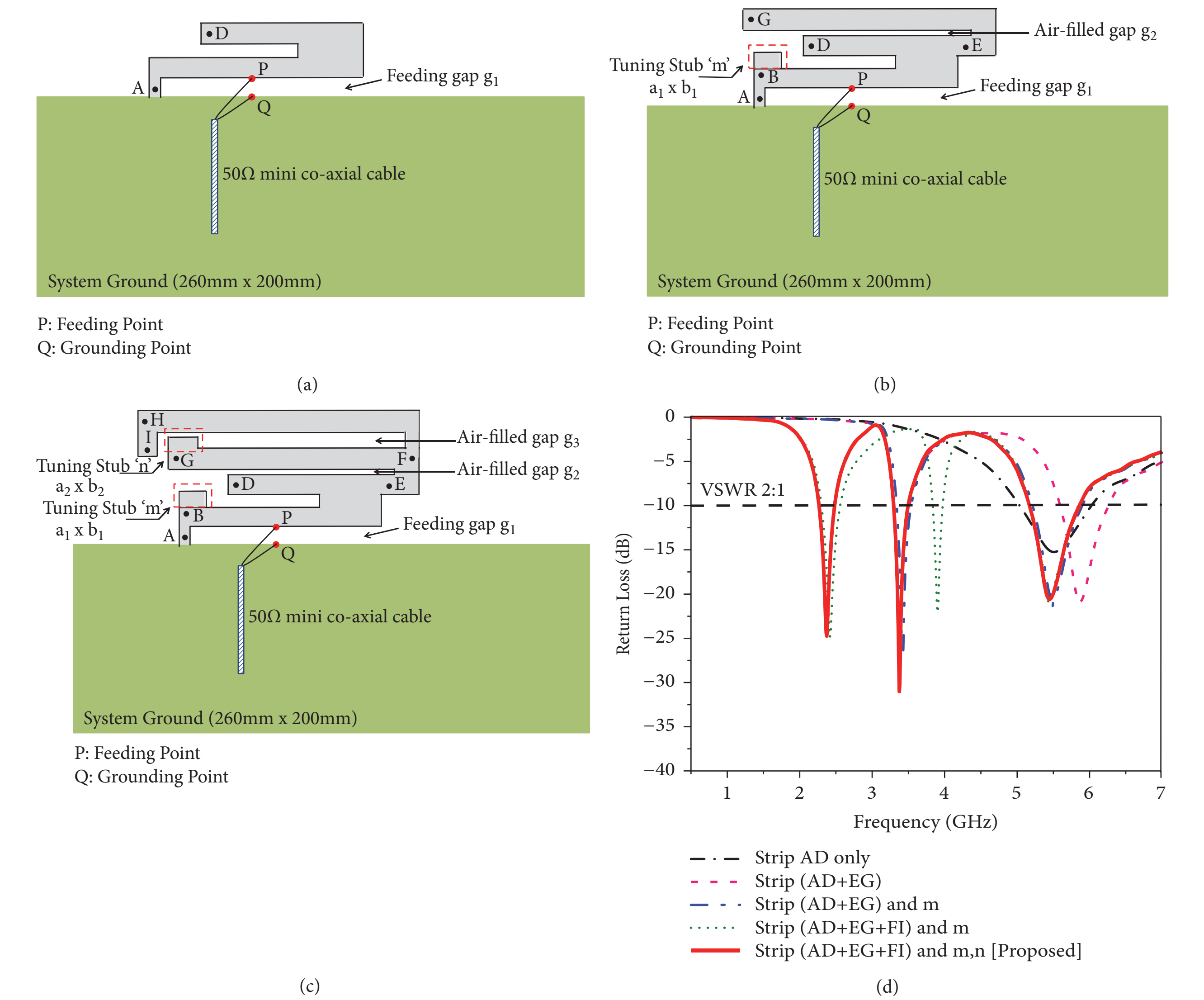


FIGURE 1: Design and working process of the proposed monopole antenna.

with EBG shape etched on the ground plane for MIMO application in laptop devices is proposed in [10], but has a large dimension of $33.5 \times 22 \times 5.4\text{mm}^3$.

From the above literature, it is understood that the deployment of miniaturized multiple antennas with low coupling coefficient and high RF performance, covering entire wireless bands for MIMO applications in the laptop computer, are posing challenges for researchers and antenna designers.

This paper proposes a triple band monopole antenna design with an overall size of $21 \times 8 \times 0.05$ mm^3 to operate in desired 2.4/5.2/5.8 GHz WLAN and 2.3/3.3/5.5 GHz WiMAX bands for MIMO applications in the laptop computer.

2. Antenna Design

The proposed antenna comprises three monopole radiating elements, namely, strip AD (inverted C), strip EG (inverted J), and strip FI (inverted U), and two rectangular open ended tuning stubs, namely, "m" (a_1xb_1) and "n" (a_2xb_2), as shown in Figure 1. In order to get the resonance at about 5.5GHz of f_u (5.2/5.8 GHz WLAN and 5.5 GHz WiMAX bands), the strip AD is designed in such a way that, its total length is approximately equal to half wavelength long at a resonant mode of 5.5GHz. The strip AD is connected to the system ground at point "A" and introduces feeding gap g_1 as shown in Figure 1(a). With the use of this strip, the proposed antenna successfully generates the desired f_u band as shown in Figure 1(d).

The strip EG is designed to obtain the resonance mode at 3.35 GHz of f_m (3.3-3.4 GHz) band in such a way that its total length is approximately equal to quarter wavelength long at a resonant mode of 3.35 GHz. The strip EG is placed above the strip AD and is connected at point "E". This introduces air-filled gap g_2 as shown in Figure 1(b). With the introduction of this strip, the proposed antenna successfully generates f_m band but shifts the f_u band towards higher frequency due to

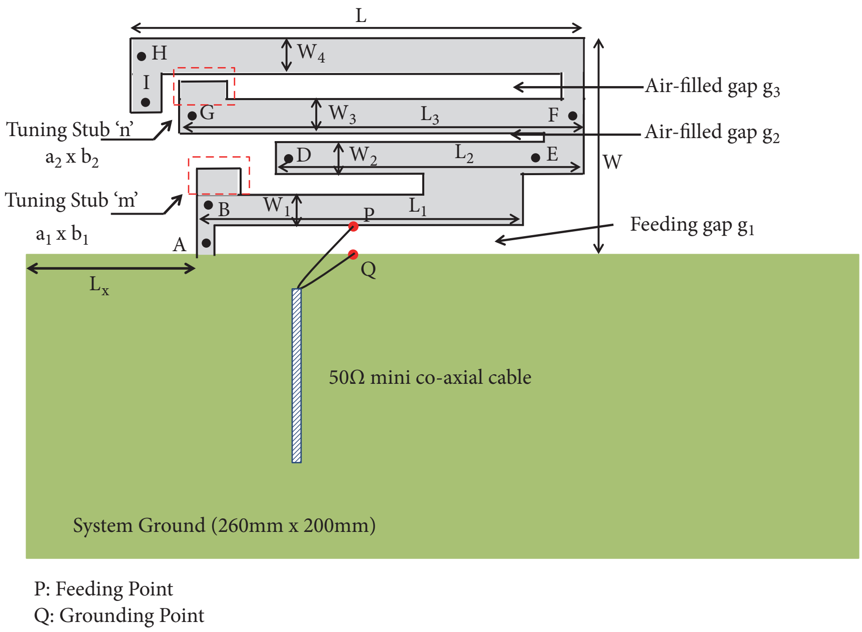


Figure 2: Complete structure of the proposed antenna.

impedance mismatch as shown in Figure 1(d). In order to tune the f_u for obtaining the required band, a rectangular open ended tuning stub "m" of length (a_1) and height (b_1) is added at point "B" to strip AD as shown in Figure 1(b).

For achieving resonant mode at about 2.4GHz to cover f_l (2.3GHz WiMAX and 2.4GHz WLAN bands), the total length of strip FI is chosen to be quarter wavelength long at the resonant mode of 2.4 GHz. The strip FI is bent at point "H" to form inverted U shape and because of this bending, the required quarter wavelength length of strip FI reduces to 25.5mm only (about 0.2λ).

The strip FI is placed above the strip EG and coupled at point "F" which introduces an air-filled gap g_3 as shown in Figure 1(c). This generates the required f_l band of the proposed antenna, but shifts the f_m band towards the higher frequency, due to more capacitive reactance produced by an air-filled gap g_3 as shown in Figure 1(d). In order to mitigate this increase in capacitive reactance, second rectangular open ended tuning stub "n" of length (a_2) and height (b_2) is added to strip EG as shown in Figure 1(c). This stub tunes the f_m band and also matches the input impedance of the antenna to the impedance of coaxial feed. Here, the desired bandwidth of f_l and f_u bands remain unaffected.

3. Proposed Antenna Geometry

The complete structure of the proposed monopole WLAN/ WiMAX antenna for the laptop computer is shown in Figure 2. The copper thickness of monopole radiating elements and tuning stubs used in the proposed antenna is chosen to be 0.05mm. The proposed antenna is placed at a distance of L_x from the left corner on the top edge of the system ground of size 260 × 200mm^2 (supports 13″ laptop display screen) which is made up of 91% brass of thickness 0.2mm. The antenna structure has a length of 21 mm and shows the height of only 8 mm above the system ground. The 8 mm height of the proposed antenna is promising for practical wireless applications in the laptop computer. The proposed monopole antenna is fed by using a 50Ω low loss mini coaxial cable whose central conductor and outer grounding sheath are connected at point P (the feeding point) on the lower edge of strip AD and at point Q (the grounding point) on the upper edge of the system ground. This feeding position makes the effective dielectric constant of all radiating elements equal to 1 and hence, contributes in attaining the desired bands of the proposed antenna [11].

4. Parametric Study of Proposed Antenna

The parametric study of the proposed antenna is carried out to find the optimum value of "m" (a_1xb_1), "n" (a_2xb_2), and L_x, respectively, in the desired f_l, f_m, and f_u bands. The rest of the optimized dimensions of the proposed antenna are as shown in Figure 2.

4.1. Effects of Rectangular Tuning Stub "m" (a_1xb_1) on the Proposed Antenna. The effects of a rectangular open end tuning stub "m" of length (a_1) and height (b_1) on return loss and the input impedance of the proposed antenna over f_u band are studied in Figure 3. From Figure 3(a), it is noted that as the value of a_1 increases from 0 mm to 1.5mm and b_1 increases from 0 mm to 0.9mm, the f_u band shifts towards lower frequency as it attenuates the capacitive reactance produced by air-filled gap g_2. With the aid of Figure 3(b), it is also seen that there is a smooth variation of the input impedance from 68Ω towards 50Ω and reactance is also becoming equal to zero at a resonant mode of 5.5 GHz. For the value of a_1=1.5mm and b_1=0.9mm, the input impedance of the antenna is equal to 50Ω and

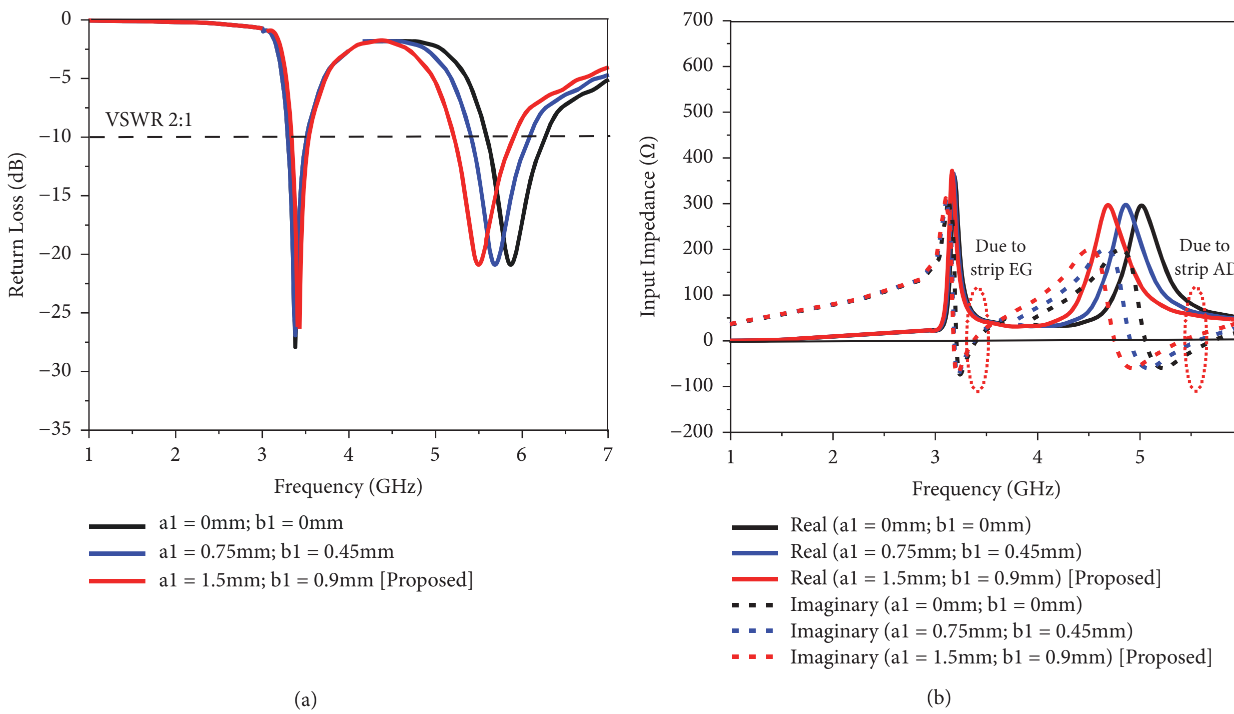


Figure 3: Simulated return loss and input impedance (Ω) of the proposed antenna as a function of tuning stub m ($a_1 x b_1$).

reactance is equal to zero at the desired resonant mode of 5.5 GHz as shown in Figure 3(b). This condition leads to impedance matching and successful generation of f_u band with the desired bandwidth. Hence, the optimized size of "m" is 1.5x0.9mm^2.

4.2. Effects of Rectangular Tuning Stub "n" ($a_2 x b_2$) on the Proposed Antenna. The effects of rectangular tuning stub "n" of length (a_2) and height (b_2) on the return loss and input impedance of the proposed antenna across f_m band are studied in Figure 4. As the value of a_2 is increased from 0 mm to 1.8mm and b_2 increased from 0 mm to 0.9mm, the f_m band shifts from the resonant mode of 3.85GHz towards a resonant mode of 3.35 GHz of f_m band, as shown in Figure 4(a). Also, as seen in Figure 4(b), for a_2=1.8mm and b_2=0.9mm, the input resistance is equal to 50Ω and capacitive reactance is equal to zero at the desired resonance of 3.35GHz. This leads to impedance matching between the antenna and coaxial feed and generation of the desired f_m band. From Figure 4, it is also seen that f_l and f_u bands remain unaffected. Therefore, the optimized size of "n" is 1.8x0.9mm^2

4.3. Effects of Varying L_x on the Proposed Antenna. The effects of varying L_x from 0 mm to 70 mm (in the step increments of 35 mm) for mounting the proposed antenna on the system ground over f_l, f_m, and f_u bands are analyzed in Figure 5. It is clearly seen that, at L_x=0mm, the resonant mode 2.4 of f_l shifts towards higher frequency with reduced bandwidth because of degradation in impedance matching, while the resonant mode 3.35GHz of f_m and 5.5 GHz of f_u bands have negligible effect. At L_x=35mm, all the desired bands of the proposed antenna are obtained with the required bandwidth and VSWR less than 2. Hence, from the above study, the optimum value of L_x =35mm is selected for mounting the proposed antenna on the system ground.

From the above parametric studies, the selected values for $a_1 x b_1$, $a_2 x b_2$, and L_x are 1.5x0.9mm^2, 1.8x0.9mm^2, and 35 mm, respectively. The other optimized values of the proposed antenna are given in Table 1.

The simulated return loss of the proposed antenna is as shown in Figure 6.

5. Two Antenna MIMO System Using Proposed WLAN/WiMAX Monopole Antenna

Possible antenna arrays formed by using proposed WLAN/WiMAX monopole antenna are studied in this section and shown in Figure 7. In first antenna array (case I) two antennas, namely, Antenna 1 and Antenna 2, are mounted on the top edge of the same system ground, at a distance of 155 mm from each other. Antenna 1 is the proposed antenna as shown in Figure 2 and Antenna 2 is an exact replica of Antenna 1. The simulated S parameters S_{11}, S_{21}, and S_{22} of case I are shown in Figure 8. In this case, the same effect on bandwidth is observed for both S_{11} and S_{22} but the return loss of f_l and f_u is higher at S_{11} whereas the return loss of f_m is higher at S_{22}. The resonant mode 2.4 GHz of f_l shifts at the frequency of 2.37GHz due to the larger inductive reactance produced by coaxial feeds at Antenna 1 and Antenna 2 and current path length of (0.2λ) towards strip FI. Hence, the 2.4GHz (2.4-2.48GHz) band is not covered. The bandwidth of f_m band remain unaffected and is the same as that of Antenna 1

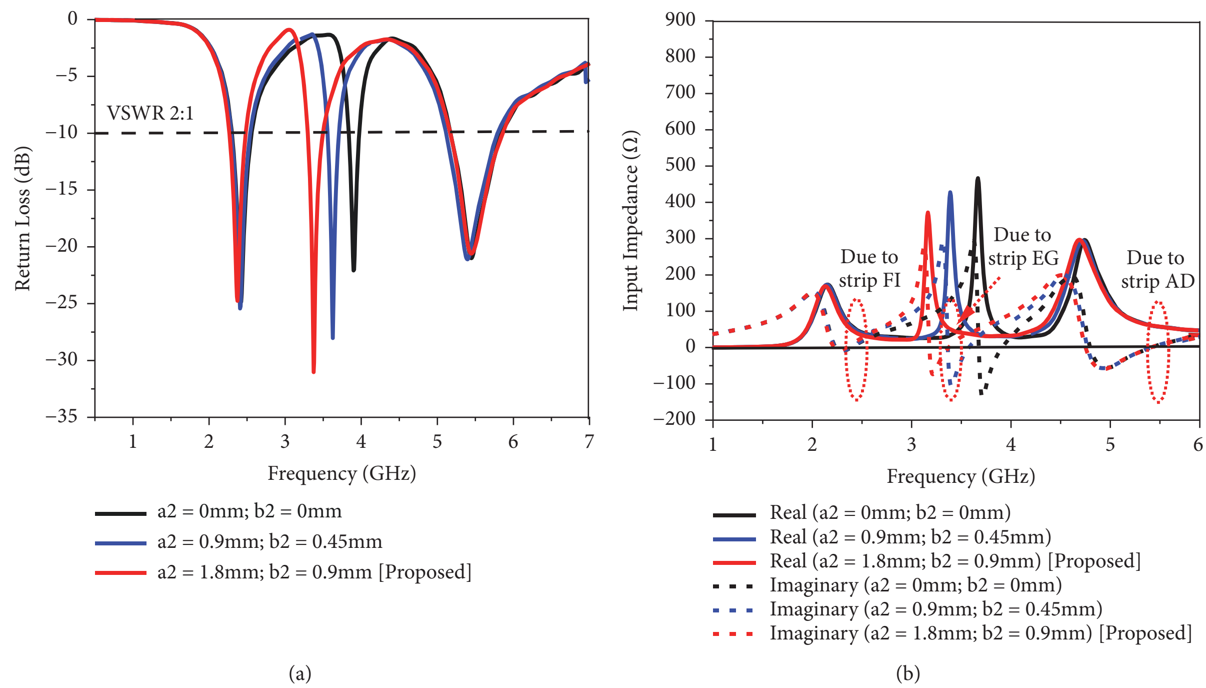


FIGURE 4: Simulated return loss and input impedance (Ω) of the proposed antenna as a function of tuning stub n ($a_2 \times b_2$).

TABLE 1: Optimized values of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	21	g_2	0.2	W_3	1.8
L_1	15	g_3	1.0	W_4	1.0
L_2	15	W	8		
L_3	19	W_1	1.1		
g_1	1.0	W_2	1.2		

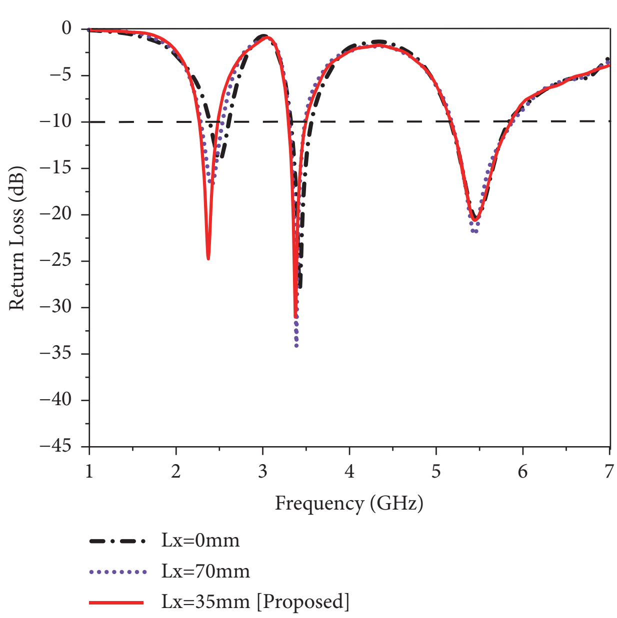


FIGURE 5: Simulated return loss of proposed antenna as a function of L_x for mounting the proposed antenna on the system ground.

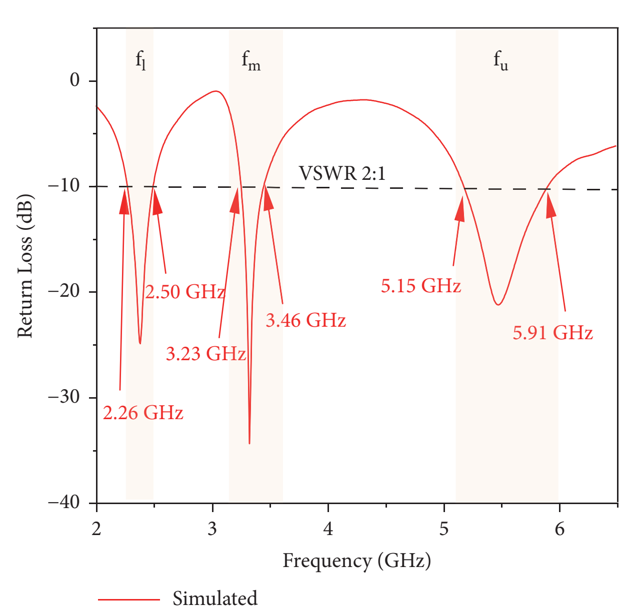


FIGURE 6: Simulated return loss of proposed antenna mounted on the system ground (supporting 13″ laptop display screen).

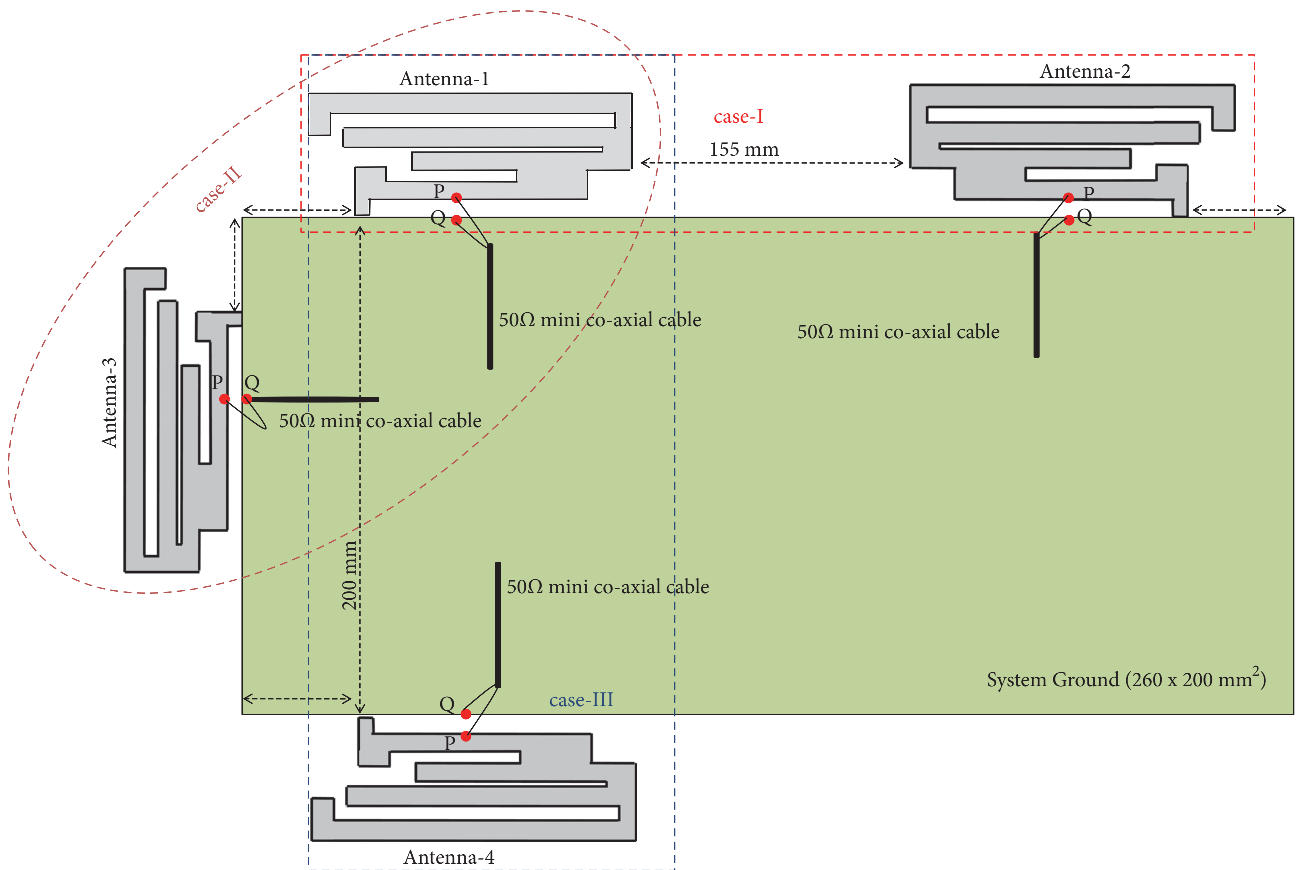


FIGURE 7: Possible Antenna Array cases for MIMO Applications mounted on the system ground.

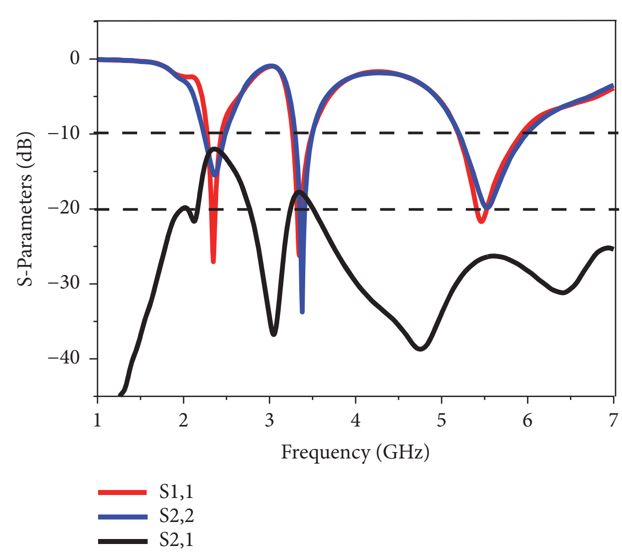


FIGURE 8: Simulated S parameters for MIMO antenna array of (case I).

(see Figure 6) because of perfect impedance matching between antennas and coaxial feeds. The resonant mode 5.5 GHz of f_u shifts towards a higher frequency of 5.9GHz and thereby, affect the 5.2GHz WLAN band. Also, as required the S_{21} is not better than -20dB for f_l and f_m bands. Hence, this case is not considered.

The second possible antenna array (case II) as shown in Figure 7, is further studied. In this case, Antenna 1 and Antenna 3 are placed adjacent to each other at a distance of 35 mm from the top left corner of the system ground. Antenna 3 is an exact replica of Antenna 1 and is rotated anticlockwise by 90° before placing it on the vertical left

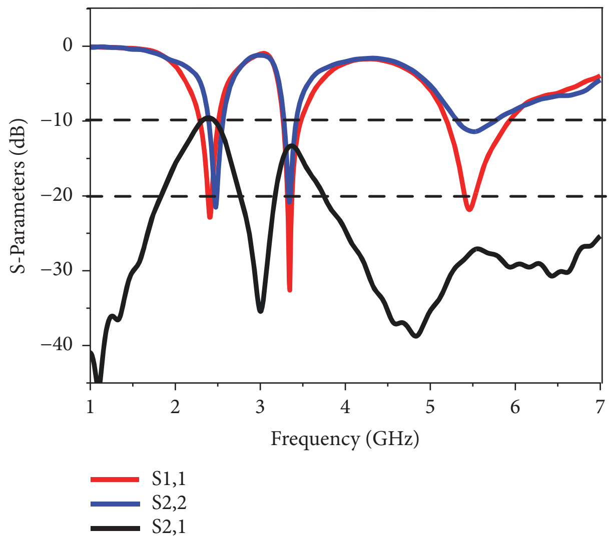


Figure 9: Simulated S parameters for the antenna array of case II.

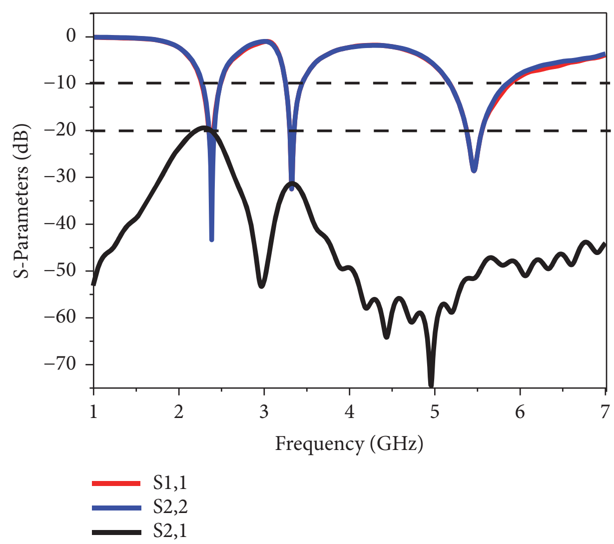


Figure 10: Simulated S parameters for the proposed MIMO antenna array of case III.

edge of the system ground. The simulated parameters are shown in Figure 9. It is seen that, there is a great mismatch between S_{11} and S_{22}. From S_{22} of Antenna 3, it is seen that the impedance bandwidth of f_l and f_u bands get reduced and does not conform the required bandwidth. Even though, the f_m band remains unaffected in both S_{11} and S_{22}, S_{21} is approximately -13dB which is not practically acceptable for high RF performance of MIMO system. Therefore, this array (case II) is not attractive for forming MIMO system in the laptop computer.

Another possible array (case III) was formed, by using Antenna 1 and Antenna 4 as analyzed in Figure 7. In this case, Antenna 4 is same as that of Antenna 1 and is rotated 180° along the x-axis. It is then placed at the bottom edge of the system ground at a distance of 200 mm from Antenna 1. Figure 10 shows the simulated S parameters of case III. Here, it is observed that the bandwidth of both S_{11} and S_{22} is same as that of Figure 6 along with good return loss across f_l, f_m and f_u bands. Also, isolation between antennas or S_{21} is achieved as -20dB, -30 dB, and -47dB across f_l, f_m, and f_u bands, respectively, because the system ground itself is acting as an isolating element between Antenna 1 and Antenna 4. The obtained isolation values are practically good for the optimal performance of the MIMO system. Hence, from the simulated results observed in Figure 10, case III was a good candidate for MIMO and was immediately taken for fabrication, the results of which are discussed further in Section 6.

6. Results and Discussion

To validate the simulated results of case III, the prototype of the proposed antenna array is fabricated as shown in Figure 11 and was tested using ROHDE and SCHWARZ (9

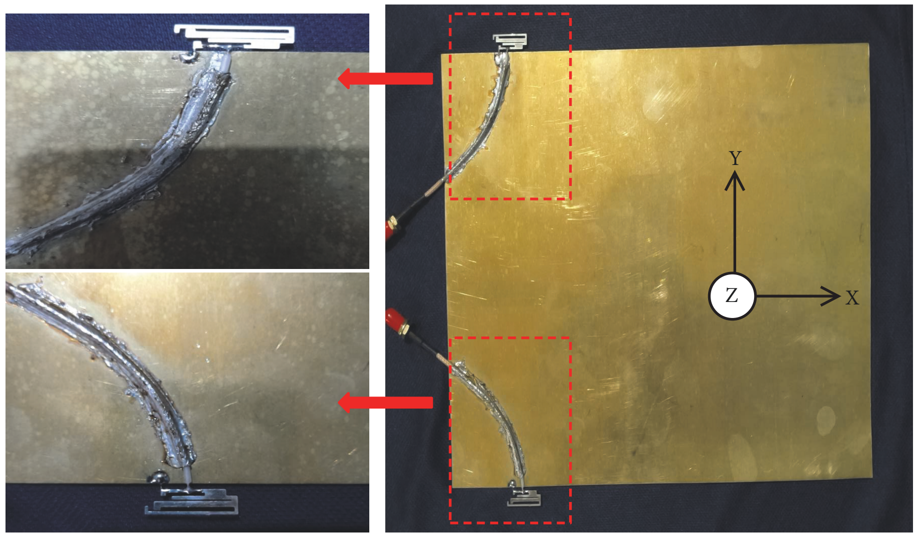


Figure 11: Fabricated photo of proposed MIMO antenna for laptop computers.

KHz-16GHz) network analyzer. The radiation performance, including radiation patterns, gain, and radiation efficiency of proposed case III, was tested in an anechoic chamber of size $8 \times 4 \times 4 m^3$.

All the parameters were measured under the condition that, while measuring Antenna 1, the Antenna 4 was terminated with 50Ω load and vice versa.

6.1. Return Loss. Figure 12 shows the comparison of simulated and measured S parameters of the proposed MIMO antenna array and presents only S_{11} and S_{21} due to the analogy with S_{22} and S_{12}, respectively. The simulated -10dB impedance bandwidth of Antenna 1 and Antenna 4 is 10.08% (2.26-2.50GHz), 6.87% (3.23-3.46GHz), and 13.74% (5.15-5.91GHz), whereas the measured values are 11.86% (2.22-2.50GHz), 5.09% (3.25-3.42), and 16.84% (5.00-5.92GHz) in f_l, f_m, and f_u, respectively. The simulated and measured isolation or S_{21} between Antenna 1 and Antenna 4 are better than -20dB accross all the three desired bands as shown in Figure 12.

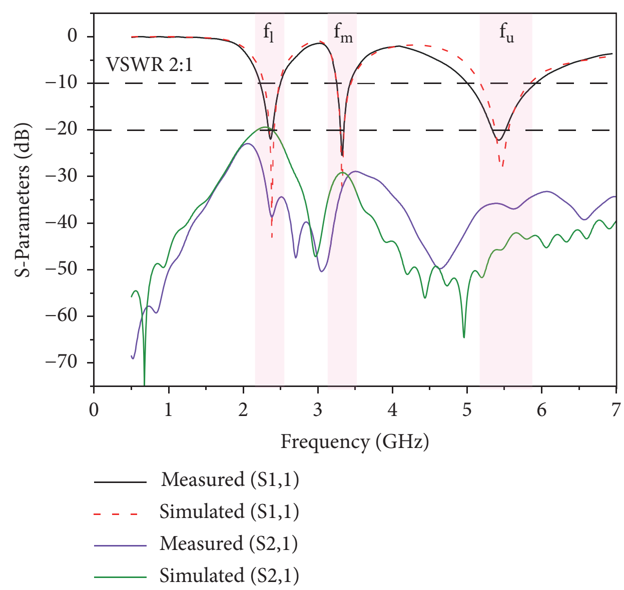


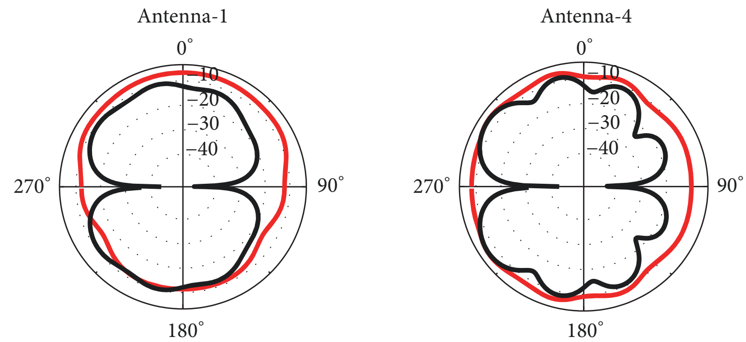
Figure 12: Simulated and Measured S parameters of proposed MIMO antenna.

6.2. Measured Radiation Pattern. The normalized radiation patterns of proposed case III are shown in Figure 13. Here, the E-plane (copolarization) and H-plane (cross-polarization) in the x-y plane of the proposed MIMO antenna array are shown at the measured resonant mode of 2.42, 3.37, and 5.5 GHz of f_l, f_m, and f_u, respectively. The E-plane pattern in both antennas, namely, Antenna 1 and Antenna 4, at all resonant modes is nearly omnidirectional, whereas H-plane contributes dipole pattern forming bidirectional radiation without having any nulls. This confirms the applicability of antenna array for MIMO applications in the laptop computer.

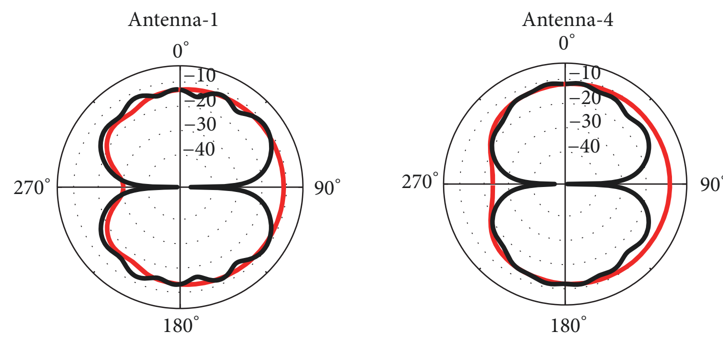
6.3. Simulated and Measured Gain and Radiation Efficiency. Figure 14 shows simulated and measured gain and efficiency of the proposed antenna array (case III). Figure 14 presents efficiency of only Antenna 1 due to the analogy with Antenna 4. The values of simulated and measured gain and efficiency are as shown in Table 2. A small deviation in simulated and measured values of gain and efficiency is observed which may be due to fabrication tolerances.

6.4. Envelope Correlation Coefficient (ECC). In a MIMO system, envelope correlation coefficient (ECC) is a very important parameter to evaluate channel capacity and cross-correlation performances between two antennas. It can be calculated using the following formula [4]:

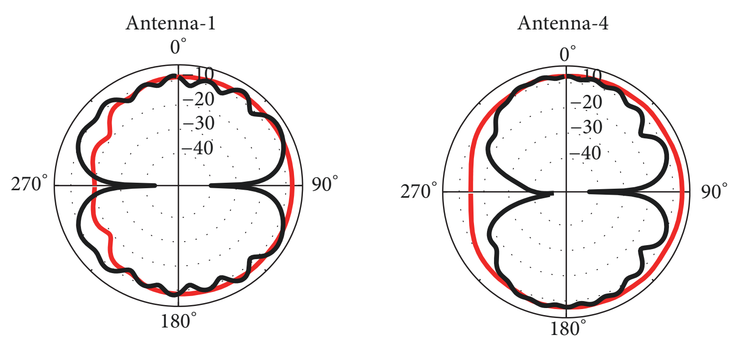
$$\mathrm{ECC} = \frac{\left|S_{11}^{*} S_{12} + S_{21}^{*} S_{22}\right|^{2}}{\left(1 - \left|S_{11}\right|^{2} - \left|S_{21}\right|^{2}\right)\left(1 - \left|S_{22}\right|^{2} - \left|S_{12}\right|^{2}\right)} \quad (1)$$



(a) 2.42 GHz



(b) 3.37 GHz



(c) 5.5 GHz

Figure 13: Measured radiation pattern of the proposed MIMO antenna.

Table 2: Comparison of simulated and measured values of gain and efficiency of the proposed antenna array (case III).

Covered bands (GHz)	Gain (dBi)		Efficiency (%)	
	Simulated	Measured	Simulated	Measured
f_l	4.61-5.25	4.42-4.90	82.24-87.86	78.5-83.9
f_m	5.82-5.95	5.52-5.70	78.69-86.88	75.43-81.0
f_u	3.92-5.14	3.64-4.87	79.59-87.58	76.15-81.5

where $*$ indicates the complex conjugate. Figure 15 shows the simulated and measured ECC using S parameters. The implemented MIMO antenna shows the optimal performance as both the simulated and measured ECC values are less than 0.004 across all the desired bands, that too without using any additional isolation techniques between the two antennas.

7. Conclusions

The triple band WLAN/WiMAX monopole antenna design for MIMO applications in the laptop computer is verified successfully. The proposed antenna has a very small size of $21 \times 8\text{mm}^2$, simple structure, easy to fabricate, and operates in 2.4/5.2/5.8 GHz WLAN and 2.3/3.3/5.5 GHz WiMAX bands. Additionally, owing to RF performance, small size, and simple structure of the proposed antenna, an antenna array formed by using the same antenna for MIMO system shows that, it has excellent gain and efficiency well above 3.65 dBi and 75%, respectively, isolation between two antennas is better than -20dB and ECC is below 0.004 over the three bands of interest. Hence, the proposed antenna and the

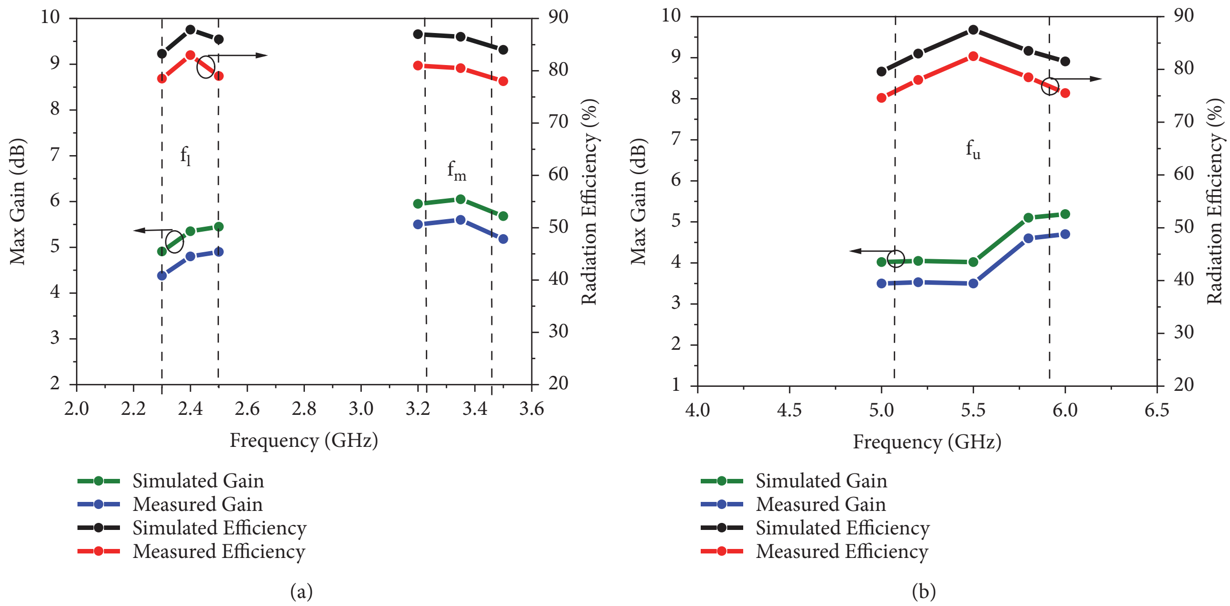


Figure 14: Simulated and measured gain and efficiency of proposed MIMO antenna.

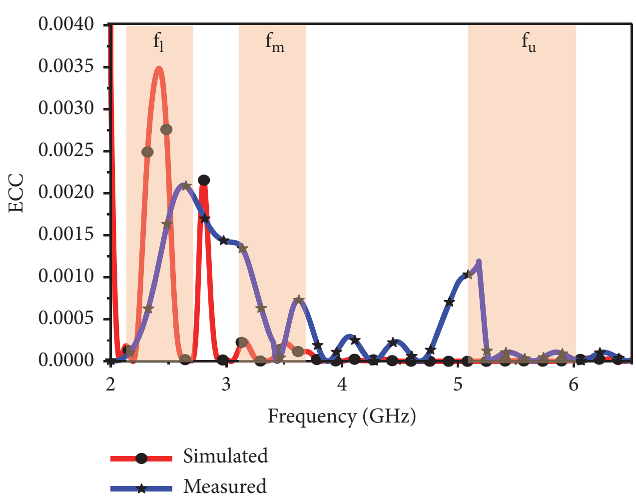


Figure 15: Simulated and measured ECC for proposed MIMO antenna.

antenna array formed are promising and good candidate for MIMO applications in the laptop computer.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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