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Design and analysis of band-notch UWB-MIMO antennas for interreference mitigation in coexisting wireless system

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=ABSTRACT

This study presents a MIMO antenna with band notch characteristics at the WLAN band, intended for applications in the ultrawide spectrum. The two identical components that make up the proposed UWB MIMO antenna are supplied via a microstrip line. To obtain excellent impedance matching qualities from 3.5 to 12.6 GHz, three slots are engraved onto the ground. In order to improve the isolation between the antenna ports by more than 15dB, a rectangular stub is extended from the ground plane. Each component has an inverted C-shaped slot to form a band-notch at the WLAN spectrum between 5 and 5.6 GHz. The suggested antenna is a good match for UW applications, according to the findings.

Keywords: MIMO antenna, Ultra-wideband, Isolation, Band-notch, WLAN band.

I. INTRODUCTION

High data rates, more channel capacity, quality of service, and compatibility with existing systems are requirements for both current and future wireless communication systems. Ultra-wideband technology presents a possible option because to its wide bandwidth, cheap cost, compatibility with other systems, and greater datarates at lower emission powers. However, in indoor situations, multipath fading affects UWB technology. In order to prevent multipath fading in UWB systems, multiple input multiple output technology is widely used. However, the poor isolation between the antenna ports in MIMO systems negatively affects the overall performance of the system. To improve the isolation, a number of techniques for doing so were created. Using a tree-like structure on the ground plane, etching a T-shaped and a line slot on the ground, protruding ground structure, adopting a wideband neutralization line, adopting a protruding ground branch structure, and adopting a wideband neutralization line are some of the methods used [4–8].

Given that UWB operates in the frequency range of 3.1 to 10.6 GHz, it is possible to experience interference from the WLAN (wireless local area network) spectrum, which spans 5.15 to 5.825 GHz. Therefore, a UWB MIMO antenna with band-notch characteristics is required to reduce the frequency interference. A variety of methods were first proposed to lessen WLAN interference, such as placing $\lambda/4$ and $\lambda/2$ slot resonators on the ground plane, [9] placing an inverted U-slot resonator on the feed line, [10] inserting an open stub in the printed folded monopole, [11] loading microstrip lines with trident-shaped strips, and [12] connecting a quarter-wave stub to the ground. 13] This communication presents an ultra-wideband MIMO antenna at the WLAN band with a frequency-notch feature. The antenna design, results, and discussion are covered in the parts that follow, followed by conclusions.

II.BACKGROUND AND THEORY

The purpose of the research project titled "Design and Analysis of Band-Notch UWB-MIMO Antennas for Interference Mitigation in Coexisting Wireless Systems" is to provide a comprehensive understanding of Ultra-Wideband (UWB), Multiple Input Multiple Output (MIMO) antenna systems, interference in wireless communication, and the significance of band-notching in antenna design for interference mitigation.

<u>Ultra-Wideband (UWB) and Multiple Input Multiple Output (MIMO) Systems:</u>

Ultra-Wideband (UWB):

- UWB may be seen as a technique that allows for the transmission of information across a broad spectrum via the use of low-power, short-duration pulses.
- Discuss the properties of UWB signals, such as their fast data speeds and very broad bandwidths, as well as their relatively low power spectral densities.
- Describe the benefits of using UWB technology, such as its fast data throughput, low power consumption, and interference resistance.

Multiple Input Multiple Output (MIMO):

- Introduce the MIMO technology, which allows for simultaneous data transmission and reception via the use of numerous antennas.
- Describe the advantages of MIMO, which include an increased data rate, higher spectrum efficiency, and enhanced reliability via the use of methods such as spatial multiplexing and diversity.
- Explain the fundamental ideas behind spatial multiplexing and diversity gain as they pertain to MIMO systems.

Interference in Wireless Communication:

Sources of Interference:

- In the context of wireless communication, please explain the many sources of interference, such as co-channel interference, neighbouring channel interference, and inter-symbol interference.
- Discuss how interference may lower the quality of the signal sent by wireless devices, lower the amount of data that can be transmitted, and impair the dependability of such systems.

Impact of Interference:

- Describe in detail the effects that interference has when many wireless systems are operating at the same time, with special emphasis on the difficulties that this causes in terms of ensuring dependable and effective communication.
- In order to keep the performance of wireless networks up to par, it is important to highlight the necessity of interference reduction strategies.

Significance of Band-Notching in Antenna Design:

Band-Notch Techniques:

- Investigate the use of band notching in antenna design as a means of reducing interference from certain frequency bands.
- Discuss the several methods that are used in band-notching, such as inserting slots or stubs or using reactive components to generate crisp rejection bands within the working frequency range of the antenna.
- Explain the trade-offs that must be made in order to achieve band-notching, including the influence on antenna bandwidth, impedance matching, and the properties of radiation.

Role of Band-Notch UWB-MIMO Antennas:

- Bring to light the significance of band-notch UWB-MIMO antennas in the process of reducing interference. These antennas provide an efficient rejection of interference-causing frequency bands while yet preserving the capabilities of both UWB and MIMO.
- Discuss the way in which these antennas make it possible for several wireless systems to coexist with one another by selectively attenuating interference signals while maintaining the required bandwidth for transmission.

By comprehensively covering these aspects in the Background and Theory section, the review paper sets the foundation for understanding the technical underpinnings and the relevance of band-notch UWB-MIMO antennas in addressing interference issues in coexisting wireless systems.

III.UWB-MIMO ANTENNA WITH SINGLE BAND-NOTCHED CHARACTERISTIC

A tiny ultra-wideband MIMO antenna with band-notch characteristics at WLAN band (5 to 5.9 GHz) is shown in this part for portable wireless devices [31]. The following subsections contain a detailed discussion of the recommended design.

A. Antenna Design

Figures 4(a) and (b) depict the suggested single band-notch UWB-MIMO antenna's geometry and a picture of the finished antenna. The design is printed on a FR4 substrate with a thickness of 0.8 mm, a dielectric constant (εr) of 4.4, and a loss tangent of 0.02. The suggested antenna's total dimensions are L × W × h mm3 = 26 × 40 × 0.8 mm3. The antenna is made up of two rectangular planar monopole radiating components with widths of LR × WR, called PM1 and PM2, which are identical, as shown in Figure 4(a). PM1 and PM2 are fed into a 50-ohm coplanar waveguide with size FL1 × WF. In addition, the LG × WG and LG × L reduced ground planes are connected to generate the common ground, which is printed on the same side of the substrate. The planar monopoles PM1 and PM2 are positioned perpendicular to each other in order to minimise mutual interaction between the components and maximise isolation between the antenna ports. A long rectangular strip of size SL × SW is added to the antenna to increase its impedance bandwidth and isolation; it extends from the common ground plane between the monopoles; it prevents surface currents and lengthens the current path, which moves the initial resonance frequency to a lower band, reducing mutual coupling; the feed line is equipped with an inverted U-slot resonator to provide a band-notch function at 5–5.9 GHz. The ideal antenna dimensions are as follows: D1 = 5.1, D2 = 6.1, D3 = 11.2, FL1 = 9.5, FL2 = 1.5, FL3 = 0.4, L = 26, LG = 8, LR = 10, SL = 18, SW = 1, W = 40, WF = 1.8, WG = 3.2, WR = 11, U1 = 7.8, U2 = 0.4, and UW = 0.3 (unit: mm). Figures 5(a) and (b) display the simulated S-parameters for the recommended antenna, Antenna 1 (a UWB-MIMO antenna without a ground strip), and Antenna 2 (a UWB-MIMO antenna with a ground strip). The proposed ultra-wideband MIMO antenna functions with outstanding impedance bandwidth from 2.2 to 11.4 GHz, except for a notch band from 5 to 5.9 GHz. Additionally, a mutual coupling of less than −20 dB is established over the whole UWB band.

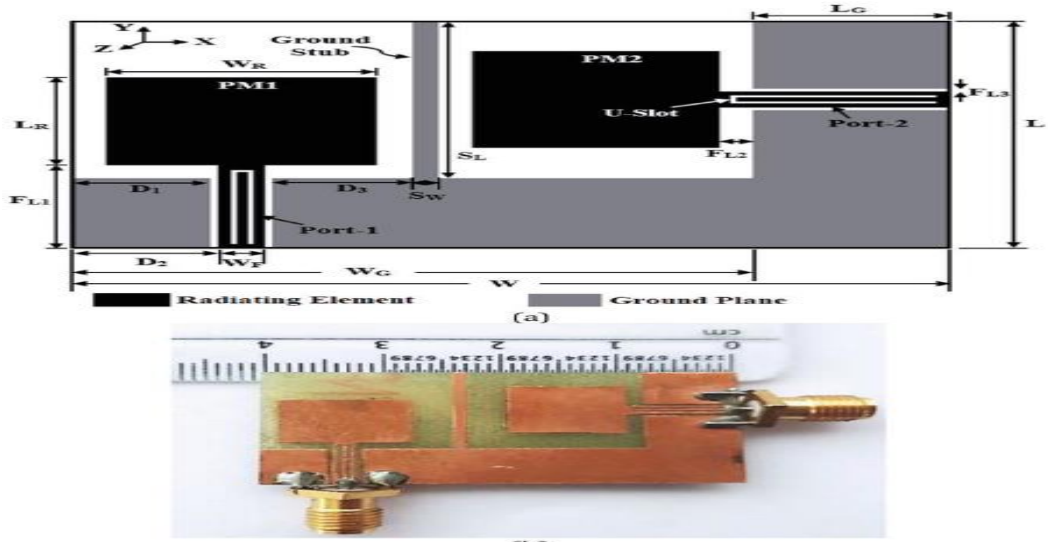


Figure 4 shows the intended antenna's geometry along with the manufactured antenna (b).

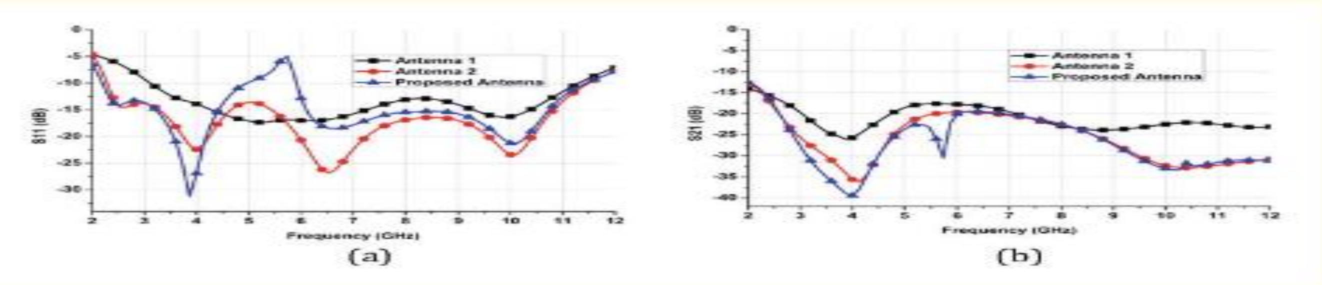
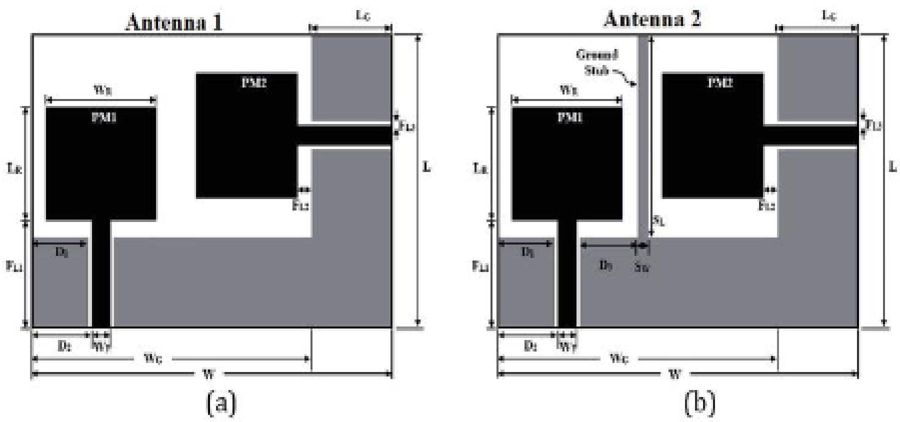


Figure 5: S-parameter simulations. (A) S11 parameter simulation. (b) A S21 parameter simulation.

B. *MIMO Antenna Study*

Due to the reduced size of the ground and radiating components, MIMO antennas' performance is restricted by the flow of surface currents on the ground plane and near-field radiation. This leads to poor impedance matching and substantial mutual coupling. Figure 6(a) and (b) depict the ultra-wideband MIMO antenna with and without a ground strip, respectively. Figure 7(a) and (b) exhibit the effects of the ground strip on the impedance bandwidth and mutual coupling between the MIMO antenna components. As shown in Figure 7(a), the initial resonance is produced at 2.5 GHz with a reduced cutoff frequency of 2.3 GHz and offers excellent impedance bandwidth from 2.3 to 11.4 GHz when the PM1 and PM2 are separated by a ground strip (Antenna 2). Furthermore, Figure 7(b) demonstrates that there is a mutual coupling between the antenna components of less than −20 dB across the UWB band, or less than −17 dB. Additionally, as demonstrated in Figure 7(c), the ground strip effectively inhibits surface current flow, minimising the amount of current that leaks into port 2 when port 1 is activated. By acting as a reflecting surface, the ground strip may change the direction of surface currents, extending the distance between the ports in the process. As a result, there is a noticeable improvement in the isolation between the MIMO antenna ports. Additionally, the ground strip that separates the MIMO antenna parts will reduce mutual coupling and enhance impedance matching properties. By altering the ground strip length (SL) and width (SW), the MIMO antenna is also examined. The findings are presented in Table 1 and shown in Figures 8(a)–(d). It can be demonstrated that the ground strip's overall length and width have a greater impact on the impedance bandwidth ($|S11| < -10$ dB) than isolation or mutual coupling. In this investigation, the ground strip length (SL = 18 mm) and width (SW = 1 mm) are employed



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The UWB-MIMO antenna configurations in Figure 6 are as follows: (a) antenna 1 (without a ground strip) and (b) antenna 2 (with a ground strip)

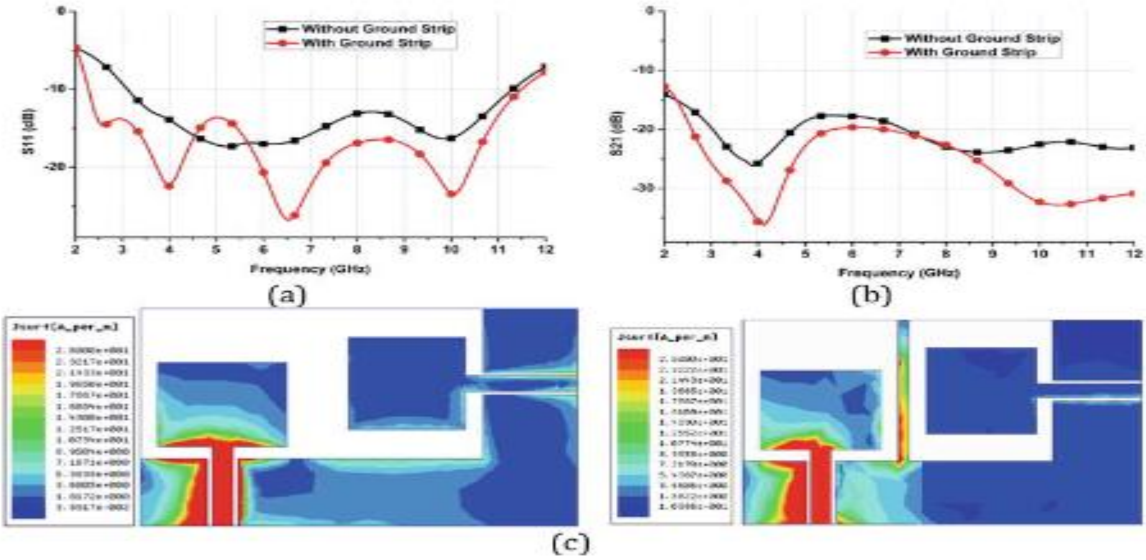
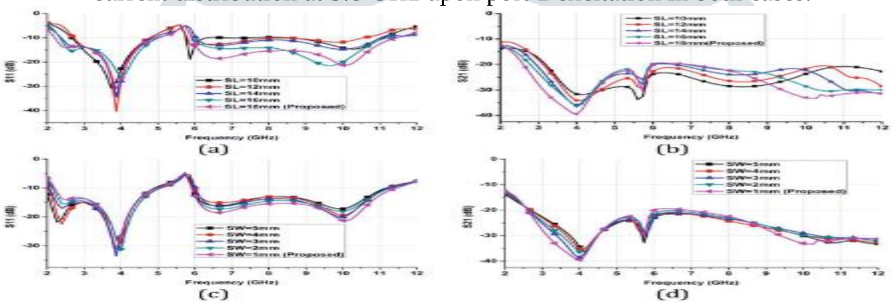


Figure 7. (a) S11 in absence of Figure 6 shows the UWB-MIMO antenna designs as follows: Antenna 1 (a) without a ground strip and antenna 2 (b) with one.t and in the presence of a ground strip, (b) S21 both in the absence and presence of a ground strip, and (c) surface current distribution at 3.8 GHz upon port 1 excitation in both cases.



In Figure 8. Examples of S11 for different strip lengths (SL), S21 for different strip lengths (SL), S11 for different strip widths (SW), and S21 for different strip widths (SW) are as follows.

Parameter	Value (mm)	Bandwidth (S11< −10 dB)	Mutual coupling (S21 < −20 dB)
Strip length SL	10	2.6–6.4	3.3–11.4
	12	2.6–8.6	3.2–11.4
	14	2.4–11.0	2.9–11.4
	16	2.4–11.3	2.8–11.4
	18 (proposed)	2.2–11.4	2.6–11.4
Strip width SW	5	2.0–11.1	2.8–11.4
	4	2.0–11.1	2.8–11.4
	3	2.1–11.2	2.8–11.4
	2	2.2–11.2	2.7–11.4
	1 (proposed)	2.2–11.4	2.6–11.4

Table 1 shows S11 and S21 for various lengths and widths of strips, not including the notch band.

As mentioned earlier, to create a band-notch filtering function for ultra-wideband systems, variously shaped slots, split-ring resonators, or strips can be used on or next to the feed line, radiating element, or ground plane. An SRR, strip, or slot may produce a band-notch resonator. The notch band centre frequency is determined by the length of the resonator, while the notch band bandwidth is controlled by the breadth of the resonator. This design employs an inverted U-shaped slot as a band-notch resonator, as seen in Figure 9(a)–(c). It is engraved on Antenna 2's feed line, resulting in the suggested band-notch UWB-MIMO antenna. The length of the U-shaped resonator is calculated using (5) [19].

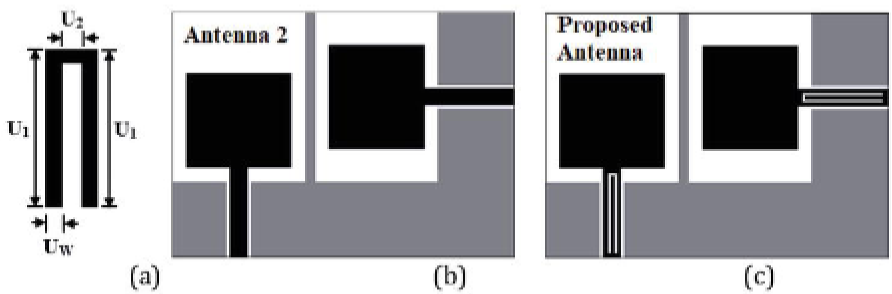


Figure 9. (a) A suggested band-notched UWB-MIMO antenna; (b) a UWB-MIMO antenna with a ground strip (Antenna 2); and (c) an inverted U-slot resonator.

$$LN = \frac{C}{2fN\sqrt{\varepsilon cff}} \approx \frac{\gamma}{2} \qquad E5$$

where LN is the whole length of the U-slot and fN is the notch centre frequency. For fN = 5.7 GHz and εr = 4.4, the predicted length of the U-slot resonator is 16.01 mm, according to equation (5). The simulated or projected length of the inverted U-slot resonator is 16 mm, which may be computed using equation (6).

$$LU - Slot = 2U1 + U2 \approx \frac{\gamma}{2} \qquad E6$$

The computed (theoretic) length and the simulated (practical) length agree quite well. Figure 10(a)–(c) displays the S11, S21, and surface currents with and without an inverted U-slot resonator. The recommended antenna, as seen in Figure 10(a), generates band-notch characteristics from 5 to 5.9 GHz with an S11 of −5 dB at 5.7 GHz and has an appropriate impedance bandwidth from 2.2 to 11.4 GHz. Furthermore, The reciprocal coupling over the operating band is less than −20 dB, as seen in Figure 10(b). This is demonstrated in Figure 10(c), where an inverted U-slot resonator is surrounded by a concentrated area of heavy current at 5.7 GHz. This area functions as a band-notch filter to stop current flow on the radiating sections and stop radiation from the antenna. Consequently, the WLAN frequency between 5 and 5.9 GHz develops a notch band.

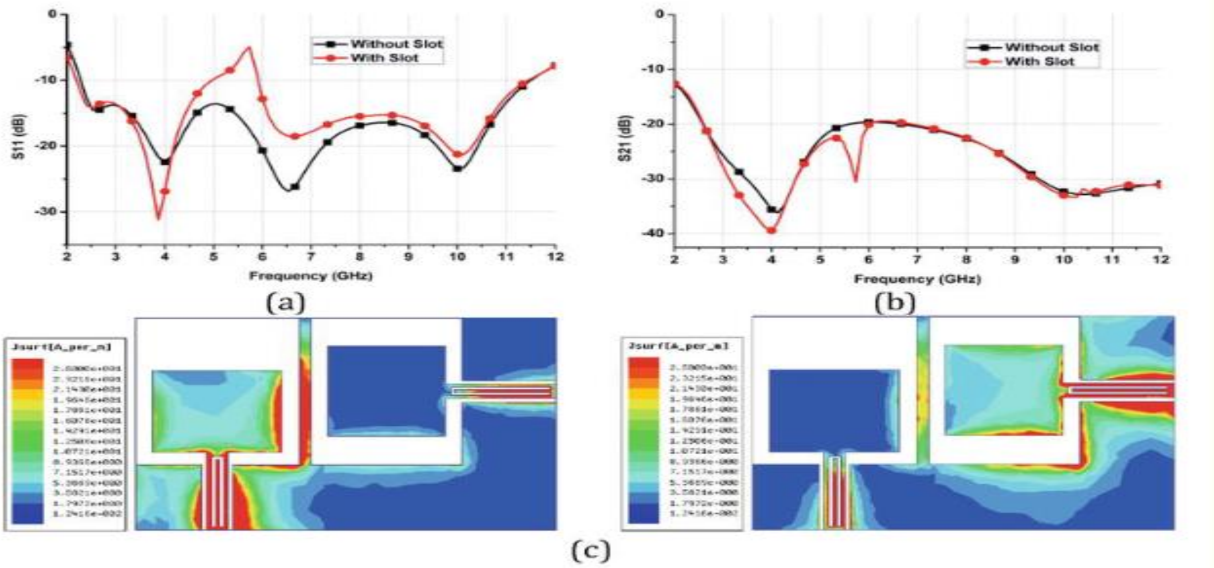
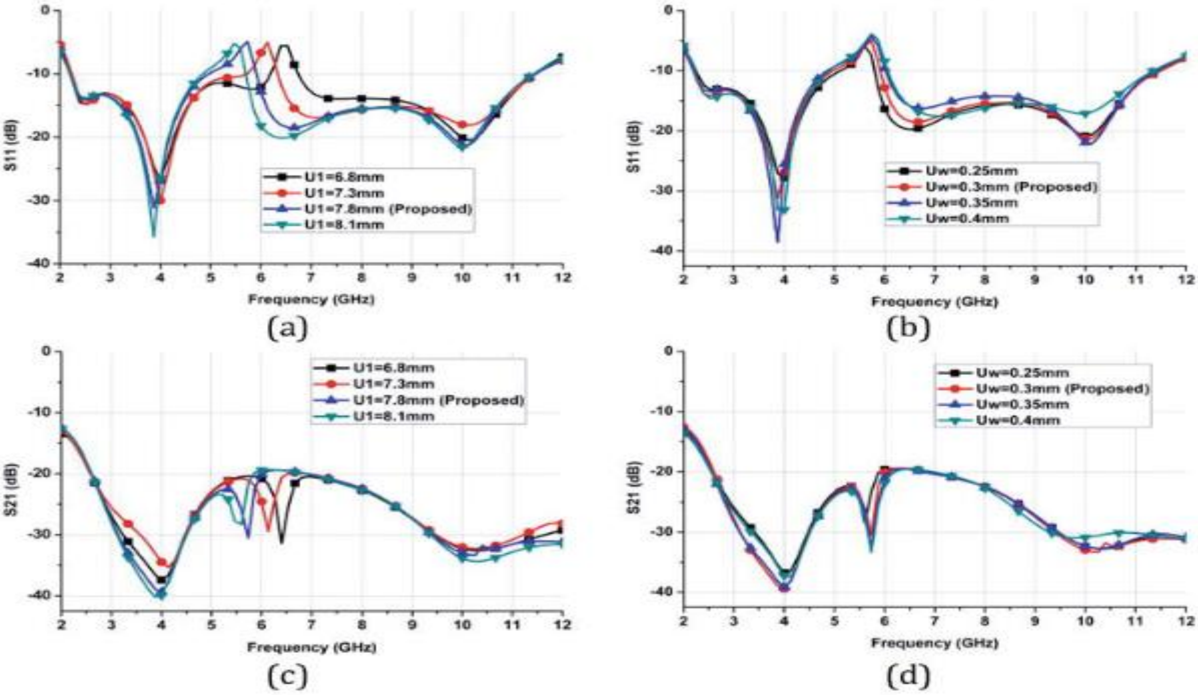


Diagram 10. When ports 1 and 2 are stimulated in (a) S11 without and with an inverted U-slot, (b) S21 without and with an inverted U-slot, and (c) both, the current distribution is at 5.7 GHz.

The slot length U1 and slot width UW are the subject of a parametric analysis to describe the effects of the inverted U-slot. Table 2 displays the notch bands and notch centre frequencies for a range of slot widths and lengths. Figures 11(a) and (b) display the S11 of the MIMO antenna for a range of slot widths (UW) and lengths (U1). It is evident that when the slot length U1 grows from 6.8 mm to 8.1 mm, the notch band shifts from 6.26–6.7 GHz to (4.8–5.7) GHz, and the notch fN centre frequency lowers from 6.5 GHz to 5.4 GHz. This design's 7.8 mm U1 creates the required band notch between 5 and 5.9 GHz. When the slot width UW is increased from 0.25 mm to 0.4 mm, as seen in Figure 11(b), With the notch centre frequency, fN, at 5.7 GHz, the notch bandwidth expands from 5.94–6.1 GHz to 5.25–5.7 GHz. In this proposed design, the necessary band notch from 5 to 5.9 GHz is achieved by using a slot width UW of 0.3 mm. Figures 11(c) and (d) illustrate how the inverted U-slot resonator affects the S21 of the MIMO antenna for various slot lengths and widths. Furthermore, it is shown that changes in the slot width UW and length U1 have minimal impact on the mutual coupling of MIMO antennas.

Parameter	Value (mm)	Notch-band (GHz)	Notch-center frequency fN (GHz)
Slot length U1	6.8	6.26–6.7	6.5
	7.3	5.73–6.4	6.2
	7.8 (proposed)	5.0–5.9	5.7
	8.1	4.8–5.7	5.4
Slot width UW	0.25	5.2–5.7	5.6
	0.3 (proposed)	5.0–5.9	5.7
	0.35	4.95–6	5.7
	0.4	4.94–6.1	5.7

The frequencies of the notch bands and notch centre are listed in Table 2 for a range of slot widths and lengths.



The S11-parameter (a) and (b) for various slot widths and lengths and the S21-parameter (c) and (d) for various slot lengths and widths are displayed in Figure 11.

IV.RESULTS AND ANALYSIS

Figure 2 shows the proposed structure's comprehensive design process. As shown in Figure 2(a), two antenna components are first placed on the common ground to construct the UWB MIMO antenna without decoupling structure, known as Antenna 1. Figure 3 shows the S11 parameter of the Antenna 1. The Antenna 1 is shown to operate between 2.5 and 10 GHz. Additionally, as shown in Figure 4, there is very little isolation between the ports, as indicated by the (S21 parameter). As shown in Figure 2(b), Antenna 2 is created by inserting a rectangular stub in between the antenna components of Antenna 1. Figure 3 shows the S11 parameter of the Antenna 2. Figure 3 shows the frequency range of operation for Antenna 2, which is 3.5 to 12.8 GHz. Furthermore, compared to Antenna 1, Antenna 2 has a higher isolation of almost 13 dB. The inclusion of stub between the parts is what improves isolation. Ultimately, each component of Antenna 2 is given an inverted C-shaped slot to create the suggested band-notched antenna.

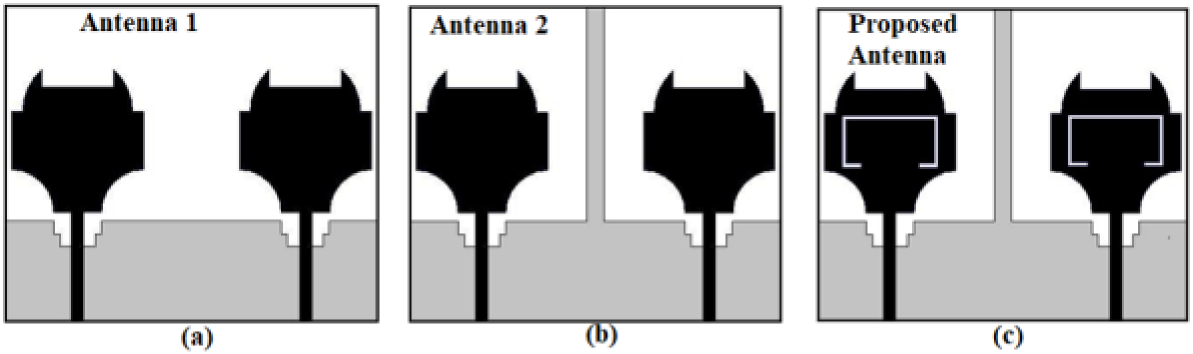


Fig. 2. The suggested antenna's design method

Figure 3 displays the S11 parameter for the suggested structure. The antenna has an impedance bandwidth of 9 GHz and operates between 3.5 and 12.5 GHz. Additionally, the antenna's isolation across the whole operating band is greater than 15 dB. Moreover, a band-notch is made between 5 and 5.6 GHz to prevent WLAN system interference. The voltage standing wave ratio (VSWR) for each of the three antenna designs is shown in Figure 5. The results show how well-suited the suggested antenna is for removing frequency interference from wireless local area networks.

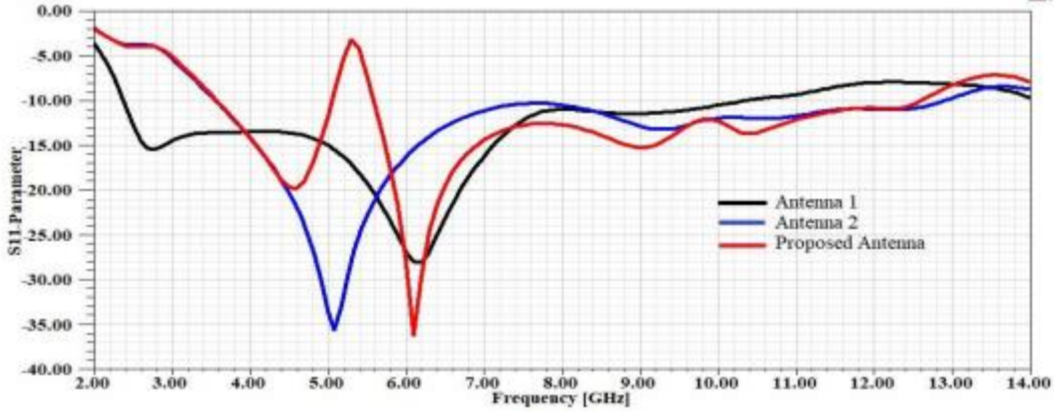


Figure 3. Three different antenna designs' S11 parameters.

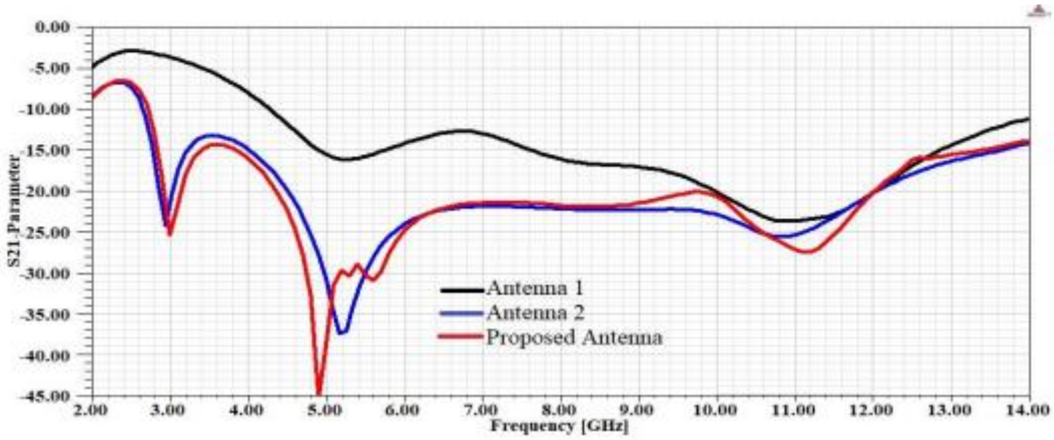


Figure 4: Three antenna designs' S21 parameters.

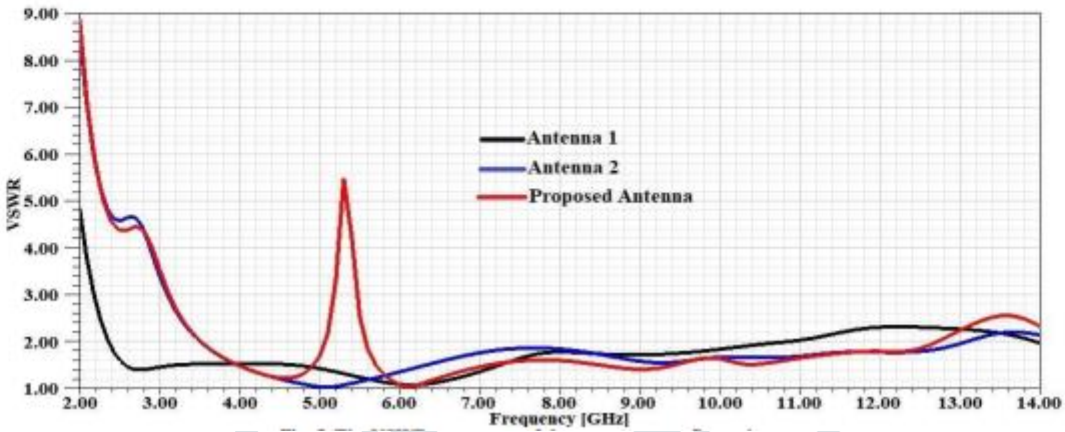


Figure 5 shows the three antenna designs' VSWR parameters.

The surface current distribution theory may be used to describe the impact of a rectangular stub extending from the ground plane. Figures 6(a) and 6(b) show the surface current distributions of Antenna 1 and Antenna 2 at 6.5 GHz when port 1 is stimulated. In Figure 6, red indicates higher radiation levels, whereas blue indicates lower radiation levels. The graphic shows that, in comparison to antenna without stub (Antenna 1), antenna with rectangular stub (Antenna 2) is obstructing radiation flowing from port 1 to port 2. Therefore, between the antenna ports, such as ports 1 and 2, the rectangular stub offers more isolation.

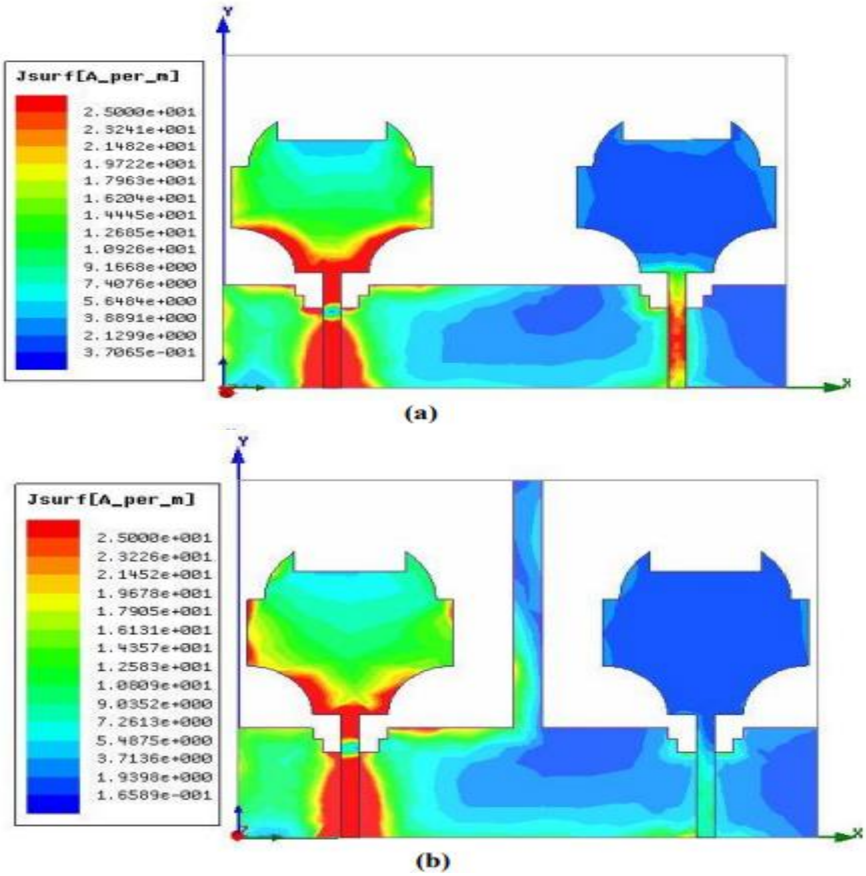
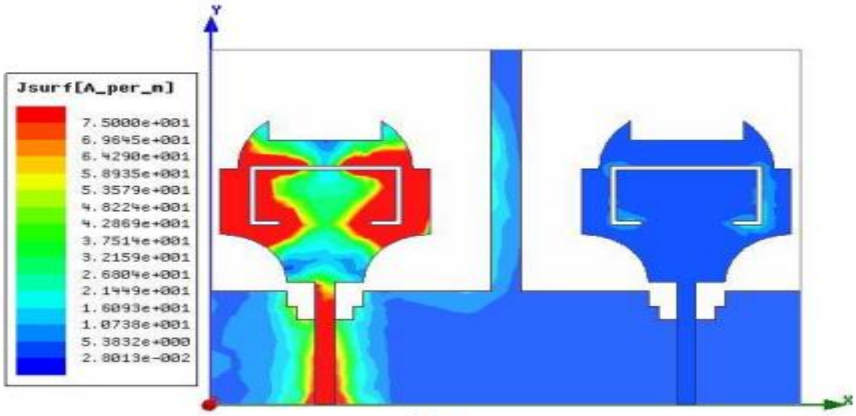
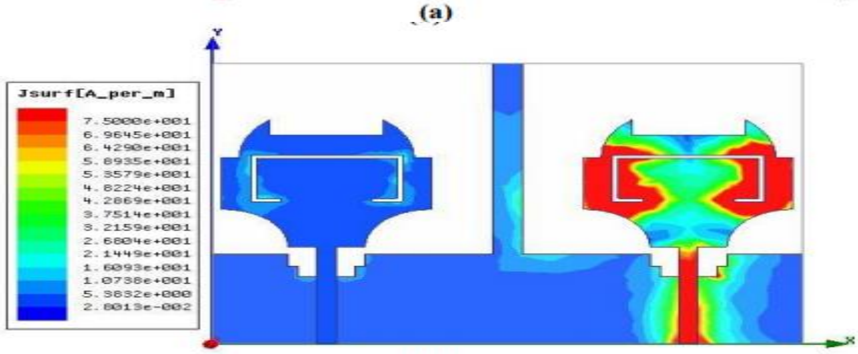


Figure 6 shows the distribution of surface current at 6.5 GHz when port 1 is activated. Antenna 1 (a) and Antenna 2 (b).

Each radiating element has an etched inverted C-shaped groove to reduce frequency interference from the current WLAN system. Figure 7(a) and (b) respectively exhibit the influence of slot on surface current distribution at 5.3 GHz when port 1 and port 2 are energized. It is evident that at the notch frequency of 5.3 GHz, the slot effectively prevents surface currents from flowing over the patch.



(a)



(b)

Figure 7 shows how a slot affects the distribution of surface current at 5.3 GHz when port 1 is stimulated and port 2 is excited**.** Figure 8 displays the proposed antenna's 2-D radiation patterns (E- and H-planes) at 4.6 GHz, 6.1 GHz, and 9 GHz when port 1 is stimulated and port 2 is terminated with a 50-ohm load, and vice versa. The illustration indicates that the antenna is providing strong diversity performance since the radiation patterns of ports 1 and 2 are similar to mirror images. Additionally, the H-plane pattern is omnidirectional, while the E-plane pattern somewhat resembles a "figure of 8 or bidirectional" pattern. The results demonstrate that the suggested antenna is a wise option for uses with portable devices.

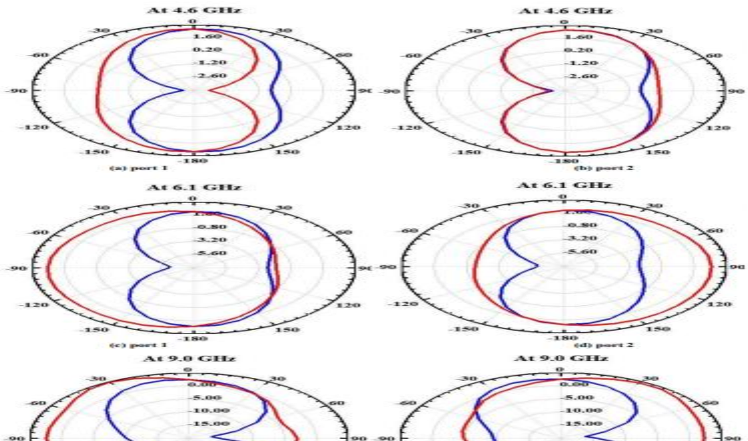


Fig. 8: The antenna's 2-D radiation patterns (Blue denotes the E-plane and Red the H-plane).

V.CONCLUSION

In this communication, the UWB-MIMO antenna that offers band-notch features at WLAN band is provided. A few comparable antenna components that are driven by a microstrip line feed make up the suggested antenna. In order to get optimal impedance matching characteristics between 3.5 and 12.6 GHz, the ground plane is carved with three slots. Additionally, a rectangular stub is added to the ground to improve the isolation between the antenna ports by more than 15dB. Each element has an inverted C-shaped slot that is used to create band-notch in the WLAN band between 5 and 5.6 GHz. The results verify that the suggested UWB-MIMO antenna is a good option for applications involving portable devices.

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