Progress In Electromagnetics Research Letters, Vol. 93, 65–71, 2020

A Novel Dual Band Notched MIMO UWB Antenna

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Abstract—A novel, miniature multiple input multiple output (MIMO) ultra wide band (UWB) antenna with dual notched characteristics is proposed. The antenna incorporates a tapered microstrip feed line with two radiating patch structures procured by the incorporation of two ellipses with a circle and a reduced ground structure. The proposed antenna is printed on an FR-4 substrate having a concise size of $40 \times 22\,\text{mm}^2$ to cover $-10\,\text{dB}$ bandwidth of 3.18–11.26 GHz with fractional bandwidth of 112%. The two notched bands 3.31–3.99 GHz for WiMAX and 4.97–5.93 GHz for WLAN accomplished by two T-shaped parasitic structures are etched above ground plane and inverted U-shaped slots etched on radiating patch, respectively. The isolation of $< -15\,\text{dB}$ is realized by inserting a T-shaped stub in between two patch elements. The measured MIMO diversity characteristics are the evidence of that the proposed antenna is appropriate for portable wireless applications.

1. INTRODUCTION

The potential of a radio communication system can be ameliorated by a multiple input multiple output (MIMO) system [1]. MIMO antennas were evolved for wireless standards WiMAX (Worldwide Interoperability for Microwave Access) and WLAN (Wireless Local Area Networks) [2, 3]. However, UWB MIMO communication turns out to be a propitious technology because UWB system has low power consumption, high data rates, long distance communication, and being employed for variety of WPAN (Wireless Personnel Area Network) applications. However, UWB signals habitually encounter electromagnetic interference (EMI) exerted by diverse narrow band wireless systems. To mitigate EMI, a variety of UWB antenna designs with band notch functionalities have been reported by researchers. In MIMO UWB antenna design, decoupling between the antennas is one momentous challenge. Multitudinous methods have been proposed to diminish mutual coupling between MIMO antennas in literature. In [4], slotted complementary split ring resonators are utilized to reduce mutual coupling between microstrip patch antennas. A wideband neutralization line is incorporated to reduce mutual coupling of higher than 22 dB between UWB MIMO antennas in [5]. Electromagnetic band structures are etched to minimize the mutual coupling between radiating patches in [6–8]. In [9], a novel method of estimating the average channel capacity per user of a spread spectrum MIMO multiple-user system is evaluated. The eminence of proposed UWB MIMO antenna with reported literature [10–14] is given in Table 1. In [10], a CPW-fed UWB MIMO antenna of $40 \times 40\,\text{mm}^2$ dimension is proposed with WLAN and X-band notch peculiarities having 111% fractional bandwidth, mutual coupling of $< -15\,\text{dB}$, ECC of < 0.5, and a peak gain of 5.3 dBi. A compact quasi-self-complementary MIMO UWB antenna with dual band notched characteristics is proposed [11]. The antenna consists of a Hilbert fractal slot to enhance isolation of $< -20\,\text{dB}$ with ECC of < 0.1, peak gain of 4, and radiation efficiency of 80%. Liu et al. [12] propose a closely spaced dual band notched UWB antenna for MIMO applications. The antenna covers an impedance bandwidth of 3.1–10.6 GHz with the isolation of $< -15\,\text{dB}$, ECC of < 0.3, peak gain of 5.1, and radiation efficiency ranging from 63 to 90%. An isolation enhanced, low profile, printed MIMO-UWB antenna with WiMAX and WLAN band notch characteristics is reported in [13]. The

Received 1 August 2020, Accepted 31 August 2020, Scheduled 11 September 2020
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Table 1. Comparison with literature.

Ref.	Size, mm^2	Bandwidth	Fractional Bandwidth, %	Notch bands	Isolation (dB)	ECC	Peak Gain	Radiation efficiency, %
[10]	40×40	3.4–12	111	5.6, 7.6	< -15	< 0.5	5.3	NR
[11]	30×41	2.2–11	133	5.5, 8.1	< -20	< 0.1	4	80
[12]	30×40	3.1–10.6	109	3.3–3.7, 5.15–5.85	≤ -15	< 0.03	5.1	63–90
[13]	26×35	2–10.6	136	3.3–3.7, 5.17–5.25	≤ -22	< 0.2	NR	NR
[14]	35×23	3.1–10.9	111	3.5, 5.3	≤ -17	< 0.012	NR	> 60
This work	40×22	3.18–11.26	112	3.3–3.99, 4.9–5.93	< -15	< 0.0002	5.41	> 90

Abbreviation: ECC — Envelope correlation coefficient, NR — Not Reported.

antenna has the mutual coupling of < -22 dB, ECC of < 0.2, and a fractional bandwidth of 136%. In [14], a compact CPW-fed UWB diversity slot antenna with dual band notch characteristics is proposed to cover 3.4–12 GHz, isolation of ≤ -15 dB, ECC of < 0.5, and a peak gain of 5.2.

In this work, a MIMO UWB antenna with dual band notch characteristics consummate at WiMAX and WLAN bands is proposed. The isolation between two closely mounted radiators is minimized to < -15 dB by etching a T-shaped stub. A pair of symmetrical T-shaped structures etched above the defected ground structure and a pair of inverted slots etched in the radiators are exploited to notch WiMAX and WLAN bands, respectively. The advantages of proposed antenna are its novel design, simple structure, compact size, omnidirectional radiation patterns, and more than 90% radiation efficiency.

2. MIMO UWB ANTENNA DESIGN

The proposed UWB MIMO antenna is designed and evolved on an FR-4 substrate with dielectric constant $\varepsilon_r = 4.4$. The geometry and prototype of proposed antenna are depicted in Figures 1(a) and (b).

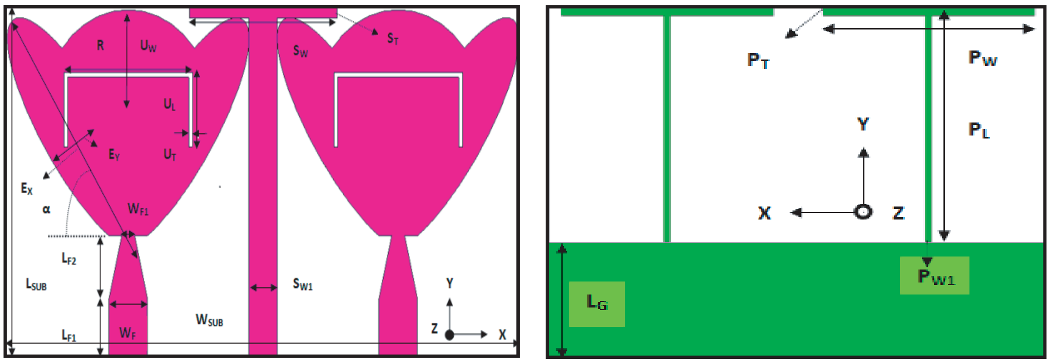
3. SIMULATION BASED ANALYSIS

3.1. Effect of Tapered Feed Structure

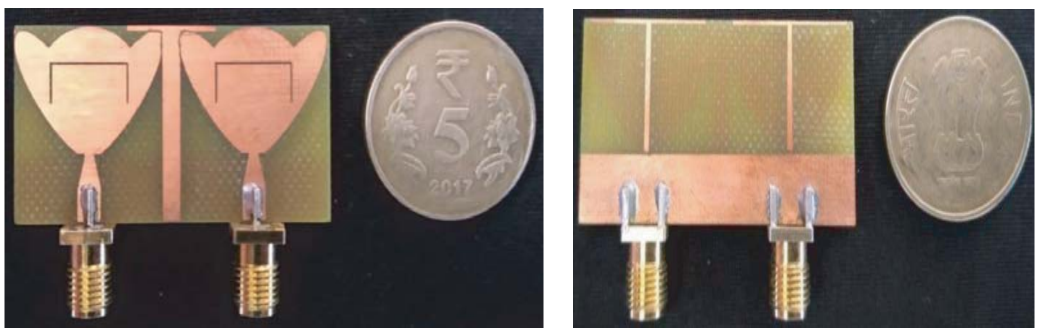
Initially, a single input single output (SISO) radiating patch as shown in Figure 2(a)(i) is achieved by amalgamation of two ellipses with a circle with a reduced ground structure and has two resonant frequencies at 3.96, 10.08 GHz with S_{11} of -18.9 and -19.24 dB respectively as depicted in Figure 2(b). For the antenna structure demonstrated in Figure 2(b)(ii), the MIMO antenna has three resonances in specified band occurring at 3.61, 6.61, and 9.58 GHz with S_{11} of -13.55, -11.69, and -16.55 dB, respectively. When microstrip line is tapered to procure the proposed MIMO UWB only the structure as depicted in Figure 2(a)(iii) covers an impedance bandwidth of 1.83–34.16 GHz with fractional bandwidth of 180% as shown in Figure 2(b) to cover UWB, X, Ku, and some portion of K band applications. The connection of tapered microstrip line to the radiating patch is to smooth the current's path, thus providing wider impedance bandwidth [15].

3.2. Band Notch Performance

The band notch performances of proposed antenna with variation in length U_L of an inverted U-shaped slot and width P_W of T-shaped parasitic stub are depicted in Figures 3(a) and (b). The total length,

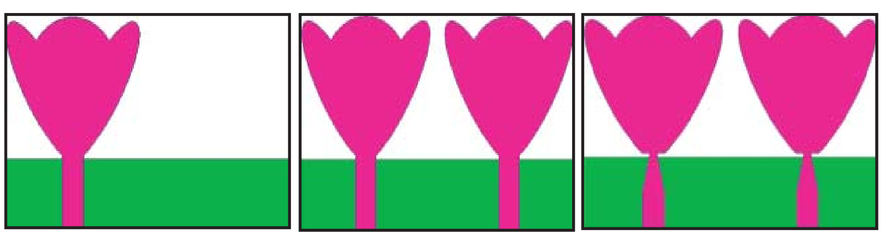


(a)



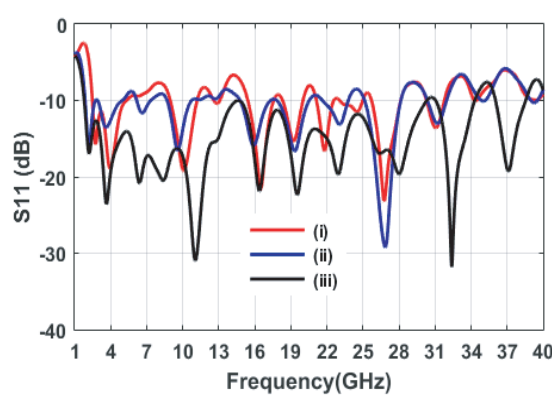
(b)

Figure 1. Proposed antenna. (a) Geometry. (b) Prototype.



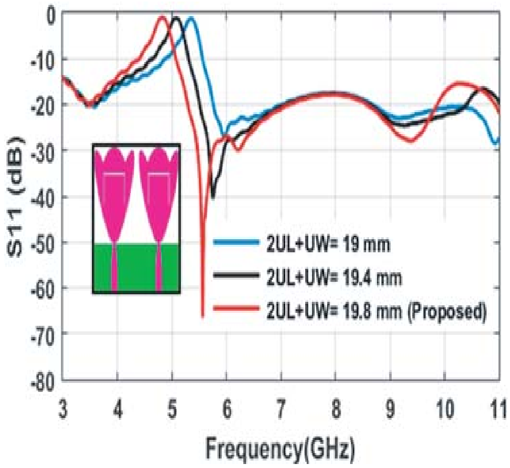
(i) (ii) (iii)

(a)

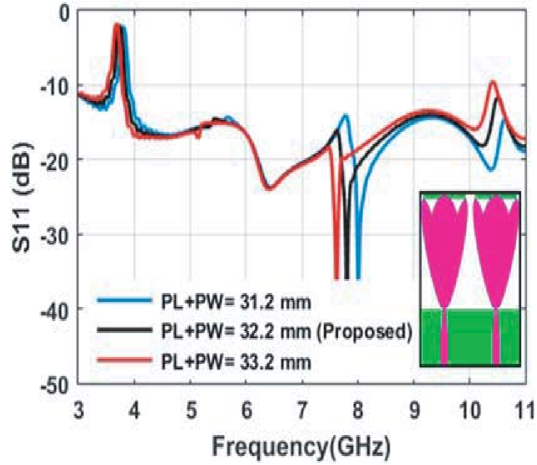


(b)

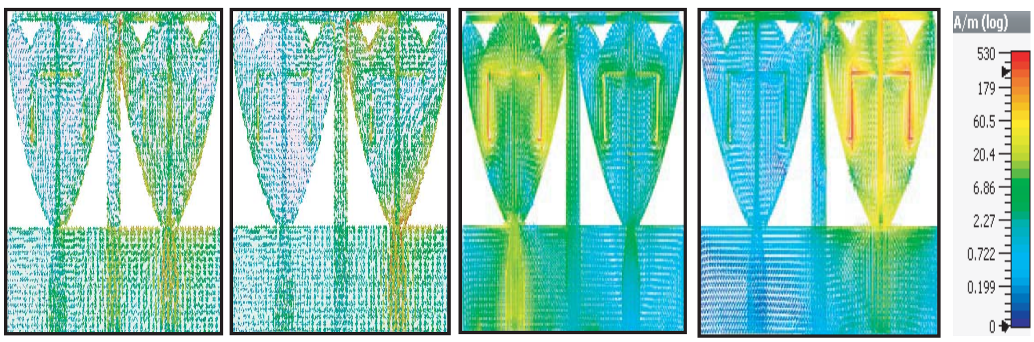
Figure 2. Evaluation of Basic UWB antenna. (a) Antenna structures. (b) S-parameters.



(a) Effect of U_L on WLAN band



(b) Effect of P_W on WiMAX band



(i) 4.39 GHz (ii) 9.87 GHz (iii) 3.36 GHz (iv) 5.61 GHz

(c) Surface currents at resonant (i), (ii) and notched frequencies (iii), (iv)

Figure 3. Band notch characteristics of proposed antenna.

L_i, of U-shaped slot and T-shaped parasitic stub is approximated as a half wave length resonator and is given by [16],

$$L_{Ti} = \frac{C}{2f_i\sqrt{\varepsilon_{eff}}}; \quad i = 1 \text{ for U-slot}; \quad i = 2 \text{ for T-parasitic} \tag{1}$$

where C is the velocity of light.

When $L_{T1} = 2U_L + U_W$ of U-shaped slot is varied in steps of 19, 19.4, and 19.8 mm, the bandwidth of notched band changes from 4.88–5.56, 4.65–5.31, and 4.4–5.07 GHz with centre frequencies of 5.35, 5.08, and 4.83 GHz respectively to notch WLAN band. For T-shaped parasitic stub, when $L_{T2} = P_L + P_W$ is varied in steps of 31.2, 32.2, and 33.2 mm, the notched bandwidth varies from 3.65–3.91, 3.58–3.84, and 3.51–3.78 GHz with centre frequencies of 3.81, 3.74, and 3.68 GHz respectively to notch WiMAX band.

The surface current distribution of suggested antenna at resonant frequencies of 4.39, 9.87 GHz and band notch frequencies of 3.36, 5.61 GHz when port 1 is excited is depicted in Figure 3(c). The surface currents are highly strenuous around inverted U-shaped slot and T-parasitic stub which epitomize the proposed antenna notch WLAN and WiMAX bands at 5.61 and 3.36 GHz frequencies, respectively.

4. RESULTS AND DISCUSSIONS

The electrical functioning of proposed antenna was tested by Anritsu MS2037C/2 network analyzer. Small disparities between simulated and measured electrical characteristics were noticed due to tolerances in fabrication, erratic in ε_r values, and quality issues in SMA connector. The simulated and measured S_{11} and S_{12} of proposed antenna are depicted in Figure 4(a).

The measured S_{11} of proposed antenna covers an impedance bandwidth ranging from 3.16 to 11.30 GHz. The measured mutual coupling, S_{21}, between two radiators is almost < -15 dB for the entire operating bandwidth. The simulated and measured radiation patterns at resonant frequencies

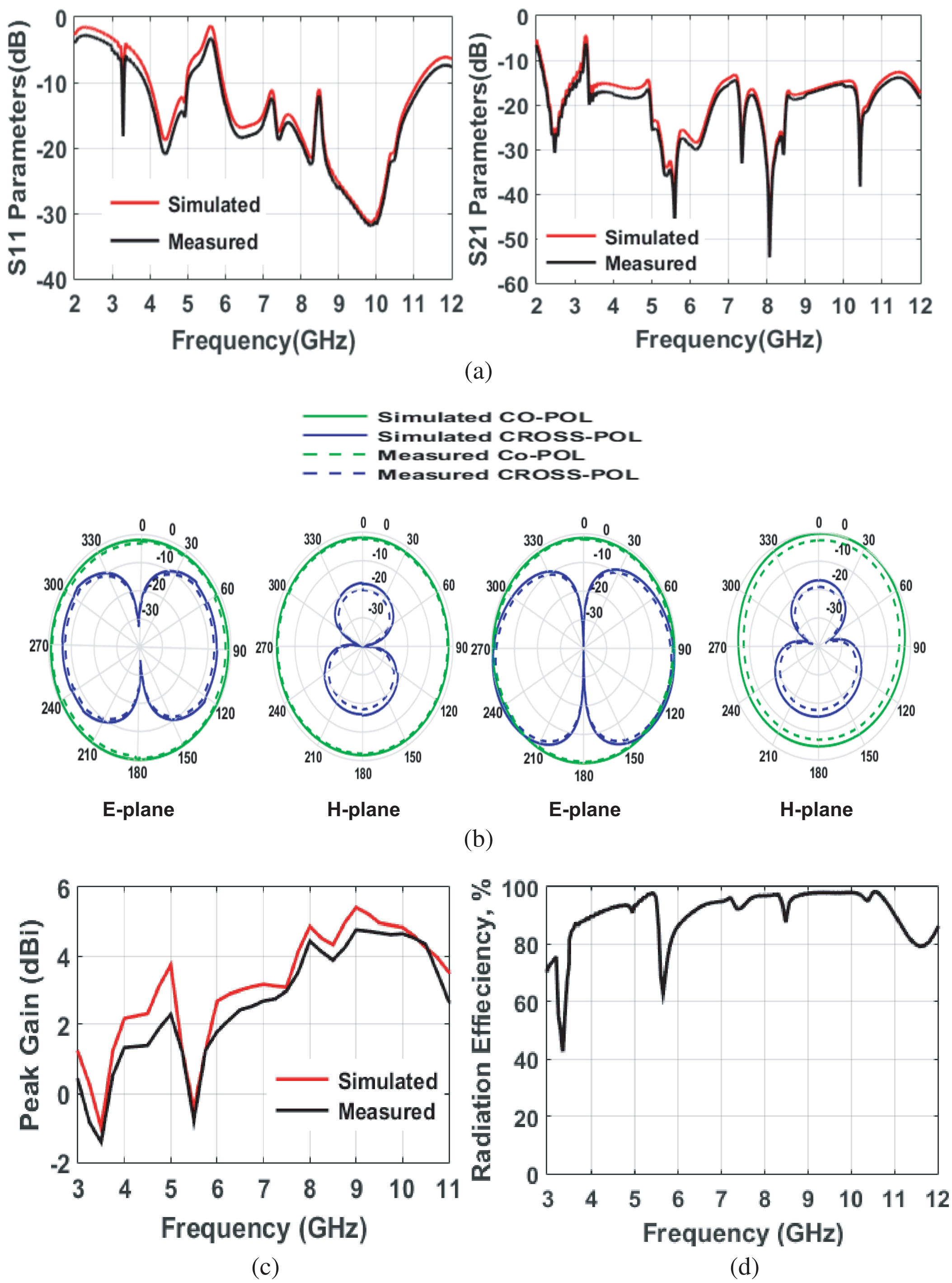
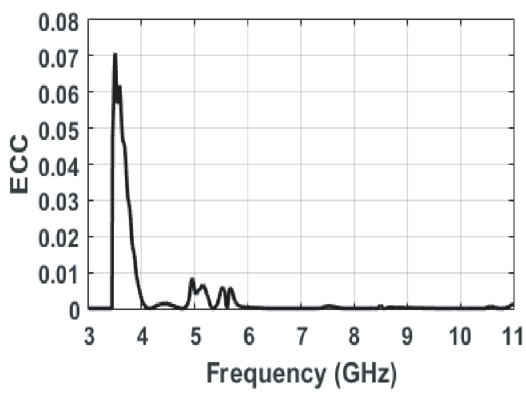


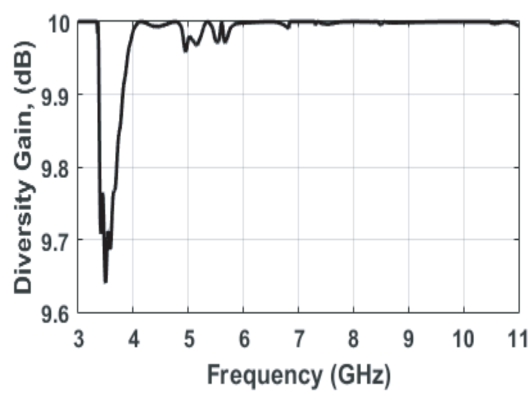
Figure 4. Radiation characteristics. (a) Simulated and Measured S_{11} and S_{12}. (b) Radiation patterns at 4.39 and 9.87 GHz. (c) Realized gain. (d) Radiation efficiency.

4.39 and 9.87 GHz are shown in Figure 4(b). The radiation patterns of proposed antenna are measured at each one degree step interval in an anechoic chamber. Thus, the accuracy of measured E-plane and H-plane radiation patterns is greatly increased as we have taken 360 points for measurement. Almost stable radiation patterns are noticed at both the frequencies 4.39 GHz and 9.87 GHz. In E-plane, the patterns are like dipole and omnidirectional in H-plane which makes the proposed antenna satisfactory for UWB wireless applications. The peak gain and radiation efficiency plot of proposed antenna are depicted in Figures 4(c) and (d). The peak gain is altered from 1.35 to 5.41 dBi within UWB and is drastically decreased to −1.76 dBi and −1.12 dBi at 3.36 GHz and 5.61 GHz to notch WiMAX and WLAN bands, respectively. From Figure 4(d), more than 90% of radiation efficiency is observed for the proposed antenna except at two notched bands. The radiation efficiencies are 42% and 60% at WiMAX and WLAN notched bands, respectively.

The diversity performance of MIMO antenna is estimated by enumerating envelope correlation coefficient (ECC) and diversity gain (DG). The ECC is a measure of correlation between two radiating patches. Ideally, ECC is 0 but is very small value practically, to indicate how potent diversity between the two MIMO elements. For the proposed antenna, from Figure 5(a), the ECC is noticed to be less than 0.0002 excluding two notched bands WiMAX and WLAN. In WiMAX notched band range of 3.31–3.99 GHz, ECC increases to 0.07, and in WLAN band notched frequency band of 4.97–5.93 GHz, ECC increases to 0.095. Consequently, the diversity performance of proposed MIMO antenna is strong enough because of a very low ECC of < 0.0002.



(a)



(b)

Figure 5. MIMO diversity characteristics. (a) Envelope correlation coefficient. (b) Diversity gain.

The diversity gain (DG) from ECC is estimated by Equation (4) as described in [17],

$$DG = 10 \times \sqrt{1 - |ECC|} \tag{2}$$

From Figure 4(b), the DG of proposed antenna swings around 10 dB in the entire operating band except at WiMAX and WLAN notched frequencies, at which it falls to 9.64 and 9.96 dB, respectively. Thus the estimated values of ECC and DG confirm that the proposed MIMO antenna is suitable for MIMO applications.

5. CONCLUSION

A UWB MIMO antenna with dual band notched characteristics integrated with Ku, K band applications is proposed. The mutual coupling between two radiators is reduced by utilizing a T-shaped stub. The band notch characteristics at WiMAX and WLAN bands are achieved by etching a U-shaped slot in radiators and T-shaped parasitic stub above the defected ground plane structure. The proposed MIMO UWB antenna is designed, fabricated, and tested for electrical parameters such as S_{11}, S_{12}, radiation patterns, peak gain, and radiation efficiency. A good acquiescence between simulated and measured parameters of proposed antenna makes it suitable for portable MIMO UWB wireless applications.

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