

Compact Dual Band-Notched UWB MIMO Antenna for USB Dongle Application with Pattern Diversity Characteristics

Deepika Sipal, Mahesh P. Abegaonkar*, and Shiban K. Koul

Abstract—In this paper a compact planar dual band-notched ultra-wideband (UWB) multiple input multiple output (MIMO) antenna is presented for universal synchronous bus (USB) dongle application with pattern diversity characteristic. The MIMO configuration has orthogonally placed elements with overall size of $16 \times 37.6 \text{ mm}^2$, and the common ground plane of the MIMO antenna is further extended by 20 mm for its practical use. The measured and simulated reflection coefficients of the antenna show good impedance bandwidth matching over the range from 3 GHz to 12 GHz excluding the dual notched bands. Both elements show good band-reject property at the notched bands. The simulated results are verified through measurements and calculations. Moreover, absence of decoupling network makes circuit less complex and very compact. Radiation pattern of the MIMO antenna is almost omnidirectional. Furthermore, diversity performance of MIMO antenna is validated with its envelope correlation coefficient (ECC) and pattern diversity characteristic. These characteristics demonstrate its candidacy as a compact dual band-notched UWB MIMO antenna for USB dongle application.

1. INTRODUCTION

Ultra-wideband (UWB) multiple input multiple output (MIMO) technology has received considerable attention in the past decade due to its property of high data rate with good reliability and range. The UWB technology uses very wide bandwidth, and MIMO technology uses multiple antennas at transmitter and receiver sides. The blend of UWB technology and MIMO technology meets the expectation of modern wireless communication system, where the data traffic is increasing exponentially [1]. Several UWB MIMO antennas have been reported till date [1–13]. On the other hand, many UWB universal synchronous bus (USB) dongle antennas [14, 15] have also been reported in the literature. However, there are very few papers which report UWB MIMO antenna for USB dongle application [1, 16].

Designing a UWB MIMO antenna for USB dongle application is a very challenging task [16]. The design gets even more challenging when dual notched bands are also required to eliminate interference from already existing wireless standards i.e., WIFI and WiMAX standards [11]. Some UWB MIMO antennas are reported with single notch band [10, 17, 18] and some are reported with dual notch bands [11–13]. For achieving dual notched bands in UWB antenna, additional circuitries are required, which further affects the isolation between antenna elements [11]. It is known that high isolation is required for effective MIMO performance. For achieving high isolation, different methods are reported in literature such as defected ground structures, neutralization line, open and short circuit stubs, use of via holes etc. [2, 4, 5, 11, 17, 19]. However, the presence of these isolating circuits occupies further space in printed circuit board (PCB) of compact device such as USB dongle. Already reported dual band-notched UWB MIMO antennas are not suitable for USB dongle applications due to its large size.

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* Corresponding author: Mahesh P. Abegaonkar (mpjosh@care.iitd.ac.in).

The authors are with the Centre for Applied Research in Electronics (CARE), Indian Institute of Technology Delhi (IITD), Hauz Khas, New Delhi-110016, India.

Therefore, this paper presents a decoupling network free very compact planar dual band-notched UWB MIMO antenna for USB dongle application with pattern diversity characteristic. The configuration of MIMO antenna has common ground plane which is further extended in $+Y$ -axis by 20 mm for its practical implementation. Size of the proposed dual band-notched UWB MIMO antenna is $16 \times 37.6 \text{ mm}^2$ which is about 26%, 75% and 50% smaller than the MIMO antennas reported in [11, 12] and [13] respectively. Each antenna element has measured $|S_{11}| \leq -10 \text{ dB}$ except at notched bands and $|S_{21}|$ is $\leq -19 \text{ dB}$ in most of the band. However, at the lower band and middle band the $|S_{21}|$ is $\leq -9 \text{ dB}$ and -14 dB respectively. Both antenna elements show good band-reject property at the dual notched bands. Moreover, orthogonal placement of antenna elements helps in achieving good diversity performance. The proposed configuration of dual band-notched UWB MIMO antenna has very compact size and does not use any isolating structure which makes it further compact to use as a USB dongle.

2. TWO ELEMENT UWB MIMO ANTENNA CONFIGURATION

The structures are simulated and optimized in 3-D electro-magnetic (EM) simulation tool CST Microwave Studio. The design is fabricated on a Neltec substrate, which has height of 0.762 mm, permittivity of 3.2 and loss tangent of 0.0024.

2.1. Chosen Configuration of the UWB MIMO Antenna

The single element of the proposed UWB MIMO antenna is a modified version of already known antenna in [1] and is replicated for MIMO application. Geometry of UWB antenna is depicted in Figure 1(a). The chosen MIMO configuration consists of two orthogonally placed identical UWB antenna elements with overall size of $15 \times 37.6 \text{ mm}^2$. In Figure 1(c) S -parameter of single UWB antenna is compared with S -parameter of UWB MIMO antenna configuration and shows that the chosen MIMO configuration has coupling less than -13.3 dB over the range of frequencies. This is due to orthogonal placement of antenna elements which provides inherent isolation between antenna elements [3]. However, Figure 1(c) shows similar reflection coefficients for single antenna and for MIMO antenna. In the MIMO configuration, values of $|S_{11}|$ and $|S_{22}|$ differ slightly due to orthogonal placement of elements but are similar whereas the values of $|S_{21}|$ and $|S_{12}|$ are exactly the same.

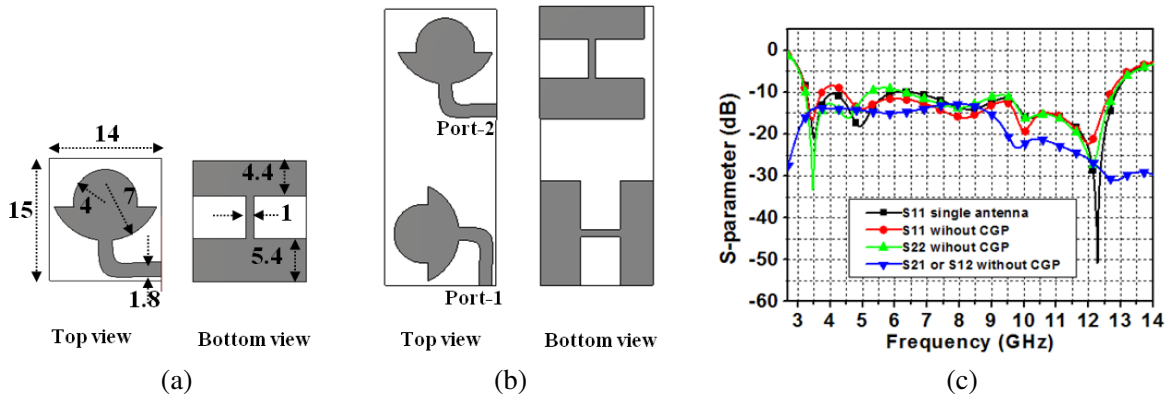


Figure 1. (a) Single UWB antenna element (All dimensions are in mm). (b) Chosen configuration of UWB MIMO antenna without common ground plane (CGP). (c) Comparison of simulated S -parameter.

2.2. Introducing Common and Extended Ground Plane in MIMO Configuration

For practical use of the device, common and extended ground plane is essential [18, 20]. Therefore in the above mentioned configuration, a thin strip of 0.2 mm is used between the ground planes of antennas to achieve common ground plane (CGP) as shown in Figure 2(a). Now, the ground plane is further extended in $+Y$ -axis by 20 mm, and another 0.2 mm thin copper strip is used to achieve common and

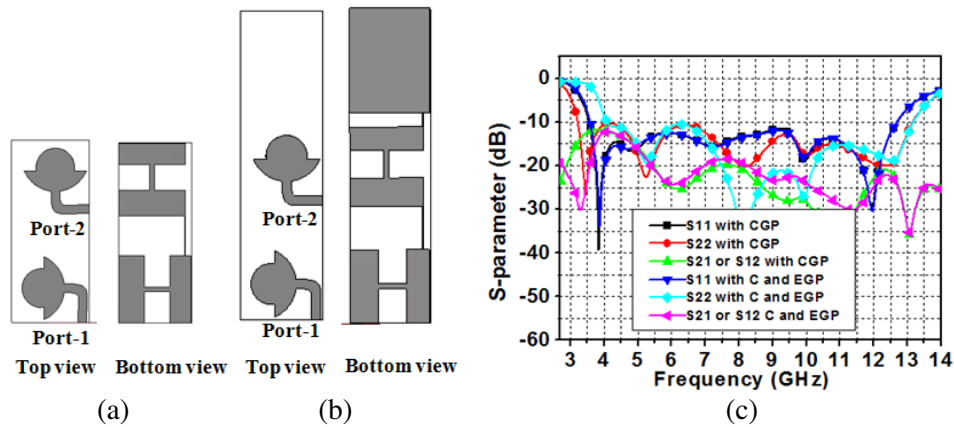


Figure 2. Configuration of UWB MIMO antenna for USB dongle application (a) with common ground plane (CGP) (b) with common and extended ground plane (C and EGP). (c) Comparison of simulated *S*-parameter.

extended ground plane (C and EGP) as shown in Figure 2(b). Due to the design of the antenna and chosen configuration of elements, implementation of common and extended ground plane in the MIMO antenna system provides good performance. The comparison of *S*-parameter of UWB MIMO antenna with common and extended ground plane is shown in Figure 2(c).

2.3. Introducing Dual Notched Bands in UWB MIMO Antenna

It has been reported in many papers that existing wireless standards such as WLAN and WiMAX cause interference to the UWB communication systems. Therefore, incorporating notches in these bands is one of the best solutions. Presence of dual notched bands introducing circuits in the UWB MIMO antenna design make it challenging to achieve good isolation between elements [11]. Moreover, achieving dual notched bands with good isolation is even more challenging for UWB MIMO antenna for USB dongle application due to its requirement of smaller size as compared to other portable devices such as tablet and smart phone.

In the proposed structure, dual notched bands are achieved by using two stubs at the ground plane of each antenna. The MIMO antenna has separate notch band introducing circuits for each element, which makes it less prone to coupling effect. Figures 3 and 4 show the effects of introducing single

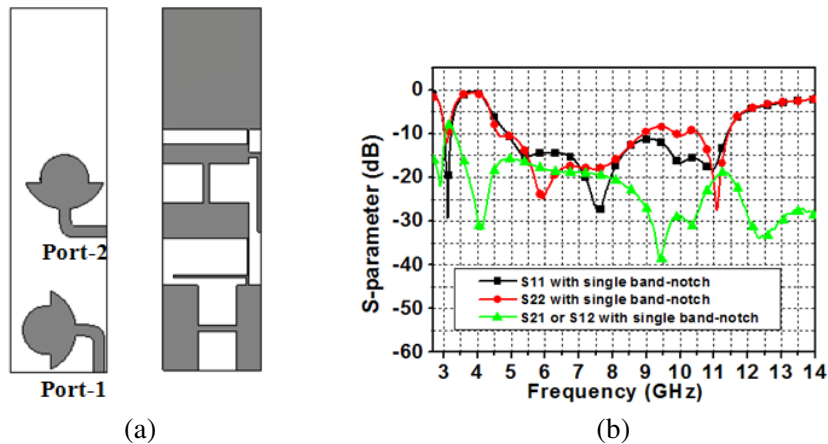


Figure 3. Simulated UWB MIMO antenna with single band-notched characteristic, (a) top view, (b) bottom view and (c) simulated *S*-parameter.

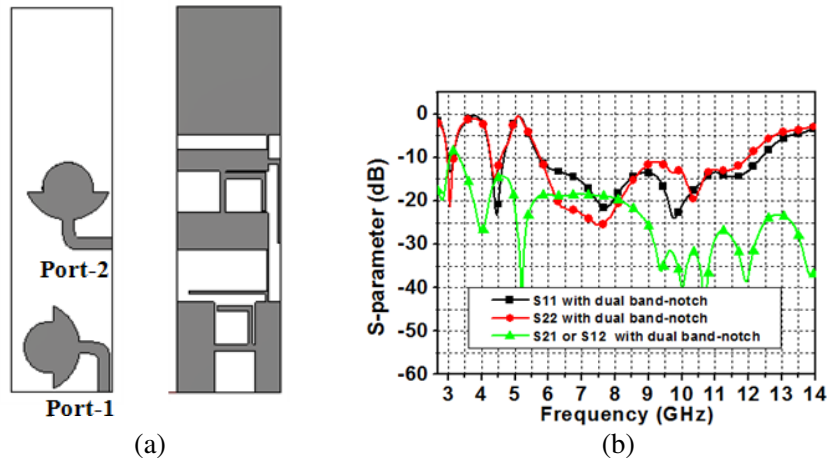


Figure 4. Simulated UWB MIMO antenna with dual band-notch characteristic, (a) top view, (b) bottom view and (c) simulated S -parameter.

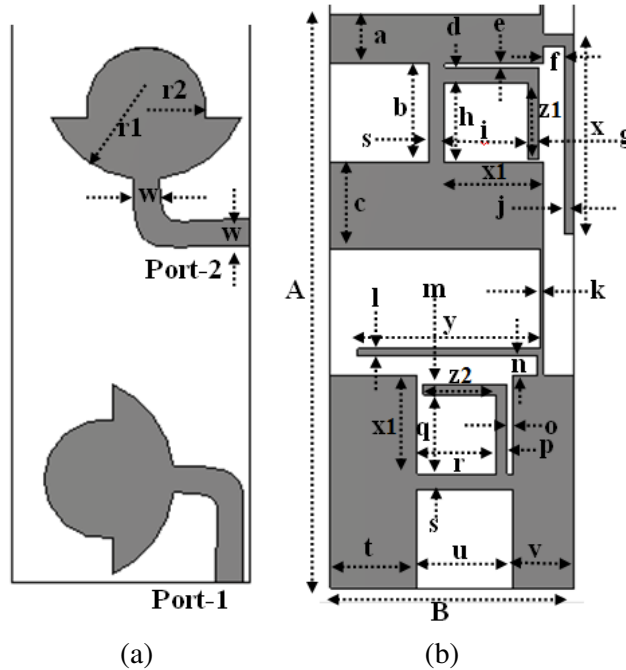


Figure 5. Geometry of the proposed dual band-notched UWB MIMO antenna for USB dongle application, (a) zoomed top view dimensions, (b) zoomed bottom view dimensions (All dimensions are in mm). $a = 3.25$, $b = 6.45$, $c = 5.7$, $d = 1$, $e = 0.25$, $f = 1.4$, $g = 0.7$, $h = 5.2$, $i = 5.5$, $j = 0.7$, $k = 0.2$, $l = 0.5$, $m = 0.7$, $n = 1.25$, $o = 0.4$, $p = 0.7$, $q = 5.2$, $r = 5.2$, $s = 1$, $t = 5.7$, $u = 6.3$, $v = 4$, $w = 1.8$, $x = 13.1$, $y = 12$, $r1 = 7$, $r2 = 4$, $z1 = 5$, $z2 = 4.8$, $x1 = 6.5$, $A = 37.6$, $B = 16$.

and dual notched bands in the UWB MIMO antenna, respectively. Zoomed views of the proposed dual band-notched UWB MIMO antenna (in Figure 4) are shown in Figure 5. Symbols depicted in Figure 5 are shown with their optimized values. The first notch band at the lower frequency (3.15–4.2 GHz) is achieved by implementing stub of length 0.25λ at 3.8 GHz. Figure 5 shows that antennas 1 and 2 have optimized length of stub ($y + n + x1 = 12 + 1.25 + 6.5$) 19.75 mm and ($x + f + x1 = 13.1 + 1.4 + 6.5$) 21 mm, respectively. After that the second notch band at higher frequency (4.6–5.7 GHz) is achieved by implementing stub of length 0.25λ at 5 GHz. Figure 5 shows that antennas 1 and 2 have optimized length

of stub ($z_2 + q + r = 4.8 + 5.2 + 5.2$) 15.2 mm and ($z_1 + i + h = 5 + 5.5 + 5.2$) 15.7 mm, respectively. For the two elements the lengths of stubs are not exactly same; this is due to non-symmetrical configuration of elements and incorporation of common and extended ground plane. The optimized length of each stub works as a band-stop filter in each antenna element and helps in achieving desired dual notched bands in UWB range. For visualizing effect of each stub at the given frequency, simulated surface current distribution of the proposed MIMO antenna is shown in Figure 6. The current distribution makes it evident that the stub of length 0.25λ , designed to resonate at the given frequency, shows maximum surface current in that particular stub at that particular frequency.

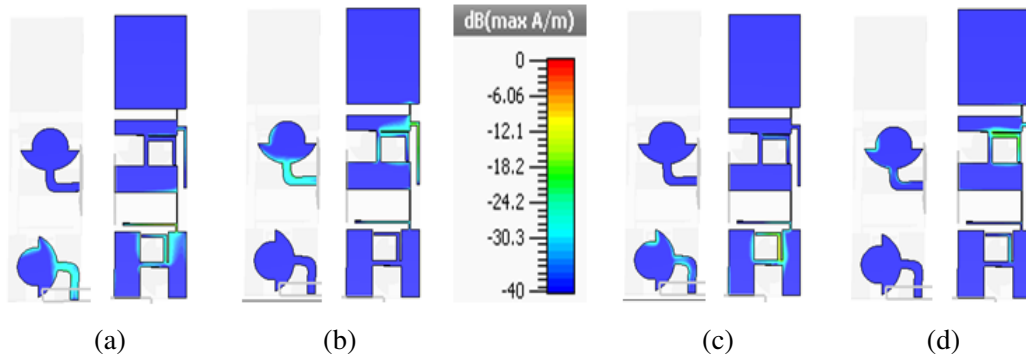


Figure 6. Simulated surface current distribution of the proposed dual band-notched UWB MIMO antenna for USB dongle application when (a) port-1 excited at 3.8 GHz, (b) port-2 excited at 3.8 GHz, (c) port-1 excited at 5 GHz and (d) port-2 excited at 5 GHz.

Most of the reported papers suggest that isolation of the MIMO antenna can be improved further by incorporating decoupling network. However, introducing these decoupling networks results in bigger circuit, which makes it unsuitable for dongle application. Therefore, the configuration of the proposed dual band-notched UWB MIMO antenna for USB dongle application is decoupling circuit free, shown in Figure 4 with its S -parameter. The overall size of the proposed design is $16 \times 37.6 \text{ mm}^2$ which is the smallest size reported in the literature. Without using any decoupling network, the MIMO antenna shows simulated $|S_{21}| \leq -8.5 \text{ dB}$, -14.3 dB and -18.5 dB at the lower band, middle band and upper band, respectively. However, simulated $|S_{11}|$ is $\leq -10 \text{ dB}$ over the range except at dual notched bands. At the notched bands, the MIMO antenna has $|S_{11}|$ and $|S_{22}|$ peak value variation in the range from -1 dB to -0.5 dB , which shows good rejection property at both the reject bands in each element.

3. EXPERIMENTAL VALIDATION OF RESULTS

The simulated prototype is validated in this section for its S -parameter response, radiation pattern, gain, efficiency, envelope correlation coefficient and diversity performance.

3.1. Testing of S -Parameter of the UWB MIMO Antenna

The fabricated prototype (shown in Figure 7) is tested for its S -parameter by using Anritsu MS2028C vector network analyzer (VNA). For measurement of reflection coefficient, one port of the MIMO antenna is connected to VNA, and the other is terminated with load. For measurement of its coupling coefficient, two ports of the MIMO antenna are connected to two ports of VNA. Comparisons of simulated and measured S -parameters of the MIMO antenna are shown in Figures 8(a) and (b), for port-1 and port-2, respectively. The measured and simulated S -parameters are similar with small discrepancies that might be due to fabrication misalignment and soldering tolerances. The measured reflection coefficient is $\leq -10 \text{ dB}$ over the entire band excluding the dual notched bands. However, the measured coupling coefficient is $\leq -9 \text{ dB}$, -14 dB and -19 dB at the lower band, middle band and upper band, respectively.

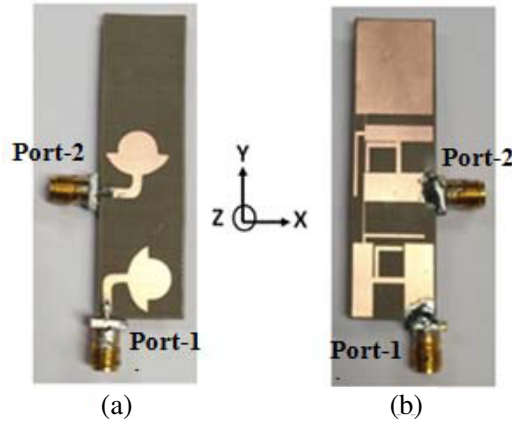


Figure 7. Fabricated design of the proposed dual band-notched UWB MIMO antenna for USB dongle application, (a) top view and (b) bottom view.

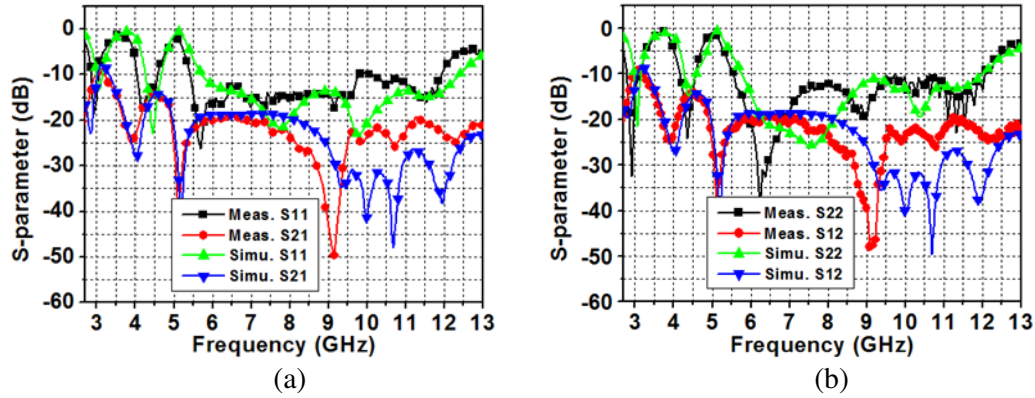


Figure 8. Measured and simulated S -parameter of the proposed dual band-notched UWB MIMO antenna (a) port-1 and (b) port-2.

3.2. Radiation Pattern Measurement

The measured radiation pattern of the MIMO antenna is shown in Figure 9 at five different frequencies as 3 GHz, 4.5 GHz, 6 GHz, 9 GHz and 12 GHz. These measurements are done inside an anechoic chamber at XZ -, YZ - and XY -planes. Figure 9 shows that port-1 has directional radiation patterns in XZ -plane and omnidirectional ones in YZ -plane, whereas port-2 has directional radiation patterns in YZ -plane and omnidirectional ones in XZ -plane. However, both ports show quasi-omnidirectional radiation patterns in XY -plane. For the proposed design, the radiation patterns of antenna elements are different due to placement of the extended common ground plane at the side of antenna-2 and orthogonal placement of antenna elements. Port-1 and port-2 have different radiation patterns in the same plane. This validates the diversity performance of the proposed design. Moreover, 3-D radiation patterns of the MIMO antenna are also shown in Figure 10, which further helps in visualization of pattern diversity performance of the MIMO antenna prototype.

3.3. Envelope Correlation Coefficient, Total Efficiency and Gain of the Proposed MIMO Antenna

MIMO antenna is mainly characterized by its envelope correlation coefficient (ECC) and is calculated by using far-field based formula given in [21]. Figure 11(a) shows that the ECC has values ≤ 0.1 , which ensures good diversity performance of the proposed MIMO antenna prototype.

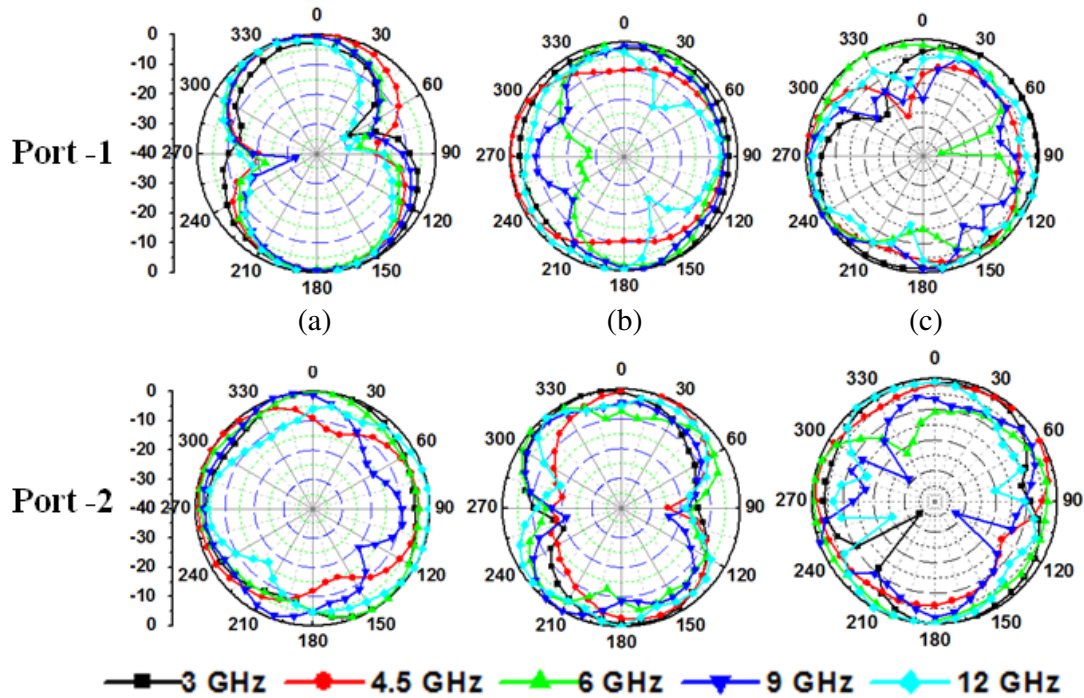


Figure 9. Measured radiation patterns of the MIMO antenna in (a) XZ , (b) YZ and (c) XY -planes at 3, 4.5, 6, 9 and 12 GHz.

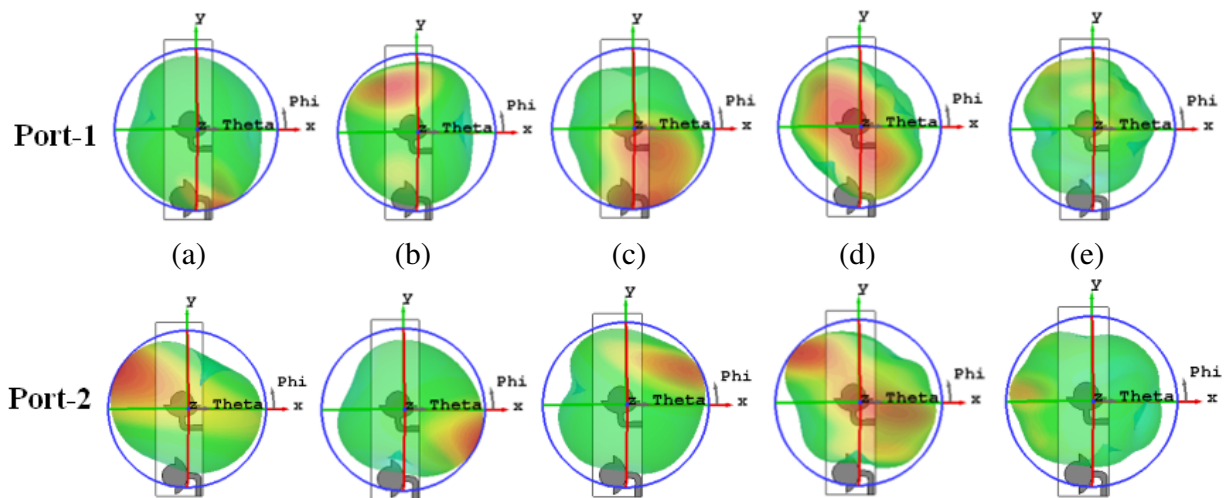


Figure 10. 3-D radiation patterns of the MIMO antenna at (a) 3 GHz, (b) 4.5 GHz, (c) 6 GHz, (d) 9 GHz and (e) 12 GHz when port-1 or port-2 are excited.

Figure 11(a) also shows simulated total efficiency of the MIMO antenna for port-1 and port-2. Both antennas have dips at 3.8 GHz and 5 GHz due to the presence of dual notched bands. These dips show good band reject ability. The total efficiency varies from 55% to 90% in the range from 3 to 12 GHz excluding the dual notched bands. In reject bands efficiency decreases to 20%. The realized gain of MIMO antenna is shown in Figure 11(b). The total efficiency and gain of antennas are low at lower band of UWB range due to small size of the antennas, and it improves with increase in frequency.

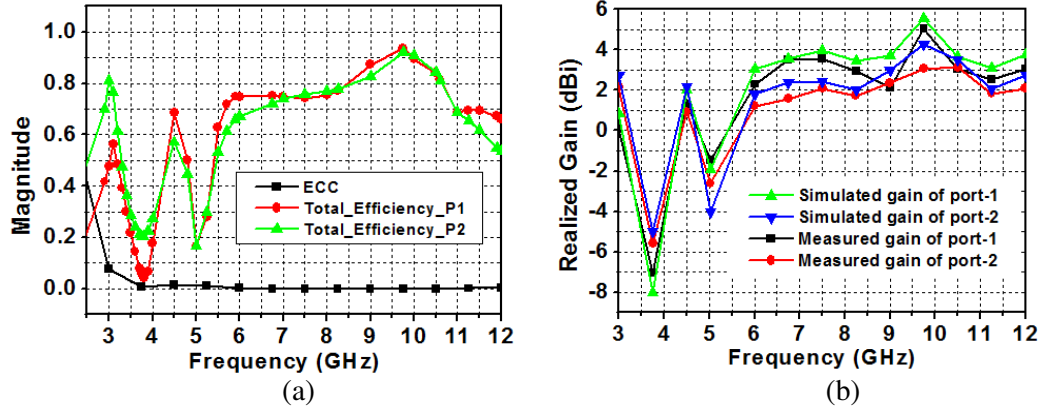


Figure 11. (a) Envelope correlation coefficient and simulated total efficiency plots (b) realized gain of the dual band-notched UWB MIMO antenna.

3.4. Channel Capacity Loss and Diversity Gain of the Proposed MIMO Antenna

In a multipath environment channel capacity loss (CCL) is estimated to limit the upper bound of rate of transmission for reliable transmission in communication link. For the proposed two-element MIMO antenna, the CCL values are < 0.4 b/s/Hz over the UWB range, except at the notched bands and calculated by using the formula given in [10]. The CCL values are within the acceptable limit in the desired band. Moreover, another important parameter i.e., diversity gain, which also determines the performance of the MIMO antenna is calculated from ECC values by using the formula given in [10]. Figure 12 shows values of calculated CCL and diversity gain over the range of frequencies.

Moreover, comparison of the proposed design and already reported designs is listed in Table 1, which shows that the overall performance is comparative and better than most of the reported designs. It also shows that the proposed design is best suitable for USB dongle application due to its very compact size.

Table 1. Comparison of dual band-notched UWB MIMO antenna designs.

Ref.	Size (mm) ²	Operating band (GHz)	Notched band (GHz)/Return Loss (dB)	MIB* (dB)	Max./Min. efficiency (%)	Max./Min. Gain (dBi)	*PPD	*DC	ECC*	DG*	CCL* (bits/s/Hz)
[8] (2018)	50 × 30 = 1500	2.5–14.5	Not present	> 20	NA	4.3/3	Not present	Present	< 0.04	> 7.4	NA
[9] (2018)	85 × 50 = 4250	2–9.5	Not present	> 20	90/70	6/1.5	Present	Not present	< 0.03	NA	NA
[10] (2018)	30 × 42 = 1260	3.1–10.6	5.2/−2	≥ 20	95/35	5/−0.5	Not present	Present	< 0.03	≈ 10	< 0.25
[11] (2013)	27 × 30 = 810	3–11	3.5/−1.8; 5.5/−3	≥ 20	80/25	NA	Not present	Present	< 0.0002	NA	NA
[12] (2016)	35 × 68 = 2380	3.1–10.65	3.45/−2; 5.85/−2.25	≥ 20	NA	5.5/−6.8	Not present	Present	< 0.002	NA	NA
[13] (2014)	30 × 40 = 1200	3.1–10.6	3.8/−2.8; 5.5/−3	≥ 17	85/20	4.0/−0.7	Not present	Present	≪ 0.05	NA	NA
This work	16 × 37.6 = 601.6	3–12	3.8/−1; 5/−0.5	≥ 19	90/20	5.5/−7	Present	Not present	< 0.1	> 9.5	< 0.4

*MIB = Maximum isolation in most of the band; *PPD = Polarization and pattern diversity; *DC = Decoupling circuit; *ECC = Envelope correlation coefficient; *DG = Diversity gain; *CCL = Channel capacity loss; NA = Not available

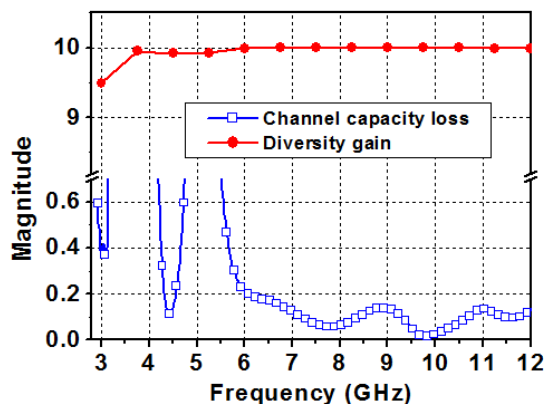


Figure 12. Calculated channel capacity loss and diversity gain of the dual band-notched UWB MIMO antenna.

4. CONCLUSION

A compact planar dual band-notched UWB MIMO antenna for universal synchronous bus (USB) dongle application is presented in this paper. The MIMO configuration is decoupling network free and has size of $16 \times 37.6 \text{ mm}^2$. Moreover, the ground plane of the MIMO antenna is further extended by 20 mm in $+Y$ -axis which makes it easy to use in practical applications. The dual notched bands show good rejection property. The antenna elements are orthogonally placed, which results in pattern diversity of the MIMO antenna. All measured results show good agreement with the simulated ones. The omnidirectional radiation pattern of the antenna makes it suitable for dongle application.

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