Two Element Band-Notched UWB MIMO Antenna with High and Uniform Isolation

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Abstract—In this paper, a single notched band at 5.2 GHz with complementary split ring resonator (CSRR) ultra-wideband (UWB) antenna and its implementation in designing of two-element multiple-input multiple-output (MIMO) with high and uniform isolation are experimentally demonstrated. The proposed UWB MIMO consists of a T-shaped stub in ground plane in between antenna elements of the size of $\lambda_{3.1\text{GHz}}/4$ to achieve minimum 20 dB isolation, which is almost uniform in entire UWB band. The size of the UWB MIMO antenna is $0.31\lambda_{3.1\text{GHz}} \times 0.434\lambda_{3.1\text{GHz}} \times 0.008\lambda_{3.1\text{GHz}} \text{mm}^3$, and it is printed on an RT/duroid 5880 substrate ($\varepsilon_r = 2.2$, tan $\delta = 0.0009$), which leads to good gain and high total efficiency of the antenna in operating bands. The simulated and measured results show good agreement for the impedance bandwidth ($|S_{11}| < -10 \text{dB}$) and isolation ($|S_{21}| < -20 \text{dB}$) in most of the operating band, excluding the notched band at 5.2 GHz in UWB range. The simulated, measured and calculated MIMO antenna diversity parameters prove that the antenna is suitable for UWB MIMO systems.

1. INTRODUCTION

In rapid development in wireless communication systems, Multiple-Input Multiple-Output (MIMO) technology offers the utility of multiple antennas at input and output terminals of wireless links. As a result, the capacity of the wireless system has been improved. These MIMO antennas require multiple transmitter and receiver antennas that can perform data transmission and reception simultaneously [1]. Ultra-wideband (UWB) technology is the most promising solution for wireless systems ranges from 3.1 to 10.6 GHz. However, it is limited by the Federal Communications Commission (FCC) regulation and produces a low equivalent isotropically radiated power (EIRP) of $-41.3 \text{dBm}$ only [2]. The MIMO antennas for the UWB system offer low multipath fading, enhance channel capacity and high data rate for reasonable range [3]. The efficient designing of UWB MIMO antenna is characterized by high isolation/less coupling, high diversity gain, pattern diversity, low envelope correlation coefficient (ECC), low capacity loss, good individual antenna gain and high efficiency for the entire UWB radiating spectrum. Therefore, several UWB MIMO antennas have been proposed in recent years to achieve good isolation between antenna elements [3–7]. Two orthogonal monopole antenna elements consist of two long ground stubs and a short ground strip to increase the isolation is reported in [3]. In order to reduce coupling between two orthogonal antenna elements at lower UWB (3–4.5 GHz), a narrow slot is inserted in the ground plane [4]. Moreover, parasitic meander lines are used between the antenna elements with reduced coupling presented in [5]. In [8], ground plane with protruded and receded rectangular steps is used to enhance isolation up to 5 dB between band notched UWB antenna elements. In [9], an antenna...
structure with two orthogonally placed monopoles in upper and lower planes to achieve 18 dB isolation between WLAN band-notched UWB antenna elements is studied experimentally. This paper presents a two-element 5.2 GHz band-notched UWB MIMO antenna with uniform and high isolation between antenna elements. In order to minimize the overall size of the MIMO antenna with high isolation, a T-shaped stub is inserted in between the antenna elements. The proposed MIMO antenna is capable to achieve minimum 20 dB and good diversity performance for the entire UWB band.

2. SINGLE ANTENNA ELEMENT DESIGN AND ANALYSIS

The evolution stages of the design of single antenna element are shown in Fig. 1. The design of band notched ultra-wideband is started with the consideration of a circular monopole structure, which is depicted in Fig. 1(a). An RT/Duroid 5880 substrate consisting of dielectric constant \( \varepsilon_r = 2.2 \), loss tangent \( \tan\delta = 0.0009 \) and thickness \( h = 0.79 \) mm is used in this work. The optimized length of the feed line is fixed at \( L_f = L_1 + L_2 + L_3 = 13 \) mm, and the width \( (W_1 = 2.45 \) mm) of the 50-\( \Omega \) feed line for the material specifications is calculated using [10]. This configuration creates resonance at around 4.5 GHz and 10.8 GHz central frequencies as displayed in Fig. 2(a). Further, to match the impedance of the antenna for the entire UWB band, a stepped feed line is introduced. The optimized sizes of the step feeds are \( L_1 \times W_1, L_2 \times W_2 \) and \( L_3 \times W_3 \), as shown in Fig. 1(b). It is found that the bandwidth is increased, ranging from 3.5 to 9.9 GHz, illustrated in Fig. 2(a). In order to enhance the bandwidth, the total length of the radiating edge of the circular patch is increased by inserting a rectangular patch of the size \( 7 \times 14 \) mm\(^2\) in the position of the upper half circle, as shown in Fig. 1(c). By inserting a rectangular patch, the current path also increases, thus the lower frequencies are incorporated. For this antenna configuration, the enhanced impedance bandwidth ranging from 2.8 to more than 11 GHz is shown in Fig. 2(a). Additionally, to reduce the signal interference, a complementary split ring resonator (CSRR) is inserted on the surface of the U-shaped radiator shown in Fig. 1(d). The dimensions of the inner and outer radii of CSRR are fixed at \( R_2 = 3.3 \) mm and \( R_3 = 3.8 \) mm, respectively, in order to achieve notched band at 5.2 GHz center frequency [11]. It is observed from Fig. 2(a) that the inserted CSRR does not affect impedance bandwidth performance other than notched band. The width of metallic contact for the inner and outer edges of the ring is \( g_2 = 0.3 \) mm. The final geometry of the single antenna element of the proposed band-notched UWB MIMO configuration is illustrated in Fig. 2(b).

The comparative simulated and measured magnitudes of \( S_{11} \) plot for the proposed single antenna element and fabricated prototype in the inset are shown in Fig. 3. Table 1 depicts the simulated and measured frequency bands of the single antenna element in terms of operating band and notched band. The surface current distributions at 5.2 GHz with and without CSRR are demonstrated in Fig. 4. It is observed from Fig. 4(a) that the surface current is uniformly distributed over the radiating edge of the U-shaped patch, without CSRR. With CSRR, the surface current is strongly concentrated around the

![Figure 1](image_url)
Figure 2. (a) Simulated magnitude of $S_{11}$ plot for different antenna configurations. (b) Single antenna element with dimensions.

Figure 3. Simulated and measured magnitude of $S_{11}$ plot and the inset is showing fabricated prototype (front and back view).

Figure 4. Surface current distributions at 5.2 GHz of single antenna element, (a) without CSRR, (b) with CSRR.

ring, as shown in Fig. 4(b). Therefore, at the notched frequency the effect of radiation is very weak, resulting in notched band around 5.2 GHz center frequency. The dimensions of the proposed single antenna element, which is shown in Fig. 2(a), are as follows: $L = 30$ mm, $L_g = 12.5$ mm, $L_r = 7$ mm, $L_1 = 8$ mm, $L_2 = 3$ mm, $L_3 = 2$ mm, $W = 16$ mm, $W_r = 14$ mm, $W_1 = 2.45$ mm, $W_2 = 1.5$ mm, $W_3 = 1$ mm, $R_1 = 7$ mm, $R_2 = 3.8$ mm, $R_3 = 3.5$ mm, $g_1 = 0.5$ mm and $g_2 = 0.3$ mm.

3. DESIGNING OF TWO ELEMENT MIMO CONFIGURATION

The single element band-notched UWB antenna proposed in Section 2 is used in a two-element UWB MIMO configuration. The next step to design the two-element MIMO configuration is initiated with
Table 1. Simulated and measured frequency bands for single antenna element.

| Antenna Results | Frequency bands (GHz) |
|-----------------|----------------------|
|                 | Operating bands | Notched band |
| Simulated       | 2.8 to 4.9 and 5.4 to more than 11 | 4.9 to 5.4 |
| Measured        | 2.8 to 4.7 and 5.4 to more than 11 | 4.7 to 5.4 |

consideration of isolation parameter ($S_{21}$ or $S_{12}$), which can be further improved by keeping space between the antenna elements. Fig. 5(a) depicts the simulated optimization of antenna element’s spacing ($W_5$) without T-shaped stub. It can be observed that as the spacing is increased, the isolation parameter improves proportionally, and $|S_{12}|$ or $|S_{21}| \leq -15$ dB is attained at $W_5 = 12$ mm for the entire UWB band, that is $\lambda_{at3.1GHz}/8$ for the lower cut-off frequency 3.1 GHz, whereas the extension of the common ground plane does not have any significant effect on the performance of the single antenna element.

Further, to improve the isolation for the entire UWB band, decoupling T-shaped stub is inserted above the upper edge of the ground plane. The T-shape stub between single antenna elements in the ground plane works as a delay structure, increases the undesired path of the surface current, and reduces coupling between antenna elements. The overall length of the T-shaped stub is $a + b + 2 \times c - 2 \times t_1 = 24.5$ mm, which is equal to $\lambda_{at3.1GHz}/4$ for the lower cutoff frequency of the UWB band. Fig. 5(a) also shows the high isolation $(|S_{12}|$ or $|S_{21}| \leq -20$ dB) for the whole UWB with the T-shaped stub. The center notched frequency 5.2 GHz does not affect the isolation performance of the MIMO antenna. Finally, the 15 dB reduction in coupling is achieved by increasing the spacing between antenna elements, and further, additional 5 dB reduction in coupling is attained using the T-shaped stub, by keeping the compatibility limitation of the proposed structure. The structure of the proposed UWB MIMO antenna with a T-shaped stub in the ground plane is depicted in Fig. 5(b). The total size of the UWB MIMO antenna is $0.31\lambda_{at3.1GHz} \times 0.434\lambda_{at3.1GHz} \times 0.008\lambda_{at3.1GHz} \text{ mm}^3$. In continuation of Section 2, the MIMO antenna dimensions are as follows: $L = 30$ mm, $L_g = 12.5$ mm, $W_s = 42$ mm, $W_4 = 23.55$ mm, $W_5 = 12$ mm, $a = 16.5$ mm, $b = 4$ mm, $c = 3$ mm, $t_1 = 1$ mm and $t_2 = 0.5$ mm. The fabricated prototype of the proposed two-element UWB MIMO antenna with front and back views is illustrated in Fig. 6. An RT/Duroid 5880 substrate ($\varepsilon_r = 2.2$, tan$\delta = 0.0009$) is used to fabricate the UWB MIMO antenna prototype, which has the thickness $h = 0.79$ mm.

Figure 5. (a) Optimization of the spacing between of individual antenna elements without and with T-shaped stub in the ground plane. (b) Geometry of the proposed two elements UWB MIMO antenna.
4. RESULTS AND DISCUSSIONS

The performance characterization of proposed antenna has been done using Anritsu MS2028C vector network analyzer, and radiation characteristics such as radiation pattern and peak gain of the antenna are measured in an anechoic chamber. The simulated and measured $S$-parameter curves representing $|S_{11}|$ and $|S_{21}|$ parameters are illustrated in Fig. 7. It can be seen that the simulated operating bands of the antenna range from 3.1 to 4.7 GHz and 5.5 to 10.6 GHz with 4.7 to 5.5 GHz notched band, and the high isolation ($|S_{12}|$ or $|S_{21}| \leq -20$ dB) is achieved for the UWB band. Good agreement between simulated and measured results has been observed. To further understand the decoupling effect between antenna elements, the surface current distributions at 3.5 and 7.5 GHz are depicted in Figs. 8(a)–(d). When the MIMO antenna is excited at port 1 without isolation T-shaped stub, the surface current of port 1 has high tendency to couple with port 2 through the common ground plane (vice-versa when port 2 is excited). It is also observed that with isolation stub, the surface current is strongly excited in T-shaped stub, which results in better inter-port isolation and thereby significantly improves the diversity performance of the UWB MIMO antenna.

![Figure 6](image_url1)  ![Figure 6](image_url2)

**Figure 6.** Fabricated prototype of the proposed two elements UWB MIMO antenna. (a) Front view. (b) Back view.

![Figure 7](image_url3)

**Figure 7.** Simulated and measured $S$-parameters ($|S_{11}|$ and $|S_{21}|$) of the UWB MIMO antenna.
5. **UWB MIMO ANTENNA PERFORMANCE CHARACTERIZATION**

The performance characterization parameters of the proposed band-notched UWB MIMO antenna are experimentally studied in this section, which comprises radiation pattern, envelop correlation coefficient, diversity gain, capacity loss, antenna gain and total efficiency of the structure.

5.1. **Radiation Pattern Characterization**

The radiation patterns of the proposed UWB MIMO antenna are obtained inside an anechoic chamber at 4, 7 and 9 GHz in \( \text{YOZ} \), \( \text{XOZ} \) and \( \text{XOY} \) planes, shown in Fig. 9. One of the two ports is excited and the other port terminated with 50-\( \Omega \) matched load. It is observed that radiation patterns are mirror images in \( \text{YOZ} \) and \( \text{XOZ} \) planes, excited with ports 1 and 2, individually. Because the structure is symmetrical along the \( Y \)-axis of the MIMO antenna, the radiation patterns in \( \text{YOZ} \) and \( \text{XOZ} \) planes are also symmetrical. However, due to the asymmetrical structure in \( \text{XOY} \) plane, the radiation patterns for ports 1 and 2 in \( \text{XOY} \) plane are also asymmetrical, which leads to pattern diversity. The radiation pattern in \( \text{YOZ} \) plane has a dipole shaped pattern, whereas in \( \text{XOZ} \) plane the pattern is almost omnidirectional, and in \( \text{XOY} \) plane is quasi-omnidirectional.

5.2. **Envelop Correlation Coefficient Characterization**

In order to observe the performance characterization of the MIMO antenna, envelop correlation coefficient (ECC) is an important parameter, which should be minimized as much as possible, so
Figure 9. Measured radiation patterns: when excited at Port 1, with matched Port 2. (a) YOZ plane, (c) XOZ plane, (e) XOY plane and when excited at Port 2, with matched Port 1. (b) YOZ plane, (d) XOZ plane, (f) XOY plane at 4, 7 and 9 GHz.
that MIMO antenna performance with low coupling between individual antenna elements and antenna diversity can be maintained. In this study, on the bases of known simulated and measured scattering parameters data, the ECC ($\rho_e$) for the MIMO antenna is calculated using the formula given in Equation (1). Fig. 10(a) depicts the simulated and measured ECC plots obtained from S-parameters. It can be seen that the ECC is less than 0.03 for the entire UWB radiating bands, except the range from 5 to 5.4 GHz (notched band), where ECC increases to 0.2. The obtained low value of the envelop correlation coefficient leads to strong diversity for UWB MIMO antenna.

$$\rho_e = \frac{|S_{11}^* S_{21} + S_{12}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}$$

(1)

5.3. Diversity Gain Characterization

To maintain the quality and reliability of the wireless system, the diversity gain of the UWB MIMO antenna should be high and calculated using the formula given in Equation (2). Fig. 10(b) displays the simulated and measured diversity gains obtained using simulated and measured ECC data. It can be observed that the diversity gain of the proposed MIMO antenna is nearly 10 dB over the entire UWB band with a small dip at 5.2 GHz, i.e., center band-notched frequency.

$$G_{app} = 10 \times \sqrt{1 - |\rho_e|}$$

(2)

5.4. Capacity Loss Characterization

Capacity loss is another important parameter, which maintains the upper bound of the rate of information that can be reliably transmitted through a communication link, and its value should be less than 0.4 bits/s/Hz for the MIMO system. Capacity loss is calculated using the formula given in Equation (3).

$$C_{loss} = - \log_2 |\psi^R|$$

(3)

where $\psi^R$ is the receiving antenna correlation matrix, which is given as:

$$\psi^R = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}$$

$$\rho_{ii} = (1 - |S_{ii}|^2 - |S_{ij}|^2) \quad \text{and} \quad \rho_{ij} = -(S_{ii}^* S_{ij} + S_{ji}^* S_{ij}) \quad \text{for} \quad i, j = 1 \text{ or } 2.$$
Figure 11. (a) Simulated and measured capacity loss of the proposed MIMO antenna. (b) Measured gain and computed total efficiency of the proposed UWB MIMO antenna.

Figure 11(a) shows the simulated and measured capacity loss curves for the proposed UWB MIMO antenna. It can be seen that the value of the capacity loss is less than 0.25 bits/s/Hz for the entire UWB band, except small variation at 5.4 bits/s/Hz for the notched band. The obtained capacity loss is well below the threshold value of 0.4 bits/s/Hz, which makes the antenna suitable for MIMO applications.

5.5. Gain and Efficiency Characterization

Measured Gain and computed total efficiency plots for the proposed UWB MIMO antenna are illustrated in Fig. 11(b). In the process of measurement of antenna gain and total efficiency, port 1 is excited, and port 2 is matched with 50-Ω. It can be observed that antenna gain varies from 2 to 5.2 dB, whereas total efficiency varies from 85 to 96% in UWB operating band. A sharp dip at 5.2 GHz (the center notched frequency) has been observed due to the presence of notched band in between the UWB band.

Table 2 represents the comparison of the proposed work with the recently reported single band-notched UWB MIMO antennas. The proposed antenna offers low volume of 995.4 mm³, high gain and good efficiency for the operating bands between 3.1 and 10.6 GHz.

### Table 2. Comparison with the reported single band notched UWB MIMO antennas.

| Reference | MIMO antenna volume $L \times W \times h = V$ (mm³) | Relative permittivity of substrate $\epsilon_r$ | Min. isolation (dB) | Gain variation in UWB radiating band (dB) | Efficiency variation in UWB radiating band (%) |
|-----------|---------------------------------|------------------|-------------------|----------------------|-------------------------------|
| This work | $0.31\lambda_0 \times 0.434\lambda_0 \times 0.008\lambda_0 = 995.4$ | 2.2 | 20 | 2–5.2 | 85–96 |
| [12]      | $0.397\lambda_0 \times 0.397\lambda_0 \times 0.016\lambda_0 = 2371.6$ | 4.4 | 15 | 1.4–3.6 | 75–78 |
| [13]      | $0.496\lambda_0 \times 0.496\lambda_0 \times 0.008\lambda_0 = 1843.2$ | 4.4 | 15 | 1.7–6.5 | Not reported |
| [14]      | $0.227\lambda_0 \times 0.372\lambda_0 \times 0.016\lambda_0 = 1267.2$ | 3.5 | 15 | 1–5 | 70–95 |
| [15]      | $0.516\lambda_0 \times 0.289\lambda_0 \times 0.016\lambda_0 = 2240$ | 4.4 | 16 | Not reported | Not reported |
| [16]      | $0.599\lambda_0 \times 0.279\lambda_0 \times 0.008\lambda_0 = 1252.8$ | 4.4 | 20 | Not reported | 80–90 |
| [17]      | $0.341\lambda_0 \times 0.268\lambda_0 \times 0.016\lambda_0 = 1372.8$ | 4.4 | 15 | 1–6 | Not reported |
6. CONCLUSION

A U-shaped monopole UWB antenna of size $30 \times 16 \times 0.79 \text{mm}^3$ is reported in this work. The notched band is introduced by inserting a CSRR structure on the radiating patch, which is tuned for the 5.2 GHz center frequency. This single antenna element is used in designing a two-element UWB MIMO antenna of the size $30 \times 42 \times 0.79 \text{mm}^3$, which is investigated experimentally. The low coupling for the whole UWB range is achieved by inserting a T-shaped stub in ground plane. The simulated and measured results show good agreement for the impedance bandwidth ($|S_{11}| < -10 \text{ dB}$) and isolation ($|S_{21}| < -20 \text{ dB}$) in most of the operating band, excluding the notched band. The simulated and measured results of MIMO antenna diversity parameters: radiation pattern of the different ports, envelop correlation coefficient (ECC), diversity gain, capacity loss, realized gain and total efficiency prove that the antenna is suitable for the UWB MIMO system.

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