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RESEARCH PAPER

Dual-band-notched antenna for UWB MIMO applications

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In this report, a compact antenna system with dual-band-notched characteristics is proposed for ultra-wideband (UWB) multiple-input multiple-output (MIMO) applications. Two antenna elements are placed side by side and fed with matched microstrip lines on a substrate with an area of 35 × 30 mm². Notched characteristics at WiMAX (3.4–3.6 GHz) and WLAN (5.725–5.825 GHz) have been achieved using complementary split ring resonator (SRR) slots etched in both the antenna elements. Electromagnetic isolation between the two elements close to each other is achieved using a ground T-stub and slots etched in the ground plane. Antenna system has been tested and measured results are close to the desired ones. Measured isolation >20 dB is obtained in most of the UWB bands. The proposed antenna system meets the requirements well for MIMO applications.

Keywords: Envelope correlation coefficient, Diversity, Isolation, MIMO

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I. INTRODUCTION

Ultra-wideband (UWB) is fast growing technology, which makes use of unlicensed frequency band (3.1–10.6 GHz) allocated by US-FCC, to transmit signals at higher data rates. This frequency band can be used to setup personal networks to control different devices within home or office [1]. As with any wireless communication there is an effect of multipath fading which degrades the system performance. Multiple-input multiple-output (MIMO) is a technique that can be employed to reduce the effects of fading and hence increase the system performance [2]. Using multiple antennas at transmitter and receiver, data rate of the system can also be increased. Performance of MIMO system depends upon the isolation between the antenna elements, it is however difficult to increase the isolation between antennas on the limited space available.

Besides there are various narrowband communication systems such as WiMAX (3.4–3.6 GHz) and WLAN (5.725–5.825 GHz) working in UWB, and in order to cancel the interference between UWB and these narrowband systems, antennas should have band-notched characteristics [3].

So far various MIMO antennas have been reported to achieve wideband isolation over entire UWB using different decoupling methods to obtain isolation [4–8]. Decoupling has been achieved by a tree-like structure in the ground plane [9], by stubs [10] and by etching slots in the ground to reduce coupling between radiators [5]. However, in the UWB MIMO antennas [4–8, 11–13] band-rejected characteristics are not employed and hence these cannot be used in environments with WiMAX and WLAN.

Though there have been reports on antennas with band rejected characteristics [14–17], yet in [14] an UWB MIMO antenna is proposed with single band-notch characteristics using $\lambda/2$ open stub. This stub will be large if WiMAX band is to be rejected using the same antenna. In [15] a polarization diversity antenna is proposed for UWB MIMO application with triple band-notched characteristics. This antenna has an overall size of 60 × 30 = 1800 mm². Dual-band-notched UWB MIMO antenna is presented in [16], wherein band-notch and decoupling ($|S12| > 15$ dB) is achieved using neutralization lines, with dimensions 40 × 30 = 1200 mm².

In this paper, a compact dual-band-notched UWB antenna is proposed for MIMO application. Our proposed antenna has size of 35 × 30 = 1050 mm² about 42 and 12% smaller than those in [15, 16], respectively. It consists of two monopoles separated by ground stub and slots to achieve maximum isolation. Notched characteristics are achieved using complementary split ring resonator (SRR) etched in the radiators. Antenna system covers entire UWB with notched bands 3.4–3.6 GHz (WiMAX) and 5.725–5.825 GHz (WLAN), thus is an ideal candidate to avoid interference in these bands. Moreover, this antenna achieves an isolation of 20 dB in most of the band with envelope correlation coefficient (ECC) value less than 0.015.

II. ANTENNA SYSTEM AND ANALYSIS

A) Antenna configuration

The proposed antenna system shown in Fig. 1 consists of two identical elements placed in mirror configuration about *Y*-axis on Roger 5870 substrate with volume 35 × 30 × 0.8 mm³.

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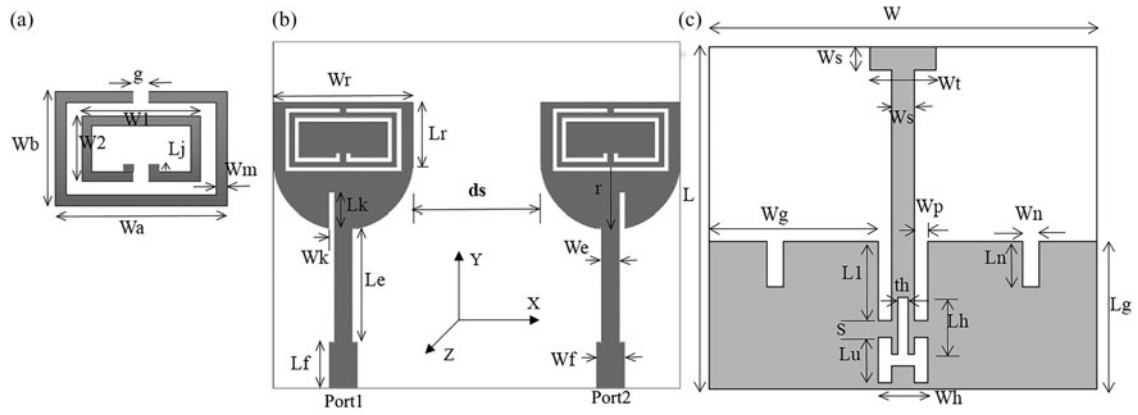


Fig. 1. Antenna configuration. (a) CSRR, (b) front side, and (c) back side.

Antenna system consists of two identical cup-shaped monopole radiators to achieve UWB characteristics. They share common ground with rectangular slots and a ground stub to achieve better isolation. Both antennas are fed with 50 Ω microstrip lines spaced by distance, ds (=0.3 $\lambda g/2$ at 3 GHz) from each other. The antenna system has been optimized using CST Microwave Studio, the optimized dimensions of the fabricated prototype is as follows (millimeters): $W = 35$, $L = 30$, $Lg = 13$, $Wa = 10$, $Wb = 5.5$, $Wm = 0.4$, $W1 = 8.4$, $W2 = 3.9$, $g = 0.5$, $Lj = 0.4$, $We = 1.5$, $Wf = 2.4$, $Le = 9.8$, $Lf = 4$, $Wn = 1.5$, $Ln = 4$, $Lk = 3$, $Wk = 0.5$, $L1 = 7$, $Wp = 1.2$, $Lh = 5$, $Lu = 4$, $Wt = 6$, $r = 6$, $Wr = 12$, $Lr = 5.5$, $th = 1$, $Wh = 4.4$, $S = 1.5$. The effect of these dimensions and effectiveness of slots and stubs are presented below. The fabricated prototype antenna is shown in Fig. 2.

B) Ground stub and rectangular slots

The rectangular slots in both the radiators next to feed lines are etched out in order to achieve impedance matching. For further matching of impedance two rectangular slots are made in the ground plane under the feed lines as shown in Fig. 2. A novel H-shaped slot is also cut in the ground plane between two radiators to improve return loss and isolation at around 7.3 GHz. By introducing H-slot, the return loss improves from 9.9 to 13 dB and isolation is increased to 23 dB at 7.3 GHz as observed in Fig. 3.

A novel T-shaped ground stub separating two radiators is added to achieve better isolation. This stub acts as monopole and resonates at frequency defined by its length. In order to increase the length of the T-stub so that it may reflect the lower frequencies between ports 1 and 2, this is done by etching the slots next to the stub in the ground plane. In this way we can achieve a good isolation at lower frequencies without any increase in the overall antenna size. This is an effective way to maintain the good isolation at this compact size. As shown in Fig. 2, the length of the T-stub is controlled by the length $L1$. It can be seen from Fig. 4(a) that with $L1 = 0$, lower cut-off frequency of the antenna is 4 GHz. With the increase in length $L1$ the return loss of antenna reduces at about 3 GHz. Another effect of increasing length $L1$ is, as the length of stub is increased isolation at lower frequencies (around 3 GHz) also increases. This could be due to the fact that the stub acts as a monopole and the distribution of surface current taking place around the stub gives rise to increased isolation. By etching slot1, two edges are formed in the ground plane. One edge controls the length of ground stub and the other acts as monopole increasing the isolation at higher frequency around 7.5 GHz as seen in Fig. 4.

C) CSRR slot

Figure 5(a) shows the S-parameters of the antenna without complementary split ring resonator (CSRR) slot. The notched characteristics at the desired frequencies 3.3 and 5.8 GHz are introduced by two complementary SRR slots etched in the radiators. As seen from the input impedance, in Fig. 6(a), antenna acts as short and open at notch frequencies 3.3 and

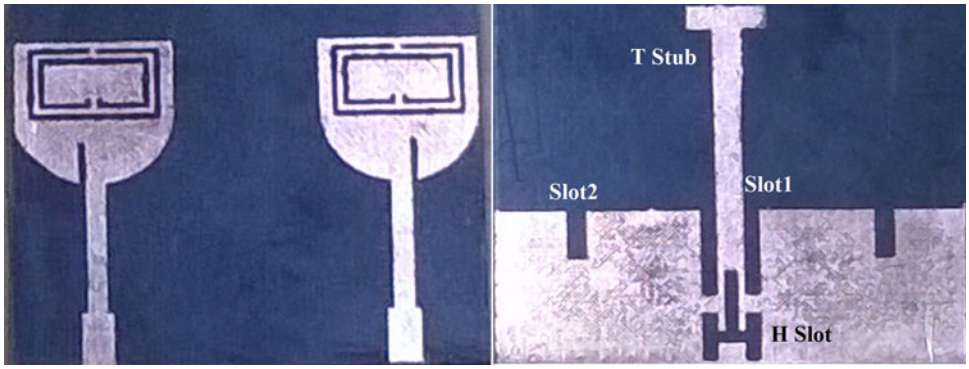


Fig. 2. Photograph of prototype antenna.

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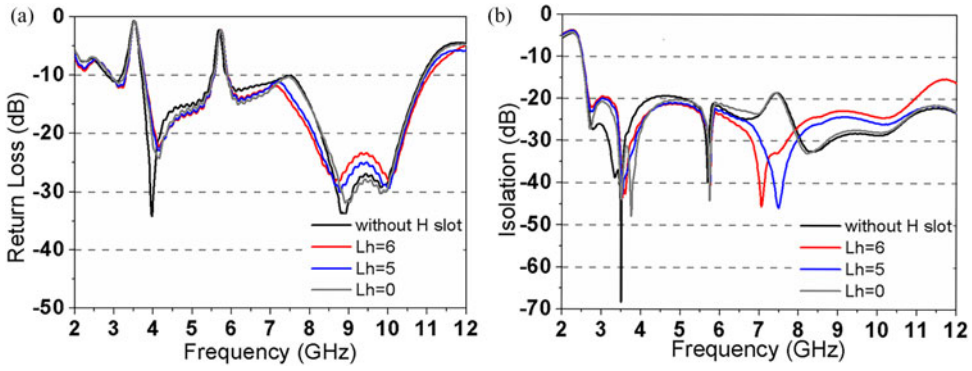


Fig. 3. Effect of H-slot and length Lh on (a) $|S_{11}|$ and (b) $|S_{12}|$.

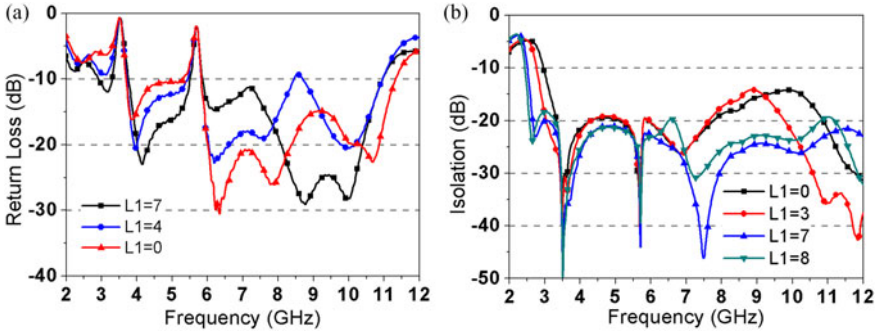


Fig. 4. Effect of variations in length L_1 on (a) $|S_{11}|$ and (b) $|S_{21}|$.

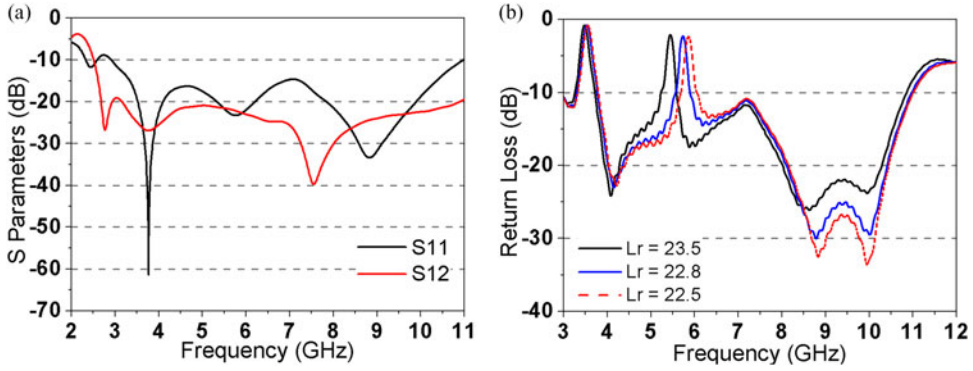


Fig. 5. (a) Antenna S-parameters without CSRR. (b) Effect of variation in CSRR length Lr on $|S_{11}|$.

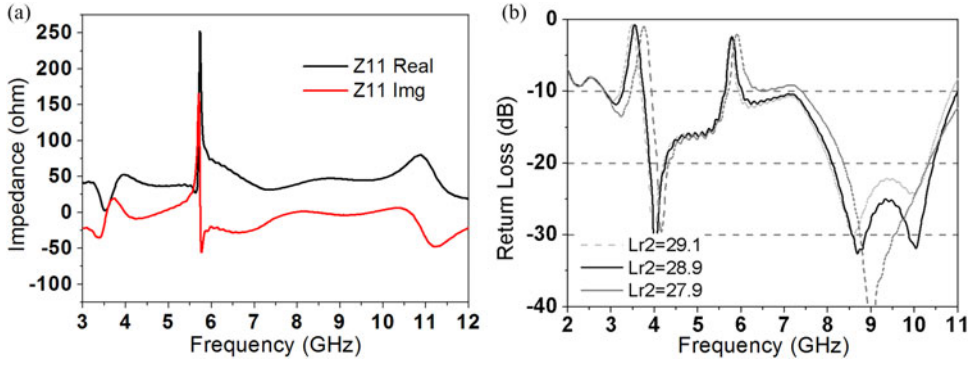


Fig. 6. (a) Input impedance plot. (b) Effect of variation in CSRR length Lr_2 on return loss.

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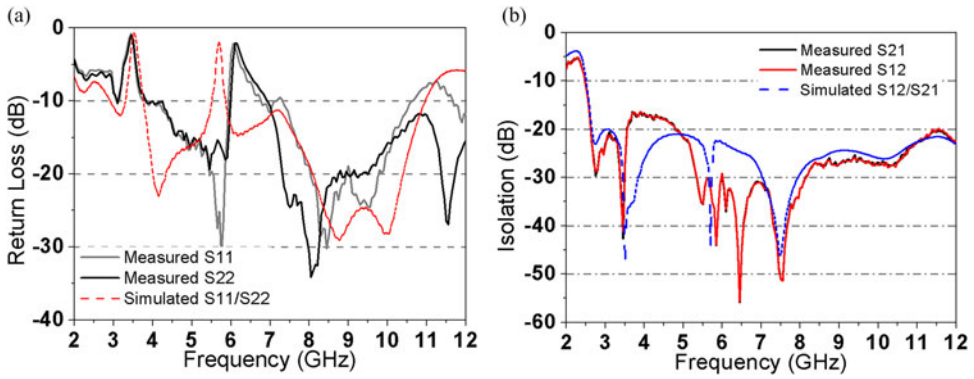


Fig. 7. Measured and simulated *S*-parameters of dual-element dual-notched antenna system. (a) Return loss. (b) Isolation.

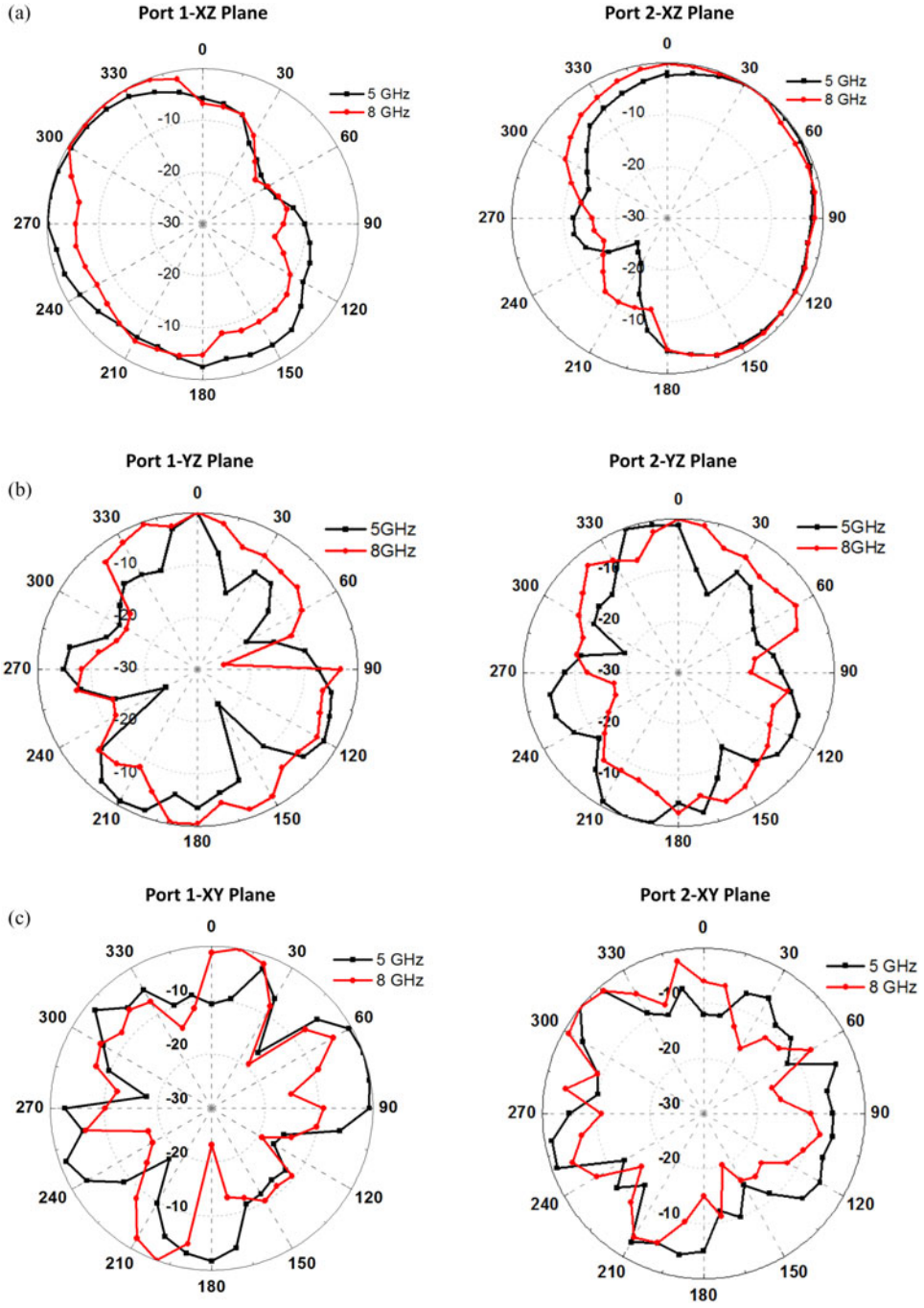


Fig. 8. Measured radiation pattern of the dual-notch proposed antenna at 5 and 8 GHz. (a) *XZ*-plane, (b) *YZ*-plane, and (c) *XY*-plane.

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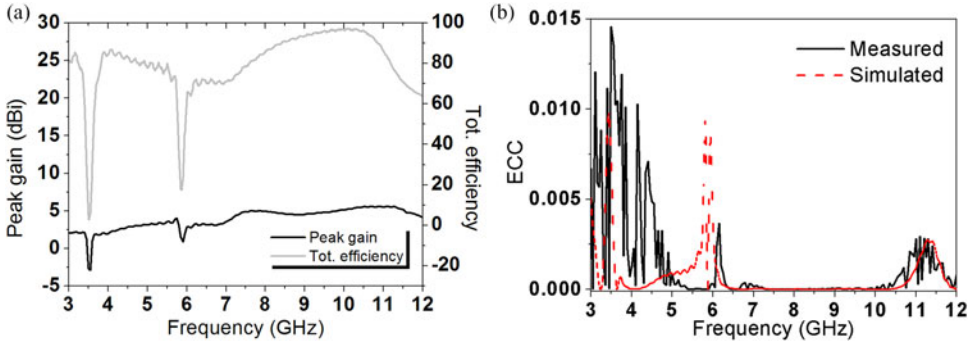


Fig. 9. (a) Simulated efficiency and gain plot. (b) Measured and simulated ECC of the antenna.

5.8 GHz, respectively. The outer split ring slot in CSRR act like two parallel open guided quarter wavelength transmission line to short the antenna at the desired frequency [18] and the inner ring working is analogous to two parallel shorted quarter wavelength transmission line, because outer and inner split rings are complementary to each other. The total length of the slot is chosen to be $\lambda/2$ at the designated frequency and can be calculated by

$$Lr = \frac{c}{2f.\sqrt{\varepsilon_{eff}}} \quad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}, \quad (2)$$

where 'c' is the speed of light, ϵ_{eff} is the effective dielectric constant and Lr ($Lr = 2(w1 + w2 + Lj) - g - 5 \times Wm$) is the average length of the SRR slot. According to (1), the length corresponding to 5.8 GHz comes out to be 20.04 mm.

Figure 5(b) shows the return loss at three different values of $Lr = 20$, 22.8, and 23 mm. It may be seen from the figure that, by increasing the length of SRR, the notched band moves to lower frequencies. In order to reject the center frequency 5.8 GHz the practical length of slot is found 22.8 mm.

Similarly, the average length of the outer SRR slot, $Lr2$ ($Lr2 = 2(wa + wb) - g - 4 \times Wm$) controls the notched frequency band around 3.3 GHz. Figure 6(b) shows the effect of varying the length $Lr2$ on the return loss. The practical length of the slot for band notching at 3.3 GHz is found to be 28.9 mm.

III. RESULTS AND DISCUSSION

A) Impedance performance

The antenna is designed using CST MWS and a prototype is fabricated with the optimized dimensions as above. The return loss of the antenna system is plotted in Fig. 7(a). It could be seen that the system covers the entire band with notched characteristics at 3.3 and 5.8 GHz. The isolation between the two radiators is shown in Fig. 7(b), the measured isolation is greater than 20 dB in the entire band. In the measured results as in Fig. 7(a), there is a shift in the upper notch frequency to 6 GHz. The increased width (Wm) in the fabricated prototype, which affects the average length (Lr) is the reason why the notch has shifted to higher frequency. Other discrepancies between the simulated and measured results might be due to the fact one the antenna system has been fabricated using chemical etching process and second the antenna ground plane is smaller in comparison with connectors [10].

B) Radiation performance

The radiation patterns of the prototype antenna are shown in Fig. 8 when it is excited at port1 and port2 at 5 and 8 GHz, respectively. As it can be seen the radiations patterns in the XY-plane are different when excited at port1 and port2 owing to pattern diversity, while as the patterns in the YZ-plane are mirror transformation of each other. The radiation patterns are stable in the entire UWB.

The simulated efficiency and gain of the antenna are plotted in Fig. 9(a). Evidently the antenna radiates efficiently with a stable gain in the entire UWB.

C) Diversity performance

Diversity is use of multiple numbers of antennas at transmitter and receiver end to increase the number of possibilities for reception of low fade signals. This performance is measured in terms of ECC and is given below [9]:

$$ECC = \frac{\left|S_{11}^{*}S12 + S_{21}^{*}S22\right|^2}{(1 - (|S11|^2 + |S21|^2))(1 - (|S22|^2 + |S12|^2))}. \quad (3)$$

Measured and simulated results show that the ECC is below 0.015 in the entire UWB as shown in Fig. 9(b), thus the proposed antenna is a potential candidate for diversity applications.

IV. CONCLUSION

Compact antenna with notched characteristics is proposed for application in the UWB MIMO system. This antenna consists of two monopole radiators formed on a low loss substrate of size $35 \times 30 = 1050$ mm^2 to achieve UWB characteristics. Isolation between the antennas is obtained using ground stub and slots. To achieve notched characteristics CSRR is etched in both the radiators. Result show good performance in terms of impedance matching, as well as the isolation and stable radiation pattern. ECC below 0.015 is obtained

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proving this antenna to be a good candidate for UWB MIMO applications.

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