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Compact Printed MIMO Antenna with 6.1 GHz Notched Band for Ultra-Wideband Applications

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Abstract—In this paper, a very compact 6.1 GHz band notched printed multiple-input multiple output (MIMO) antenna with the size of only $25 \times 25\,\text{mm}^2$ is presented for Ultra-wideband (UWB) applications. Two symmetrical antenna elements are placed in vertical direction which make it easy to realize good diversity performance. The antenna elements are made up of a microstrip feed line and rounded patch. One slit is in the diagonal position, and one slot line is designed to improve the isolation between two orthogonal antenna elements. The 6.1 GHz band notch weakens the probable interference between C band satellite uplink communications and UWB system. Simulated and measured results show that it covers from 3.1 to 12 GHz with $S_{11} < -10\,\text{dB}$ except rejected band, and the isolation is better than 15 dB in full UWB spectrum.

1. INTRODUCTION

Nowadays, smart devices become an essential part of modern life. It is a big issue for smart devices to achieve high speed data transmission and low power consumption. Ultra-wideband (UWB) communication is a good way to solve these issues due to its high date rate and low spectral density radiator power. However, UWB antennas, as well as other wireless communication systems, suffer from multipath fading. Multiple-input multiple-output (MIMO) technology is designed for overcoming this. With this demand, UWB antennas combined with MIMO technology become an excellent choice for smart devices.

Meanwhile, smart devices are usually easy to take with, which need to have small size or be compact. It is very challenging to realize UWB MIMO antennas in compact size with high isolation between antenna elements, since typically the separated radiating structures have strong mutual coupling in limited spaces. In the last few years, various types of UWB MIMO antennas are proposed [1–7]. For instance, T-shaped ground-stub is utilized as a decoupling structure. However, the T-shaped ground-stub should be longer than the antenna element to decrease the coupling, so the areas of above UWB MIMO antennas are often relatively large, for instance, $60 \times 40\,\text{mm}^2$ in [2], $35 \times 30\,\text{mm}^2$ in [3], $32 \times 26\,\text{mm}^2$ in [5]. New materials are also attempted for decoupling, for example, carbon black film [6] which could absorb electromagnetic signal, but the radiation patterns do not exhibit perfectly. Some complex decoupling structures, such as Minkowski structure, are employed in the ground [7], but still, the overall size of $26.75 \times 41.5\,\text{mm}^2$ has plenty of space to optimize, and the structures are difficult to fabricate. Neutralization line is also a way to reduce the coupling [8]. However, this technique is limited in bandwidth. Furthermore, there are some other narrowband communication systems over the entire UWB, such as C-band satellite uplink communications from 5.8 GHz to 6.5 GHz. So it is unavoidable for UWB antennas to interfere with these systems. The band-notched characteristic is required in the antenna design. In recent publications, many band rejection techniques have been used. For instance,

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in [2], they use C-shape strips as a filter to achieve the notched band, but it needs more copper material. The band notched L-strip structure is combined with the decoupling structure in [9]. The peak return loss of the rejection is just 5 dB. In this paper, the open-ended quarter wavelength slots are introduced, and the method is easy to realize. The slot saves copper material, and the peak return loss of rejection is better.

In this letter, a compact UWB MIMO antenna with 6.1 GHz band notched is proposed. The overall size of the proposed antenna is $25 \times 25\,\text{mm}^2$, which is 27.1% of [10], 44.6% of [11] and 69.4% of [12]. Two antenna elements are placed orthogonally to each other, and each antenna will radiate with a different polarization, thus it is easy to realize high isolation. The antenna is suitable for polarization diversity system such as base station, but it may not fit in several propagation environments. To reach a higher isolation, the slit in the diagonal position and line in the slot are adopted. By slitting an L-shaped slot on the ground, the rejection band of 6.1 GHz center frequency is realized. Basically, the antenna is equivalent to a slot antenna in lower frequency bands and monopole antenna in higher operating bands. Based on previous experience, it is easy for a slot antenna to realize compact size. However, the combination of slot antenna characteristic with that of monopole antenna has not been well reported, which reveals the novelty of this work. Therefore, this compact antenna is an excellent option for smart devices.

2. ANTENNA DESIGN

The geometry and configuration of the proposed antenna are shown in Figure 1. Two symmetrical antenna elements are placed in perpendicular directions which make them achieve high isolation easily. Two radiation elements are placed on top side of a low-cost fr4 substrate that has relative permittivity 4.4 and loss tangent 0.02, where the thickness is 1.6 mm. Each of the radiation elements consists of a $50\,\Omega$ microstrip feed line and rounded printed patch. On the bottom side, a quasi-circular open is notched on the ground. The ground plane acts as a compensating radiator in the low frequency. The reason for this particular geometry can be considered as that the top circular part and bottom circular open increase equivalent capacitances in low frequency. In this case, the surface current route has been significantly changed, thus good radiation characteristics are achieved in a smaller area, especially at lower frequency band. A slot in the diagonal is cut on the ground plane, and a thin line is placed. The slot and inside line both enhance the isolation of two elements. The parameters are optimized by the commercial software ANSYS high frequency structure simulator (HFSS) v13.0. The decided dimensions of this antenna are (units: mm): $W = L = 25$, $R_1 = 3.4$, $R_2 = 4.7$, $W_1 = 14$, $W_2 = 19.6$, $W_3 = 1.41$, $W_4 = 0.56$, $L_1 = 1$, $L_2 = 19.8$, $S_{w1} = 0.2$, $S_{w2} = 1$, $S_{l1} = 5.4$, $S_{l2} = 0.9$, $d_l = 0.5$, $W_t = 2.3$, $L_t = 8.6$.

Figure 2 shows the design process of the UWB MIMO antenna. Firstly, the ground with quasi-circular cutout is the initial antenna prototype, but the isolation of the prototype antenna does not

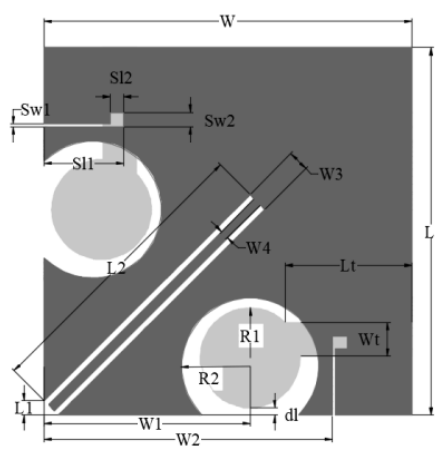


Figure 1. Geometry of the proposed UWB MIMO antenna.

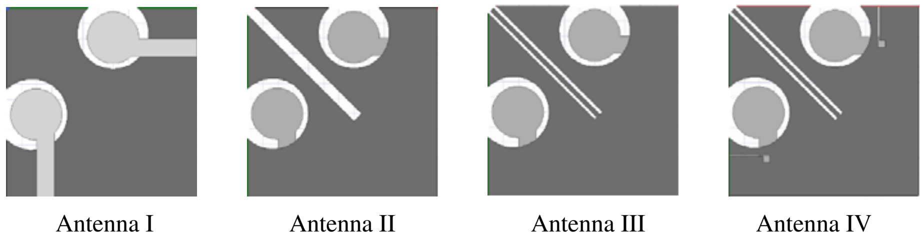


Figure 2. Design process of the proposed UWB MIMO antenna.

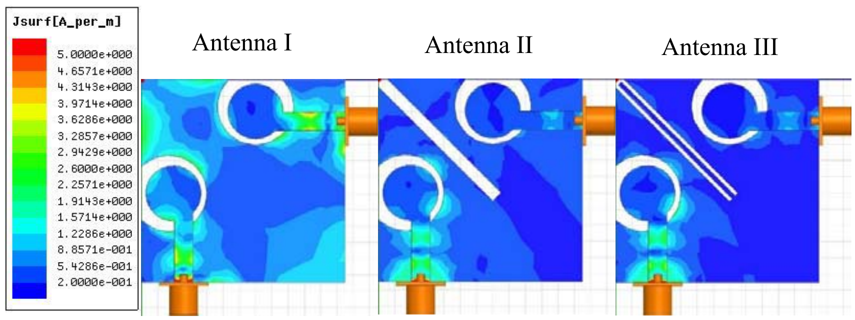


Figure 3. Simulated current distributions of Antenna I to Antenna III at 3.4 GHz.

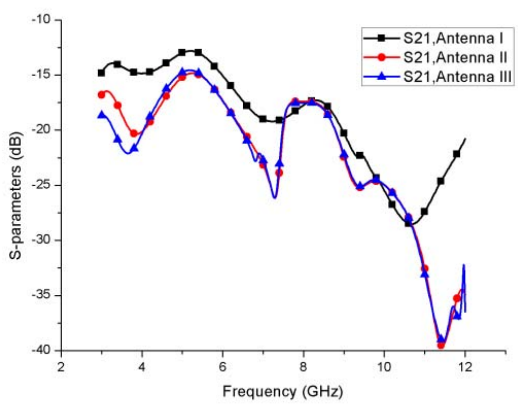


Figure 4. Simulated isolation (S_{21}) of antenna I to antenna III.

perform well at low UWB frequency, and the S_{21}-parameters are above -15 dB from 3 GHz to 5.7 GHz. In order to enhance isolation between two antenna elements, a slot in the diagonal is slit on the ground plane. Figure 3 shows the surface currents difference between antenna I and antenna II. A thin line is placed in the diagonal slot, and it improves the isolation further. As shown in Figure 4, isolation of antenna III is better than that of antenna II from 3 GHz to 4.2 GHz.

In order to decrease mutual interference between the UWB antenna and C-band satellite uplink transmission system, a 5.6–6.5 GHz rejection band is introduced in this antenna. An L-shaped slit is cut on the ground plane. The open-ended quarter wavelength L-shaped slit becomes a resonator whose surface current is offset, and filters the particular band. The frequency of rejection band is determined by slit length. The length can be approximately calculated by the following equation:

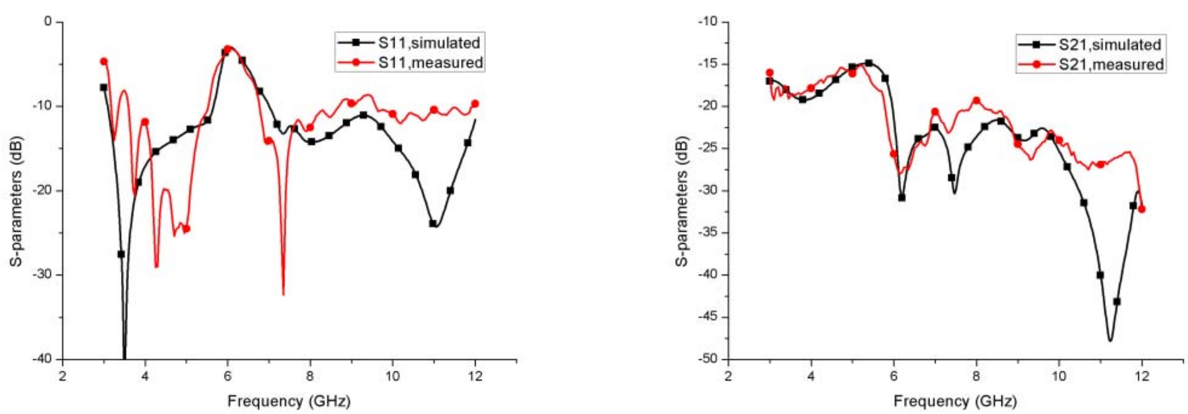
$$L_{slit} = \frac{c}{4f_c\sqrt{\dfrac{\varepsilon_r + 1}{2}}} \tag{1}$$

Here, c is the speed of light in free space, L_{slit} the length of L-shaped slit, ε_r the permittivity of the substrate, and f_c the center frequency of the band-rejection. Considering the center frequency of 6.1 GHz, the value of L_{slit} is calculated as 7.4 mm. It is close to the simulation value of $S_{l1} + S_{w2} + S_{l2} =$ 7.3 mm. The S_{11} from 5.6 to 7.0 GHz is above -10 dB.

3. RESULTS AND DISCUSSION

Photographs of the manufactured MIMO antenna are shown in Figure 5. The S-parameters of the proposed UWB MIMO antenna are measured by the Agilent N9928A vector network analyzer. Simulated and measured S-parameter results are shown in Figure 6. As shown in Figure 6(a), simulated and measured return losses are both below -10 dB in 3.1–12 GHz except 6.1 GHz band-rejection. The difference between the simulated S_{11} and measured S_{11} is owing to soldering, SMA connector loss and ambient interference. Figure 6(b) shows that the measured isolation results agree well with the simulated results. The coupling of this antenna is less than -15 dB in full UWB, and it is lower than -20 dB in most UWB frequency spectrum which is from 5.8 to 12 GHz. Figure 7 depicts the measured normalized radiation patterns. It is observed that the proposed antenna produces quasi-omnidirectional patterns in the YZ-plane at 4.5 GHz, 7.5 GHz, 10 GHz. The measured radiation patterns have ripples owing to the fabrication imperfections, connector losses, etc. Figure 7 represents good stabilization of radiant property across the broad frequency band. The measured average peak gains are 1.36 dBi at operating bands in Figure 8(a). Meanwhile, there is a sharp reduction from 5 to 6 GHz, and there are directional radiation characteristics in the high frequency. The envelope correlation coefficient (ECC) is

Figure 5. Fabricated prototype of proposed antennas.



(a) (b)

Figure 6. Measured and simulated S-parameters of proposed antenna: (a) S_{11} and (b) S_{21}.

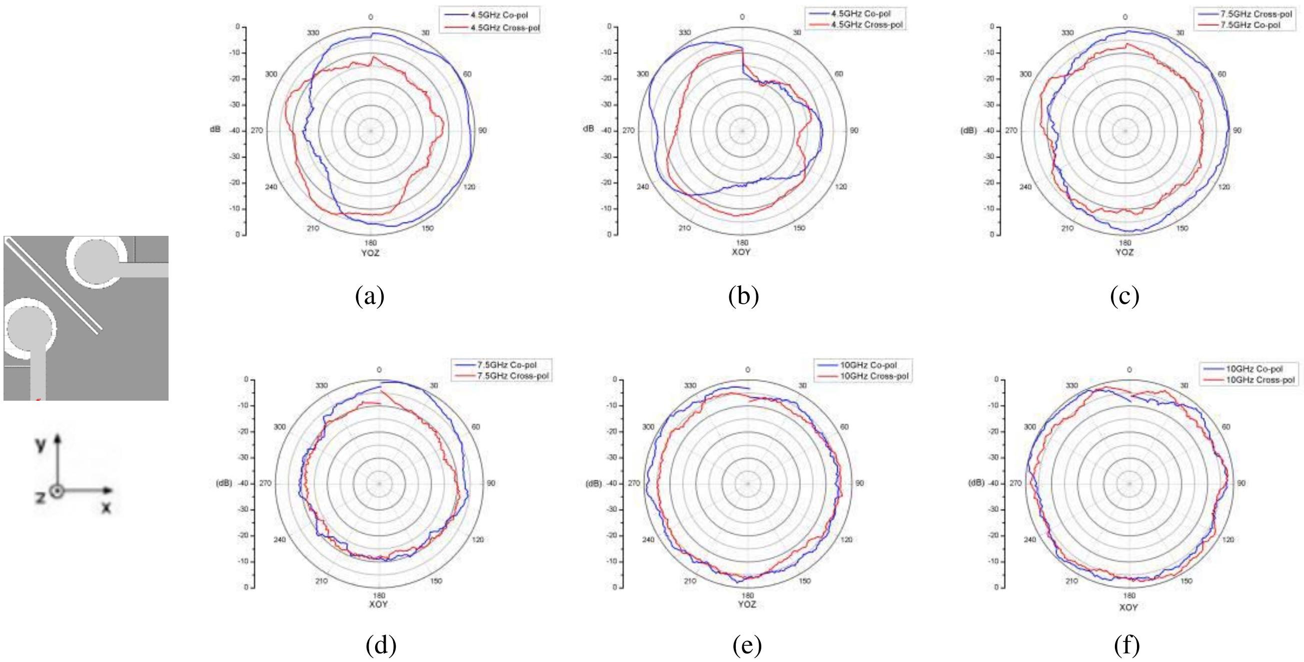


Figure 7. Measured radiation patterns of the proposed antenna: (a) 4.5 GHz YZ-plane, (b) 4.5 GHz XZ-plane, (c) 7.5 GHz YZ-plane, (d) 7.5 GHz XZ-plane, (e) 10 GHz YZ-plane, (f) 10 GHz XZ-plane.

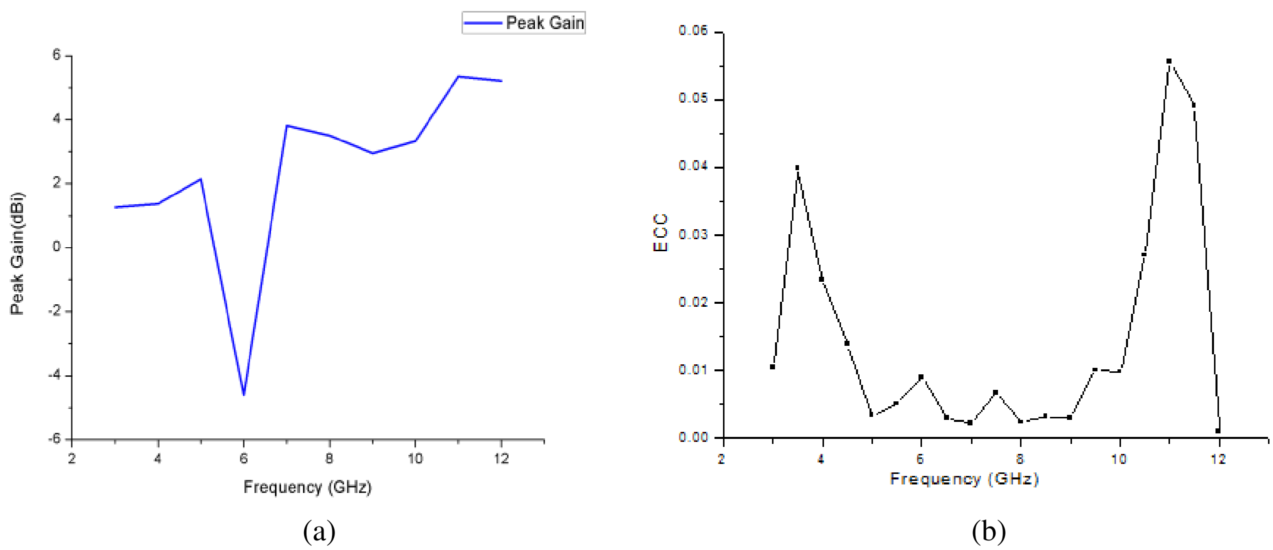


Figure 8. (a) Measured peak gains of proposed antenna and (b) ECC of the proposed antenna.

another parameter to evaluate its diversity performances characterization. The ECC is calculated from the far-field radiation patterns [17]. As seen in Figure 8(b), the ECC of the antenna is below 0.06 during the operating bands, so it is indicated that a good diversity performance of the antenna can be achieved. In addition, diversity gain (DG) is another parameter to measure antenna diversity performances. The diversity gain is a function of ECC as the value of the parameter increases in [18, 19], and it is calculated to be greater than 9.64 dB based on formula (2) in [18]. Table 1 shows the performance comparison with previous UWB MIMO antennas.

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

Table 1. Performance comparison with previous UWB MIMO antennas.

Reference	antenna size (mm)	antenna area (mm^2)	band width (GHz)	Mutual coupling (dB)
[13]	45 × 45	2025	3–12	< -17
[14]	40 × 40	1600	3.4–12	< -15
[15]	38 × 33.4	1296.2	2.1–12	< -20
[7]	26.75 × 41.5	1110.2	3.1–11.5	< -19
[12]	30 × 30	900	2.85–11.9	< -20
[16]	33 × 26	858	3.1–11	< -15
this work	25 × 25	625	3.1–12	< -15 (full) < -20 (5.8–12 GHz)

4. CONCLUSION

In this paper, a very compact printed MIMO antenna for ultra-wideband application with 6.1 GHz rejection band and the size of only $25 \times 25\,\text{mm}^2$ is proposed. Two antenna elements are placed orthogonally. An open-ended slot located diagonally and a line inside slot enhance the isolation further. The total S_{11} is less than -10 dB except notched C band, and S_{21} is below -15 dB in the full band. Thus, the designed compact UWB MIMO antenna is an excellent choice for the smart devices.

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