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Closely Spaced Dual Band-Notched UWB Antenna for MIMO Applications

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Abstract—A closely spaced dual-band notched UWB MIMO antenna is proposed in this paper. A traditional semi-circular monopole with ultra-wideband operation is chosen as an element of the proposed MIMO antenna. When two of the UWB monopoles are put together closely, the mutual coupling between them is apparently strong. To reduce the coupling between the antenna elements, a T-shaped branch is inserted between them, which reduces the mutual coupling obviously over the entire operating band. Also, the T-shaped branch can perform as a compensating radiator which can lower the operating frequencies of the proposed antenna. In order to achieve dual band-notched characteristics, meandering slots are cut in the patches, and symmetrical C-shape strips are nearly placed to the monopoles' feed-lines. The meandering slot is for lower band notch (WiMAX, 3.3–3.7 GHz) while the C-shape strips are for upper band (WLAN, 5.15–5.825 GHz). The measured radiation efficiencies, peak gains and radiation patterns are illustrated and show good agreement as anticipated.

1. INTRODUCTION

By adopting multiple antennas at both the transmitter and receiver ends to exploit the spatial channel, the multiple-input multiple-output (MIMO) systems can increase the channel capacity without additional transmit power or spectrum [1]. However, the strong mutual coupling among antenna elements will make the technology degrade. To make full use of the MIMO technology, there is an essential need of high isolation between MIMO antenna elements. It is quite easy to implement in base stations, in which the space is abundant to isolate the antenna elements by proper spacing. But it is a challenge when the space is limited for MIMO antennas, especially in smaller and smaller mobile handsets. Also, since the Federal Communications Commission (FCC) released the unlicensed frequency band of 3.1–10.6 GHz for commercial ultra-wideband (UWB) applications [2], UWB antenna has been expanding rapidly as a promising technology. UWB technology enables a wide variety of WPAN (Wireless Personal Area Network Communication Technologies) applications, and UWB system has been reported to be resistant against fading effects, which is frequency selective and does not affect the entire occupied bandwidth [3, 4]. There have already been some local wireless communication protocols, such as Wireless Local Area Networks (WLAN, 5.15–5.85 GHz) and Worldwide Interoperability for Microwave Access (WiMAX, 3.3–3.7 GHz), which overlap with the ultra-wide operating band. This will cause interferences between UWB MIMO and other local wireless system; this is especially true to UWB systems, for it works in an extremely low power level.

Till now, most of researches, which have been concerned about MIMO antennas, are single, dual or wide band. Few reports have been seen on UWB MIMO antenna [5–9], let alone UWB MIMO antenna with notch-band to immune from interferences with other systems [10]. In this paper, a simple and effective UWB MIMO antenna with dual notch-band characteristics is proposed. A traditional semi-circular monopole antenna is adopted as the MIMO antenna element, which is inherently with ultra-wideband operation. Then, a T-shaped branch is also inserted between the two closely placed (8.3 mm edge to edge, which is 0.083λ at frequency of 3 GHz) elements to reduce the mutual coupling,

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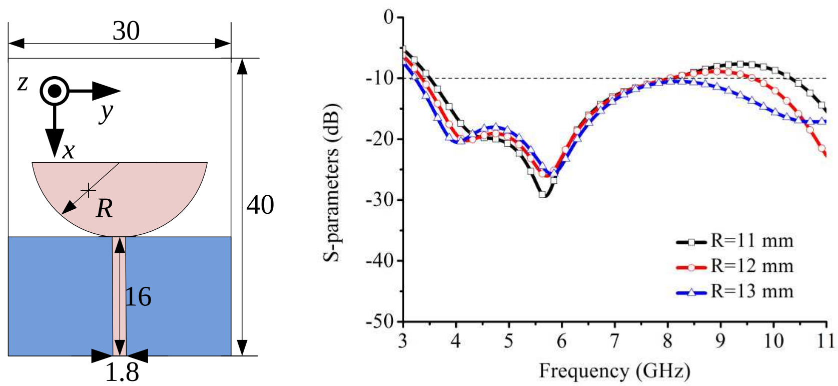
which is improved and reaches higher than 15 dB ($|S_{21}| \leq -15$ dB) across the entire operating band. Actually, the conception of inserting branches between antenna elements for mutual coupling reduction is broadly used in many designs, though they are in different practical implementations [6, 8, 9, 11]. To eliminate the interferences mentioned above, the UWB MIMO antenna is also notched, and the methods used in [12] are adopted. The meandering slot is for notched band at 3.3–3.7 GHz (WiMAX) while the symmetrical C-shape strips are for 5.15–5.85 GHz (WLAN).

This paper is organized as four parts. Section 2 gives the design procedure of the antenna, and some key parameters and design steps are analyzed. In Section 3, the proposed dual band-notched UWB MIMO antenna is fabricated and measured. Then, the results are depicted and discussed. Finally, the whole paper is summarized in Section 4.

2. DESIGN OF PROPOSED DUAL BAND-NOTCHED UWB MIMO ANTENNA

2.1. Antenna Element Design

The element for UWB MIMO antenna array is chosen as a traditional semi-circular monopole with inherently wideband operation. Initially, the monopole is designed on a FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with total size of $30 \times 40 \times 1\,\text{mm}^3$. The initial geometry and dimensions are shown in Figure 1(a), and Figure 1(b) depicts the influence of patch size on monopole's S-parameters. It can be seen that the bigger patch size obtains lower operating frequency and better impedance matching at high frequencies.



(a) (b)

Figure 1. (a) Geometry of UWB element for MIMO antenna. (b) S-parameters varies with different patch radius, R. (unit: mm).

2.2. Evolution of the Proposed Dual Band-Notched UWB MIMO Antenna

Figure 2 shows the evolution of dual band-notched UWB MIMO antenna, i.e., the design procedure of the dual band-notched UWB MIMO antenna. Firstly, two UWB monopoles, which are pre-chosen in Section 2.1, are put together closely and marked as antenna I. This arrangement will lead to strong mutual coupling between antenna elements and cause impedance mismatching. Then, to reduce the mutual coupling, a T-shaped branch is inserted between them and marked as antenna II. Noticeably, to achieve the best performances, the geometry and dimensions of the T-shaped branch is elaborately selected. Also, the elements need some modifications to adjust this insertion. Figure 3 compares the S-parameters of MIMO antenna with and without T-shape branch. It can be seen that the mutual coupling is obviously reduced over the entire band, and the operating frequency of the MIMO antenna extends lower. So the T-shaped branch here not only performs the role of an isolator, but also acts as a compensating radiator for the MIMO antenna. Thirdly, meandering slots are cut on the patches, and symmetrical C-shape strips are added to feed-line. The single notched MIMO antennas are marked

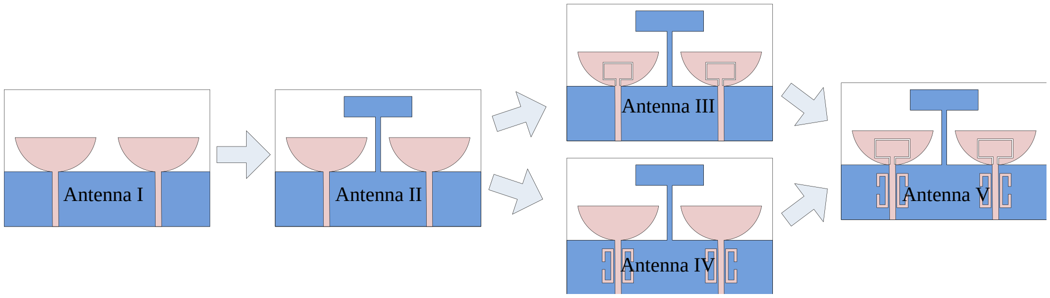


Figure 2. Evolution of the proposed dual band-notched UWB MIMO antenna.

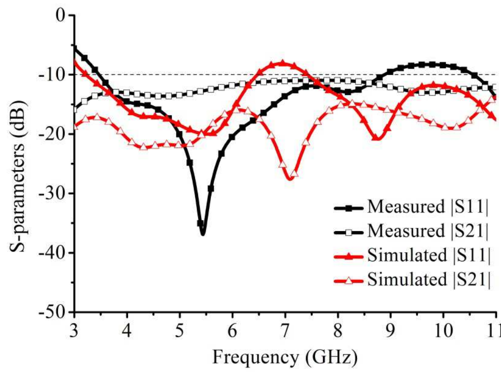


Figure 3. Simulated S-parameters of antenna I and II.

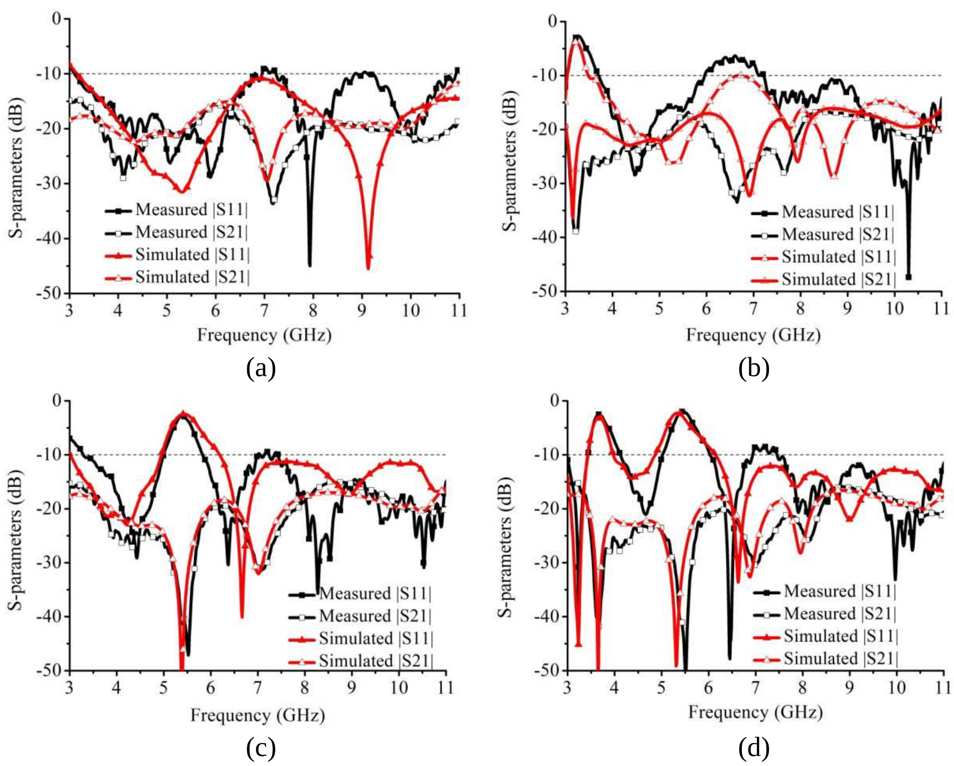


Figure 4. Measured and simulated S-parameters of antenna II, III, IV and V. (a) Antenna II. (b) Antenna III. (c) Antenna IV. (d) Antenna V.

as antennas III and IV, respectively. Finally, using the method for antenna III and IV, a dual band-notched UWB MIMO antenna is obtained and marked as antenna V. Figure 4 shows simulated and measured S-parameters of antennas II, III, IV and V. The numerical simulations are implemented in CST2010 transient solver, while the measurements are experimented by using Wiltron 37269A vector network analyzer. In the confrontation of the simulated and measured results, good agreements can be seen except the return losses at high frequencies ($|S_{11}|$ at frequencies higher than 8 GHz), which are quite different. This may be because the return losses at high frequencies are more sensitive to soldering connections and permittivity inaccuracy ($\varepsilon_r = 4.4 \pm 0.3$). Figure 5 shows a photograph of antennas II, III, IV and V. Specially, antenna V is fabricated and measured as the final proposed dual band-notched UWB MIMO antenna of this paper.

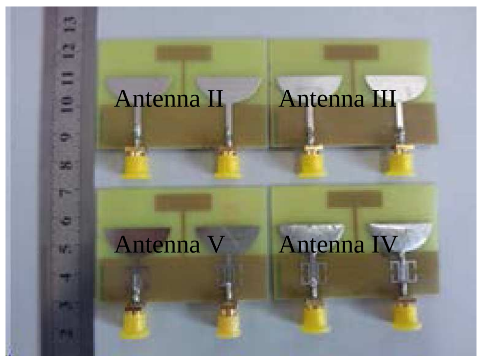


Figure 5. Prototypes of antenna II, III, IV and V.

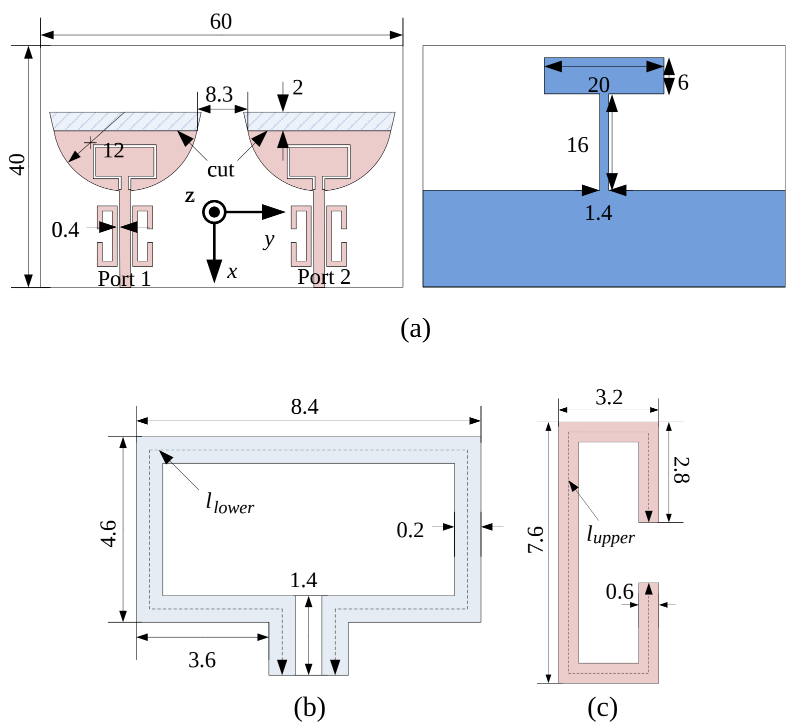


Figure 6. Geometry and dimensions of the proposed dual band-notched UWB MIMO antenna, (a) overview, (b) slot view, and (c) strip view. (unit: mm).

2.3. Fabrication of the Proposed Dual Band-notched UWB MIMO Antenna

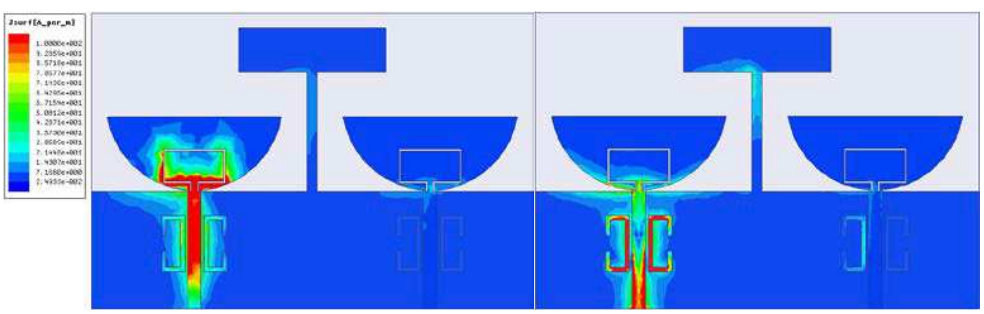
An overview of final geometry and dimensions of the proposed dual band-notched UWB MIMO antenna is given in Figure 6(a), and details of the meandering slots and symmetrical strips are zoomed in and depicted in Figures 6(c) and (d). To obtain a more compact MIMO antenna, the UWB elements are top-cut, so they are no longer semi-circular patches, and the cuts are marked in Figure 6(a). Although the cuts will raise the monopoles' lowest operating frequency, it can be compensated by the protruding T-shaped branch inserted between the antenna elements for mutual coupling reduction, which is quite true as pre-mentioned and can be seen in Figure 3. Then, the proposed dual band-notched UWB MIMO antenna is fabricated on a 1-mm thick FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with dimensions of $60 \times 40\,\mathrm{mm}^2$. Its simulated and measured results are revealed in Figure 4(d).

2.4. Analysis and Discussions

Surface current distributions at 3.5 and 5.5 GHz are depicted and shown in Figure 7. It can be seen that, at these frequencies, the surface currents either gather around the meandering slot or concentrate on the symmetrical C-shape strips, which show how the dual notch-bands obtained. For the surface currents at notch-bands are confined in a very limited space, which brings little disturbance to the original performances of the UWB MIMO antenna (antenna II). Also, the lengths of the meandering slot, l_{lower}, and the C-shape strip, l_{upper}, can be theoretically calculated by following equations,

$$l_i = \frac{c}{2f_i\sqrt{\frac{\varepsilon_r+1}{2}}} \quad i = \text{lower, upper} \tag{1}$$

where c is the speed of light in free space, ε_r the permittivity of the substrate, and f_i the center frequency of the corresponding notch-band. According to Equation (1), theoretically, $l_{lower} = 26.1\,\mathrm{mm}$ and $l_{upper} = 16.6\,\mathrm{mm}$, while, practically, $l_{lower} = 27.6\,\mathrm{mm}$ and $l_{upper} = 19.6\,\mathrm{mm}$. Apparently, the theoretical and practical lengths of meandering slot match well. But the practical length of C-shape strip is longer than theoretical one, which may be because the strips are attached to the feedline through indirect coupling instead of directly touching, which induces more capacitive effect to the parasitic strips. The longer length of the C-shape strip is to compensate this capacitive effect.



(a) (b)

Figure 7. Surface current distributions of the proposed dual band-notched UWB MIMO antenna at (a) 3.5 GHz and (b) 5.5 GHz.

3. MEASURED RESULTS

Figure 8 gives the radiation efficiency and peak gains of the proposed MIMO antenna. It can be seen that both radiation efficiencies and peak gains at notch-band obtain a sharp reduction. Across the entire operating band, the proposed antenna has radiation efficiencies of 63%∼90% while the peak gains keep stable and reach 3.5∼5.1 dBi. Figure 9 shows the measured group-delay of the proposed UWB MIMO

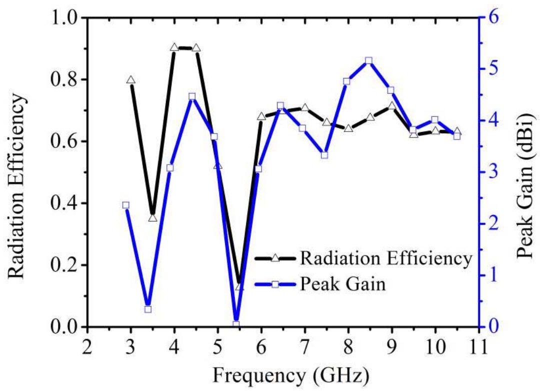


Figure 8. Measured radiation efficiencies and peak gains of the proposed dual band-notched UWB MIMO antenna.

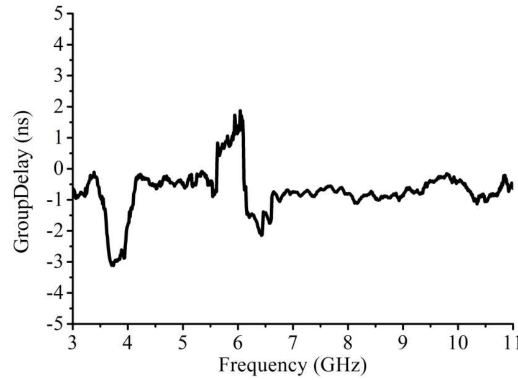


Figure 9. Measured group-delay.

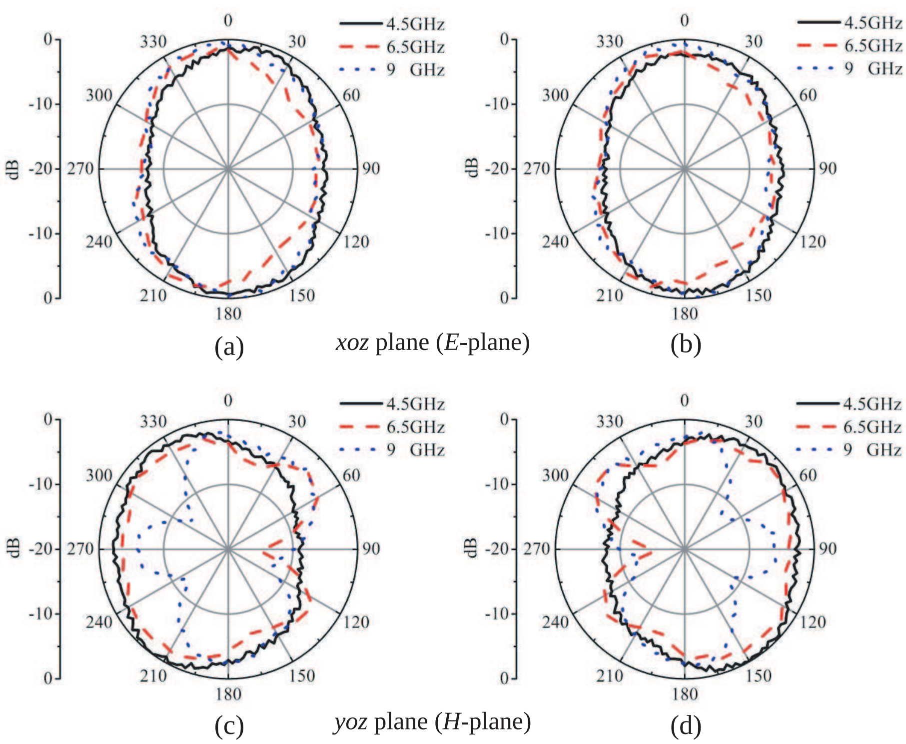


Figure 10. Measured radiation patterns of proposed dual-band notched UWB MIMO antenna at 4.5, 6.5 and 9 GHz excited by port 1 and port 2, respectively. (a) Port 1 excited. (b) Port 2 excited. (c) Port 1 excited. (d) Port 2 excited.

antenna, face to face with distance of 30 cm. It can be seen that two distortions (≥ 1 ns) occurred at 3.5 and 5.5 GHz, respectively while the other part of the operating band keeps relatively flat (≤ 1 ns).

For a MIMO antenna, besides port isolation and efficiency, envelope correlation coefficient (ECC) is another paramount parameter to weight its diversity performances. According to [13] or [14], ECC can be derived from either the *S*-parameters or the radiation patterns. But *S*-parameters method derivation is an approximation to the ECC and demands high antenna efficiency which is usually higher than 80% [15]. In this paper, for the existence of notched-bands which bring the proposed MIMO antenna lower efficiency at notch band, so the *S*-parameters method cannot be adopted. Then, by using the definition with the radiation patterns,

$$\rho_{\mathrm{ECC}} = \frac{|\iint \vec{E}_1(\theta,\phi)\cdot\vec{E}_2^*(\theta,\phi)d\Omega|^2}{\iint |\vec{E}_1(\theta,\phi)|^2 d\Omega \iint |\vec{E}_2(\theta,\phi)|^2 d\Omega} \tag{2}$$

The measured ECC at 4.5, 6.5 and 9 GHz are 0.03, 0.02 and 0.01, respectively, which mean very low antenna correlations and can meet the diversity demands. Also to study the MIMO antenna's far-field properties, the radiation patterns at 4.5, 6.5 and 9 GHz are measured. Figures 10(a) and (b) illustrate the E-plane (xoz plane) of the proposed MIMO antenna with port 1 excited, port 2 terminated or port 1 terminated, port 2 excited, while Figures 10(c) and 10(d) show H-plane (yoz plane). It can be seen that E-planes are quite stable and bi-directional like a dipole while the H-planes are symmetrical and no longer omnidirectional.

4. CONCLUSION

A dual band-notched UWB MIMO antenna with elements closely spaced is proposed in this paper. A kind of traditional semi-circular UWB monopole is selected as an element of MIMO antenna, by putting two of them together, an original MIMO antenna is obtained. To reduce the mutual coupling of the original MIMO antenna, a T-shaped branch is inserted. Also, the T-shaped branch performs like a compensating radiator which, by stretching the surface current path, can lower the antenna's operating frequencies. Then, in order to eliminate the interferences with other wireless systems (such as WLAN and WiMAX), two notch-bands (3.3–3.7 GHz and 5.15–5.85 GHz) are introduced into the UWB MIMO antenna. For the simplicity of the proposed dual band-notched MIMO antenna and its design concept, one can do a similar design by using the same concept. And for the presented antenna in this paper, it can also be expanded to three or more antenna elements, which, of course, need proper spacing and tuning work.

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