A Compact CPW-Fed MIMO Antenna with Band-Notched Characteristic for UWB System

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Abstract **─** A compact coplanar waveguide (CPW)-fed multiple-input-multiple-output (MIMO) band-notched antenna with a small size of 20×36×0.8 mm^3 for ultra-wideband (UWB) system is proposed in this paper. The two rectangular monopole (RM) elements fed by CPW are printed on the FR4 substrate. To improve impedance bandwidth and the isolation, a T-shaped stub structure is positioned in the middle of two RM elements. The band-notched characteristic is achieved by etching a U-shaped loop resonator slot on each RM element. The S_{11} reflection coefficients, S_{12} coupling isolation, radiation pattern, peak gain and radiation efficiency of the MIMO antenna are measured. The MIMO performance of the proposed MIMO antenna is analyzed and evaluated by the envelope correlation coefficient (ECC) and total active reflection coefficient (TARC).

Index Terms **─** Band-notched, CPW, ECC, MIMO, TARC, UWB.

I. INTRODUCTION

Since the Federal Communication Commission (FCC) assigned an unlicensed 3.1-10.6 GHz bandwidth, ultra-wideband (UWB) devices have been one of the most rapidly developing technologies in wireless applications due to its numerous blessings, including low power, high transmission rate, and so on [1-2]. The multipath fading in UWB system has been becoming more and more serious because of the low power limited by FCC. Multiple-input-multiple-output (MIMO) generation has incomparable advantages in improving the wireless link transmission capacity and reliability [3]. Therefore, combining MIMO technology with UWB technology is an efficient way to decrease multipath fading in UWB system [4]. However, there is a strong mutual coupling among two close radiating elements, which result in the loss of antenna bandwidth and radiating efficiency and make it difficult to design MIMO antenna in a compact dimension. Besides, the UWB overlaps with other wireless frequency bands, especially the wireless local area network (WLAN) frequency band at 5.15-5.85 GHz, which can cause some potential interference and noisy to the UWB system. Thus, it is inevitable to reduce both the mutual coupling among UWB MIMO antenna and the electromagnetic interference caused by WLAN system with some simple and effective methods.

Researchers have proposed various MIMO antennas [5-10]. Using electromagnetic band-gap (EBG) structure [5], or a tree-shaped parasitic structure [6], or a T-shaped protruded ground stub [7] to minimize the mutual coupling between radiating elements, or a complementary split-ring resonator (CSRR) etching on the antenna ground [8]. The MIMO antenna in [9] don't use any decoupling structure, the high isolation performance is achieved by the asymmetrical and complementary structures of the quasi-self-complementary antenna (QSCA). The antenna in [10] has the smallest dimension in those UWB MIMO antennas, etching a T-shaped slot at the antenna ground to enhance the impedance bandwidth and reduce the mutual coupling. However, the antenna in [5] is not suitable for UWB system due to their narrow operation band. The operation band of antennas in [6], [8], [9] and [10] is UWB level, but it can't avoid the noise and interference in WLAN band.

In this paper, a compact CPW-fed UWB MIMO antenna with WLAN band-notched characteristic is proposed. The size of the proposed antenna is 20×36×0.8 mm^3, which is smaller than those in [5-10]. This UWB MIMO antenna consists of two identical RMs fed by CPW. The distance between two RM elements is only 8 mm to make the MIMO antenna a small dimension. A T-shaped ground stub which is protruded at the middle of two RM elements acts as a reflector to achieve UWB characteristic and high isolation between two ports. In order to obtain the band-rejected characteristic at WLAN band, a U-shaped loop resonator slot (about half wavelength at 5.5 GHz) is etched on each RM. Measured results show that the designed antenna exhibits an impedance match with S_{11} < -10 dB, high isolation better than 15 dB, peak gain varies 2.4 dBi to 4.4 dBi, radiation efficiency are more than 85%, ECC < 0.02 and TARC < -30 dB over the UWB band except for a notched band at 5-6 GHz. Compared to the previous UWB MIMO antennas in [5-10], proposed UWB MIMO antenna has

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the superiority of a smaller antenna structure, higher radiation efficiency, and better MIMO performance.

II. ANTENNA DESGIN

A. Antenna geometry

The geometry of the proposed UWB MIMO antenna is illustrated in Fig. 1. The antenna which is printed on a 20×36×0.8 mm^3 FR4 (dielectric constant of 4.4 and loss tangent of 0.02) substrate contains two symmetrical RM (RM1 and RM2) elements with coplanar CPW-fed and a perfect conductor ground plane. To match with 50 Ω load, the width of the feed line and the slot is wf = 2 mm and $g1$ = 0.3 mm respectively. Other parameters and its value are shown in Fig. 1. All parameters are in millimeter and optimized by simulating in ANSYS Electromagnetics Suite 17.1.

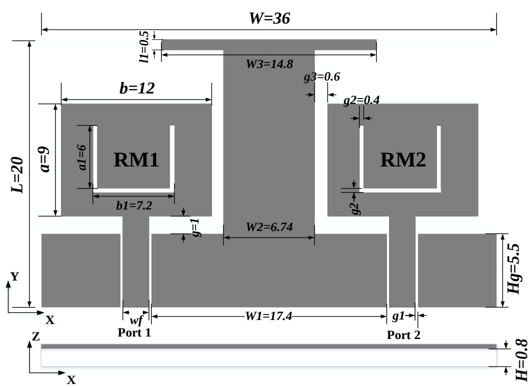
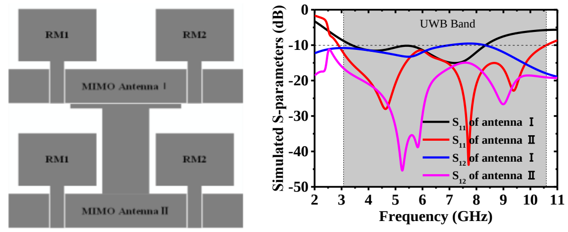


Fig. 1. The geometry of the proposed UWB MIMO antenna.

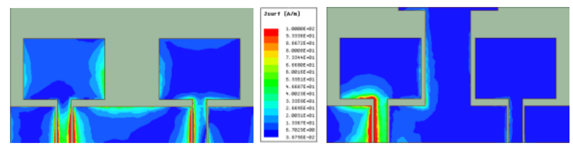
B. The effect of the T-shaped

Putting two RM elements together to obtain a two-port UWB MIMO antenna, denoted as MIMO antenna I. Then, on the basis of antenna I, protruding a T-shaped ground stub between two RM elements, denoted as MIMO antenna II, as seen in Fig. 2 (a). Simulated *S*-parameters of the MIMO antenna I and antenna II are illustrated in Fig. 2 (b). It can be observed that the T-shape stub plays a significant role in MIMO antenna II. Firstly, the gap between rectangle patch and the T-shape stub operates as a resonator to produce three resonances at 4.6 GHz, 6.9 GHz, and 9.4 GHz. Thus, the operation bandwidth is improved to UWB level, as shown in the pink curve in Fig. 2 (b). Secondly, the T-shape stub acts as a reflector to prevent current from flowing port 1 to port 2. Figure 3 shows the surface current distributions at 4.6 GHz of MIMO antenna I and MIMO antenna II when port 1 is excited. Amount of current is focusing on the excited port and the gap between rectangle patch and the T-shaped stub, the T-shaped stub prevents current flowing from port 1 to port 2. Thus, the S_{21} isolation is improved to more than 15 dB, as illustrated in red curve in Fig. 2 (b)



(a) (b)

Fig. 2. Geometry (a) and simulated *S*-parameter (b) of the MIMO antenna I and MIMO antenna II.



MIMO antenna I MIMO antenna II

Fig. 3. Surface current distributions of MIMO antenna I and MIMO antenna II at 4.6 GHz.

C. Achievement of the band-notched characteristic

The band-notched characteristics at WLAN spectrum (5.15 GHz-5.85 GHz) for the presented UWB MIMO antenna is accomplished by a U-shaped slot etching on each RM element of MIMO antenna II. The length of the slot is about half wavelength corresponding to 5.5 GHz and estimated by the formula (1):

$$Ls = \frac{c}{2f_0\sqrt{\varepsilon_{re}}}, \quad (1)$$

where c is the velocity of the light, $\boldsymbol{\varepsilon_{re}}$ is the relative dielectric constant of FR4, Ls=2a1+b1 is the length of the slot and f0 is the central frequency of WLAN band. Using formula (1), the Ls is 18 mm approximately.

Figure 4 illustrates the simulated S11 and S21 results for different value of Ls. The rejected band is shifting to the low frequency with the increase of Ls, but almost no impact on S21 isolation. The value of Ls is selected to 19.2 mm for obtaining notched band from 5 GHz to 6 GHz. Figure 5 shows the surface current distributions at 5.5 GHz of the MIMO antenna II and the proposed MIMO antenna when port 1 is excited. A large number of current are trapped in the U-shaped slot, which achieves the band-notched characteristics.

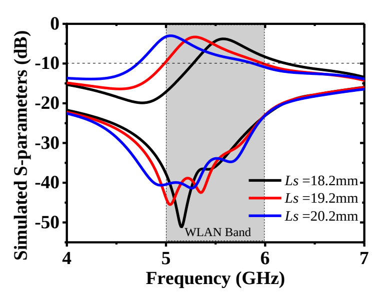
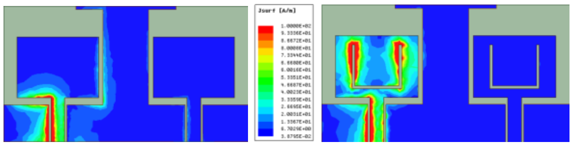


Fig. 4. Simulated S_{11} and S_{12} results of the proposed UWB MIMO antenna for different *Ls*.



MIMO antenna II Presented

Fig. 5. Surface current distributions of the MIMO antenna II and the proposed MIMO antenna at 5.5 GHz.

III. MEASURED RESULTS

The prototype of the UWB MIMO antenna is shown in Fig. 6. The port 1 is measured and port 2 ceased with a 50 Ω load during the measurement.

A. *S*-parameters

The measured *S*-parameters tested with Agilent E5071C network analyzer are presented in Fig. 8. Some discrepancies can be seen between simulated and measured results, which is caused by the manufacture tolerance and SMA connector. Measured results show that the proposed MIMO antenna operates from about 2.9 GHz to 11 GHz with $S_{11} < -10$ dB and $S_{12} < -15$ dB except for a notched band from 5 GHz to 6 GHz.

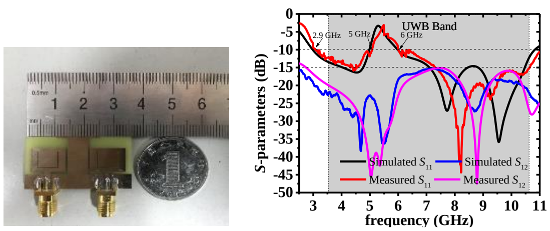


Fig. 6. The prototype and *S*-parameters of the UWB MIMO antenna

B. Radiation performance

Three frequency points (4 GHz, 7 GHz, 10 GHz) are selected to indicate the radiation pattern for low frequency, middle frequency, and high frequency in the UWB band, respectively. Figures 7 (a-d) illustrate the radiation pattern of UWB MIMO antenna at 4 GHz, 7 GHz, and 10 GHz. Besides, the peak gain and radiation efficiency cover the UWB range of the proposed MIMO antenna, when port 1 is measured are shown in Fig. 8. The peak gain varies from 2.4 dBi to 4.4 dBi and radiation efficiencies are higher than 85% over the UWB spectrum except for the notched band.

C. MIMO performance

The MIMO performance of the MIMO antenna is analyzed and figured out by the ECC and TARC. The value of ECC signifies how the two antennas are coupled to each other. For achieving good channel characteristics and antenna diversity, the ECC must be less than 0.05. The ECC between two elements can be calculated from the S-parameters using the formula (2) when the radiation efficiency of the MIMO antenna is high [12]:

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

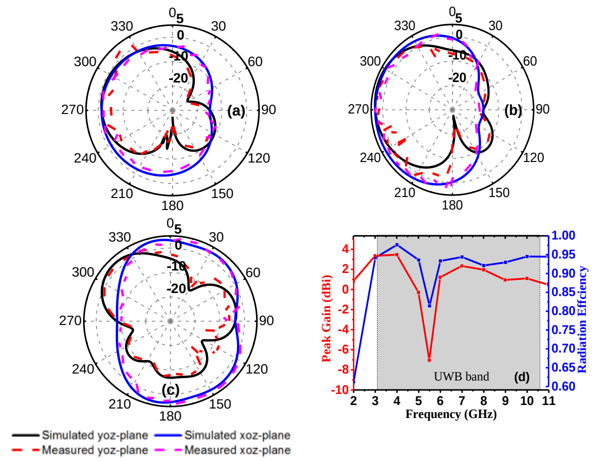


Fig. 7. Simulated and measured radiation pattern of UWB MIMO antenna at: (a) 4 GHz, (b) 7 GHz, (c) 10 GHz, and (d) measured peak gain and radiation efficiency of the proposed UWB MIMO antenna.

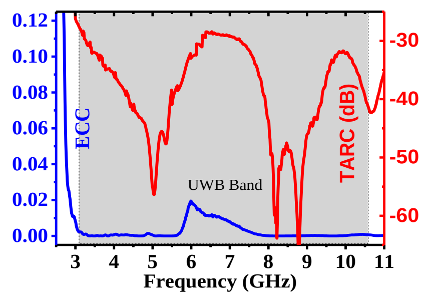


Fig. 8. Measured ECC and TARC of the proposed UWB MIMO antenna against frequency.

For MIMO antenna systems, traditional scattering matrixes are not sufficient to predict the real antenna performance. TARC which take coupling effect into account has been proposed. The TARC for the 2-port MIMO antenna could be described as [11]:

$$TARC = -\sqrt{\frac{(S_{11}+S_{12})^2+(S_{21}+S_{22})^2}{2}}. \qquad (3)$$

As depicted in Fig. 8, the measured ECC is less than 0.02 and TARC is less than -30 dB for the UWB band.

IV. CONCLUSION

A compact CPW-fed UWB MIMO antenna with the band-notched characteristic in a small size of 20×36×0.8 mm^3 has been designed successfully. The available distance (0.19λ) between two RM elements is very small. A T-stub structure as a means to reduce mutual coupling between two RM elements of the MIMO antenna, and a U-shaped loop resonator slot etching on each RM element to achieve a notching band at WLAN spectrum. In addition, the proposed scheme retains full planarity of the UWB MIMO antenna, involves simple and straightforward fabrication process. All the simulated, measured and calculated results indicate that the proposed UWB MIMO antenna is a good candidate for UWB system.

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