# A Quadruple Band-Notched UWB Antenna by Using Arc-Shaped Slot and Rotated E-shaped Resonator

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***Abstract*** **─** A simple quadruple band-notched ultra-wideband (UWB) antenna is proposed and its performance is investigated both numerically and experimentally. The proposed quadruple band-notched UWB antenna is realized based on an asymmetric planar monopole antenna which consists of a fan-shaped radiation patch, a microstrip feeding line and a trapezoidal ground plane. By etching an arc-shaped slot with a gap and adding a rotated E-shaped resonator beside the microstrip feeding line, four notched bands are achieved to suppress potential interferences from WiMAX (3.3-3.6 GHz), WLAN (5.15-5.35 GHz, 5.725-5.825 GHz) and uplink of X-band satellite communication system (7.9-8.4 GHz). The proposed monopole antenna can operate over 2.94-12 GHz band with VSWR<2 except these notch bands. Simulation and measurement results of the fabricated prototype demonstrate that the proposed antenna has quadruple band-notched characteristics and near-omnidirectional radiation patterns, making it suitable for UWB communication applications.

***Index Terms*** **─** Arc-shaped slot, monopole antenna, quadruple notch bands, rotated E-shaped resonator, UWB antenna.

## I. INTRODUCTION

UWB system is famous for its excellent characteristics of high transmission rate, high safety for its low transmitting power, low interception rate and amazing performance of anti-multipath attenuation [1]. Furthermore, the UWB system has a bandwidth of 7.5 GHz (FCC defined UWB band from 3.1 GHz to 10.6 GHz). Thus, it has more advantage to transmit signals than conventional narrow-band communication system. As an important component of the UWB system, UWB antennas have attracted more attention and have potential applications in medical imaging and indoor communication applications.

In order to cover the entire UWB band, a UWB antenna should have wide bandwidth, and hence, it will overlap with existing narrowband communication systems. In sequel, band-notched UWB antennas have been proposed to filter out potential interference bands to address this problem. Recently, various slots have been used to achieve the desired notch bands, including the modified shovel-shaped defected ground structure (DGS) [2], U-shaped and H-shaped slots on the radiation patch and ground plane [3], split-ring resonator (SRR) on the patch [4-7], and so on. Furthermore, parasitic strips or stubs have been used as resonators to produce stop-band filters to suppress the unwanted narrowband signal interferences [8-12], which include the SIR resonators [11], crescent-shaped resonator [12]. In [13], Che et al. designed a UWB antenna with a T-shaped stub embedded in the square slot shaped radiation patch and a pair of U-shaped parasitic strips along the feeding line to create the designated dual band notched characteristics. To enhance the notched performance of the UWB antennas, many double and multiple band-notched UWB antennas are investigated in recent years [14-19]. Moreover, several quadruple band-notched UWB antennas are designed [15-16]. Although they can achieve quadruple notch characteristics, each notched is implemented corresponding to a band-notched structure, which may increase the complexity of the antenna. In [17], a rectangular tuning stub and a tapered-shape slot are used to achieve dual-notched bands. In [18], multilayered resonators are used to achieve four notch bands, which increase the complexity of the antenna fabrication. Thus, we should design a UWB antenna with multi-band-notched function and simple structures to expand the application of the UWB antennas.

In this paper, a quadruple band-notched UWB antenna is proposed to reduce the potential interferences with the narrowband signals and to expand the applications of the band-notched UWB antenna. The

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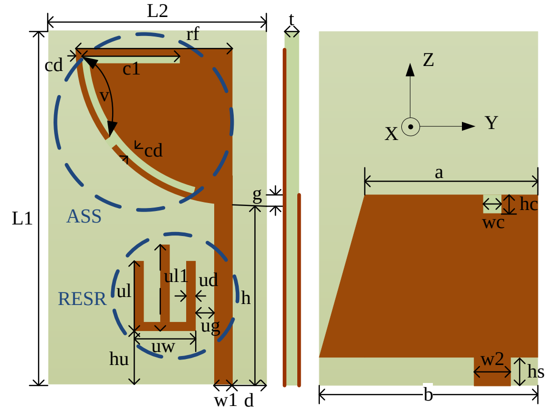
proposed UWB antenna can operate from 2.94 GHz to 12 GHz to cover the entire UWB band, which provides a bandwidth of 121.2% with respect to VSWR<2. By using etching arc-shaped slots on the radiation patch and adding a rotating E-shaped resonator beside the microstrip feeding line, the proposed UWB antenna can produce four notched bands to give resistance to the interferences from WiMAX (3.3-3.6 GHz), WLAN (5.15-5.35 GHz and 5.725-5.825 GHz) and the uplink of the X-band satellite communications (7.9-8.4 GHz). Furthermore, the proposed antenna has nearly omnidirectional radiation patterns and a good impedance matching characteristic, which has very broad prospects for modern UWB communication systems.

## II. ANTENNA DESIGN

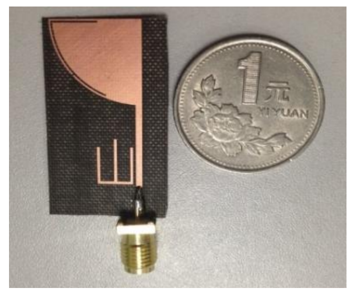
In this section, we will introduce geometry and the design procedure of the proposed quadruple band-notched UWB antenna.

### A. Antenna schematic and dimensions

The proposed quadruple band-notched UWB antenna is designed based on the monopole UWB antenna [20-21]. Figure 1 depicts the configuration and the fabrication prototype of the proposed antenna. From Fig. 1, we can see that the proposed antenna consists of fan-shaped radiation patch with arc-shaped slots (ASS), 50-Ohm microstrip feeding transmission line and rotated E-shaped resonator (RESR) printed on the top layer of the proposed antenna. On the back layer, there is a trapezoidal ground plane. The antenna is printed on a substrate with a dielectric constant of 2.65 and thickness of 0.5 mm. The total size of the antenna is 35.6×20 mm$^2$. A slit divides the ASS into two segments (upper segment and lower segment) to implement the dual notch bands, which are located at WiMAX and the uplink of the X-band satellite communication bands. Additionally, the RESR is used for achieving another two narrow notch bands operated at WLAN bands. On the basis of the principle of the proposed quadruple band-notched UWB antenna, the proposed antenna is optimized by the Ansoft HFSS Ver. 13 and the optimized dimensions are listed as follows: w1=1.05 mm, h=21 mm, g=-0.4 mm, rf=15 mm, a=16 mm, b=20 mm, w2=6 mm, hs=1 mm, wc=3 mm, hc=1.2 mm. The dimensions of the designed two notch structures, including ASS and RESR, are given by c1=7.6 mm, cd=0.3 mm, hu=6 mm, uw=6.1 mm, ug=0.45 mm, ul=6.9 mm, ul1=8.4 mm, ud=0.5 mm. The angle of the ASS is 66°, and it is divided into two segments at an angle of 40°. Herein, the optimized parameters are obtained by using the HFSS and are rendered to meet both the desired UWB bandwidth and the designated notch bands referred to the VSWR.




(a) Configuration of the proposed antenna



(b) Fabricated antenna

Fig. 1. Schematic and the prototype of the proposed UWB antenna.

### B. Design procedure of the proposed antenna

The design procedure of the proposed quadruple band-notched UWB antenna is depicted in Fig. 2. Here, we will introduce how to design the proposed antenna step by step. Also, the dimensions of the corresponded notched structures, namely the arc-shaped slot and the RESR, are given by:

$$L_{notch} = \frac{c}{2 f_{notch} \sqrt{\frac{\varepsilon_r + 1}{2}}},$$

where $\varepsilon_r$ is the dielectric constant of the substrate, $c$ is the speed of the light, $f_{notch}$ is the center frequency of the notch, and $L_{notch}$ is the resonance length of the notch structure.

Firstly, a UWB antenna is used to design the proposed antenna, which is denoted as Antenna 1. Antenna 1 has a wide bandwidth, covering UWB band 3.1-10.6 GHz, and it has small size and good omnidirectional radiation characteristic [20-21]. Then, an ASS with a slit is etched on the fan-shaped radiation patch to create the Antenna 2 which is to design dual notch bands at WiMAX and X-band satellite communication band. Finally, a RESR is set along the feed transmission line of the Antenna 2 to construct the proposed antenna which is named as Antenna 3. Antenna 3 is the proposed antenna, which is designed for providing four designated notch bands and suppressing unwanted interference signals from the above narrowband systems.

To verify the effectiveness and feasibility of the proposed antenna, the proposed antenna is investigated by using the HFSS based on the finite element method (FEM) and its performance is shown in Fig. 3. From Fig. 3, we can see that the frequency band of the Antenna 1 is 2.94-12 GHz with VSWR<2, which covers the entire UWB frequency band. Also, we can see that the Antenna 2 is also a UWB antenna which has two notch bands at 3.4 GHz and 7.32-9.07 GHz to suppress the potential narrowband interferences. In this case, the dual notch bands can be controlled by adjusting the dimensions of the ASS. Antenna 3 is our proposed quadruple band-notched UWB antenna. It is obvious that Antenna 3 has four notch bands located at 3.4 GHz, 7.32-9.07 GHz, 5.25 GHz and 5.75 GHz, which can be used for filter out potential interferences from WiMAX, WLAN, the uplink of the X-band satellite communications and 8 GHz ITU band. Thus, we can say that the four notch bands are generated by the ASS and RESR. Thus, we can design the dimensions of the ASS and RESR to create the desired notch bands.

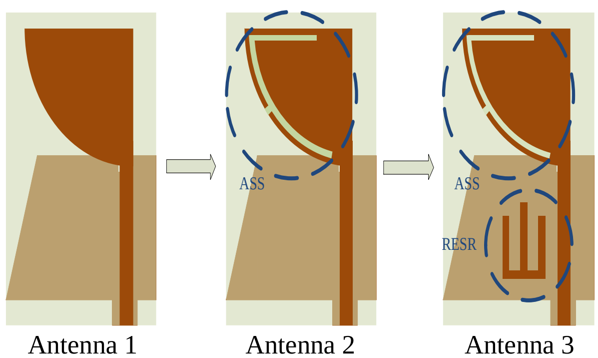



Fig. 2. Design procedure of the proposed antenna.

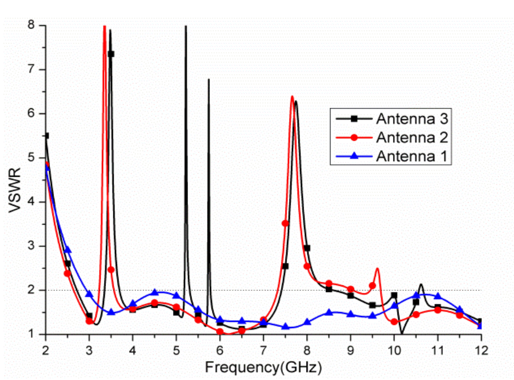



Fig. 3. Performance of the design procedure of the proposed antenna.

## III. PERFORMANCE OF THE PROPOSED ANTENNA

In this section, we will discuss the performance of the proposed antenna by using the HFSS, which includes the impedance characteristic, current distribution and radiation patterns.

### A. Impedance characteristic and parameter performance

Here, the quadruple band-notched UWB antenna is optimized by using the HFSS, and the optimized S11 and VSWR are shown in Fig. 4. We can see that the antenna operates from 2.94 GHz to 12 GHz which can cover the entire UWB band. Also, it has four notch bands with respect to S11>-10 dB or VSWR>2 to filter out the potential interferences from the WiMAX system ranging from 3.3 to 3.6 GHz, WLAN frequency band 5.25-5.35 GHz and 5.725-5.825 GHz, and the uplink of the X-band satellite systems ranging from 7.9 to 8.4 GHz. The input impedance of the proposed antenna is given in Fig. 5. It is found that the real part is around 50-Ohm and the imaginary part is about 0 ohm at operating frequency range, which indicates the antenna has a good matching with 50-Ohm terminals. In addition, the real part and the imaginary part changes very quickly in the notch bands, which result in no resonance, and hence, the desired notch characteristics has been produced.

Next, we will investigate the parameter effects on the VSWR. Here, the parameters v and ul are selected for evaluating the effects on the proposed quadruple band-notched UWB antenna and the results are demonstrated in Fig. 6 and Fig. 7, respectively. It is found from Fig. 6 that v has important effects on the notch band at uplink of X-band satellite communication. The degree of v controls the lower resonator of ASS. By adjusting the degree of v from 65 degree to 67 degree, the center frequency of 8 GHz notch band moves from high frequency to low frequency. This is caused by the increased resonance length of the lower ASS. In this paper, the optimized value of v is 66 degree referred to Fig. 6, which can be used for producing a notch to cover 7.9-8.4 GHz for uplink band of X-band satellite communication.

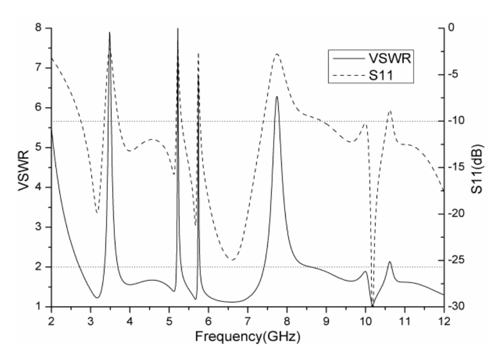



Fig. 4. S11 and VSWR of the proposed quadruple band-notched UWB antenna.

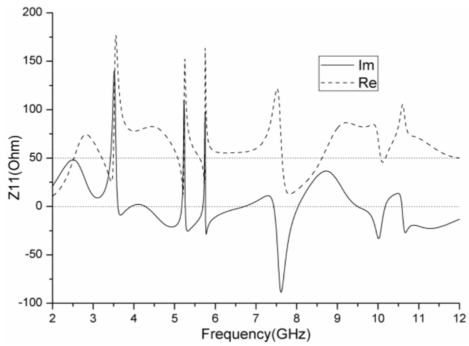



Fig. 5. Z11 of the proposed quadruple band-notched UWB antenna.

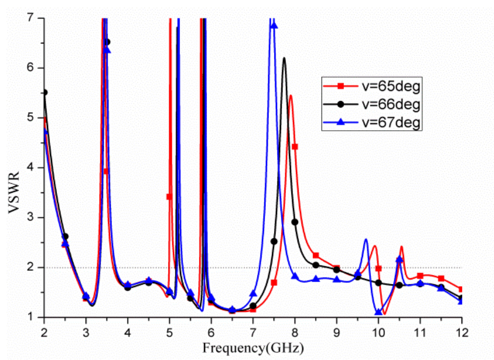



Fig. 6. VSWR of the proposed quadruple band-notched UWB antenna with varying v.

The parameter ul can control the resonance length of the RESR, which is depicted in Fig. 7. When ul increases from 6.8 mm to 7 mm, the center frequencies of the two WLAN notch bands all move from high frequency to low frequency. This is because the resonance lengths of RESR become larger with an increasing ul.

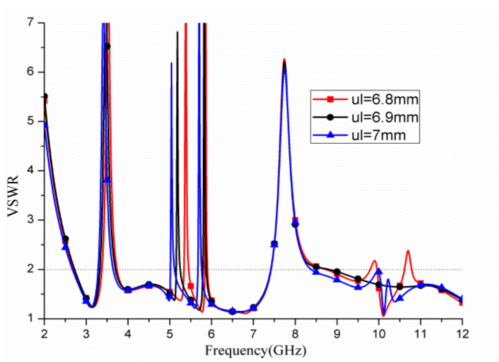



Fig. 7. VSWR of the proposed quadruple band-notched UWB antenna with varying ul.

**B. Measured S11, radiation patterns, gain and current distributions**

To verify the effectiveness of the proposed antenna, the optimized antenna is fabricated and its S11 is measured by using Agilent N5224A vector network analyzer. The comparisons of the simulated and measured S11 are shown in Fig. 8. It can be seen that the measurement results agree well with the simulation ones. It is worth noting that there are some differences between the measured and simulated results, which may be caused by fabrication tolerances and inaccuracies introduced by manual welding.

The radiation patterns of the proposed quadruple band-notched UWB antenna at 3.1 GHz, 4.5 GHz and 7 GHz are shown in Fig. 9, where we define the YOZ plane as E-plane and the XOZ plane as H-plane. From Fig. 9, we can see that the radiation plane of E-plane looks like a digit '8' and H-plane is almost omnidirectional at 3.1 GHz and 4.5 GHz. There is some distortion at 7 GHz, which may be caused by the effects of the ASS, RESR and the asymmetric antenna structure.

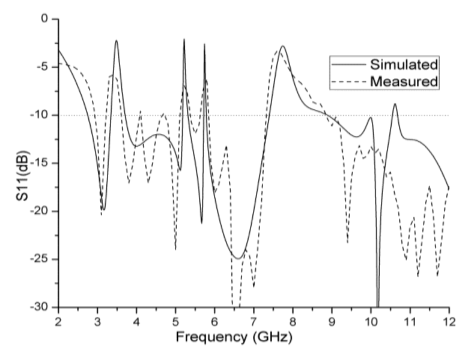
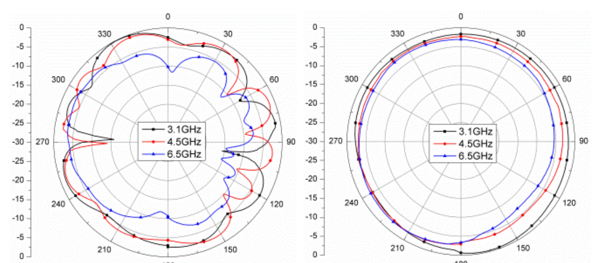



Fig. 8. S11 of the proposed antenna.




(a) E-plane (b) H-plane

Fig. 9. Measured radiation patterns of the proposed quadruple band-notched UWB antenna.

The gain of the proposed quadruple band-notched UWB antenna is given in Fig. 10. From 3.1-10.6 GHz, the value of gain ranges from 0.8-5.7 dB. At 3.4 GHz, 5.25 GHz, 5.75 GHz and 7.9 GHz, the gains drop very quickly and they are -2.8 dBi, 0.2 dBi, 0.4 dBi and 3.3 dBi, respectively. It means that the radiation ability of the antenna is strong at UWB band except four notch bands which comply with the design requirements.

To understand the principle of the designed quadruple band-notched UWB antenna, the current distribution of the proposed antenna is investigated and is illustrated in Fig. 11. The current distribution at the notch bands 3.4 GHz, 5.25 GHz, 5.75 GHz and 7.8 GHz are discussed herein. We can clearly see that the current is focus on the upper ASS at 3.4 GHz, and the currents on the microstrip feeding line are small. At 7.8 GHz, the current is mainly on the lower ASS. Thus, we can say that the 3.4 GHz and 7.8 GHz notches are generated by the ASS. Similarly, the current distributions focus on the RESR structure at 5.25 GHz and 5.75 GHz. Thus, the RESR can provide two notch bands at WLAN bands.

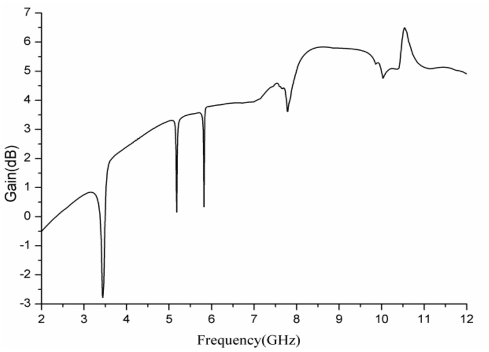



Fig. 10. Gain of the proposed quadruple band-notched UWB antenna.

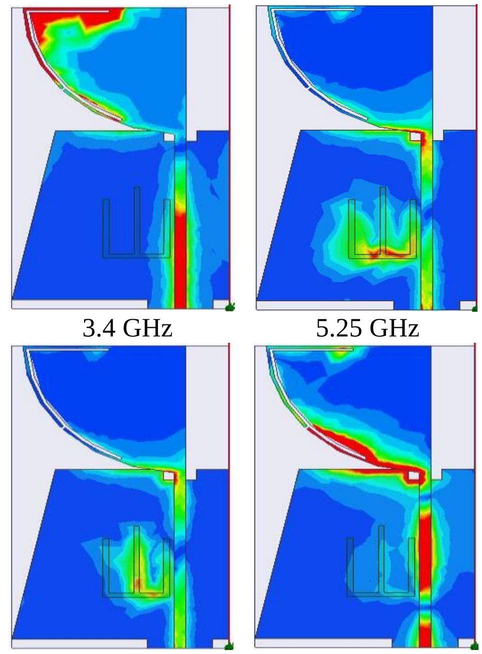



Fig. 11. Current distributions of the proposed quadruple band-notched UWB antenna.

Table 1 gives comparisons of the proposed antenna with previously reported band-notched UWB antennas with respect to the size, the number of notch bands bandwidth and gains. From Table 1, we can see that most of the antennas only have single, dual and triple notch bands. Although the references [2] and [7] have smaller size, they can only provide two stop bands. In [5] and [12], the UWB antenna can provide three notch bands. However, they are embarrassed in large size. In a word, the proposed quad notch-band UWB antenna can provide four designated notch bands and have smaller size, making it suitable to meet the requirements of ultra-wideband systems.

Table 1: Comparisons of several existing band-notched UWB antennas

| References | Dimensions ($mm^2$) | Rejection Bands | Bandwidth | Gain (dBi) (Operating Bands) |
|---|---|---|---|---|
| [2] | 15×18 | 5.13 GHz-6.1 GHz | 3.1-13.4 GHz | 3~5 |
| [3] | 21×28 | 5 GHz-6 GHz & 7.7 GHz-8.5 GHz | 2.8-12 GHz | 2~4 |
| [4] | 25×25 | 5.15 GHz-5.35 GHz | 3.8-11 GHz | -1.8~4 |
| [5] | 30×26 | 3.3 GHz-3.6 GHz & 5.25 GHz-5.35 GHz & 7.725 GHz-7.825 GHz | 3.1-12 GHz | 3.8~5.6 |
| [6] | 22×26 | 3.8 GHz-4.28 GHz & 5.76 GHz-6.16 GHz | 2.6-12 GHz | ____ |
| [7] | 12×18 | 3.38 GHz-4.31 GHz & 5.1 GHz-5.95 GHz | 3.1-13.4 GHz | 2.8~5 |
| [8] | 40×31 | 4.1 GHz-5.8 GHz | 3.1-9.9 GHz | 2.7~6.2 |
| [10] | 23×28 | 3.5 GHz WLAN & 5.8 GHZ WLAN | 2.7-11 GHz | 0~5 |
| [12] | 25×28 | 4.94 GHz-5.52 GHz & 5.72 GHz-6.02 GHz & 7.25-7.76 GHz | 3.1-12 GHz | 1.9~5.8 |
| [13] | 26×32 | 3.3 GHz-4.0 GHz & 5.05 GHz-5.9 GHz | 3.1-12 GHz | 1~3.5 |
| [17] | 22×24 | 3.35-3.8 GHz & 5.12 GHz-5.84 GHz | 3.0-10.6 GHz | -1.8~5 |
| [21] | 30×32 | 4.2 GHz-6.15 GHz & 6.5 GHz-7 GHz, 10 GHz-12.4 GHz | 3.1-14 GHz | 2~6 |
| Proposed | 20×35.6 | 3.3 GHz-3.6 GHz & 5.25 GHz-5.35 GHz & 5.725 GHz-5.825 GHz & 7.9 GHz-8.4 GHz | 2.94-12 GHz | 0.5~6 |

## VI. CONCLUSION

In this paper, a quadruple band-notched UWB antenna has been proposed and its performance has been investigated in detail. The desired four notches are generated by ASS and RESR. The antenna can operate over the entire UWB band and can provide a good rejection function for unwanted narrowband signal interferences. Additionally, the proposed antenna only uses two notch structures to construct the desired four notch band. Also, the proposed antenna has a small size. The experiment results showed that the antenna has a good impedance match and omnidirectional radiation patterns, rendering it suitable for UWB communication applications.

## ACKNOWLEDGMENT

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