

## A Miniaturized Quasi-Self-Complementary UWB Antenna with Band-Rejection Characteristic

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**Abstract**—A miniaturized ultra-wideband (UWB) quasi-self-complementary antenna (QSCA) with band-rejection characteristic is presented and discussed. With the tapered microstrip-fed line and flower-shaped QSC structure, a lower cut-in frequency (3.18 GHz) is obtained with a compact size ( $9 \times 17.5 \times 1 \text{ mm}^3$ ). By embedding a five-star-shaped ring resonator under the radiation patch, a band-notched feature is achieved. The measured impedance bandwidth below 2 : 1 VSWR is from 3.18 GHz to 13.4 GHz with a rejection band from 5.45 GHz to 5.95 GHz, and the simulated and measured results of the proposed antenna are in good agreement. Thus, the antenna is suitable to be integrated with the space-limited wireless system without electromagnetic interference at the WLAN (5.47–5.825 GHz) band.

### 1. INTRODUCTION

With the advantage of high-speed data rate, large data capacity and low power consumption, ultra-wideband technology has received much attention in recent years. In this context, since the design of UWB antennas is a key component of a UWB system having operating band between 3.1 and 10.6 GHz, it has become a hot topic for academic and industrial research [1–5]. To this end, QSC radiating structures with broadband characteristics have shown promising prospects in the design of UWB antennas [6–8].

However, the existing wireless systems including 3.6 GHz IEEE 802.11y Wireless Local Area Networks (WLAN) (3.6575–3.69 GHz), 4.9 GHz public safety WLAN (4.94–4.99 GHz) and 5 GHz IEEE 802.11a/h/j/n WLAN (5.15–5.35 GHz, 5.25–5.35 GHz, 5.47–5.725 GHz, 5.725–5.825 GHz) may cause interference with the UWB systems. Therefore, UWB antennas with filtering technique are needed. There are several methods that can be adopted to realize a band-notched UWB antenna. They consist in putting parasitic patches near the radiator [9, 13], embedding a quarter wavelength tuning stub within the slot on the patch [12], or inserting a slit on the radiator patch [11, 14]. In addition, band-rejected filtering properties are achieved by using a rectangular and meander line microstrip resonators in [10]. Nevertheless, the sizes of the aforesaid antennas are very large, although they operate well for UWB with band-notched facility. Since miniaturization is a significant aspect when fabrication cost and integration are important issues, size reduction of the antenna becomes a crucial task. The comparison between the proposed antenna and the antennas mentioned above is shown in Table 1. Although the antenna in [14] presents a considerable size reduction compared to that of the other antennas presented in literature, its lower frequency begins from 4.6 GHz without covering the 3.1–4.6 GHz UWB. Obviously, the proposed antenna achieves a lower cut-in frequency with a size reduction of 11% compared to that presented in [14].

In this paper, a miniature and quasi-self-complementary UWB antenna with a notched band centered at 5.7 GHz is proposed. A QSC structure with a flower-like fractal boundary and stepped

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**Table 1.** Comparison of recently reported UWB band-notched antennas.

Reference#	Size (mm × mm)	Area (mm <sup>2</sup> )	Bandwidth (GHz)
[9]	37 × 47	1739	2.8–13.5
[10]	40 × 40	1600	2.8–11.34
[11]	26 × 28.5	741	2.82–13.86
[12]	24 × 28	672	3–10.5
[13]	25 × 25.5	637.5	3–11
[14]	11 × 16	176	4.6–25.5
Proposed antenna	9 × 17.5	157.5	3.18–13.4

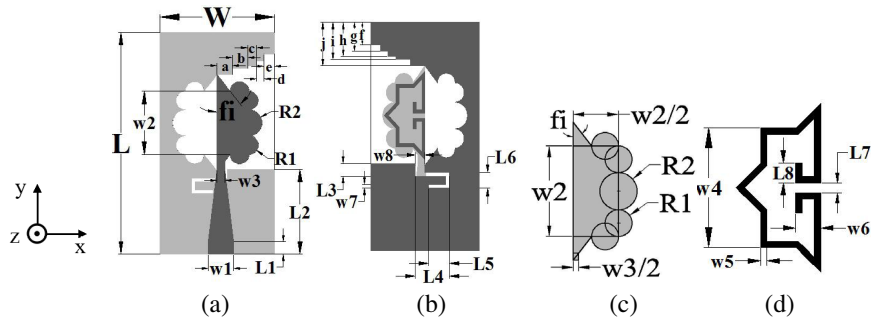
impedance matching structure is used in the design process. Thus, a wide operational band (3.18–13.4 GHz) and a compact antenna having a limited occupation area of 157.5 mm<sup>2</sup> are accomplished. Moreover, in order to reject the interference with 5 GHz IEEE 802.11j/n WLAN (5.47–5.725 GHz, 5.725–5.825 GHz) wireless systems, a five-star-shaped split ring resonator is embedded under the radiation patch. Details of the proposed antenna are discussed and studied in the following sections.

## 2. ANTENNA DESIGN

Figures 1(a), 1(b) show the geometry of the QSCA with a flower-shaped boundary for UWB application and a band-notched characteristic. The antenna is designed using High Frequency Structure Simulator (HFSS 13.0) and fabricated on a Rogers 4350 substrate with relative permittivity  $\epsilon_r = 3.66$ . The overall size of the QSCA is  $9 \times 17.5 \times 1$  mm<sup>3</sup>. The detailed dimensions of the proposed antenna are listed in Table 2.

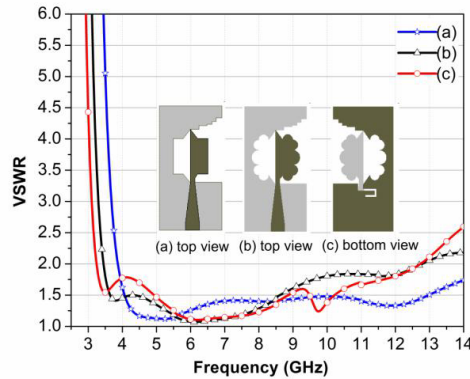
**Table 2.** Design parameters (mm) of the proposed antenna.

$L$	$L1$	$L2$	$L3$	$L4$	$L5$	$L6$	$L7$	$L8$	$R1$
17.5	1	6.7	1	2.8	1.7	1.2	0.4	0.8	0.74
$W$	$w1$	$w2$	$w3$	$w4$	$w5$	$w6$	$w7$	$w8$	$R2$
9	2	5	0.6	4.8	0.25	1	0.3	0.8	1.02
$a$	$b$	$c$	$d$	$e$	$f$	$g$	$h$	$i$	$j$
1.2	1.2	0.7	0.6	0.8	1.72	2.22	2.62	2.82	3.32

**Figure 1.** Structure of the proposed antenna: (a) Top view. (b) Bottom view. (c) Detailed composition of the top patch with flower-shaped boundary. (d) Detailed view of the five-star-shaped split ring resonator.

### 2.1. UWB QSCA Design

The design is started with a QSC antenna having rectangular boundary and fed by a tapered microstrip line, which helps in achieving a wide impedance band. A stepped impedance matching structure and fishhook-like slit are created on the ground plane to obtain a better impedance matching over the UWB. The flower boundary shown in Fig. 2 is beneficial for achieving antenna compactness as it increases the current path length of the proposed antenna. The flower-shaped boundary is obtained through making a composition of five circles and two triangles as shown in Fig. 1(c). The radius of the four smaller circles is calculated by equation  $R1 = (w2 - w3)/(4(1 + \sin(fi)))$ , and the radius of the bigger circle is calculated by equation  $R2 = (w2 - 4 \times R1)/2$ . By adjusting parameter “ $fi$ ” ( $fi = 38^\circ$ ), the angle of the triangular shape described in Fig. 1, a lower cut-in frequency is obtained. Fig. 2 shows the impedance matching evolution of the QSCA without notch band. As shown in Fig. 2, a lower cut-in frequency decreased from 3.85 GHz to 3.25 GHz is obtained with a compact size of  $9 \times 17.5 \times 1 \text{ mm}^3$ .



**Figure 2.** UWB QSCA design process: (a) with rectangular boundary (top view); (b) with flower-shaped boundary (top view); (c) with flower-shaped boundary and fishhook-like slit (bottom view).

### 2.2. UWB Band-Notched Antenna Design

To realize band-notched characteristic in the proposed UWB QSC antenna, a five-star-shaped ring resonator shown in Fig. 1(d) is inserted on the bottom layer of the UWB antenna. The notch frequency is controlled by adjusting the value of geometrical parameter  $w4$ . The relationship between the notch frequency and parameter  $w4$  in Fig. 3 is presented with Equation (1):

$$f_{notch} = c/(2Ls\sqrt{\epsilon_{eff}}), \quad Ls = (8 - 3 \times \sqrt{2})w4 - L7 \tag{1}$$

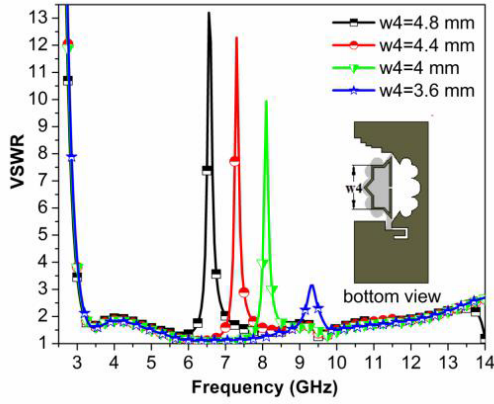
The value of parameter  $w4$  is inversely related to the desired notch frequency as shown in Fig. 3. There is almost no extra space for the split ring resonator when  $w4$  is increased above 4.8 mm. Hence, an L-stub is added on the split ring resonator to enlarge the total length of the resonator, thereby the lower notch frequency decreases as shown in Fig. 4. The notch frequency is approximately estimated using Equation (2).

$$f_{notch} = c/(2L_{res}\sqrt{\epsilon_{eff}}), \quad \epsilon_{eff} = (\epsilon_r + 1)/2 \tag{2}$$

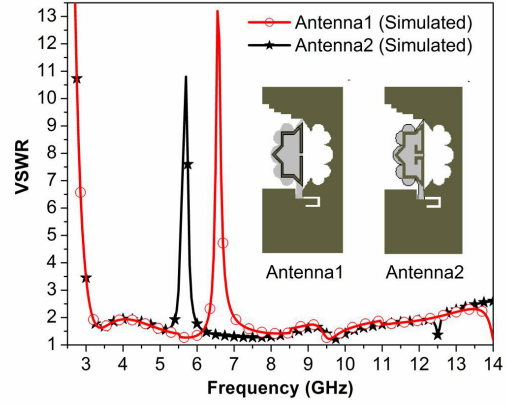
where  $c$  is the velocity of the light in free space,  $L_{res}$  the total length of the resonator,  $\epsilon_{eff}$  the effective permittivity, and  $\epsilon_r$  the relative permittivity of the substrate. The antenna is designed so to reject the interference with WLAN (5.47–5.725 GHz, 5.725–5.825 GHz) band. The value of  $L_{res}$  is 17.24 mm, when it is computed using Eq. (2) with a notch center frequency of 5.7 GHz and takes the final value  $L_{res} = 18.2 \text{ mm}$  after an optimization process performed through HFSS.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

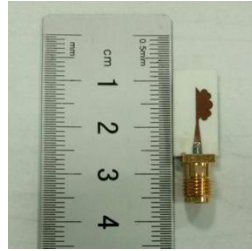
The antenna prototype, fabricated and measured to validate the simulation results, is shown in Fig. 5. As shown in Fig. 6, the simulated and measured VSWRs are in good agreement. The measured impedance



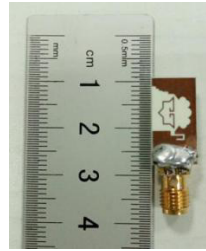
**Figure 3.** The effect of the size variation on VSWR and the notch band ( $w_5 = 0.25$  mm).



**Figure 4.** Comparison between Antenna 1 and the Antenna 2 (loaded with L-stub) ( $w_4 = 4.8$  mm).

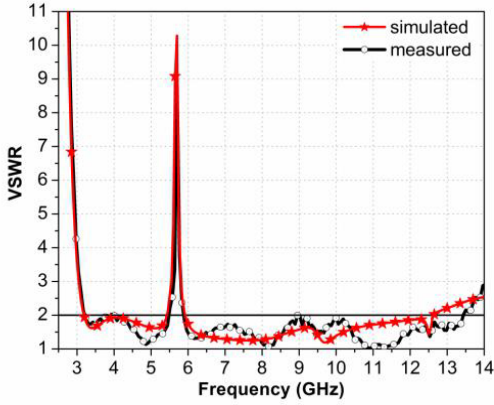


(a)

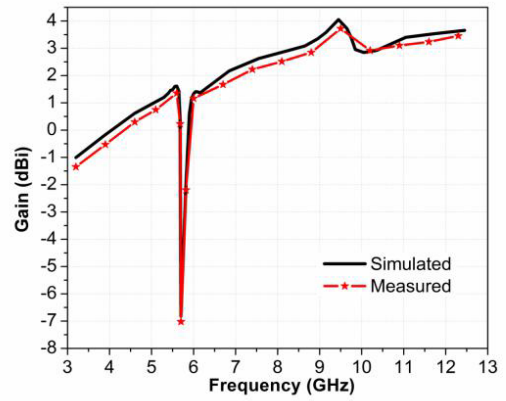


(b)

**Figure 5.** Photographs of the proposed UWB band-notched antenna. (a) Top view. (b) Bottom view.



**Figure 6.** Simulated and measured VSWR of the fabricated antenna (notch band is 5.45–5.95 GHz).



**Figure 7.** Simulated and measured total gain of the proposed antenna (notch frequency is 5.7 GHz).

bandwidth below 2 : 1 VSWR is from 3.18 GHz to 13.4 GHz with a rejection band from 5.45 GHz to 5.95 GHz.

The simulated value of total gain is depicted in Fig. 7. The antenna shows a  $-7$  dBi gain at 5.7 GHz. This gain reduction at the stop band conforms with the notched operation. The radiation efficiency of the proposed antenna is all above 90% except the notch band as shown in Fig. 8(a).

The radiation mechanisms can be explained through analyzing the current distribution of the

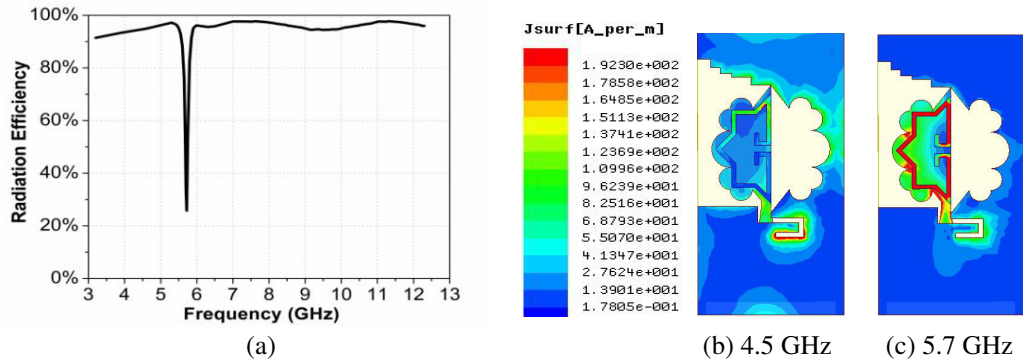


Figure 8. (a) Measured radiation efficiency; (b), (c) surface current distribution plot.

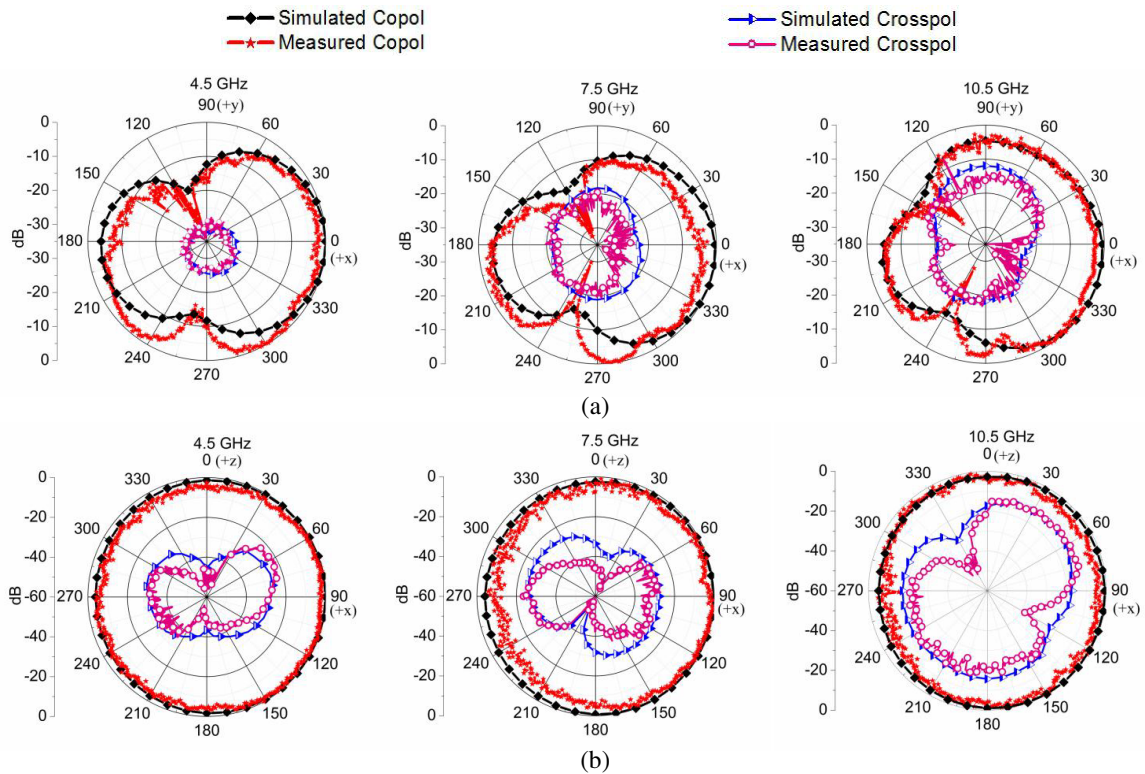


Figure 9. Simulated and measured normalized radiation pattern of the proposed antenna: (a) *E*-Plane (*xy*-plane); (b) *H*-Plane (*xz*-plane).

antenna [15]. As shown in the surface current distribution plot in Fig. 8(b), the maximum current density is accumulated near the flower-shaped boundary which ensures proper radiation of the signal through the radiator at the operational band. Fig. 8(c) shows that the maximum concentration of the current is observed around the five-star-shaped split ring resonator ensuring effective band stop at the band from 5.45 GHz to 5.95 GHz.

The simulated and measured normalized radiation pattern results of the proposed band-notched UWB QSC antenna at selected frequencies (4.5 GHz, 7.5 GHz, 10.5 GHz) are shown in Fig. 9. The radiation pattern in *E*-plane (*xy*-plane) reflects the asymmetry of the QSC structure showing a wide radiation beam whose angular extension tends to slightly decrease as the frequency increases. The radiation pattern in *H*-plane (*xz*-plane) is nearly omnidirectional, and these results are favorable in wireless device application.

#### 4. CONCLUSION

A compact quasi-self-complementary antenna with band-rejected characteristics has been designed, realized and tested. The antenna, based on a QSC structure with flower-like boundary and excited by a tapered microstrip line, so to achieve a wide impedance bandwidth, presents a compact size ( $9 \times 17.5 \times 1 \text{ mm}^3$ ). The designed band-notch is realized by embedding a five-star-shaped split ring resonator on the bottom layer. The effects of the size and L-stub of the resonator are analyzed to find the optimized configuration of the resonator to achieve a band rejection of WLAN band. A good agreement is presented between the simulated and measured results with a wide bandwidth from 3.18 GHz to 13.4 GHz. Thus, the antenna is suitable to be integrated in space-limited wireless systems without causing electromagnetic interference with systems working in the WLAN frequency band (5.47–5.825 GHz).

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