

# A Novel Planar Monopole UWB Antenna with Quad Notched Bands Using Quad-Mode Stepped Impedance Resonator

Zhiguang Zhong\*, Zhouyan He, Zhang Wang, and Chang Yao

**Abstract**—In this paper, a novel planar monopole ultra-wideband (UWB) antenna with quad notched bands is investigated. The proposed antenna is composed of a circular-shaped radiating element, a  $50\ \Omega$  microstrip feed line, a quad-mode stepped impedance resonator (SIR), and a partially truncated ground plane. By coupling a quad-mode SIR with an additional outer line beside the microstrip feedline, band-rejected filtering properties around C-band (5.2/5.8 GHz) WLAN bands, and X-band (8.5/10.5 GHz) satellite communication bands are generated. The measurement of voltage standing wave ratio (VSWR) is in agreement with simulation. The results show that the proposed antenna not only retains an ultrawide bandwidth but also owns quad band-rejections capability. The UWB antenna demonstrates omnidirectional radiation patterns across nearly the whole operating bandwidth that is suitable for UWB applications.

## 1. INTRODUCTION

Ultra-wideband (UWB) radio technology has attracted much attention since the U.S. Federal Communications Commission (FCC) allocated a frequency range with a bandwidth of 7.5 GHz (3.1 ~ 10.6 GHz) for unlicensed radio applications. Many applications have been developed based on UWB technology such as short-range broadband communication, radar sensing, and body-area networking [1]. It is a well-known fact that planar monopole antennas present attractive features, such as simple structure, small size, low cost, stable radiation patterns, and constant gain over the entire operating band. Owing to these characteristics, planar monopoles are attractive for the use in emerging UWB applications, and research activity is increasingly being focused on them [2–5].

However, the existing wireless networks such as C-band (4.0 ~ 8.0 GHz) WLAN signals, and X-band (8.0 ~ 12.0 GHz) satellite communication systems (XSCS) signals can interfere with UWB systems, thus compact UWB monopole antennas with multiple notched-bands are emergently required to reject these unwanted interfering signals [6–10]. To achieve desired band-notched performance, slots such as U-shaped and V-shaped ones are usually inserted on the initial UWB monopole antenna in [7] and [8]; however, only one notched band is created. In [9] and [10], two notched bands can be introduced; however, considering that other services exist within the UWB band, wideband antennas with dual notch-bands are insufficient. Very few UWB antennas having quad notched bands have been reported [11]; however, the proposed structure is difficult to fabricate.

In this communication, a novel, compact, planar UWB monopole antenna with quad band-notched function using quad-mode stepped impedance resonator (SIR) is proposed. Firstly, the resonance properties of the quad-mode resonator are studied. Then, the quad notched-bands characteristic is achieved by putting the quad-mode resonator near the feed line of the UWB antenna. To validate the design concept, a novel planar UWB monopole antenna with quad notched bands respectively centered at frequencies of 5.2 GHz, 5.8 GHz, 8.5 GHz and 10.5 GHz is designed and fabricated. The

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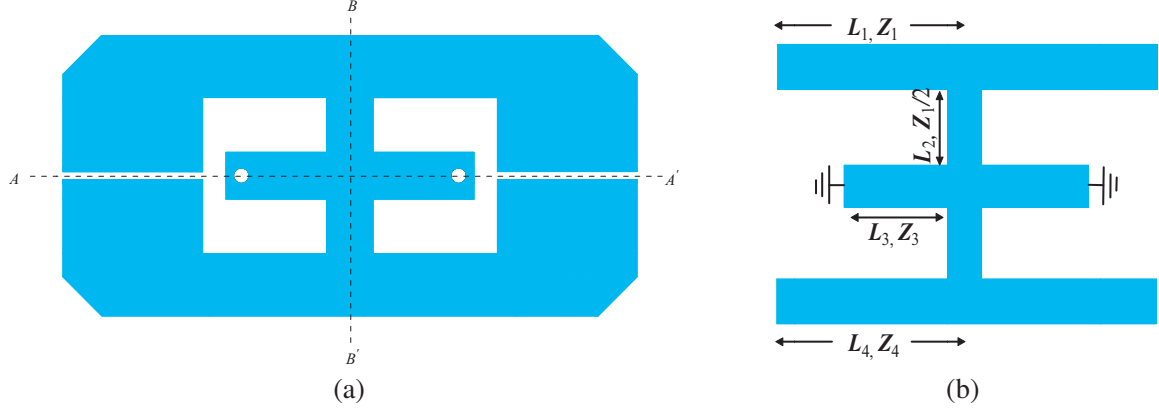
\* Corresponding author: Zhiguang Zhong (elezhiguangzhong@163.com).

The authors are with the College of Science and Technology, Ningbo University, Ningbo 315211, China.

simulation and measurement show that the antenna achieves an ultra-wide bandwidth ranging from 2.8 GHz to 13.0 GHz and avoids the WLAN/XSCS interference. An omnidirectional pattern across the entire bandwidth in the  $H$ -plane of the antenna is achieved.

## 2. QUAD-MODE SIR ANALYSIS

Figure 1 shows the geometry of the proposed quad-mode SIR. It consists of two half-wavelength SIRs and two short-circuited stubs on its center plane.



**Figure 1.** Geometry of the quad-mode stepped impedance resonator (SIR).

Since the resonator is symmetrical to the  $A-A'$  plane and  $B-B'$  plane, the odd-even-mode method is implemented. For odd-mode excitation, the resonant frequency can be deduced as:

$$f_{notch-ino} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \quad (1)$$

where  $f_{ino}$  is the center frequency of the notch band,  $\varepsilon_{eff}$  the effective dielectric constant, and  $c$  the light speed in free space.

For even-mode excitation, the resonant frequencies can be determined as follows:

$$f_{notch-ine1} = \frac{c}{4(L_1 + L_2 + L_3)\sqrt{\varepsilon_{eff}}} \quad (2)$$

$$f_{notch-ine2} = \frac{c}{(2L_1 + 2L_2 + 2L_4)\sqrt{\varepsilon_{eff}}} \quad (3)$$

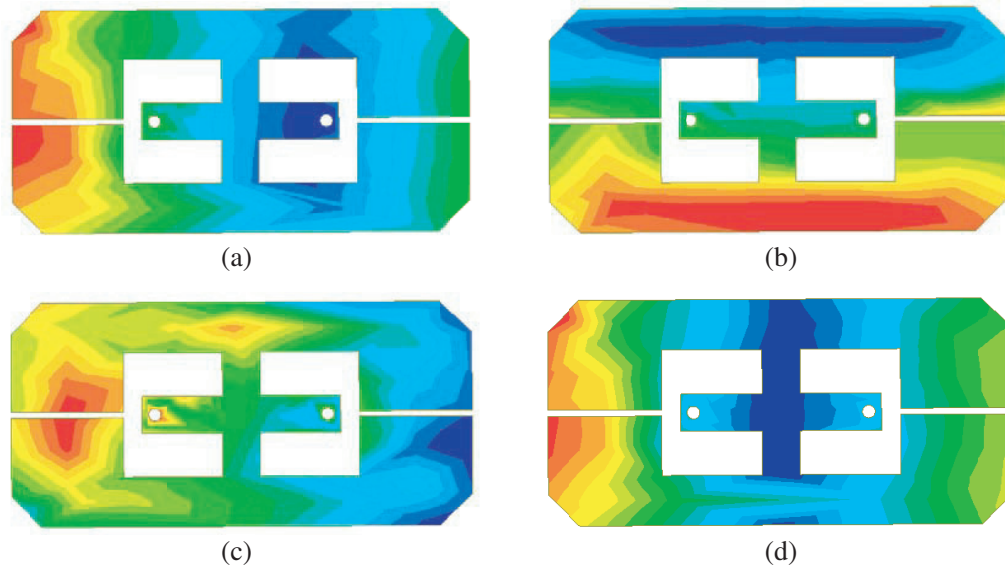
$$f_{notch-ine2} = \frac{c}{(2L_1 + 2L_2 + 2L_3)\sqrt{\varepsilon_{eff}}} \quad (4)$$

where  $Z_1 = Z_2 = Z_3 = Z_4$  are assumed for simplicity. The resonance frequencies can be determined by the electrical length.

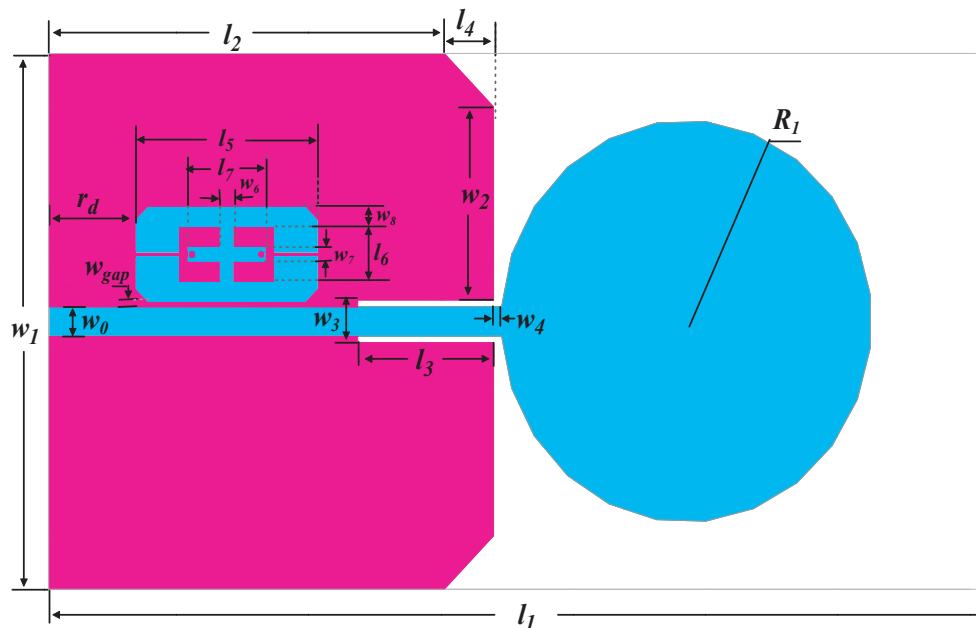
Figure 2 shows the simulated current distribution on the surface of the resonator at four frequencies: 5.2, 5.8, 8.5 and 10.5 GHz. The figure shows that the current is more sparsely distributed as it nears the areas marked in blue, while its distribution grows denser in the red areas. Maximum and minimum values are set equal in order to allow an accurate comparison among Figs. 3(a)–(d).

## 3. QUAD BANDS-NOTCHED UWB ANTENNA DESIGN

Figure 3 depicts the geometry of the proposed monopole UWB antenna with quad band-notched characteristics. It consists of the following major parts: the main patch with a feed, a quad-mode resonator on the front surface of the substrate, and a conductor ground plane in the back. It is printed on a Rogers 5880 microwave substrate of thickness 0.508 mm and relatively permittivity 3.38. The quad



**Figure 2.** Simulated current distribution of the proposed structure at the four resonant frequencies: (a) 5.2 GHz, (b) 5.8 GHz, (c) 8.5 GHz, (d) 10.5 GHz.

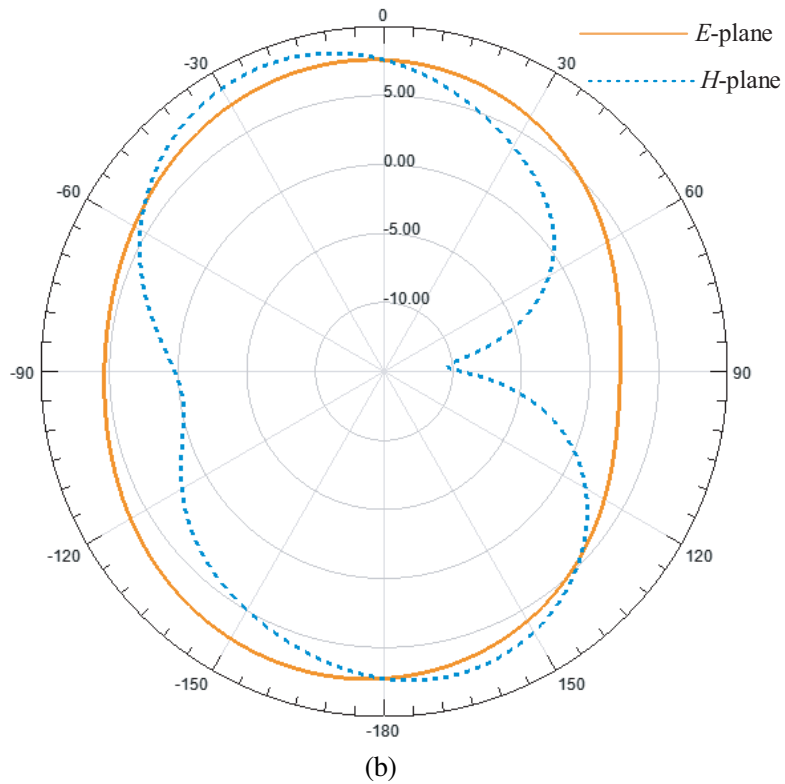
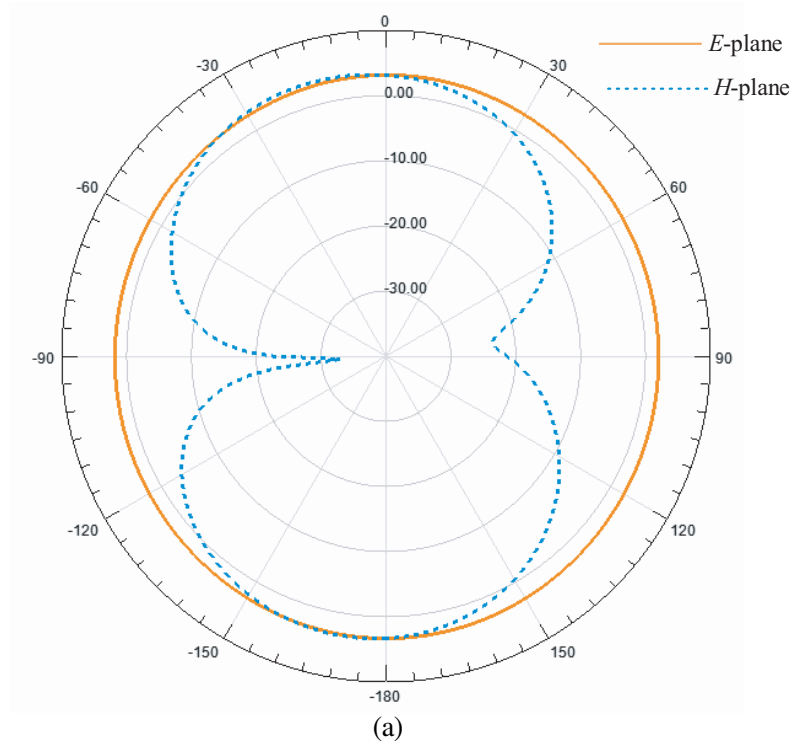


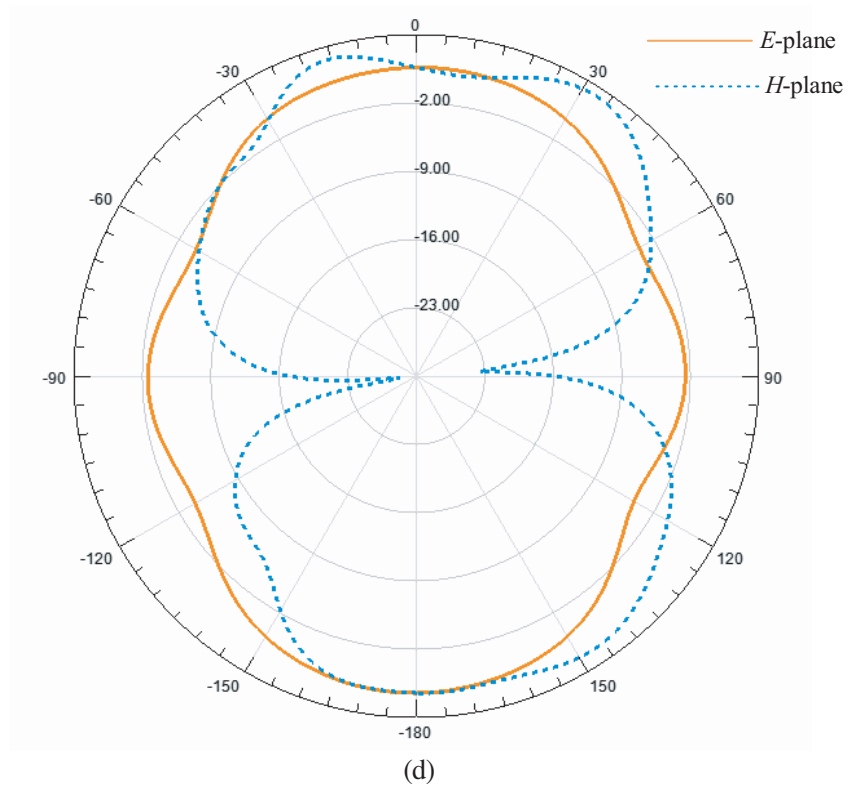
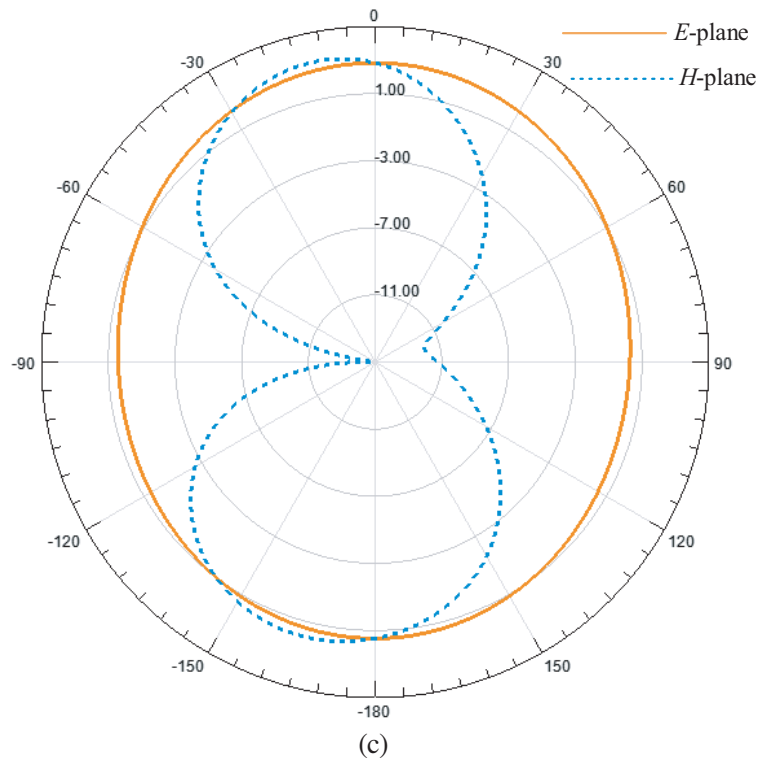
**Figure 3.** Layout of the proposed UWB antenna with quad notched characteristics.

notched-bands are realized by coupling the quad-mode SIR to  $50\ \Omega$  microstrip feed-lines. The proposed planar UWB antenna has a circular patch with radius  $R_1 = 7.5\ \text{mm}$ , which is fed by  $50\ \Omega$  microstrip line of width  $w_0 = 1.1\ \text{mm}$ . In order to improve impedance matching performance, a rectangular slit is embedded in the ground plane, located under the microstrip feed line. The final optimized parameters of the planar UWB antenna are as follows:  $w_1 = 1.1\ \text{mm}$ ,  $w_1 = 20\ \text{mm}$ ,  $w_2 = 7.0\ \text{mm}$ ,  $w_3 = 1.6\ \text{mm}$ ,  $w_4 = 0.3\ \text{mm}$ ,  $w_4 = 0.3\ \text{mm}$ ,  $w_5 = 0.8\ \text{mm}$ ,  $w_6 = 0.6\ \text{mm}$ ,  $w_7 = 0.6\ \text{mm}$ ,  $w_7 = 0.5\ \text{mm}$ ,  $l_1 = 38\ \text{mm}$ ,  $l_2 = 16\ \text{mm}$ ,  $l_3 = 5.5\ \text{mm}$ ,  $l_4 = 2.0\ \text{mm}$ ,  $l_5 = 7.4\ \text{mm}$ ,  $l_6 = 2.0\ \text{mm}$ ,  $l_7 = 3.8\ \text{mm}$ ,  $r_d = 3.5\ \text{mm}$ ,  $w_{gap} = 0.1\ \text{mm}$ .

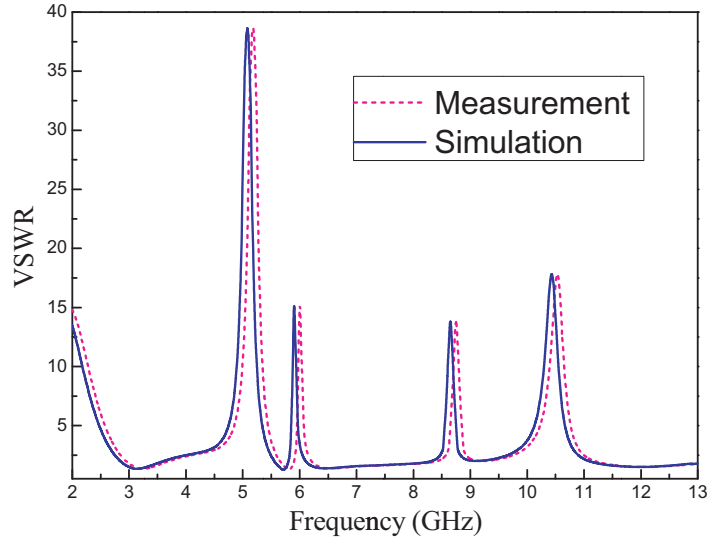
#### 4. EXPERIMENTAL RESULTS

Finally, a novel UWB planar monopole antenna with quad band-notched characteristics is designed and fabricated. All simulations have been carried out using Ansoft HFSS 13.0 simulation software based

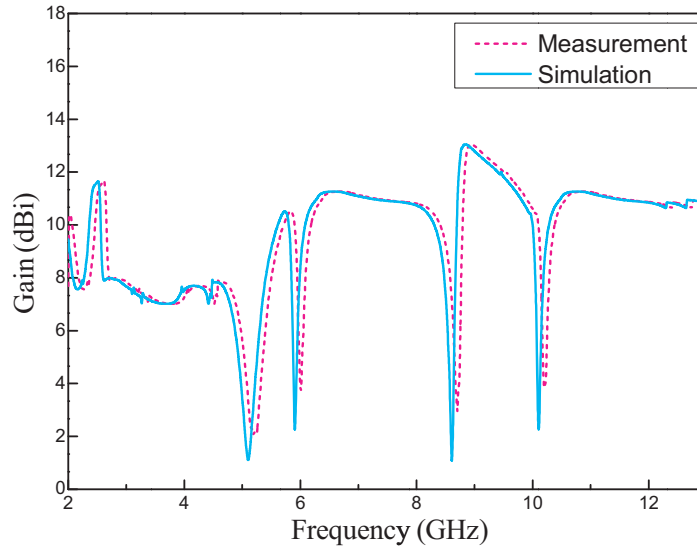




**Figure 4.** Measured radiation pattern of the UWB planar monopole antenna: (a) 3.5 GHz, (b) 5.0 GHz, (c) 7.5 GHz, (d) 10.0 GHz.



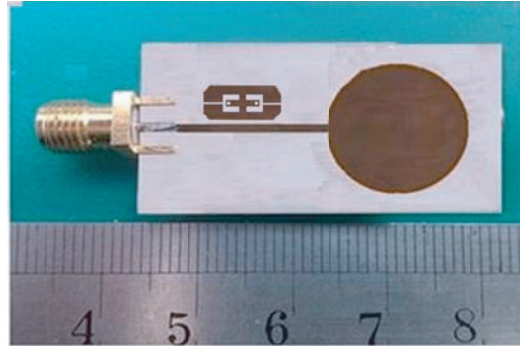
**Figure 5.** Measurement and simulation of VSWR.



**Figure 6.** Measured and simulated peak gain of the proposed UWB antenna with quad notched bands.

on the finite element method (FEM). The normalized radiation patterns in the  $E$ - and  $H$ -planes are measured at 3.5 GHz, 5.0 GHz, 7.5 GHz, and 10.0 GHz as in Fig. 4. It can be found that the antenna has good omnidirectional radiation patterns in the  $H$ -plane (dotted). The radiation patterns in the  $E$ -plane (continuous) are in symmetry.

Simulated and measured VSWRs of the UWB antenna are shown in Fig. 5 for comparison. We notice that the UWB antenna possesses impedance bandwidth from 2.8 GHz to 13.0 GHz for  $VSWR < 3$  except in notched bands from 4.5 ~ 5.5 GHz, 5.8 ~ 6.1 GHz, 8.5 ~ 8.9 GHz, and 9.9 ~ 10.9 GHz, respectively. The central frequencies of the notched-bands are about 5.2 GHz, 5.9 GHz, 8.6 GHz, and 10.5 GHz. The notched-bands are very suitable for implementing the rejection of 5.2/5.8 GHz (WLAN) signal and 8.5/10.5 GHz X-band satellite communication systems (XSCS) signal. The measured peak gain in the  $E$ -plane is given in Fig. 6. The proposed antenna exhibits four significant antenna gain decreases at 5.2 GHz, 5.9 GHz, 8.6 GHz, and 10.5 GHz; this is indicative of the effect of the notched bands. The deviations of the measurements from the simulations are expected mainly due to the



**Figure 7.** Photograph of the fabricated UWB antenna with quad notched bands.

reflections from the connectors and the finite substrate. Comparisons with other reported UWB antennas with notched bands are listed in Table 1. It shows that the proposed antenna has good performance. Fig. 7 shows a photograph of the fabricated planar UWB antenna with quad notched bands. The overall size is about 20 mm  $\times$  38 mm.

**Table 1.** Comparisons with other proposed UWB antenna with notched band.

Ref.	Circuit dimension	Pass band (GHz)	VSWR	Notch frequency (GHz)
[6]	3-D	2.0 ~ 5.7	N/A	3.0/4.7
[7]	2-D	3.0 ~ 11.0	$\leq 2.0$	5.0/5.9
[8]	2-D	2.8 ~ 10.6	$< 2.0$	5.25
[9]	3-D	2.8 ~ 11.0	$\leq 2.0$	3.4/5.8
[10]	2-D	N/A	$\leq 2.0$	3.8/5.5
[11]	3-D	N/A	$\leq 2.0$	2.4/3.6/5.2
[12]	2-D	3.0 ~ 12.0	$\leq 2.0$	3.1/5.6/9.0
[13]	2-D	3.0 ~ 10.5	$\leq 2.0$	4.1 (Tunable)
[14]	2-D	2.5 ~ 11.0	N/A	5.3/7.9
This work	2-D	2.8 ~ 13.0	$\leq 3.0$	5.2/5.8/8.5/10.5

## 5. CONCLUSION

In this work, a high-performance UWB planar monopole antenna, with quad band-notched characteristics, has been successfully implemented and investigated. The proposed antenna covers the frequency range for the UWB systems, between 2.0 GHz and 11.0 GHz, with a rejection band around 5.2/5.8 GHz (WLAN) signal and 8.5/10.5 GHz X-band satellite communication systems (XSCS) signal. The introduced quad-mode SIR is simple and flexible for blocking undesired narrow band radio signals appearing in UWB band. Using the advantage of small real estate, outstanding performance can be realised for broadband antennas, which are now widely demanded in UWB applications. The measured results show good performance in terms of the reflection coefficient, antenna gain and radiation patterns. To summarise, because of its simple structure, compact size, and excellent performance, the proposed antennas are expected to be good candidates for the use in various UWB systems.

## ACKNOWLEDGMENT

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