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Compact Monopole UWB Antenna with Quad Notched Band Characteristics Using Quad-Mode Stepped Impedance Resonator

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Abstract—In this communication, a new planar monopole ultra-wideband (UWB) antenna with quad notched band characteristics using quad-mode stepped impedance resonator (QMSIR) is investigated. The proposed antenna is composed of a circular-shaped radiating element, a 50 Ω microstrip feed line, a QMSIR, and a partially truncated ground plane. By coupling a QMSIR with an additional outer line beside the microstrip feedline, band-rejected filtering properties around the (5.2/5.8 GHz) WLAN bands and (7.4/8.2 GHz) satellite communication bands are generated. The measurement of voltage standing wave ratio (VSWR) is in agreement with simulation. The results show that proposed antenna not only retains an ultra-wide bandwidth but also owns quad band-rejections capability. The UWB antenna demonstrates omnidirectional radiation patterns across nearly 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 use in emerging UWB applications, and research activity is increasingly being focused on them [2–5].

However, the existing wireless networks such as the wireless local area network (WLAN) for IEEE802.11a operating at 5.15 ∼ 5.35 GHz/5.725 ∼ 5.825 GHz, and 7.2 ∼ 7.5 GHz/8.1 ∼ 8.3 GHz satellite communication systems (SCS) signals can interfere with UWB systems, thus compact UWB monopole antenna with multiple notched-bands are emergently required to reject these unwanted interfering signals [6–11]. To achieve desired band-notched performance, slots such as U-shaped, V-shaped, etc. are usually inserted on basic the UWB monopole antenna in [7, 8], however, only one notched band is created. In [9–11], two notched bands can be achieved use two or three single-mode resonators, however, these circuits are relatively large. In [12, 13], three notched bands can be introduced using defected ground structure (DGS), however, they are all based on multi-layer structure that would increase fabrication cost and hardly compatible with the existing microwave-integrated circuit. What is more, they cannot reject unwanted four band interfering signals.

In this communication, a new, compact, planar UWB monopole antenna with quad band-notched function using quad-mode stepped impedance resonator (QMSIR) is proposed based on our previous works [14]. Firstly, the resonance properties of the QMSIR are studied. Then, the quad notched-bands

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characteristic is achieved by putting the QMSIR near by 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, 7.4 GHz, and 8.2 GHz is designed and fabricated. The simulation and the measurement show that the antenna achieves an ultra-wide bandwidth ranging from 2.8 GHz to 13.0 GHz and avoids the WLAN/SCS interference. An omni directional pattern across the entire bandwidth in the H-Plane of the antenna is achieved.

2. QUAD BANDS-NOTCHED UWB ANTENNA DESIGN

Figure 1 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 QMSIR on the front surface of the substrate, and a conductor ground plane in the back. It is printed on Rogers 4350B microwave substrate of thickness 0.508 mm and relatively permittivity 3.48. The quad notched-bands are realized by coupling the QMSIR to 50 Ω microstrip feed-lines. The radius of the circular radiating patch is fixed at $R_1 = 7.5$ mm. The width of the feeding microstrip line is $w_0 = 1.1$ mm and its characteristic impedance is 50 Ω. The gap distance between the radiating patch and the ground plane is fixed at 0.3 mm. An SMA is connected to the port of the feeding microstrip line. In order to improve impedance matching performance, a rectangular slit is embedded in the ground plane, located under the microstrip feed line [15]. The final optimized parameters of the planar UWB antenna are as follows: $w_0 = 1.1$ mm, $w_1 = 20$ mm, $w_2 = 1.35$ mm, $w_3 = 0.2$ mm, $w_4 = 0.9$ mm, $w_5 = 0.9$ mm, $l_1 = 38$ mm, $l_2 = 12.6$ mm, $l_3 = 5.5$ mm, $l_4 = 2.85$ mm, $l_5 = 9.6$ mm, $l_6 = 1.43$ mm, $l_7 = 7.2$ mm, $l_8 = 0.7$ mm, $l_9 = 0.4$ mm, $l_{10} = 16$ mm, $l_{11} = 2.0$ mm, $r_d = 3.5$ mm, $d_0 = 0.2$ mm, $d_1 = 0.2$ mm.

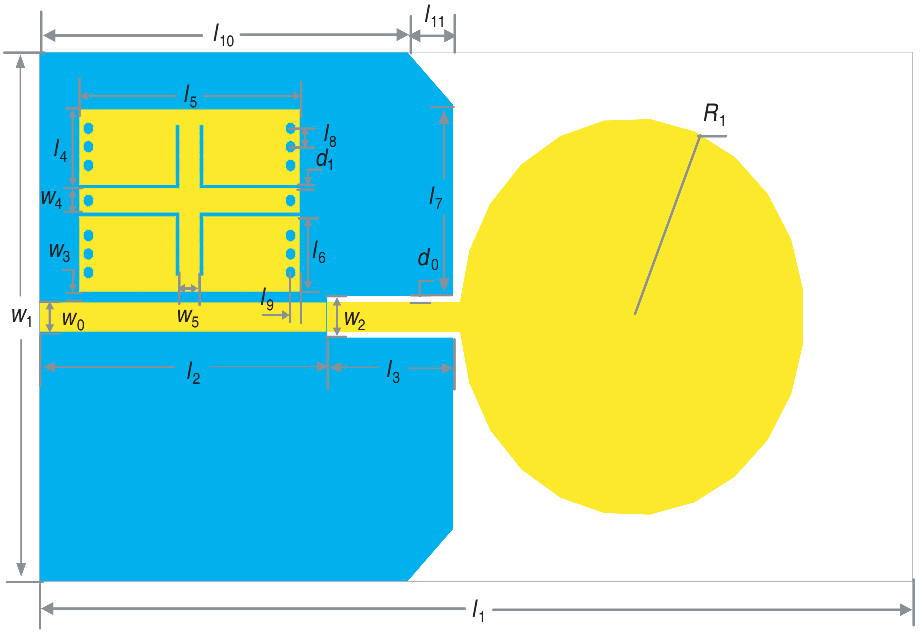


Figure 1. Layout of the proposed UWB antenna with quad notched characteristics.

Figure 2 shows the geometry and equivalent circuit of the proposed coupled QMSIR. The QMSIR can result in quad band-stop performance when placed next to the microstrip line and it can be equivalent to four shunt-connected series resonance circuits. The QMSIR can result in quad band-stop (i.e., the quad notched-bands) performance when placed next to the microstrip line and it can be equivalent to four shunt-connected series resonance circuits. The final optimized parameters of the shunt-connected series resonance circuits are as follows: $L_{11} = 0.6$ nH, $C_{11} = 1.6$ pF, $L_{12} = 0.5$ nH, $C_{12} = 1.5$ pF, $L_{13} = 0.4$ nH, $C_{13} = 1.2$ pF, $L_{14} = 0.3$ nH, $C_{14} = 1.3$ pF.

The frequency characteristics of the proposed coupled QMSIR with various dimensions are

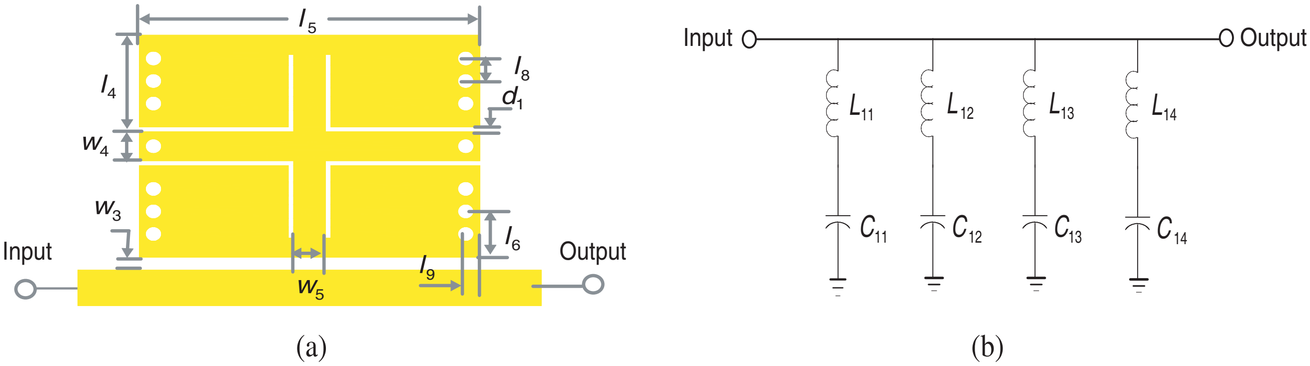


Figure 2. Geometry and equivalent circuit of the proposed coupled QMSIR.

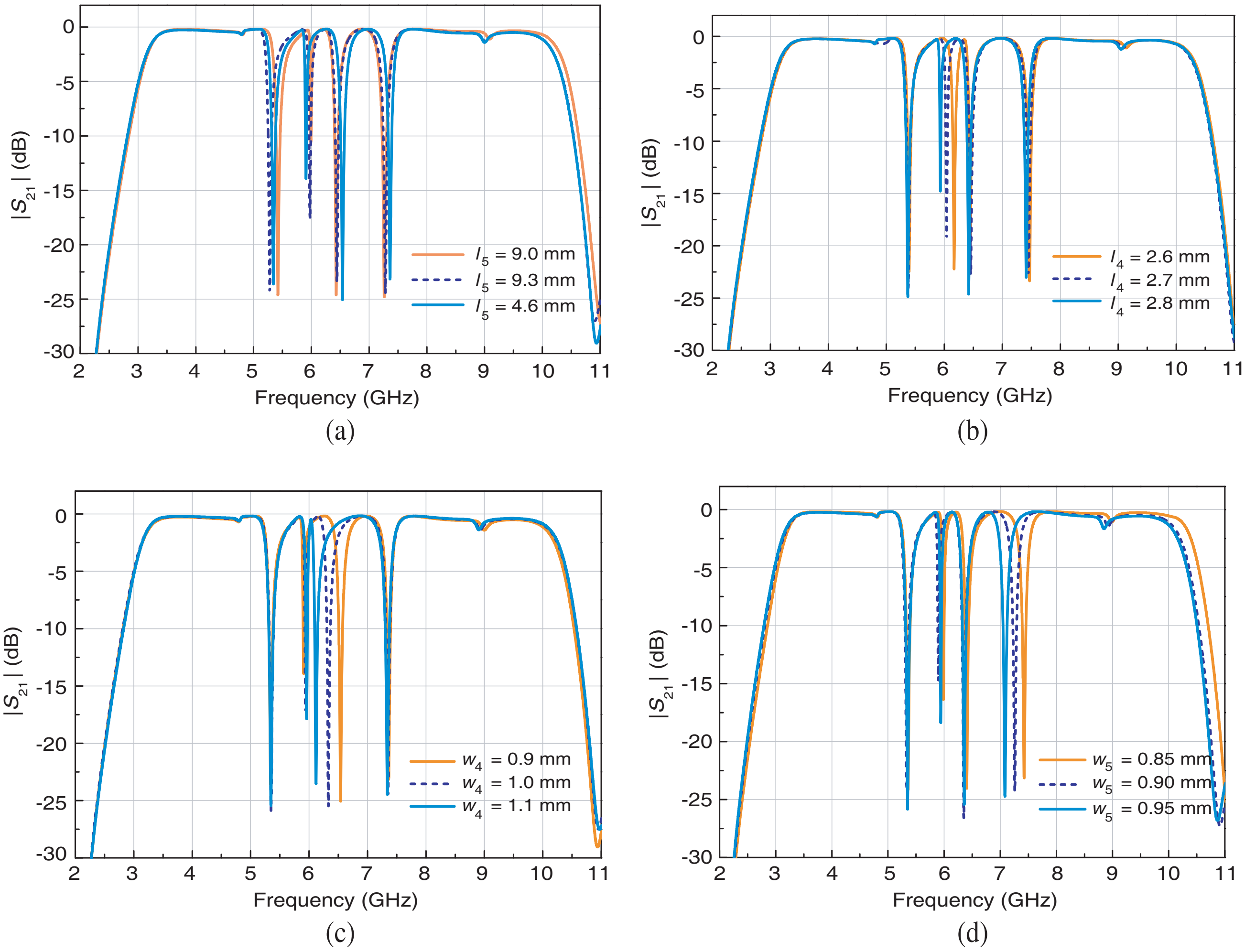


Figure 3. Simulated S-parameters of the coupled QMSIR for various dimensions: (a) l_5, (b) l_4, (c) w_4, (d) w_5.

simulated by HFSS 13.0 to validate the resonant properties, as shown in Fig. 3. It can be found that by respectively varying each QMSIR dimension, the frequency location of corresponding notched band can be widely adjusted, while the other three frequency locations of the notched bands keep almost unchanged. Therefore, four notched bands can be independently achieved at desired frequencies.

In addition, the bandwidth of the notched band can be adjusted by tuning the coupling coefficient k_m of the coupled QMSIR. It should be mentioned that the coupling coefficient k_m is defined by:

$$k_m = \frac{f^2_{\text{notch-ino}} - f^2_{\text{notch-ine1}}}{f^2_{\text{notch-ino}} + f^2_{\text{notch-ine1}}} \tag{1}$$

Referring to Fig. 4, the coupling coefficient k_m decreases as w_3 is increased. In this work, the coupling

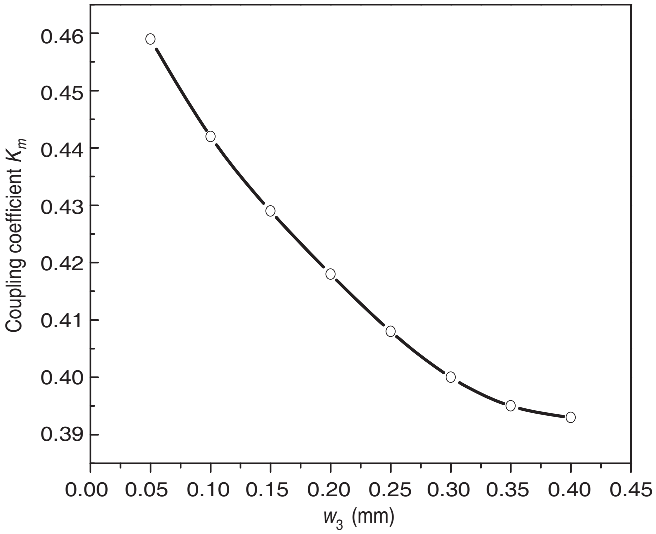


Figure 4. Simulated coupling coefficient k_m of the coupled QMSIR with different w_3.

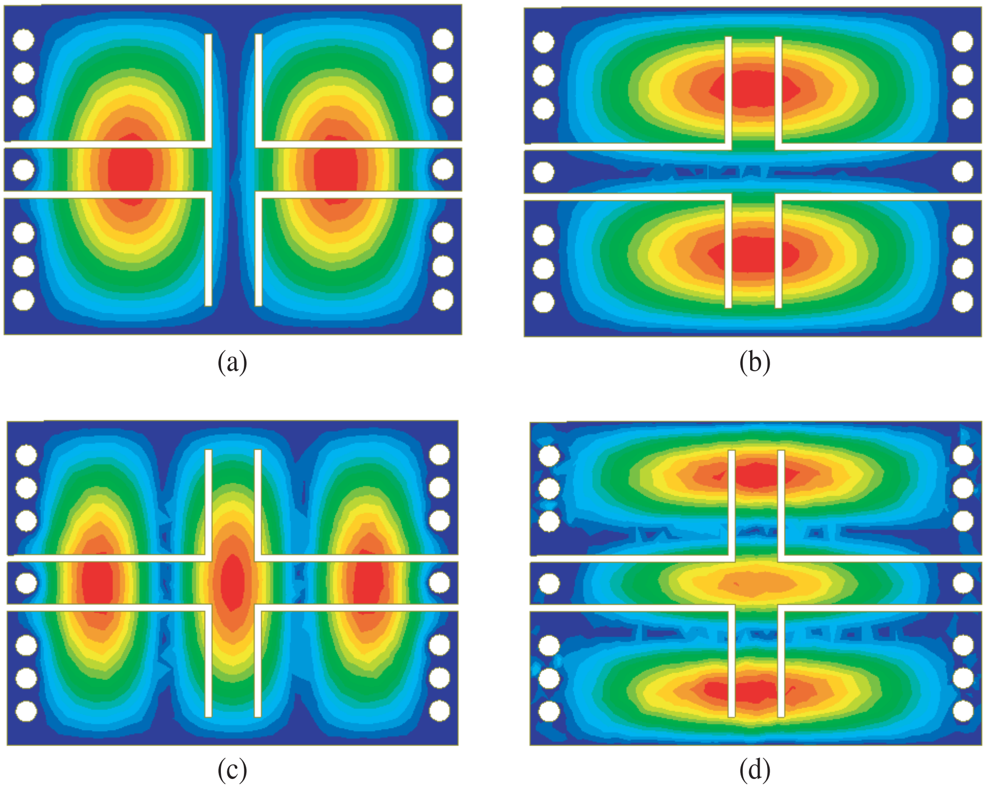
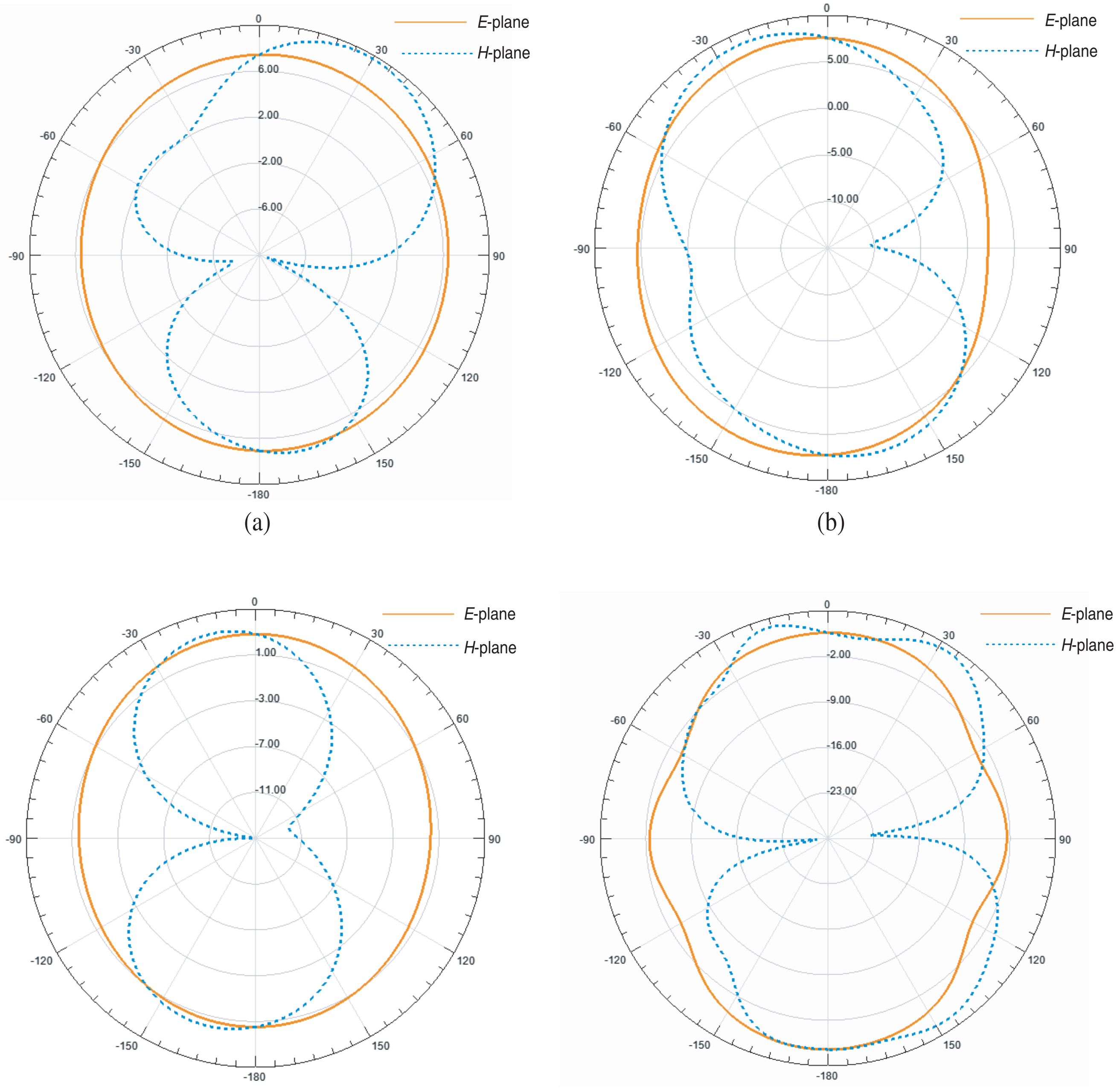

(a)
(b)
(c)
(d)

Figure 5. Electrical field distribution of the QMSIR.

coefficient is selected $k_m = 0.442$. Fig. 5 shows the resonator electrical field distribution of the QMSIR at 5.2 GHz, 5.8 GHz, 7.4 GHz, and 8.2 GHz using HFSS 13.0 simulation software. It can be found that the electrical field distribution of the QMSIR corresponds to the frequency location of notched band.

3. EXAMPLE RESULT

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. The



(a) (b)

(c) (d)

Figure 6. Measured radiation pattern of the UWB planar monopole antenna: (a) 5.2 GHz, (b) 5.8 GHz, (c) 7.4 GHz, (d) 8.2 GHz.

normalized radiation patterns in the E- and H-planes are measured at 5.2 GHz, 5.8 GHz, 7.4 GHz, and 8.2 GHz as in Fig. 6. It can be found that the antenna has good omni directional 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 as shown in Fig. 7 for comparison. The discrepancy in the reflection coefficients between the simulated and measured results should be caused by the fluctuation in the dielectric constant and tolerance in manufacturing. We can notice that the UWB antenna possesses the impedance bandwidth from 2.8 GHz to 12.5 GHz for VSWR ≤ 3 except in notched bands from 5.0 ~ 5.3 GHz, 5.7 ~ 5.9 GHz, 7.2 ~ 7.5 GHz, and 8.1 ~ 8.3 GHz, respectively. The central frequencies of the notched-bands are about 5.2 GHz, 5.8 GHz, 7.2 GHz, and 8.2 GHz. The notched-bands are very suitable to implement the rejection of 5.2/5.8 GHz WLAN signal, and 7.4/8.2 GHz SCS signal. The measured peak gain in the E-plane is given in Fig. 8. The proposed antenna exhibits two significant antenna gain decreases at 5.2 GHz, 5.8 GHz, 7.4 GHz, and 8.2 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 reflections from the connectors and the finite substrate. Comparisons with other reported UWB antenna with notched bands are listed in Table 1, demonstrates that the proposed UWB antenna has good characteristics. Fig. 9 shows the photograph of the fabricated planar UWB antenna with quad notched band characteristics. The overall size is about 20 mm × 36 mm.

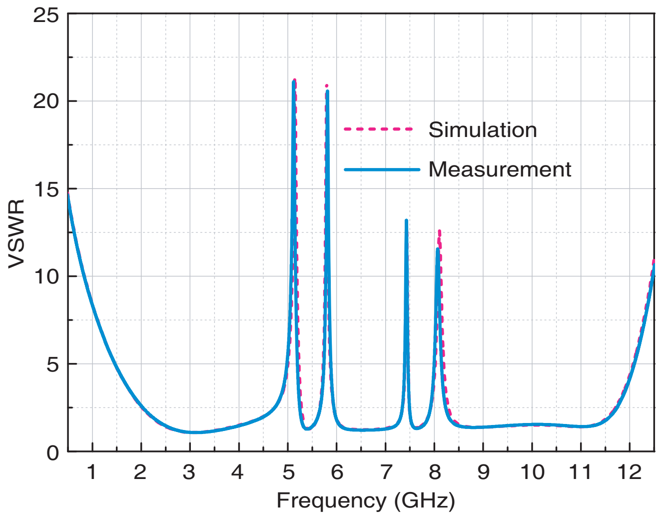


Figure 7. Measurement and simulation of VSWR.

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	≤ 2.0	5.0/5.9
[8]	2-D	2.8 ~ 10.6	≤ 2.0	5.25
[9]	3-D	2.8 ~ 11.0	≤ 2.0	3.4/5.8
[10]	2-D	N/A	≤ 2.0	3.8/5.5
[11]	3-D	N/A	≤ 2.0	2.4/3.6/5.2
[12]	2-D	3.0 ~ 10.0	≤ 2.0	3.5/5.78/7.8
[13]	2-D	3.0 ~ 11.0	≤ 2.0	3.6/5.2/5.78
This work	2-D	2.8 ~ 12.5	≤ 3.0	5.2/5.8/7.4/8.2

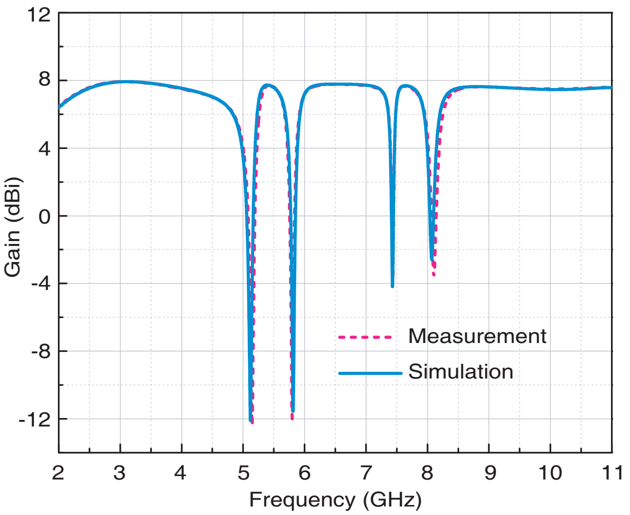


Figure 8. Measured and Simulated peak gain of the proposed UWB antenna with quad notched band characteristics.

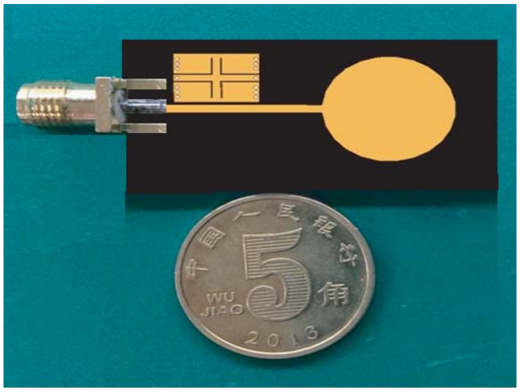


Figure 9. Photograph of the fabricated UWB antenna with quad notched band characteristics.

4. 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 7.4/8.2 GHz SCS signal. The introduced QMSIR is simple and flexible for blocking undesired narrow band radio signals appeared 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 use in various UWB systems.

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