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Triple Band-Notched UWB Planar Monopole Antenna Using Triple-Mode Resonator

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Abstract—In this paper, a novel printed microstrip-fed monopole ultra-wideband (UWB) antenna with triple-notched bands using triple-mode stepped impedance resonator (SIR) is presented. The proposed triple-mode SIR is found to have the advantages of introducing triple-notched bands and providing higher degree of freedom to adjust the resonant frequencies. By coupling the triple-mode SIR beside the microstrip feedline, band-rejected filtering properties around the 5.2 GHz WLAN band, the 6.8 GHz RFID band, and the X-band satellite communication band, are generated. To validate the design concept, a novel compact UWB antenna with three notched bands is designed and measured. Results indicate that the proposed compact antenna not only retains triple band-rejections capability but also owns omni directional radiation patterns across nearly whole operating bandwidth for UWB communications.

1. INTRODUCTION

Ultra-wideband (UWB) radio technology has attracted much attention since the US 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 IEEE 802.16 WiMAX system operating at 3.3∼3.6 GHz, the wireless local area network (WLAN) for IEEE802.11a operating at 5.15∼5.35 GHz/5.725∼5.825 GHz, and 6.7∼6.9 GHz RF identification (RFID) communication signals, X-band (7.9∼8.2 GHz) satellite communication systems (XSCS) signals can interfere with UWB systems, thus compact UWB monopole antenna with multiple notched-bands are emergently required to reject these unwanted interfering signals [6–15]. To achieve desired band-notched performance, slots such as U-shaped, V-shaped, etc. are usually inserted on initial the UWB monopole antenna in [7, 8], however, only one notched band is created. In [9, 10], two 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. In [11, 12], two notched bands can also be obtained and these antenna structures are very simple and easy to fabricate, however, they use two or three single-mode resonators. Then, the spurious notched bands obtained by spurious resonances of the conventional resonance structures [13–15].

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In this communication, a novel compact printed UWB monopole with triple-notched bands based on triple-mode stepped impedance resonator (SIR) is presented. Firstly, the properties of the proposed triple-mode SIR are analyzed theoretically, which has three resonance frequencies and higher degree of adjusting freedom. The analyzed results reveal that triple band-stop performance can be obtained based on the triple-mode resonant property of the triple-mode SIR. Then, the triple notched-bands characteristic is achieved by putting the triple-mode SIR near by the feed line of the UWB antenna. Notice that the spurious notched-band of the triple-mode SIR is also far away from the UWB antenna work band. To validate the design concept, a novel planar ultra-wideband (UWB) antenna with triple sharply rejected notched bands respectively centered at frequencies of 5.2 GHz, 6.8 GHz and 8.0 GHz is designed and measured. The simulation and the measurement show that the antenna achieves an ultra wide bandwidth ranging from 2.0 GHz to 11.0 GHz and avoids the WLAN/RFID/XSCS interference. An omni directional pattern across the entire bandwidth in the H-Plane of the antenna is achieved.

2. UWB PLANAR MONOPOLE ANTENNA CONFIGURATION

The geometry of the proposed UWB antenna triple-notched bands is shown in Figure 1. It can be seen that the antenna composed of a triple band-stop filter and a conventional planar circular monopole antenna. It is fabricated on Rogers 4350B microwave substrate of thickness 0.508 mm and relatively permittivity 3.38. The band-stop filter (i.e., the triple notched-bands) is realized by coupling the triple-mode SIR to 50 Ω microstrip feed-lines. The design of triple-notched bands will be discussed in Section 3. The proposed planar UWB antenna has a circular patch with radius $R_1 = 7.5$ mm, which is fed by 50 Ω microstrip line of width $w_0 = 1.1$ 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: $w_1 = 20$ mm, $w_2 = 7.1$ mm, $w_3 = 1.8$ mm, $l_1 = 38$ mm, $l_2 = 20$ mm, $l_3 = 2.0$ mm, $r_d = 2.5$ mm, $w_{gap} = 0.1$ mm.

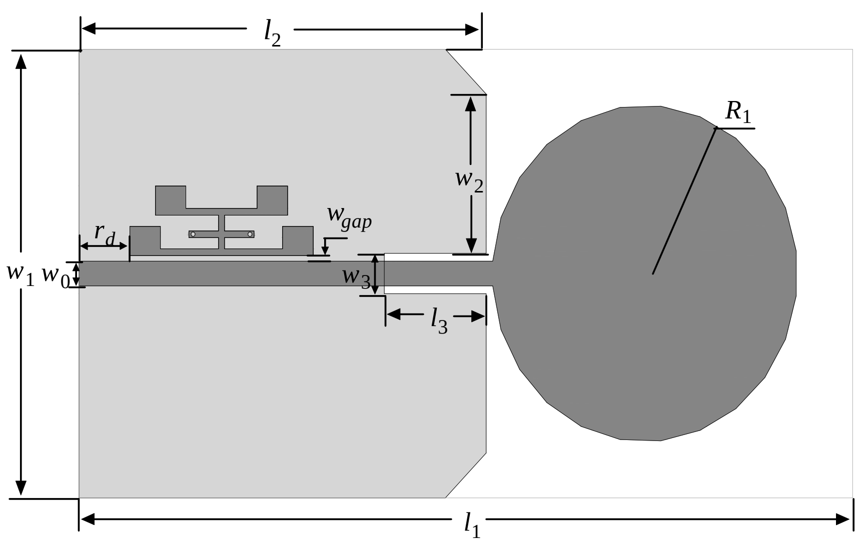


Figure 1. Layout of the proposed UWB antenna with triple sharp notched-bands.

3. TRIPLE-MODE STEPPED IMPEDANCE RESONATOR UNIT ANALYSIS

Figure 2(a) shows the geometry of the proposed triple-mode SIR. It consists of two half-wavelength SIRs and two short-circuited stubs on its center plane. Since the resonator is symmetrical to the T-T' plane, the odd-even-mode method is implemented. For odd-mode excitation, the equivalent circuit is one quarter-wavelength resonator with one end grounded, as shown in Figure 2(b). From the resonance

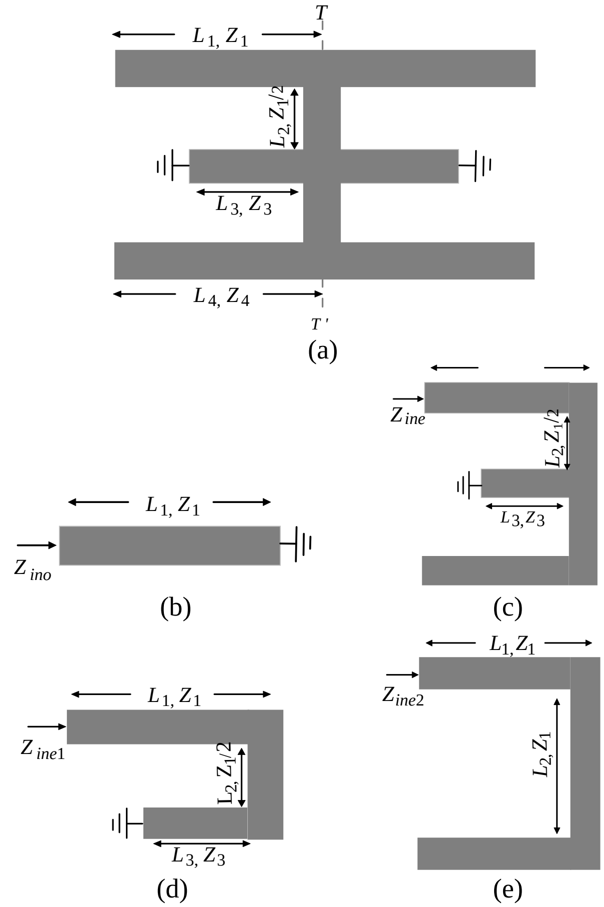


Figure 2. (a) Configuration of the proposed novel triple-mode SIR. (b) Odd-mode equivalent circuit. (c) Even-mode equivalent circuit. (d) Path I of even-mode equivalent circuit. (e) Path II of even-mode equivalent circuit.

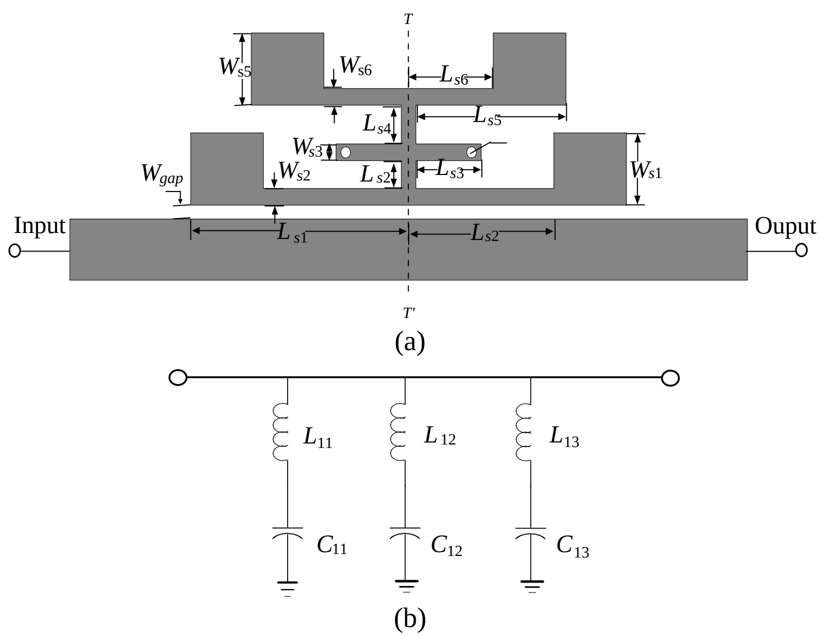


Figure 3. Geometry and equivalent circuit of the proposed coupled triple-mode SIR.

condition of $Y_{ino} = 0$, the odd-mode resonant frequency can be deduced as:

$$f_{ino} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \tag{1}$$

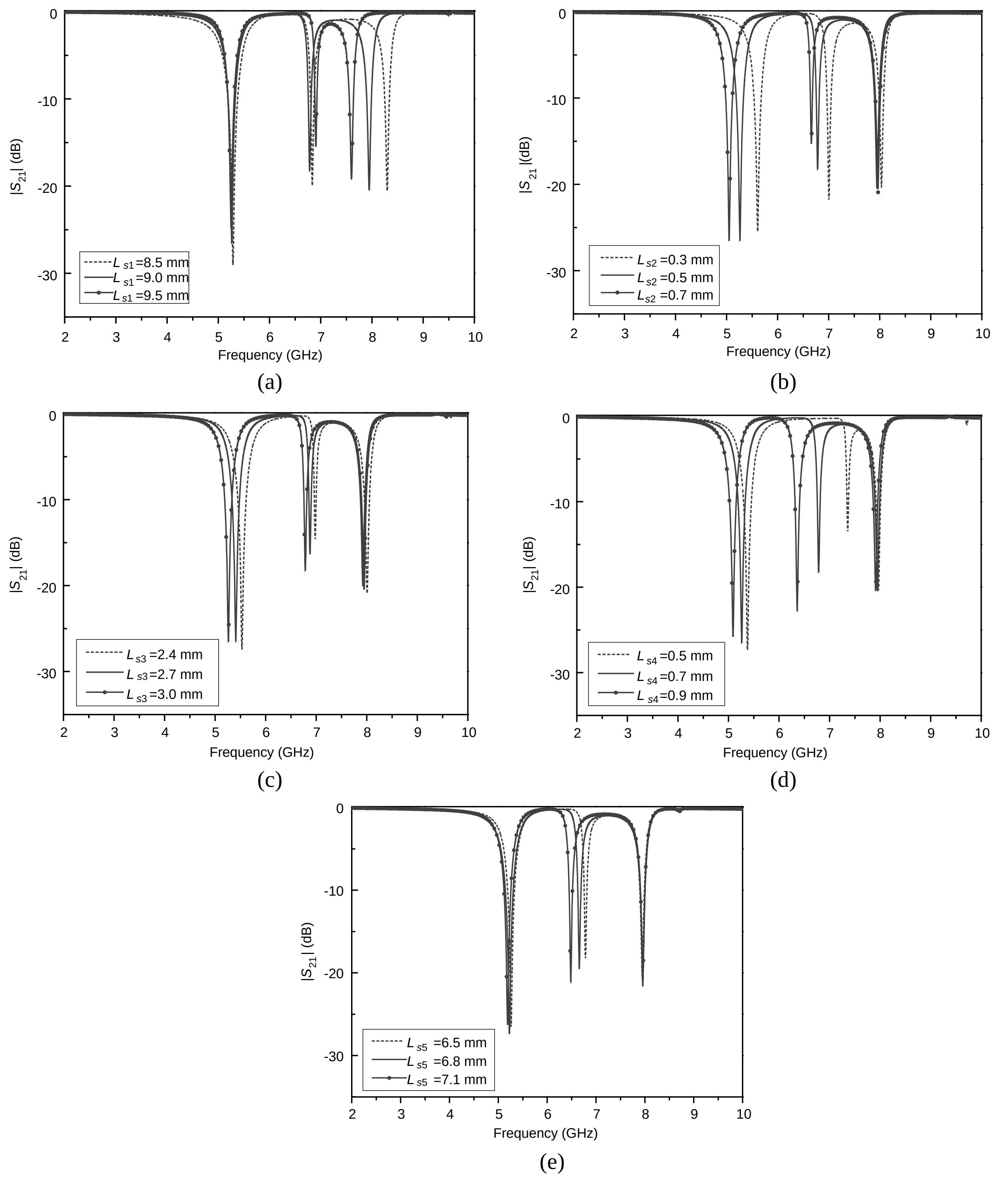


Figure 4. Simulated S-parameters of the coupled triple-mode SIR for various dimensions: (a) L_{S1}, (b) L_{S2}, (c) L_{S3}, (d) L_{S4}, (e) L_{S5}.

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

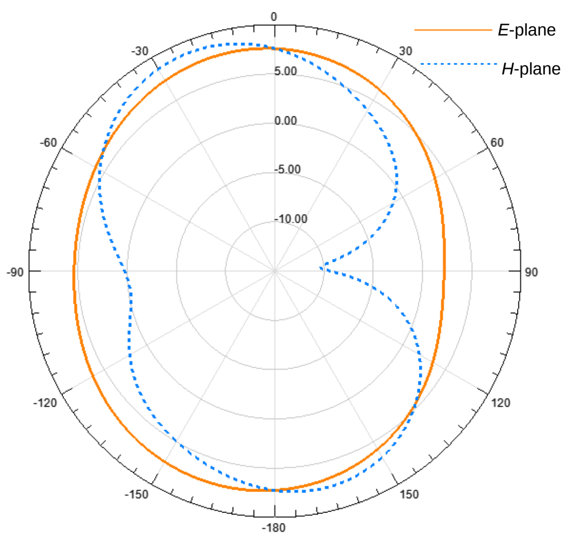
For even-mode excitation, the equivalent circuit is shown in Figure 2(c), which contains two resonant circuits: a quarter-wave-length resonator and a half-wavelength resonator, as shown in Figures 2(d) and (e). The even-mode resonant frequencies can be determined as follows:

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

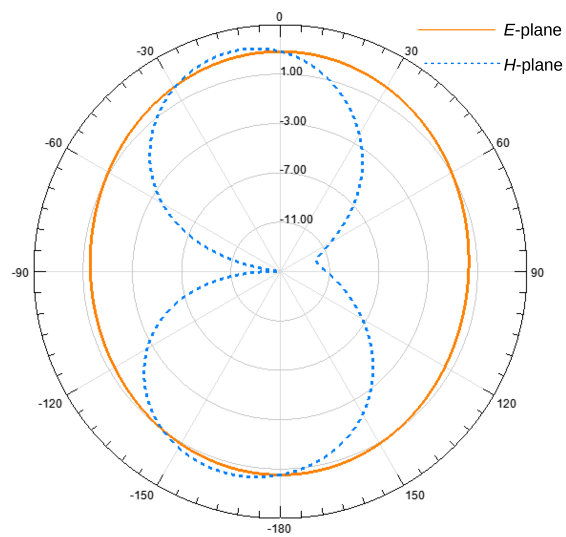
$$f_{ine2} = \frac{c}{(2L_1 + 2L_2 + 2L_4)\sqrt{\varepsilon_{eff}}} \tag{3}$$

where are $Z_1 = Z_3 = Z_4$ assumed for simplicity. The resonance frequencies can be determined by the electrical length. Compared with dual-mode resonator, the proposed structure can provide three resonant frequencies and higher degree of freedom in adjusting the locations of the resonant modes.

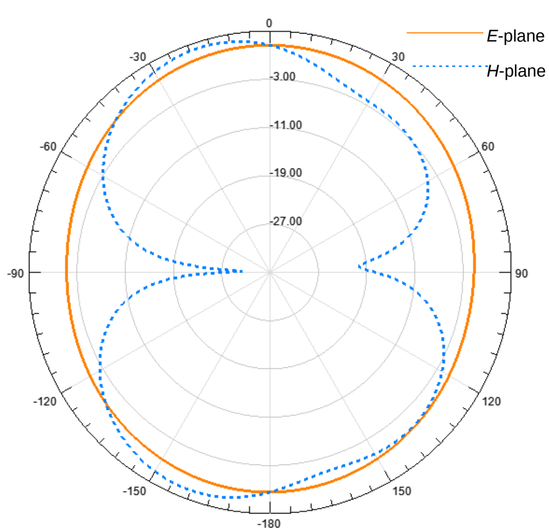
The triple-mode SIR can result in triple band-stop performance when placed next to the microstrip line and it can be equivalent to three shunt-connected series resonance circuits, as shown in Figure 3. The triple-mode SIR can result in triple band-stop (i.e., the triple notched-bands) performance when placed



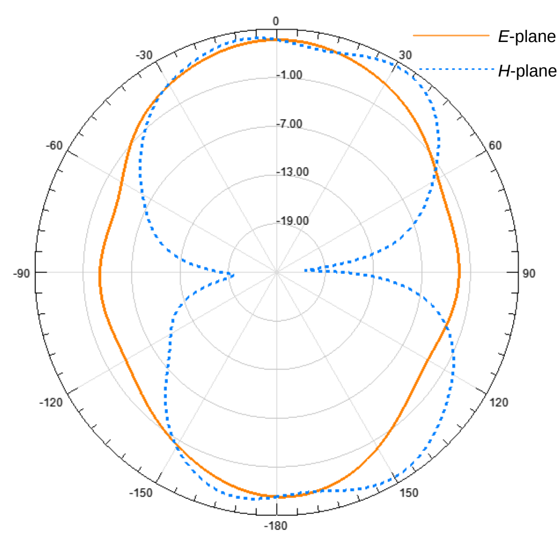
(a)



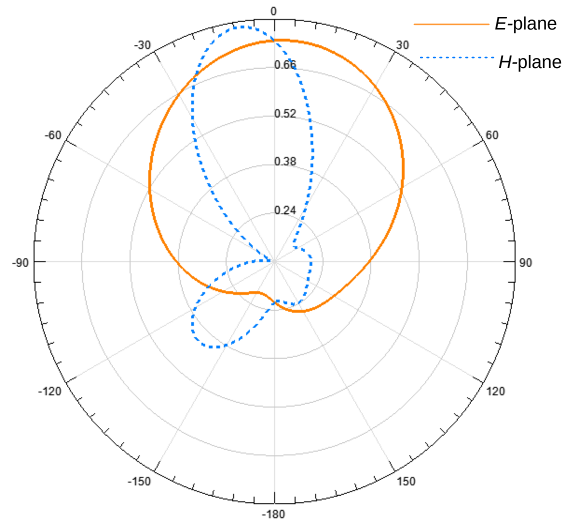
(b)



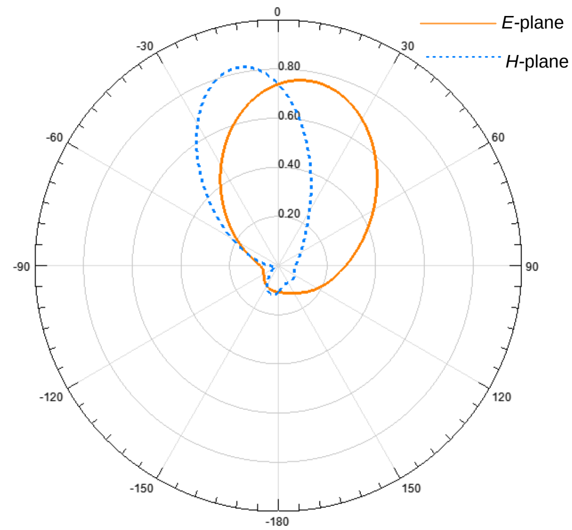
(c)



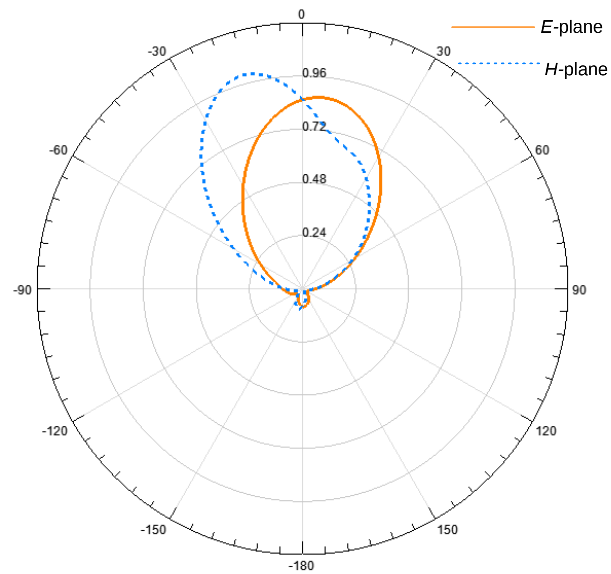
(d)



(e)



(f)



(g)

Figure 5. Measured radiation pattern of the UWB planar monopole antenna: (a) 2.5 GHz, (b) 5.0 GHz, (c) 7.5 GHz, (d) 10.0 GHz, (e) 5.2 GHz, (f) 6.8 GHz, (g) 8.0 GHz.

next to the microstrip line and it can be equivalent to three shunt-connected series resonance circuits. In this paper, the triple-mode SIR dimensions are selected as follows: $w_{s1} = 1.3\,\mathrm{mm}$, $w_{s2} = 0.3\,\mathrm{mm}$, $w_{s3} = 0.3\,\mathrm{mm}$, $w_{s5} = 1.3\,\mathrm{mm}$, $l_{s1} = 4.5\,\mathrm{mm}$, $l_{s2} = 0.5\,\mathrm{mm}$, $l_{s3} = 1.45\,\mathrm{mm}$, $l_{s4} = 0.7\,\mathrm{mm}$, $l_{s5} = 3.1\,\mathrm{mm}$, $l_{s6} = 1.6\,\mathrm{mm}$, $r_e = 0.1\,\mathrm{mm}$.

The frequency characteristics of the coupled triple-mode SIR with various dimensions are investigated by HFSS 11.0 to validate the multi-mode resonant property as shown in Figure 4. It can be seen that the frequency locations of the first and the second notched bands move down simultaneously as increase the dimensions of L_{s2} and L_{s4}. And the frequency locations of the second and the third notched bands move down simultaneously as increase the dimensions of L_{s1}. But only the first the notched band increases as decreases L_{s3} and the second notched band increases as decreases L_{s5}. Therefore, by appropriately adjusting the resonator dimensions, triple notched bands can be achieved at desired frequencies.

4. UWB ANTENNA WITH TRIPLE-NOTCHED BANDS

Based on the triple band-stop characteristics previously described, a novel UWB planar monopole antenna with triple rejected notched bands is proposed and designed. All simulations have been carried out using Ansoft HFSS 11.0 simulation software based on the finite element method (FEM). The normalized radiation patterns in the E- (Phi = 180 deg) and H-planes (Phi = 90 deg) are measured at 2.5 GHz, 5.0 GHz, 5.2 GHz, 6.8 GHz, 8.0 GHz, 7.5 GHz, and 10.0 GHz as in Figure 5. 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 VSWR of the UWB antenna as shown in Figure 6 for comparison. We can notice that the UWB antenna possesses the impedance bandwidth from 2.0 GHz to 11.0 GHz for VSWR $<$ 3 except in notched bands from 4.7∼5.5 GHz, 6.7∼7.1 GHz, and 7.6∼8.3 GHz, respectively. The central frequencies of the notched-bands are about 5.2 GHz, 6.8 GHz, and 8.0 GHz, as well as the notch frequencies of the triple band-stop performance designed in Section 3. The notched-bands are very suitable to implement the rejection of 5.2 GHz wireless local area networks (WLAN) signal, 6.8 GHz RF identification (RFID) signal, and 8.0 GHz X-band satellite communication systems (XSCS) signal. Figure 7 shows the simulation of group delays in the UWB antenna with pulse response. The measured peak gain in the E-plane is given in Figure 8. The proposed antenna exhibits three significant antenna gain decreases at 5.2, 6.8, and

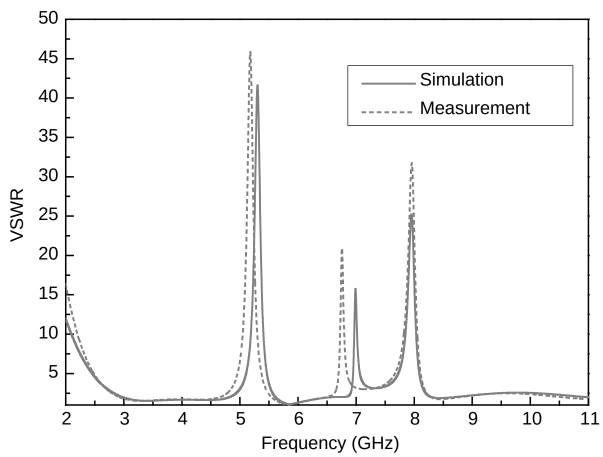


Figure 6. Measurement and simulation of VSWR.

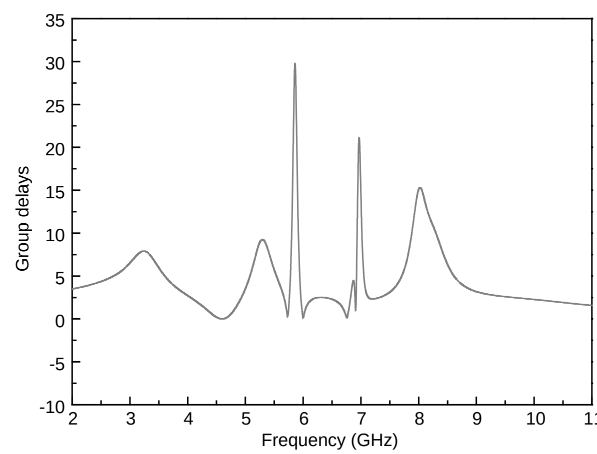


Figure 7. Simulation of group delays in the UWB antenna with pulse response.

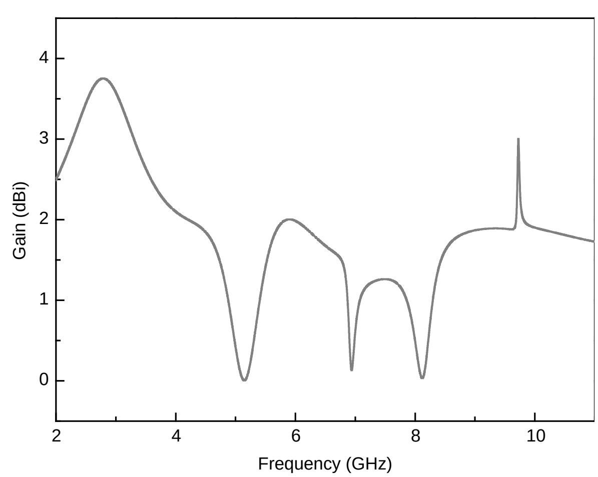


Figure 8. Measured peak gain of the proposed UWB antenna with triple-notched.

8.0 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. The overall size is about $38 \times 20\,\mathrm{mm}^2$.

5. CONCLUSIONS

In this work, a high-performance UWB planar monopole antenna, with triple highly rejected notched-bands, has been successfully implemented and investigated. The triple notched-bands can be easily tuned to the desirable frequency location by controlling the parameters of the proposed triple-mode SIR. The proposed antenna covers the frequency range for the UWB systems, between 2.0 GHz and 11.0 GHz, with a rejection band around WLAN, RFID, and XSCS. The introduced triple-mode SIR 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, the proposed planar monopole antenna is very useful for modern UWB wireless communication systems owing to its marked properties of simple topology, compact size, and excellent performance.

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