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A Novel Compact UWB Antenna with Triple Notched Bands Using Square Ring Short Stub Loaded Resonator

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Abstract—A novel planar ultra-wideband (UWB) antenna with triple notched bands is investigated and presented in this paper. The initial UWB antenna consists of a circular-shaped radiating element, a 50 Ω microstrip feed line, and a partially truncated ground plane. Then, by embedding a square ring short stub loaded resonator (SRSSLR) beside the microstrip feedline of the basic UWB antenna, band-rejected filtering properties in the satellite communication/wireless local area network/radio frequency identification for microwave access bands are generated. The notched frequencies can be adjusted according to specification by changing the SRSSLR. The results indicate that the proposed compact antenna not only retains an ultra wide bandwidth, but also owns triple band-rejections capability. The UWB antenna demonstrates omnidirectional radiation patterns across nearly the whole operating bandwidth that is suitable for UWB communications.

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 focused on them [2–5].

However, the existing wireless networks such as IEEE 802.16 WiMAX system operating at 3.3 ∼ 3.6 GHz, C-band (3.7 ∼ 4.2 GHz) satellite communication systems (CSCS) signals, 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 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, 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 using defected ground structure (DGS); however, they are all based on a multi-layer structure that will increase fabrication cost and are hardly compatible with the existing microwave-integrated circuit.

In this paper, a compact planar UWB antenna with triple notched bands using SRSSLR is proposed. Firstly, the resonance properties of the SRSSLR are studied. The analyzed results reveal that triple band-stop performance can be obtained based on the triple-mode resonant property of the SRSSLR. Then, the triple notched bands characteristic is achieved by putting the SRSSLR near the feed line of the UWB antenna. Notice that the spurious notched band of the SRSSLR is also far away from the

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UWB antenna work band. To validate the design concept, a novel planar UWB antenna with triple sharply rejected notched bands respectively centered at frequencies of 4.0 GHz, 5.2 GHz and 6.8 GHz is designed and fabricated. The simulation and measurement show that the antenna achieves an ultra wide bandwidth ranging from 2.0 GHz to 11.0 GHz and avoids the CSCS/WLAN/RFID interference. An omnidirectional pattern across the entire bandwidth in the H-plane of the antenna is achieved.

2. UWB ANTENNA CONFIGURATION

The geometry of the proposed compact UWB antenna triple notched bands is shown in Fig. 1. It can be seen that the antenna is composed of a triple band-stop filter and a conventional planar circular monopole antenna. The planar monopole antenna consists of a circle-shaped radiating element, a 50 Ω microstrip feed line, and a partially truncated ground plane. It is printed on a Rogers 4350B microwave substrate of thickness 0.508 mm and relative permittivity 3.48. The band-stop filter (i.e., the triple notched bands) is realized by coupling the SRSSLR to the 50 Ω microstrip feed-lines. The design of triple notched bands will be discussed in Section 3. The proposed compact UWB antenna has a circular patch with radius $R_1 = 8.0$ mm, which is fed by 50 Ω microstrip line. The width of the feeding microstrip line is 3.5 mm, and its characteristic impedance is 50 Ω. In order to improve impedance matching performance, a rectangular slit is embedded in the ground plane, located under the microstrip feed line. An SMA is connected to the port of the feeding microstrip line. The final optimized parameters of the planar UWB antenna are as follows: $w_1 = 20$ mm, $w_2 = 9.1$ mm, $w_3 = 1.8$ mm, $w_4 = 0.27$ mm, $l_1 = 40$ mm, $l_2 = 20$ mm, $l_3 = 2.94$ mm, $r_d = 3.0$ mm, $w_{gap} = 0.1$ mm.

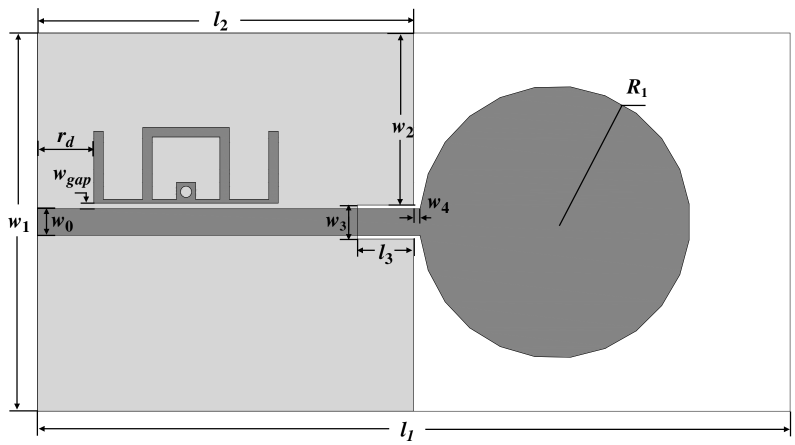

Figure 1. Layout of the proposed triple notched-bands UWB antenna.

3. SQUARE RING SHORT STUB LOADED RESONATOR UNIT ANALYSIS

The concept of the square ring loaded resonator (SRLR) has been studied extensively to develop various types of microwave devices. The basic SRLR consists of two open folded microstrip lines and a square ring, and the SRSSLR is composed of SRLR loaded by a short-end stub in the center. Fig. 2 shows the layout of a SRSSLR resonator coupled to one main transmission line section. The resonance properties of SRSSLR can be analyzed by the even-odd modes analysis method. Under mode excitation, the resonator electric field distribution of the resonator exhibits either an even or an odd mode distribution property as shown in Fig. 3. For the odd mode, the electric fields exhibit an anti-symmetric distribution along the A-A' axis, and there is no electric field on the short-end stub as shown in Fig. 3(b). On the other hand, for the even mode, the electric fields exhibit a symmetric distribution along the A-A' axis as shown in Figs. 3(a) and (c). Therefore, based on the electric field distribution property, the even-odd mode resonant frequency can be expressed as:

$$f_{notch\text{-}even1} = \frac{c}{4(L_{S1} + L_{S2} + L_{S3})\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$f_{notch\text{-}odd1} = \frac{c}{4(L_{S1}+L_{S2})\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$f_{notch\text{-}even2} = \frac{c}{2(L_{S2}+L_{S3}+L_{S4})\sqrt{\varepsilon_{eff}}} \tag{3}$$

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

The triple-mode SRSSLR can result in triple band-stop (i.e., the triple notched bands) performance when placed next to the microstrip line, and it can be equivalent to three shunt-connected series resonance circuits. In this paper, the SRSSLR dimensions are selected as follows: $w_{s1} = 0.2\,\text{mm}$, $w_{s2} = 0.5\,\text{mm}$, $w_{s5} = 1.0\,\text{mm}$, $l_{s1} = 4.9\,\text{mm}$, $l_{s2} = 4.5\,\text{mm}$, $l_{s3} = 5.0\,\text{mm}$, $l_{s4} = 2.3\,\text{mm}$, $l_{s5} = 0.9\,\text{mm}$, $r_e = 0.3\,\text{mm}$.

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

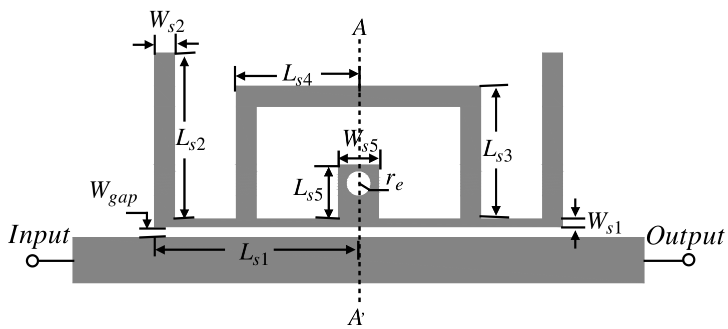

Figure 2. Layout of the coupled SRSSLR.

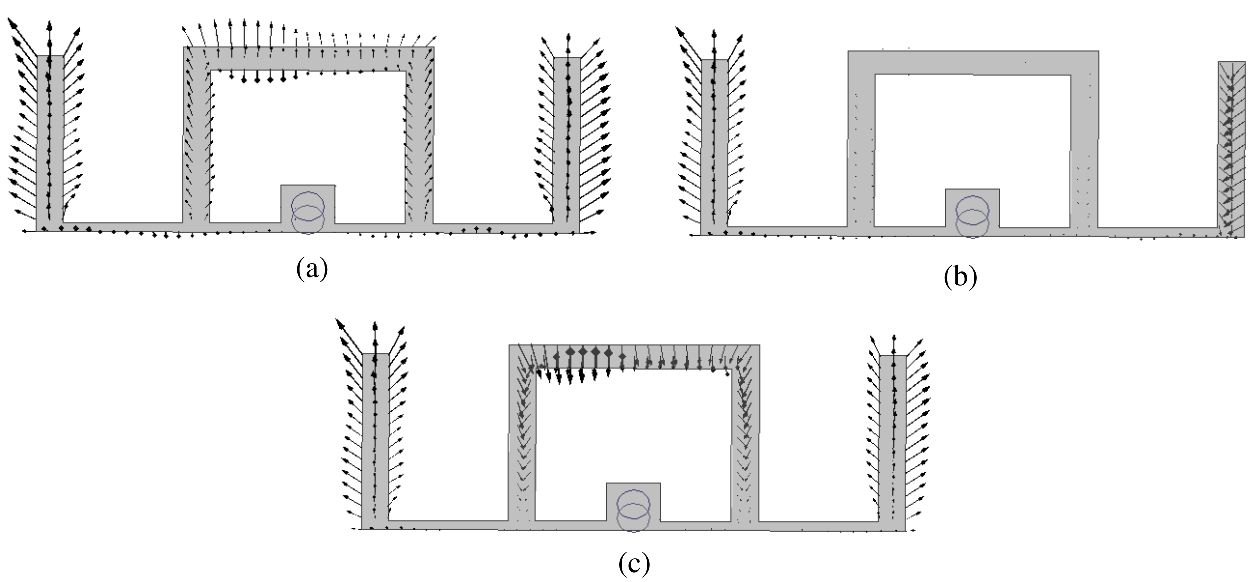

Figure 3. Electric field distribution of the SRSSLR: (a) Even mode, (b) Odd mode, (c) Even mode.

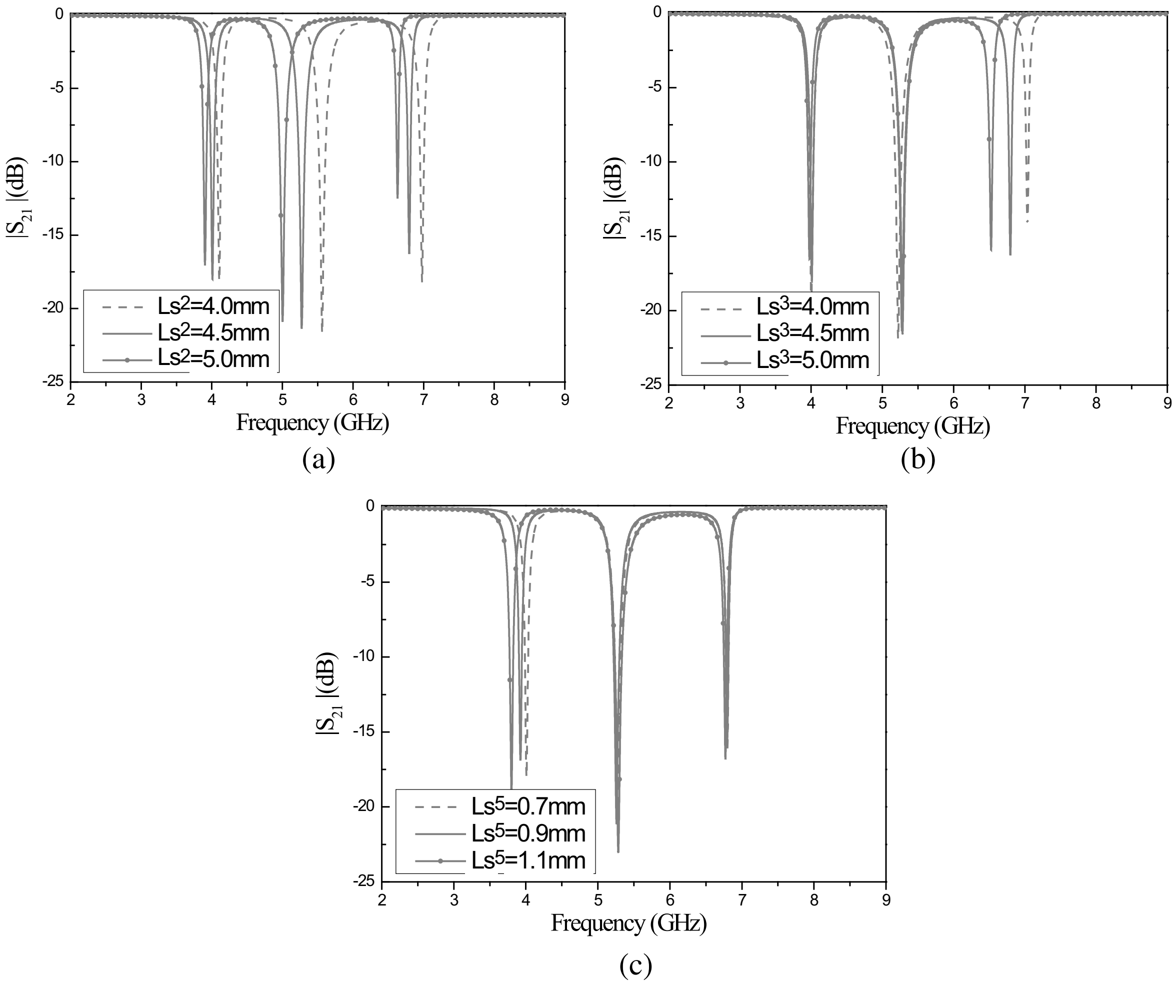

Figure 4. Simulated S-parameters of the coupled SRSSLR for various dimensions: (a) L_{S2}, (b) L_{S3}, (b) L_{S5}.

4. UWB ANTENNA WITH TRIPLE NOTCHED BANDS

Based on the triple band-stop filter previously described, a novel compact UWB monopole antenna with triple sharply rejected notched bands is proposed and designed. All simulations have been carried out using HFSS 11.0 simulation software based on the finite element method (FEM). The normalized radiation patterns in the E- and H-planes are simulated at 2.5 GHz, 5.0 GHz, 7.5 GHz, and 10.0 GHz as in Fig. 5. It can be found that the antenna has good omnidirectional radiation patterns in the H-plane. The radiation patterns in the E-plane are in symmetry. Simulated and measured VSWRs of the UWB antenna are as shown in Fig. 6 for comparison. We can see that the UWB antenna possesses the impedance bandwidth from 2.0 GHz to 11.0 GHz for VSWR < 2.5 except in notched bands from $3.9 \sim 4.1$ GHz, $5.0 \sim 5.7$ GHz, and $6.6 \sim 6.9$ GHz, respectively. The central frequencies of the notched bands are about 4.0 GHz, 5.2 GHz, and 6.8 GHz, as well as the notch frequencies of the filter designed in Section 3. The notched bands are very suitable for implementing the rejection of 4.0 GHz C-band CSCS signal, 5.2 GHz WLAN signal, and 6.8 GHz RFID signal. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate. The measured peak gain in the E-plane is given in Fig. 7. The proposed antenna exhibits three significant antenna gain decreases at 4.0, 5.2, and 6.8 GHz; this is indicative of the effect of the notched bands. Fig. 8 shows a photograph of the fabricated triple notched bands UWB antenna. The overall size is about $38 \times 20\,\text{mm}^2$.

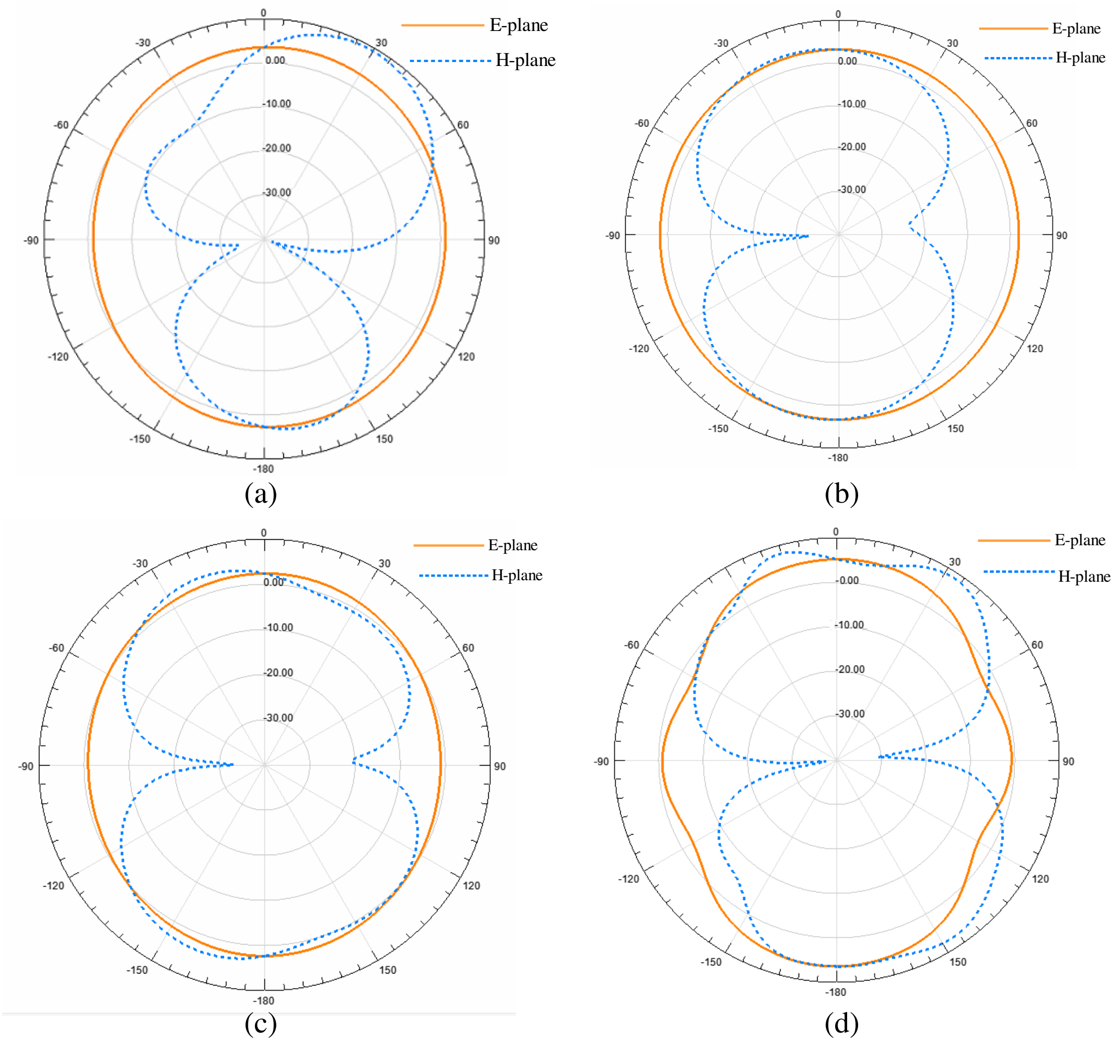

Figure 5. Measured radiation pattern of the UWB planar monopole antenna: (a) 2.5 GHz, (b) 5.0 GHz, (c) 7.5 GHz, (d) 10.0 GHz.

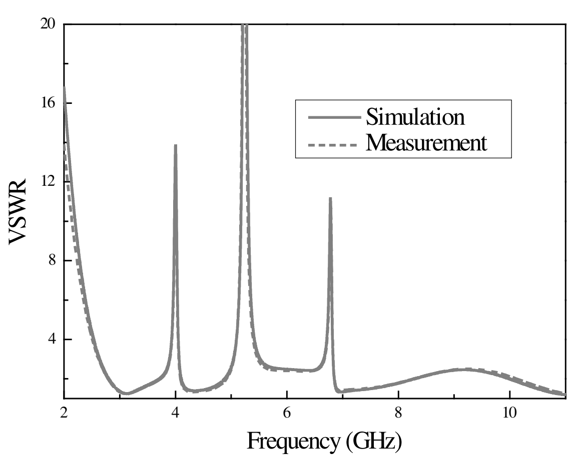

Figure 6. Measurement and simulation of VSWR.

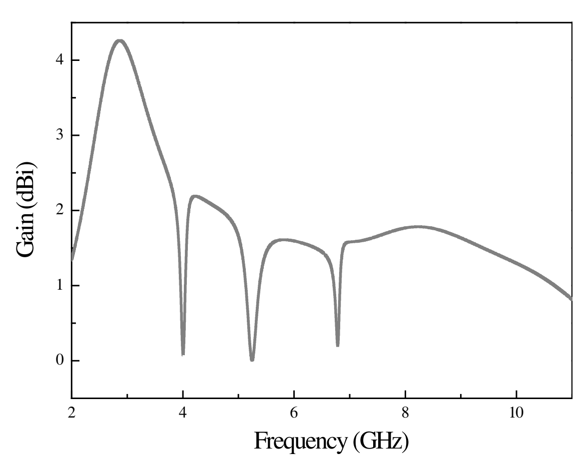

Figure 7. Measured peak gain of the proposed triple notched UWB antenna.

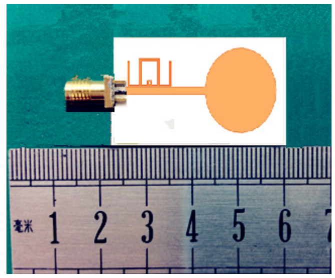

Figure 8. Photograph of the fabricated triple notched bands UWB antenna.

5. CONCLUSION

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 SRSSLR. The proposed antenna covers the frequency range for the UWB systems, between 2.0 GHz and 11.0 GHz, with a rejection band around CSCS, WLAN, and RFID services. 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 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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