Compact UWB Antenna with Triple Band-Notches Using C-Shaped and S-Shaped Structures

Zhenyang Ma [1], Feifei Dong [2], Zheng Han [3], Shaocheng Han [3], and Qiannan Xue [1]

[1] Tianjin Key Laboratory of Civil Aircraft Airworthiness and Maintenance
Civil Aviation University of China, Tianjin, 300300, China
zyma@mail.xidian.edu.cn, qiannanxue@163.com

[2] Chengdu Monitoring Station of the State Radio Monitoring Center
Chengdu, 610000, China
dong.f.f@srrc.org.cn

[3] Basic Experimental Center
Civil Aviation University of China, Tianjin, 300300, China
hanzhengcauc@163.com, schan_cauc@163.com

Abstract **─** A semi-ellipse planar monopole UWB antenna with triple band-notched characteristics is presented. The proposed antenna with three band notches can operate in 3-13.9 GHz which covers the UWB (3.1-10.6 GHz) frequency range. Triple band-notched characteristics is achieved by etching a C-shaped slot on main radiator and adding two novel modified S-shaped cells on either side of microstrip line. The antenna is designed to reject the WiMAX (3.3-3.7 GHz), WLAN (5.15-5.825 GHz), and the downlink of X-band satellite communication systems (7.25-7.75 GHz). The proposed antenna is designed on FR4 substrate of size 20×26×1 mm^3. Details of the antenna design and analysis are presented in this paper.

Index Terms **─** Modified S-shaped structure, semi-ellipse antenna, triple notched bands, UWB.

I. INTRODUCTION

With the rapid development of ultra wideband technology, UWB antennas with band-notched characteristics have gained wide attention in academic fields. Over the UWB frequency range, there are some other wireless communication systems, such as microwave access (WiMAX) in 3.3-3.7 GHz, wireless local-area network (WLAN) in 5.15-5.825 GHz and the downlink of X-band satellite communication systems in 7.25-7.75 GHz, etc. So, in order to filter the interference, new UWB antennas with band-notched characteristics need to be designed.

Lots of band-notched antennas have been proposed in literature. Some papers use the method of etching various types of slots in the patch of the antenna or ground floor (i.e., U-shaped [1-3], H-shaped [4-5], L-shaped [6], E-shaped [7], C-shaped [8-10], π-shaped [11], r-shaped [12], and SRR-shaped [13-16]) to generate notched bands. In some other literatures, the rejection bands can also be realized by adding various structures in antenna. In [17-19], various types of electromagnetic band gap (EBG) structures are applied to obtain notched bands. In [14-15, 20-21], some structures are placed adjacent to the feed-line to achieve one or two band-notched performance. Nevertheless, in order to achieve long current path, the structures closing to the feed-line general have large length, and one structure corresponds to one notched band. For instance, the size of the split rectangular ring filter is 6.2×16 mm^2 in [15], the L-shaped stub is 2.25×9.5 mm^2 in [20], and the G-shaped structure is 1.25×4.75 mm^2 in [21]. In this work, we have designed a novel modified S-shaped structure. From the results of the simulation, we can found the single modified S-shaped cell can generate dual notched bands, and we can increase current path with the modified S-shaped structure.

The proposed UWB antenna is composed of a semi-ellipse patch and fed by a microstrip line. A C-shaped slot is etching in the patch to achieve the WiMAX notched band, and two symmetrical modified S-shaped patches are put nearing the feed-line to avoid the interference of WLAN and the downlink frequency of X-band satellite communication systems. The simulation results of voltage standing wave radio (VSWR), current distribution, radiation pattern, gain, and efficiency are carried out using CST Microwave Studio.

II. ANTENNA DESIGN

The geometry of the proposed monopole antenna is illustrated in Fig. 1. A patch is printed on FR-4 substrate

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with a relative dielectric constant of ε_r =4.4, size of 20×26 mm^2 and thickness of 1 mm. The semi-ellipse patch is the main radiating element with radius a=9 mm, b=14 mm. In order to achieve triple band-notches, one slit and two S-shaped cells are used in the proposed antenna, as shown in Fig. 1 (a). A rectangular ground plane with gap is placed on the other side of the substrate and a 50 Ω microstrip line is used to excite the monopole antenna. The dimensions of the designed antenna after optimization are as follows: W_1=20 mm, L_1=26 mm, L_2=2 mm, L_3=2 mm, W_2=11 mm, W_3=3 mm, L_4=8 mm, h=0.5 mm, L_5=2.45 mm, W_4=2 mm, d=0.2 mm, W_5=2 mm, L_6=2.6 mm, L_7=9.6 mm, W_6=0.3 mm, L_i=2.8 mm, L_o=4.3 mm.

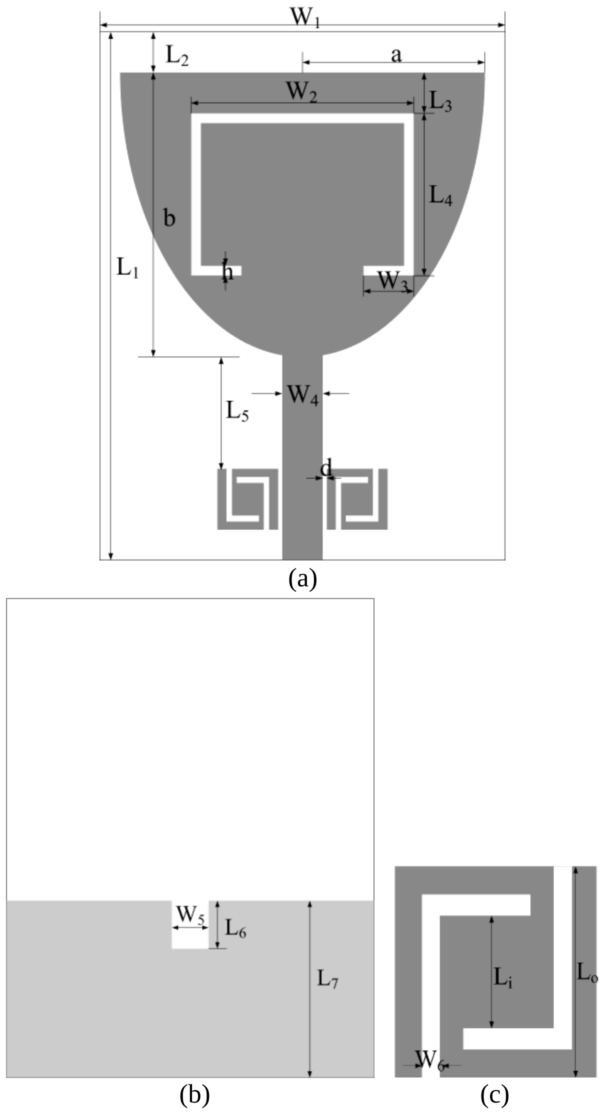


Fig. 1. Configuration and parameters of the UWB antenna: (a) top view, (b) bottom view, and (c) modified S-shaped cell.

A. C-shaped slot design

The design of the first notched band is obtained by etching a C-shaped slot in the semi-ellipse patch. Generally speaking, the length of the slot is about half wave-length at the center frequency of the notch-band. In [15], the notch frequency given the dimensions of the band notched feature can be assumed as:

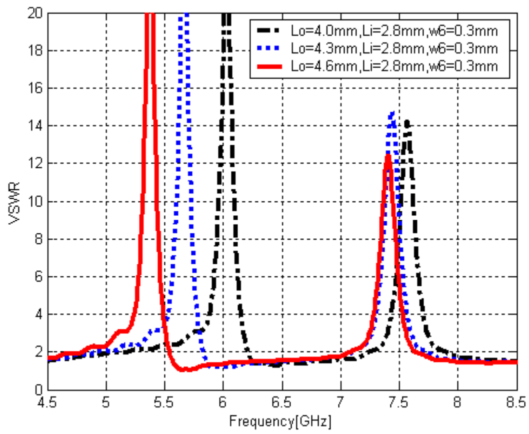
$$f_{notch} = \frac{c}{2L\sqrt{\frac{\varepsilon_r + 1}{2}}}, \tag{1}$$

where f_{notch} is the center frequency of the notch band, c is the velocity of light in free space, L is the total length of the C-shaped slot, and ε_r is the dielectric constant. By adjusting the length of slot, we can get the optimal parameter, L=W_2+W_3×2+L_4×2.

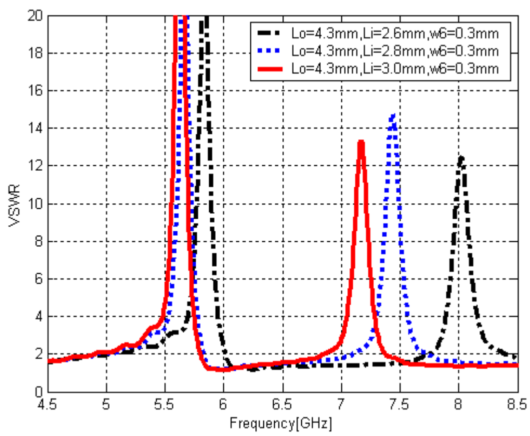
B. Modified S-shaped patch design

The notched band can be achieved by adding some structures closing to the feed-line. In order to achieve long current path, structures with large length are needed to generate band-notched characteristics. In this paper, a modified S-shaped structure is proposed as shown in Fig. 1 (c). The modified S-shaped structure has the advantage of small size, relatively long current path, and dual band-notched characteristics. The two band stop filters are designed to reject the WLAN band (5.15-5.825 GHz) and the downlink of X-band satellite communication systems (7.25-7.75 GHz).

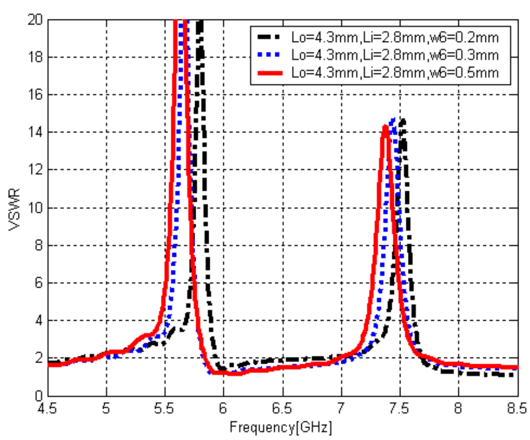
The modified S-shaped structure is composed by a square patch and two L-shaped slots with center symmetry. The structure is help to generate dual band-notched and increase current path. The size of the square patch, width and length of slots, and size of the central patch are the parameters that we need to be further studied based on previous research experience and CST software. By using CST Microwave Studio, we observe the influence of the parameters (L_o, L_i, and W_6) on the modified S-shaped structure. Simulations with different variables are carried out as shown in Fig. 2. The first notch corresponds to WLAN, and the second notch corresponds to the downlink frequency of X-band satellite communication systems. From Fig. 2 (a), it can be seen that with the increasing of L_o, the center frequencies of the two notched bands decrease and vice versa. And the outer length of L_o has more obvious effects on the first notch. Similarly, Fig. 2 (b) shows the center frequencies of the two notched bands decrease with the increasing of L_i. But the inner length of L_i has a larger impact on the second notch. Figure 2 (c) indicates the center frequencies of the two notched bands change with the slit width of W_6. So, by selecting proper parameters of the S-shaped patch, wanted band-notches will be received.



(a) L_o



(b) L_i



(c) W_6

Fig. 2. Simulated VSWR versus frequency with different parameters.

Furthermore, we study the effect of the symmetrical S-shaped structure on the property of the proposed antenna. The S-shaped cell equivalents two *LC* resonators, and it can produce two stop bands. We use symmetrical S-shaped cells on either side of the microstrip line rather than a single S-shaped cell on one side can enhance radiation effect and increase bandwidth as shown in Fig. 3.

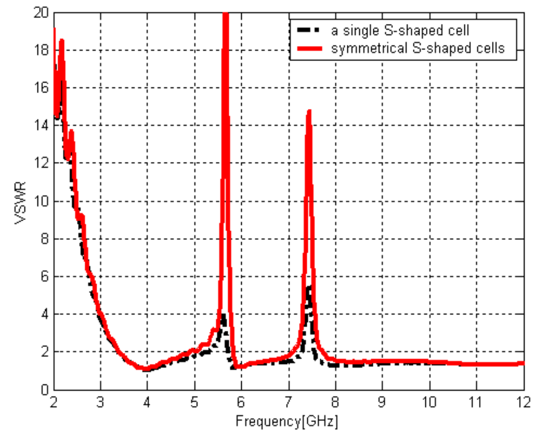
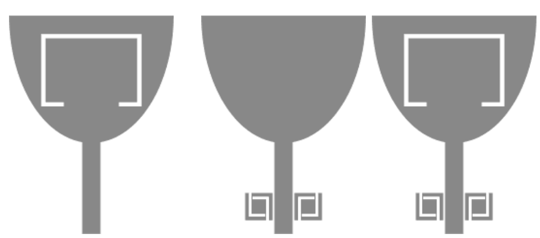


Fig. 3. Simulated VSWR of the antenna with a single S-shaped cell and symmetrical S-shaped cells.

III. RESULTS AND ANALYSIS

To better understand the design process and the band-notched characteristics of the proposed antenna, three different antennas were investigated for comparison. As shown in Fig. 4, antenna (a) is a UWB antenna with a C-shaped slot resonator in the radiation element. Antenna (b) is designed with two S-shaped resonator configurations on both sides of microstrip line. And both the C-shaped slot and S-shaped patches are integrated in antenna (c). The simulated VSWR of the three types of antennas are represented in Fig. 5. The VSWR of antenna (c) basically coincides with antenna (a) and (b). It indicates the structures in (a) and (b) are independent of each other. And the three notch bands are 3.23-3.77 GHz, 5.09-5.86 GHz and 7.11-7.77 GHz, which can filter the interference of WIMAX, WLAN and the downlink of X-band satellite communication systems, respectively.



(a) (b) (c)

Fig. 4. Three types of antennas: (a) UWB antenna with C-shaped slot, (b) UWB antenna with S-shaped patches, and (c) proposed UWB antenna.

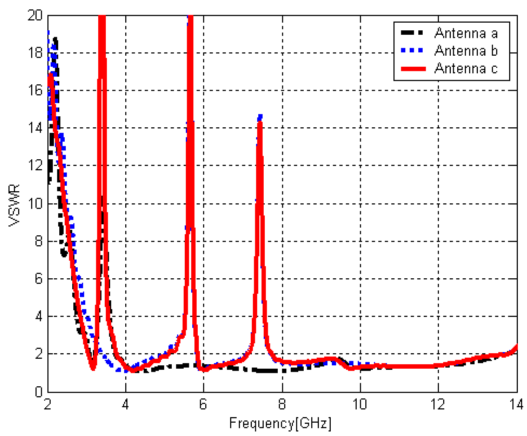
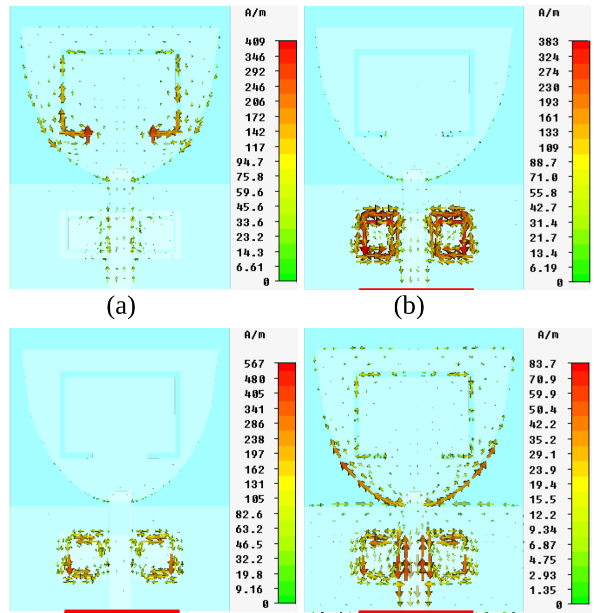


Fig. 5. Simulated VSWR of three types of antennas.

The simulated current distribution of the proposed antenna at frequency of 3.4, 5.6, 7.4, and 9 GHz is presented in Fig. 6. It can be observed in Fig. 6 (a) that the current concentrated around the C-shaped slot, and only a small amount of current flows on the other area at 3.4 GHz. Similarly, we can see more and stronger current distributions on the two S-shaped patches than any other area at 5.6 and 7.4 GHz in Figs. 6 (b) and (c). Most of the current is drawn to band notched structures at notched frequencies. In other words, the antenna resonates near the notched frequencies, and the energy cannot be radiated effectively. Compared with current distribution at notched frequencies, the current flows along the feed and wave is propagated in forward to the antenna at pass frequency form Fig. 6 (d). Also, the current density is smaller than the other three pictures. The current distribution results confirm that the independence of the C-shaped slot and S-shaped patches, and we can change the rejection characteristic of antenna by changing the structure.

Figure 7 depicts the radiation patterns in both E- and H-planes at four frequencies of 4, 6, 8 and 10 GHz. As can be seen from Fig. 8, the antenna has a stable bidirectional radiation patterns in E-plane and nearly omni-directional radiation characteristic in H-plane over the whole UWB frequency range.

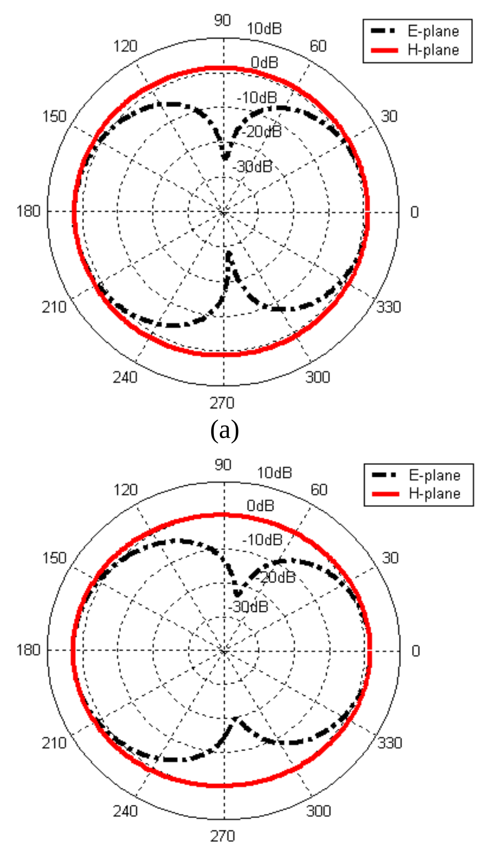
The simulated antenna gain and total efficiency is shown in Fig. 8. The gain varies approximately from 2 dBi to 5.2 dBi over the operating frequency range except three notched bands. And the gain is very low at the notched bands, which drops to -2.3 dBi at 3.4 GHz, -6.1 dBi at 5.7 GHz, and -0.38 dBi at 7.5 GHz. The radiation efficiency is bigger than 80% except three notched bands. The frequencies of the efficiency minimum are as the same as the gain, which verify the design of triple band-notched characteristics once again.



(a) (b)

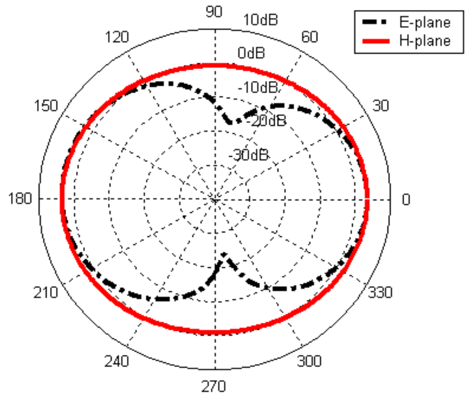
(c) (d)

Fig. 6. Simulated current distribution at frequencies of: (a) 3.4 GHz, (b) 5.6 GHz, (c) 7.4 GHz, and (d) 9 GHz.

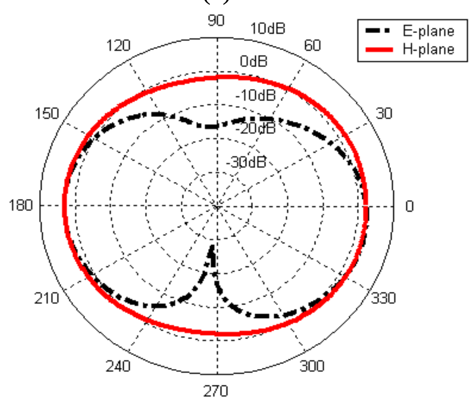


(a)

(b)



(c)



(d)

Fig. 7. Simulated radiation pattern at frequencies of: (a) 4 GHz, (b) 6 GHz, (c) 8 GHz, and (d) 10 GHz.

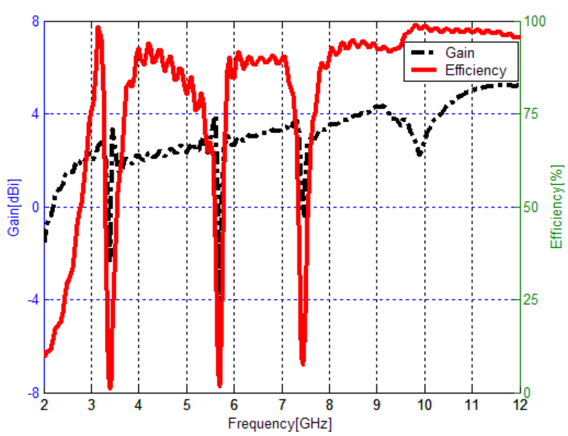


Fig. 8. Simulated gain and total efficiency of the proposed antenna.

At last, the proposed antenna and the other antennas with triple band-notched characteristics are compared in Table 1. From the table, the antenna in [12] has the similar size and performance with the proposed antenna, but it adopts four r-shaped slits and a G-slot. So, it is more complex in structure and difficult to manufacture relative the antenna in this work. By comparison, the antenna proposed in this paper has certain advantages on the property.

Table 1: Performance comparison

Antennas	Dimensions (mm^2)	UWB Ranges (GHz)	Gain (dBi)
Ref. [1]	28×32	2.9-13.4	-4-4
Ref. [2]	42×46	3.1-13	2.8-6.6
Ref. [5]	24×35	Not reported	-2-11.5
Ref. [12]	20×24	2-17.6	0-5
This work	20×26	3-13.9	2.5-5

IV. CONCLUSION

A novel UWB antenna with triple notched bands has been presented. The proposed antenna has the advantages of small size, simple configuration and good band notched feature. By etching a C-shaped slot on the radiator and employing two symmetrically S-shaped patches, three bands are obtained to filter the interference of WiMAX, WLAN and the downlink frequency of X-band satellite communication systems in UWB band. The design is simulated and optimized by using CST Microwave Studio. From the results, stable radiation pattern, good gain and efficiency of the antenna make it suitable for UWB applications.

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Zhenyang Ma received the B.S. degree in Applied Physics from Shandong Normal University, Jinan, China, in 2008, and the Ph.D. degree in Microelectronics and Solid State Electronics from XiDian University, Xi'an, China, in 2013. His research interests include VLSI technology and reliability, the damage effect and mechanism of micro-devices and circuits induced by high-power microwaves and lightning/HIRF protection technology.

Feifei Dong was born in Gansu Province. She graduated from the University of Electronic Science and Technology of China (UESTC) in 2009. Now she is working for State Radio Regulating Committee. Her research interests are the radio monitoring, antenna and magnetron design.

Zheng Han received the B.S. degree in Communication Engineering from Tianjin University of Technology in 2006, and the M.S. degree in Signal and Information Processing from Civil Aviation University of China in 2009. Her research interests include analysis and design of microstrip antenna, ultra-wideband antenna, and electromagnetic compatibility of airborne equipment.

Shaocheng Han received the B.S. degree in Information and Communication Engineering from North University of China in 2004, and the M.S. degree in Signal and Information Processing from Civil Aviation University of China in 2009. His research interests include image processing, digital watermarking and finger vein identification.

Qiannan Xue received the B.S. degree in Physical Electronics from Institute of Electronics, Chinese Academy of Sciences, China, in 2012. Her research interests include Micro Sensor and System, Micro-wave Sensor, System on a Chip, and Wireless Sensor Network.