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BAND-NOTCHED UWB CROSSED SEMI-RING MONOPOLE ANTENNA

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Abstract—A novel type of ultra-wide band (UWB) crossed semi-ring monopole antenna with band notched characteristics is presented. The proposed antenna consists of a wideband crossed semi-ring monopole and four L-shaped slots, producing band-notched characteristic. Effects of the various parameters for antenna performances are discussed. The central frequency and bandwidth of the notched band can be controlled easily by adjusting three key design parameters. A prototype is constructed and measured finally.

1. INTRODUCTION

Since Federal Communication Commission of USA allowed 3.1–10.6 GHz unlicensed band for low power ultra-wideband (UWB) communication, the UWB technology has attracted a lot of attentions as one of the most promising solutions for future high data-rate wireless communications, high-accuracy radars, and imaging systems [1–3]. Consequently, as a critical part of the entire system, UWB antennas have been receiving increasing interests from both the academia and industries [4–8]. Monopole antennas are considered as one of the most promising candidates fitting UWB applications requirements [9–12]. The advantages of monopole antennas include very wide frequency bandwidth, good radiation performance and simple geometric structure. Furthermore, many studies have proved that the cross-shaped monopole antennas can overcome the pattern distortion and keep stable omni-directional radiation in the H-plane through the operating frequency band [13–15]. And many

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modifications have been proposed to improve the monopole antennas' performance as well as miniaturize antenna size [16–20]. Although numerous research papers ([17, 21], etc.) have shown that printed monopole antennas have more convenient integration with circuits, cross-shaped monopole antennas have more stable radiation patterns especially at high frequencies [13, 14, 19].

Another requirement for UWB antennas has also emerged with the consideration of the existence of other wireless standards, such as IEEE 802.11a. That is to reject some bands within the ultra wide passband. As a result, a filtering function is desired by the UWB antennas. A number of different methods can be used to achieve the band-notch function, for example, inserting a narrowband resonant slot in the radiating patch (i.e., U-shaped, arc-shaped, and a pie-shaped slot) [22–27], embedding a tuning attachment element or radiator within a slot on the radiating patch [28–30], utilizing parasitic patches near the radiator to form band-notched characteristic [31, 32], or inserting a slit on the patch [33–36].

In this paper, a cross typed UWB monopole antenna with band-notched characteristic is presented. It uses a crossed semi-ring structure which can achieve stable radiation pattern at high frequencies compared with planar monopoles, as well as a reduced antenna size with a top-loaded patch. Meanwhile, the band-notched characteristic is obtained by embedding four L-shaped slits in the radiating patch. The central frequency and bandwidth of the notched band can be adjusted easily. This approach provides more degrees of freedom in design. A prototype is constructed and measured. The measured 10-dB return loss shows that the proposed antenna achieves a bandwidth ranging from 3.1 to over 12 GHz with a notched band of 5.4–6 GHz. The antenna radiator has a compact size of $28\,\mathrm{mm} \times 28\,\mathrm{mm} \times 14\,\mathrm{mm}$. The proposed antenna presents omni-directional patterns across the whole operating band in the H-plane.

2. ANTENNA CONFIGURATION

The geometry of the band-notched crossed semi-ring monopole antenna is shown in Figs. 1(a) and 1(b). When we remove the four L-shaped slots, it becomes the construction of the crossed semi-ring monopole antenna, which is transformed from the crossed semi-circle monopole antenna [19]. The crossed semi-ring monopole has the similar impedance matching and radiation characteristics as the crossed semi-circle monopole according to the current distribution principle. The surface current is mainly concentrated along the edge of the semi-circle disc. Hence, cutting the central part of the disc to form

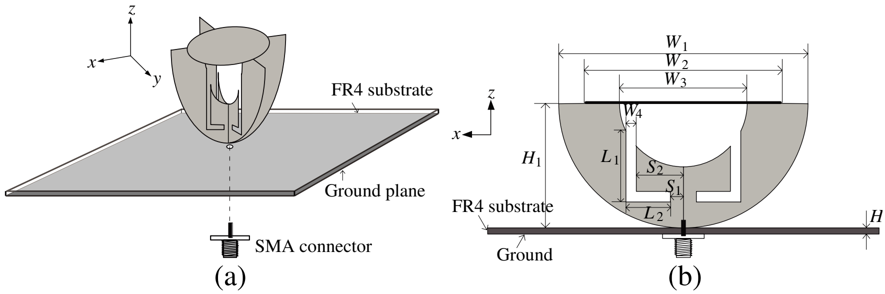


Figure 1. Geometry of the proposed semi-ring cross-plate probefed monopole antenna with L-shaped slots. (a) Three-dimensional view. (b) Planar view.

a semi-ring monopole will not affect the performance of the monopole, which has also been examined [10].

In the proposed antenna design, the two semi-ring discs are arranged to have a "crossed" structure, and one circle disc is arranged on the top of this "crossed" structure. The cross-plate configuration makes it possible to improve the omnidirectional radiation performance, and the top circle disc is adopted to improve the impedance matching of the antenna. Furthermore, the four L-shape slots are etched on both semi-ring discs, which provide the band-notched characteristic. All prototypes fabricated in this paper are vertically mounted on a FR4 substrate ($\epsilon_r = 4.4$, $H = 40\,\text{mil}$) with an SMA connector. The mounting gap between cross-shaped semi-ring structure and the FR4 substrate is designed to be zero. The size of the finite ground plane is $80 \times 80\,\text{mm}^2$ and the radiation element is made up of copper sheet of thickness 0.1 mm.

3. EFFECT OF THE GEOMETRICAL PARAMETERS

In order to better understand the antenna's characteristics, some key parameters are varied to analyze the structure through simulation. The top-loaded circle with diameter $W_2 = 22\,\text{mm}$ is introduced to reduced the antenna vertical dimension without worsening the lower frequency band of the UWB antenna. Fig. 2 shows the comparison of S_{11} with/without the top-loaded circle disc. It is clear that the lower frequency end is extended by adding the top-loaded circle disc.

The next variation is performed by adjusting the diameter of the inner cutoff semi-circle of the proposed antenna without the L-shaped slots, which is shown in Fig. 3. It is observed that the input impedance response does not change a lot when $W_3 < 14\,\text{mm}$, however, the wide

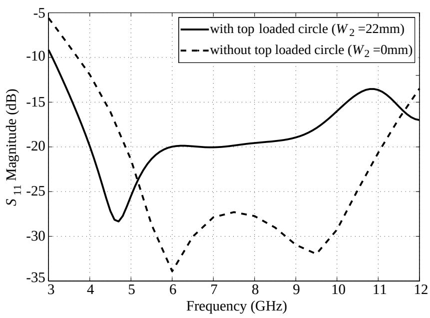


Figure 2. Variation of the W_2.

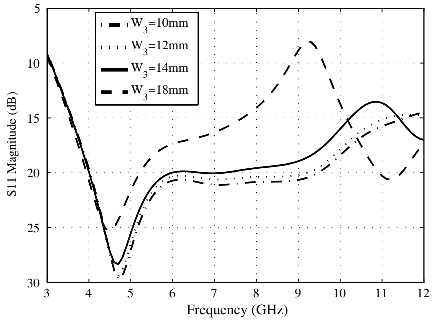


Figure 3. Variation of the W_3.

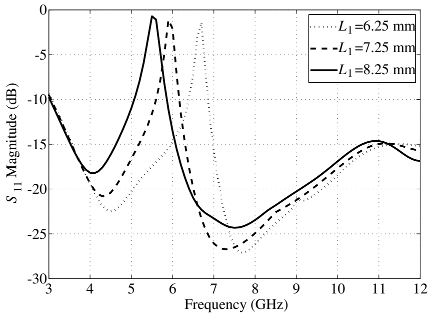


Figure 4. Variation of the L_1.

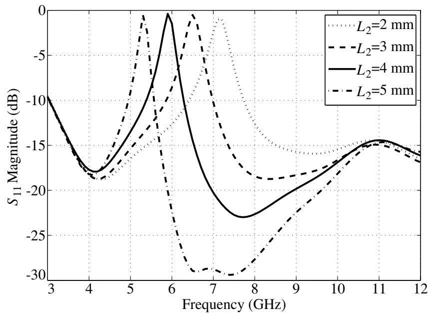


Figure 5. Variation of the L_2.

band impedance matching will be deteriorated when $W_3 \geq 18\,\text{mm}$. That means appropriate cutting size of the central part of the antenna will not affect much on the current distribution. In order to embed the notch-band characteristic into this monopole antenna, a cutting ring with $W_3 = 14\,\text{mm}$ is adopted. Based on the selected W_3's value, the key parameters which influence the notched bandwidth BW_n (where $|S_{11}| > -10\,\text{dB}$) and central frequency of the notched band f_n are studied.

Tables 1, 2, and 3 show the simulated results for BW_n and f_n against different L_1, L_2 and W_4, separately. Firstly, f_n varies to lower frequency band gradually when L_1 increases, at the same time, BW_n becomes wider. Fig. 4 shows the impedance responses with different values of L_1. Secondly, f_n varies to lower frequencies gradually when L_2 increases, however, BW_n becomes narrower at the same time. Fig. 5 shows the impedance responses with different values of L_2. Thirdly, the width of slots W_4 also influences the BW_n and f_n independently. When the slot's width W_4 varies from 0.5 mm to 2.5 mm, the central

Table 1. Simulation results for f_n and BW_n versus L_1 (unit length: mm, frequency: GHz, $L_2 = 4.5$, $W_4 = 1$, $W_1 = 28$, $W_2 = 22$, $W_3 = 14$, $H_1 = 14$, $S_1 = 2$, $S_2 = 5.5$).

L_1	f_n	BW_n
6.25	6.625	0.45
7.25	5.875	0.55
8.25	5.45	0.7

Table 2. Simulation results for f_n and BW_n versus L_2 (unit length: mm, frequency: GHz, $L_1 = 8.25$, $W_4 = 1$, $W_1 = 28$, $W_2 = 22$, $W_3 = 14$, $H_1 = 14$, $S_1 = 2$, $S_2 = 5.5$).

L_2	f_n	BW_n
2	7.05	1.3
3	6.45	1.1
4	5.85	0.9
5	5.25	0.6

Table 3. Simulation results for f_n and BW_n versus W_4 (unit length: mm, frequency: GHz, $L_1 = 8.25$, $L_2 = 4.5$, $W_1 = 28$, $W_2 = 22$, $W_3 = 14$, $H_1 = 14$, $S_1 = 2$, $S_2 = 5.5$).

W_4	f_n	BW_n
0.5	5.225	0.65
1	5.45	0.7
1.5	5.825	0.85
2	6.3	1
2.5	6.7	1

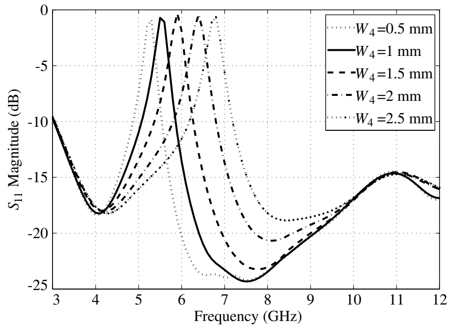


Figure 6. Variation of the W_4.

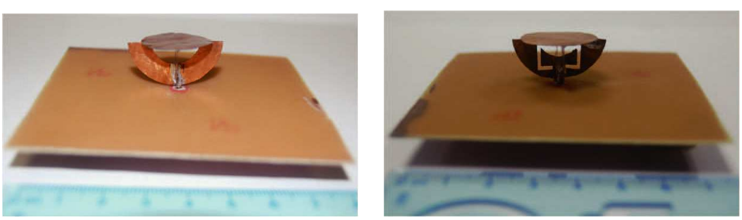
frequency of the notch varies from 5.225 GHz to 6.7 GHz, and BW_n increases from 0.65 GHz to 1 GHz. Furthermore, BW_n stops increasing when $W_4 > 2$ mm. Fig. 6 shows the impedance responses with different values of the slot width W_4.

From the above parametric study, we can observe that the total length of the slot $(L_1 + L_2)$ is around quarter wavelength at the notch frequency when the slot width W_4 is around 1.5 mm. Increasing either L_1 or L_2 will reduce the resonance frequency of the slots, which in turn results as a lowering of the notch frequency f_n. On the other hand, by enlarging the value of W_4 but keeping L_1 and L_2 unchanged, the total length of the slots' outer line is reduced. As a result, the resonance frequency for such slots is increased and the rejection band moves towards the higher frequencies. By proper selection of these parameters' values, the center frequency and bandwidth of the notched band can be adjusted. For the proposed antenna, the lower frequency end is determined by the ring diameter and the top-loaded circle disc size. The upper frequency end is determined by the mounting gap between the cross-shaped semi-ring structure and the FR4 substrate.

4. DESIGN EXAMPLE

The antenna is composed of two same semi-ring plates and one circle plate. The outer and inner diameters of the semi-ring are $W_1 = 28$ mm and $W_3 = 14$ mm, respectively. The diameter of the top circle plate is $W_2 = 22$ mm. The height of the proposed antenna is $H_1 = 14$ mm. The design parameters as shown in Fig. 1(b) are set to be $L1 = 8.25$ mm, $L_2 = 4.5$ mm, $S_1 = 2$ mm, $S_2 = 5.5$ mm and $W_4 = 1$ mm, respectively.

Figure 7 shows the photographs of the fabricated semi-ring cross-plate monopole antenna and the band-notched antenna.



(a) (b)

Figure 7. Photographs of the fabricated semi-ring cross-plate probefed monopole antenna. (a) Semi-ring cross-plate monopole antenna. (b) Semi-ring cross-plate band-notched monopole antenna.

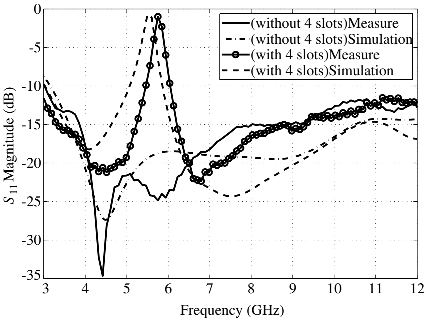


Figure 8. The measured and simulated return loss of the crossed semi-ring monopole antenna and band-notched crossed semi-ring monopole antenna.

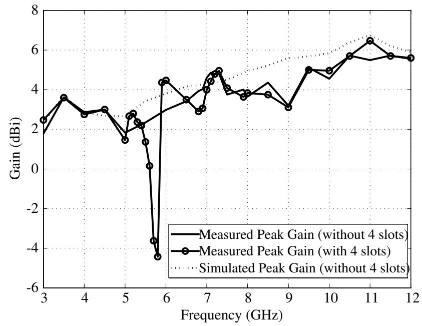


Figure 9. The measured y-z plane antenna gain of the crossed semi-ring monopole antenna and the band-notched crossed semi-ring monopole antenna.

Figure 8 shows the measured and simulated reflection coefficients of the crossed semi-ring monopole antenna and the corresponding band-notched antenna. The proposed antennas were simulated by using ANSOFT HFSS. The results indicate that the impedance bandwidth (10 dB return loss) of the crossed semi-ring monopole antenna is in the frequency range from 3.1 to 12 GHz, which covers the bandwidth of the FCC definition for UWB indoor communication systems.

The measurement result of the band-notched crossed semi-ring monopole antenna has a small shift compared with the simulated one. The discrepancy between simulation and measurement could be due to the fabrication tolerance. According to the measurement result, the operating bandwidths of the band-notched crossed semi-ring antenna are $3.1 \sim 5.4$ GHz and $6.0 \sim 12$ GHz.

Figure 9 shows the measured peak gain from $3 \sim 12$ GHz for the proposed antenna with and without the L-shaped slots. From the figure, it is seen that the antenna with slots has very similar gain with the one without slots, except that a sharp antenna gain drop in the notched frequency band 5.4 to 6.0 GHz.

Figure 10 shows the E- and H-plane radiation pattern of the band-notched antenna at 4, 6 and 10 GHz, respectively. The radiation pattern in H-plane almost keep omnidirectional across the ultra wide bandwidth. Even at 10 GHz, the antenna shows stable omni-directional pattern only with slightly distortion.

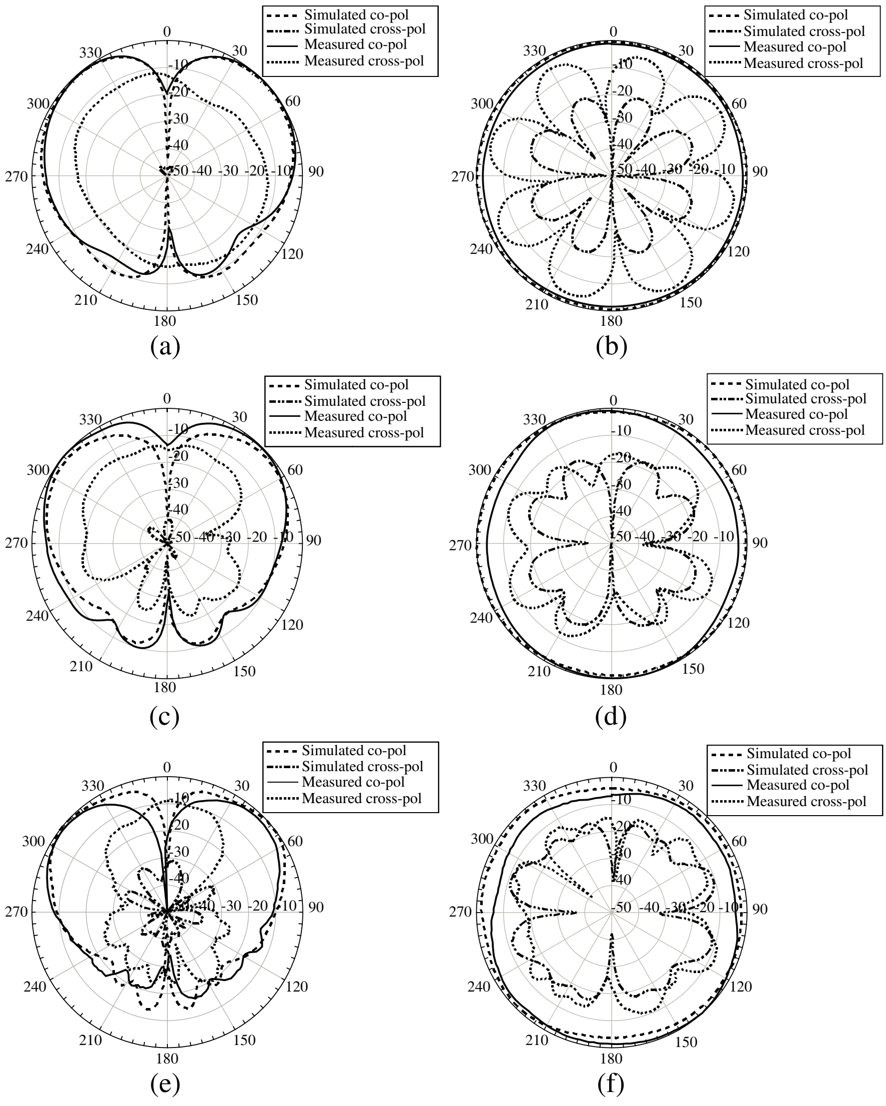


Figure 10. Simulated and measured E- and H-plane radiation pattern for the crossed semi-ring band-notch monopole antenna at 4, 6 and 10 GHz. (a) E-plane pattern at 4 GHz. (b) H-plane pattern at 4 GHz. (c) E-plane pattern at 6 GHz. (d) H-plane pattern at 6 GHz. (e) E-plane pattern at 10 GHz. (f) H-plane pattern at 10 GHz.

5. CONCLUSION

The design of band-notched crossed semi-ring monopole antennas has been considered. The frequency-notch function is obtained by adding four L-shaped slots in the radiating disc. A detailed study of the effect of band-notching feature geometry on the characteristics of the notch band has been carried out. It was found that the central frequency and bandwidth of the notched band can be controlled easily by adjusting three key design parameters. The proposed antenna also has compact size and stable radiation pattern across whole operating frequency band. A prototype has been constructed and measured. Experimental results show that the proposed antennas have appropriate UWB performance and could be good candidates for practical UWB applications.

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