Progress In Electromagnetics Research Letters, Vol. 42, 55–64, 2013

TRIPLE BAND-NOTCHED ULTRAWIDEBAND (UWB) ANTENNA USING A NOVEL MODIFIED CAPACITIVELY LOADED LOOP (CLL) RESONATOR

Junhui Wang*, **Yingzeng Yin, and Xianglong Liu**

National Key Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, Shannxi 710071, China

Abstract—In this letter, a novel microstrip-fed monopole ultrawideband (UWB) antenna with triple notched band is proposed. By embedding a novel modified capacitively loaded loop (CLL) resonator beside the microstrip feed line, band-rejected filtering properties in 3.3–3.6 GHz for WiMAX, 5.15–5.825 GHz for WLAN, and 7.25–8.295 GHz for the X-band satellite is generated. The notched frequencies can be adjusted according to specification by altering the parameters of the modified CLL resonator. Both the experimental and simulated results of the proposed antenna are presented, indicating that the antenna is a good candidate for various UWB applications.

1. INTRODUCTION

Stemming from military radar applications, ultrawideband (UWB) communications are being researched intensively in both academic and industrial environments [1]. The UWB antenna is one of the key components in UWB radio systems. Researchers have made many efforts to investigate different UWB antennas. Until now, various structures have been developed to achieve wideband antennas. However, in practical applications, antenna design for UWB systems is still facing many challenges. Particularly, the UWB systems have encountered a hostile radio environment, which causes potential interference to the UWB working bands. For instance, IEEE 802.16 WiMAX system operates at 3.3–3.6 GHz, IEEE 802.11a WLAN system operates at 5.15–5.35 & 5.725–5.825 GHz and X-band satellite communication service operates at 7.25–7.745 (down-link) & 7.9–8.395 GHz (up-link). Therefore, it is necessary to design antennas with multiband filtering function for practical UWB systems.

Received 28 May 2013, Accepted 10 August 2013, Scheduled 25 August 2013

* Corresponding author: Junhui Wang (xidian_wjh@163.com).

Recently, some designs of UWB antennas with notched frequency bands have been reported in [2–14]. The methods to realize band-rejected filtering in these antennas mainly include cutting slots with different shape in the radiation patch, inserting slits on the feed line, and adding parasitic strips or split rings near the feed line or around the ground plane. However, each structure in these antennas can generate only one notched frequency band. Therefore, multiple resonators are applied in the UWB antenna to yield multiple notched bands. The use of multiple resonators will increase the complexity of the UWB antenna design. Employing a single resonator with UWB antennas to obtain multi-notch-band antennas is still little reported in recent literatures.

In this paper, a novel compact UWB monopole antenna with triple band-notched characteristics is proposed. By adjusting the dimension of the modified capacitively loaded loop (CLL) resonator located beside the feed line, triple notched bands of the antenna can be achieved easily. Compared with the antenna reported in [2–14], this design uses one single resonator, instead of two or more resonators, to realize triple band-notched property. Moreover, the proposed antenna also has a simple configuration and is easy to fabricate. A practical antenna example operating from 3 to 11 GHz is demonstrated, with triple notched bands at 3.3–3.6 GHz, 5.15–5.825 GHz and 7.25–8.395 GHz.

2. ANTENNA DESIGN

The proposed triple band-notched monopole antenna is shown in Figure 1. It mainly comprises of a shovel-shaped radiation patch, a

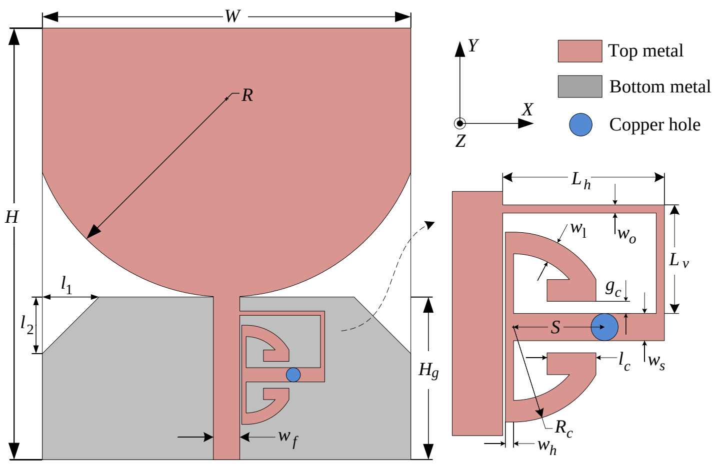


Figure 1. Geometry of the proposed antenna.

partially ground plane, and a novel modified CLL resonator. The proposed antenna fed by a microstrip line is printed on a FR4 substrate with thickness of 1 mm, relative dielectric constant of 4.4 and loss tangent of 0.02. The radiation patch and feed line are printed on the top side of the substrate, and the ground plane on the bottom side. Beveled ground plane results in a smooth transition from one mode to another, ensuring a good impedance match over a broad frequency range. The width of the microstrip line is chosen as 1.86 mm to achieve the characteristic impedance of 50 Ω. To achieve the triple band-notched characteristic, a novel modified CLL resonator near the feed line is adopted to generate notched bands with central frequencies of 3.4, 5.5 and 7.8 GHz. The gap between the feed line and the resonator is fixed at 0.1 mm. The proposed antenna is fabricated for verification with optimized parameters and shown in Figure 2. The dimensions of the optimized antenna are shown in Table 1.

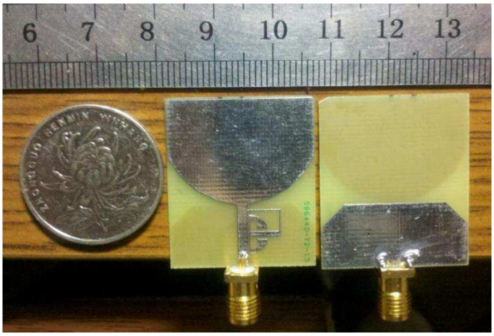


Figure 2. Prototype of the proposed antenna.

Table 1. Optimized antenna parameters.

Parameter	W	H	R	H_g	l_1	l_2	w_f	R_c	w_h
Values (mm)	26	30.5	14	11.5	4	4	1.86	7	0.3
Parameter	w_l	l_c	g_c	S	w_s	l_v	l_h	w_o	
Values (mm)	0.8	1.8	0.45	3.35	1	4	5.95	0.3	

3. MODIFIED CLL RESONATOR

Figure 3 shows the evolve process of obtaining the proposed modified CLL structure presented in this paper. Type I is the conventional CLL

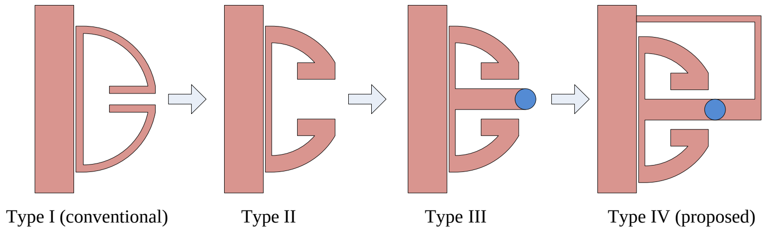


Figure 3. Evolve process of the notch structures.

structure to be used as the notch filter for UWB antenna. Similar to the split ring resonator (SRR) element, the CLL structure is self-resonant and has a resonance frequency that is determined primarily by its loop inductance and the capacitance from the cut which open the loop. The resonant notch frequency can be given approximately by the expression [10]

$$f_{notch} = \frac{c}{2L_{\text{CLL}} \cdot \sqrt{\varepsilon_{eff}}} \tag{1}$$

where L_{CLL} is the total length of the CLL structure, ε_{eff} is the effective dielectric constant, and c is the speed of the light. Type II is the modified stepped CLL element. The low-high-low impedance line in this structure is adopted to increase the harmonic frequency [15], thus improving the impedance matching at high frequency band. Additionally, the structures of Type III and IV are designed based on the Type II structure. In Type III, the middle of the high impedance line is connected to the ground plane through a horizontal line and a via hole. The final notch structure proposed in this paper is developed form the structure of Type III. As shown in Figure 3, an outer line is added to the Type III structure. One end of the outer line is connected to the via hole, while the other end is connected to the main signal line (feed line).

To describe the frequency response characteristics of the structures shown in Figure 3, the UWB monopole antenna with different structures are simulated. Simulation is carried out using the ANSYS High Frequency Structure Simulator (HFSS), one commercial 3-D full wave electromagnetic simulation software. Figure 4 shows the simulated VSWR results of the antenna with different resonators of Type II, III and IV, respectively. The reference antenna refers to the antenna without resonators. The simulated results show that the Type II structure displays a single resonance characteristic in the 5.5 GHz band, In the structure of Type III, the introduction of a middle horizontal line and a via hole results in the formation of a new resonance in the 3.5 GHz band. Furthermore, an added outer line results in another new resonance in the 7.8 GHz band. Therefore, the proposed structure (Type IV) shows a triple resonance (f_1, f_2, f_3) characteristic. Figure 5 shows simulated VSWR results of Type III structure according to the variation of length S. From the simulated results, it is found that the resonant frequency f_1 decrease as the length S increases, while the resonant frequency f_2 remains unchanged. The resonant frequencies f_1 and f_2 of the proposed structure are formed due to Type III resonator, whereas f_3 is formed due to outer line. Figures 6(a) and (b) show the simulated band-rejecting characteristics of the proposed notch structure in case of different lengths L_h of and L_v, which correspond to the horizontal and vertical lengths, respectively. Simulated results show that the resonance frequency f_3 changed with the two lengths (L_h and L_v). Simulated results show that the resonant frequency f_3 is varied with the two lengths. Appropriately adjusting each related parameter allows the placement of the notch frequency f_1 around 3.4 GHz, f_2 close to 5.5 GHz and f_3 near by 7.8 GHz, as shown in Figure 4.

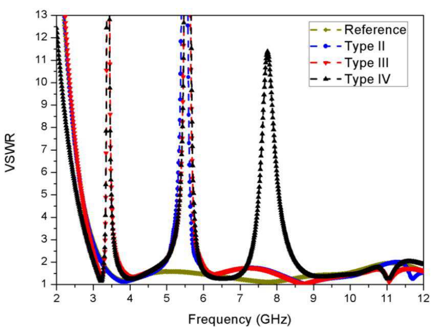


Figure 4. Simulated VSWR results of antenna with resonator of Type II, III and IV, respectively.

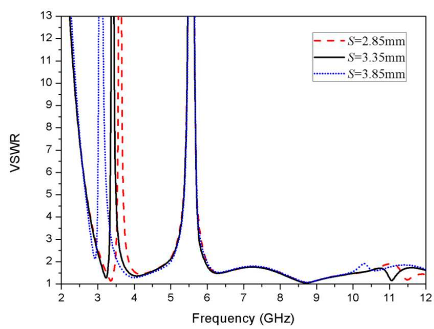


Figure 5. Simulated VSWR results of the Type III resonator with different lengths S.

The simulated surface current distributions of the proposed resonator at three resonant frequencies are shown in Figure 7. As shown in Figure 7(a), the current at 3.4 GHz is mainly distributed on the vertical line, the middle horizontal line and the via hole of the resonator. It can be seen that the signal coupled from the feed line to the resonator flows to the ground plane through the via hole, generating the first notch resonance. The current distribution at 5.5 GHz is mainly concentrated on the CLL element as shown in Figure 7(b). It captures and stores most of the input energy at the second resonance frequency

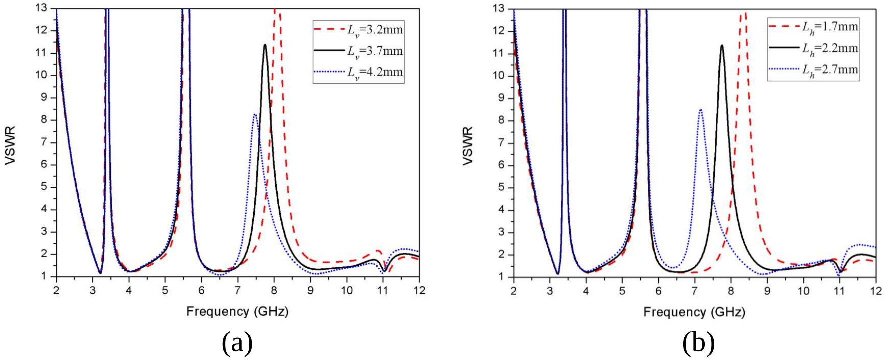


Figure 6. Simulated VSWR results of the proposed resonator with (a) different lengths L_v, (b) different lengths L_h.

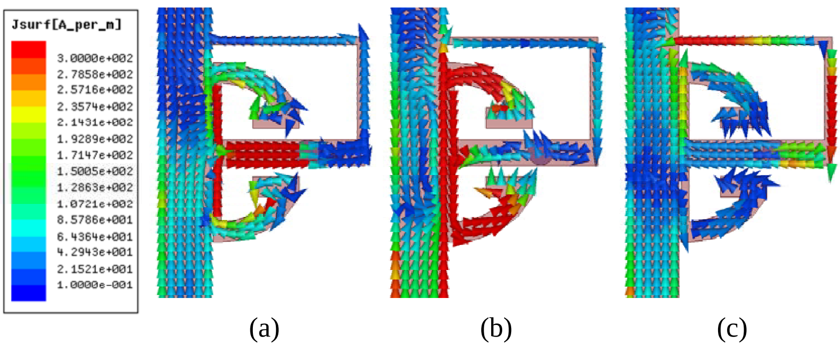


Figure 7. Simulated current distributions at (a) 3.4 GHz, (b) 5.5 GHz, (c) 7.8 GHz.

and thus obtain a filtering function. Comparing with other parts of the notch structure in Figure 7(c), a significant amount of current at 7.8 GHz is distributed on the outer line. Notch characteristic is found in this band, since the signal coupled from the main feed line to the resonator returns back to the feed line along the outer line, and the two signals meet at a phase difference of 180° [16, 17]. Therefore, the proposed modified CLL resonator can result in triple band-stop performance when placed next to the feed line and it can be equivalent to three shunt-connected series LC resonance circuits as shown in Figure 8. The transfer characteristics of the proposed CLL resonator are shown in Figure 9. It can be seen that it creates the desired notched bands at 3.3–3.6, 5.15–5.285 and 7.25–8.295 GHz bands by employing the proposed resonator along the main signal line.

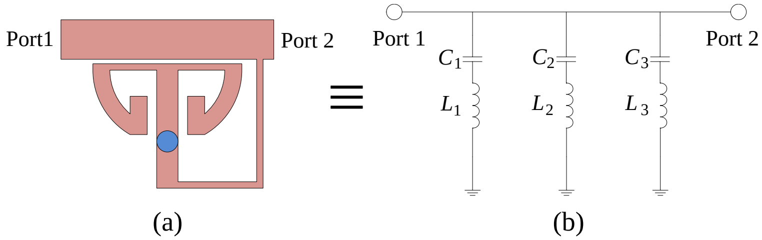


Figure 8. Geometry and equivalent circuit of the proposed CLL resonator.

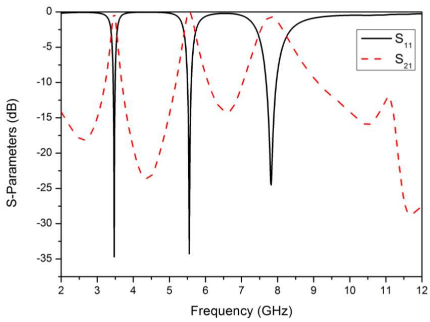


Figure 9. Transfer characteristic of the proposed CLL resonator.

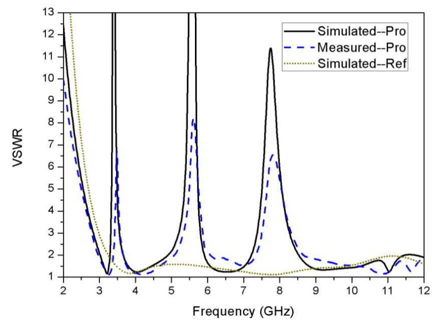
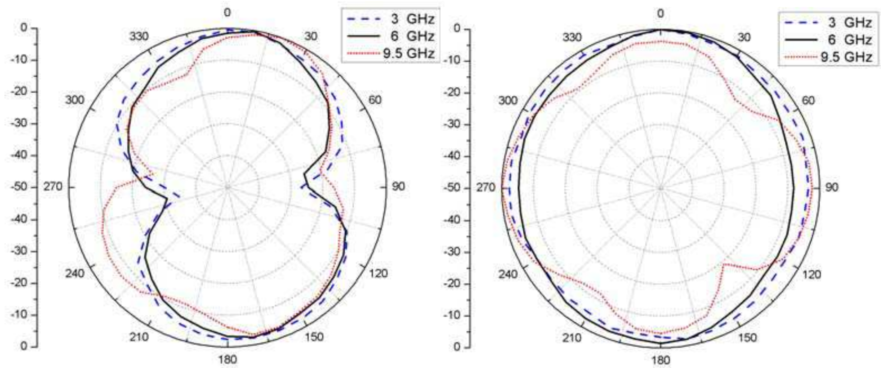


Figure 10. Simulated and measured VSWR results of the proposed antenna.

4. MEASUREMENT RESULTS AND DISCUSSION

The monopole antenna with the proposed resonator is successfully fabricated and measured. Figure 10 displays the measured and simulated VSWR for the antenna. Result of the reference antenna without notched characteristics is also shown for comparison. It can be observed that the designed antenna exhibits three rejected bands of 3.3–3.6, 5.15–5.825 and 7.25–8.395 GHz, while achieving a wideband performance from 3 to 12 GHz for VSWR < 2, which covers the entire UWB frequency band. The discrepancy between the simulated and measured results is probably owing to the fluctuation of the dielectric constant and tolerance in the manufacturing.

The measured radiation patterns in the E- (xy-) and H- (xz-) plane at 3, 6 and 9.5 GHz are plotted in Figure 11. It can be seen that the proposed antenna has a nearly omnidirectional radiation pattern in the H-plane and a dipole-like radiation pattern in the E-plane. The measured peak gains of the designed antenna are depicted in Figure 12,



E-plane (*yz*-plane) *H*-plane (*xz*-plane)

Figure 11. Measured E- and H-plane radiation patterns of the proposed antenna at 3, 6 and 9.5 GHz.

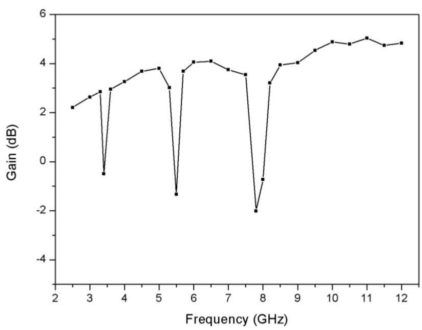


Figure 12. Measured gains of the proposed antenna.

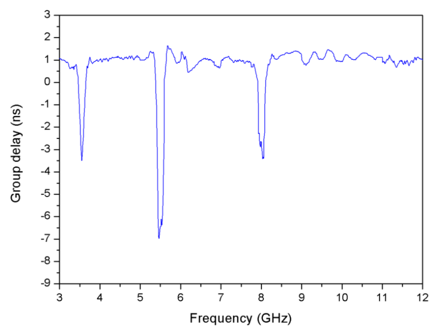


Figure 13. Measured group delay of the propose antenna.

which exhibits three sharp gain decreases at 3.4, 5.5 and 7.8 GHz as desired. To analyze the signal dispersion, the group delay is measured between two identical antennas in the face-to-face orientations, with a distance of 0.3 m between them. As presented in Figure 13, stable group delay is achieved except the three notched bands.

5. CONCLUSION

A novel compact microstrip-fed printed monopole antenna with triple-notched characteristics has been proposed for various UWB applications. By adjusting the parameters of the proposed modified CLL resonator, the desired rejected bands can be achieved. Employing this resonator in the vicinity of the feed line does not perturb the behavior of the radiating element, and this is the main advantage of the proposed method. Moreover, the simple structure, compact size and excellent performance make the proposed antenna a good candidate for various UWB applications.

REFERENCES

1. Federal Communications Commission, "Revision of Part 15 of the commission's rules regarding ultra-wideband transmission systems, first note and order," ET-Docket 98-153, Washington, DC, 2002.
2. Nguyen, D. T., D. H. Lee, and H. C. Park, "Very compact printed triple band-notched UWB antenna with quarter-wavelength slots," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 411–414, 2012.
3. Azim, R. and M. T. Islam, "Compact planar UWB antenna with band notch characteristics for WLAN and DSRC," *Progress In Electromagnetics Research*, Vol. 133, 391–406, 2013.
4. Hu, Y.-S., M. Li, G.-P. Gao, J.-S. Zhang, and M.-K. Yang, "A double-printed trapezoidal patch dipole antenna for UWB applications with band-notched characteristic," *Progress In Electromagnetics Research*, Vol. 103, 259–269, 2010.
5. Chu, Q. X. and Y. Y. Yang, "3.5/5.5 GHz dual band-notch ultra-wide-band antenna," *Electronics Letters*, Vol. 44, No. 3, 172–174, 2008.
6. Li, W. T., Y. Q. Hei, W. Feng, and X. W. Shi, "Planar antenna for 3G/Bluetooth/WiMAX and UWB applications with dual band-notched characteristics," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 61–64, 2012.
7. Li, C. M. and L. H. Ye, "Improved dual band-notched UWB slot antenna with controllable notched bandwidths," *Progress In Electromagnetics Research*, Vol. 115, 477–493, 2011.
8. Zhu, F., S. Gao, A. T. S. Ho, C. H. See, R. A. Abd-Alhameed, J. Li, and J. Xu, "Design and analysis of planar ultra-wideband antenna with dual band-notched function," *Progress In Electromagnetics Research*, Vol. 127, 523–536, 2012.
9. Weng, Y. F., S. W. Cheung, and T. I. Yuk, "Design of multiple band-notch using meander lines for compact ultra-wide band antennas," *IET Microwaves, Antennas & Propagation*, Vol. 6, No. 8, 908–914, 2012.

10. Lin, C.-C., P. Jin, and R. W. Ziolkowski, "Single, dual and tri-band-notched ultrawideband (UWB) antennas using capacitively loaded loop (CLL) resonators," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 1, 102–109, 2012.
11. Sung, Y., "UWB monopole antenna with two notched bands based on the folded stepped impedance resonator," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 500–502, 2012.
12. Emadian, S. R., C. Ghobadi, J. Nourinia, M. H. Mirmozafari, and J. Pourahmadazar, "Bandwidth enhancement of CPW-fed circle-like slot antenna with dual band-notched characteristic," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 543–546, 2012.
13. Zaker, R., C. Ghobadi, and J. Nourinia, "Bandwidth enhancement of novel compact single and dual band-notched printed monopole antenna with a pair of L-shaped slots," *IEEE Transactions on Antennas and Propagation*, Vol. 57, No. 12, 3978–3983, 2009.
14. Islam, M. T., R. Azim, and A. T. Mobashsher, "Triple band-notched planar UWB antenna using parasitic strips," *Progress In Electromagnetics Research*, Vol. 129, 161–179, 2012.
15. Tang, W. and J.-S. Hong, "Coupled stepped-impedance-resonator bandstop filter," *IET Microwaves, Antennas & Propagation*, Vol. 4, No. 9, 1283–1289, 2010.
16. Sanchez-Soriano, M. A., E. Bronchalo, and G. Torregrosa-Penalva, "Compact UWB bandpass filter based on signal interference techniques," *IEEE Microwave and Wireless Components Letters*, Vol. 19, 692–694, 2009.
17. Feng, W. and W. Che, "Novel ultra-wideband bandpass filter using shorted coupled lines and transversal transmission line," *IEEE Microwave and Wireless Components Letters*, Vol. 20, 548–550, 2010.