Progress In Electromagnetics Research, PIER 84, 321–332, 2008

A COMPACT ULTRA-WIDEBAND MICROSTRIP ANTENNA WITH MULTIPLE NOTCHES

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Abstract—In this paper, a new compact circular monopole ultra-wideband antenna with multiple narrow bands notched is proposed, which is implemented by using the existing techniques, such as loading a L-type band-stop filter, inserting a split ring resonator (SRR), and the method we proposed that connecting L branches on the radiation disk. Four sharp notches at 2.4 GHz, 3.5 GHz, 5.5 GHz, and 7.6 GHz are achieved separately. The measured VSWR shows a good agreement with the simulation results. The radiation patterns are obtained from Ansoft HFSS simulations and verified by CST Microwave Studio. The results prove that this kind of antenna can be applied in the UWB communication systems to avoid interference with other wireless systems, such as the 2.4 GHz WLAN, 3.5 GHz WiMax, and 5.8 GHz WLAN etc. The parameters determining the antenna's band notched characteristic are discussed.

1. INTRODUCTION

The commercial usages of frequency band from 3.1 GHz to 10.6 GHz, was approved by Federal Communications Commission (FCC) in 2002 [1]. To satisfy such requirement various ultra-wideband antennas have been studied [2–16]. But the frequency range for UWB systems will cause interference to the existing wireless communication systems, so the UWB antennas with a band-notched characteristic are required. To satisfy such requirement various ultra-wideband antennas with notched band have been studied [17–26]. The slot was used in [17–21] to achieve the band-notched characteristic. The method of add the parasitic patch was used in [22, 23]. And Ren at al. [24] proposed an inverted-T structure. An L-type band-stop filter was first proposed in [27], and was used in [25, 26] to produce the band-notched characteristic in their ultra-wideband antennas. But most of the antennas can generate no more than two notched bands.

In the paper, we present a new compact circular monopole ultrawide band antenna with four narrow bands notched, which is implemented by using the existing techniques, such as loading a L-type band-stop filter [25, 26], inserting a split ring resonator (SRR), and the method we proposed that connecting L branches on the radiation disk. Details of the antenna design are described. And the antenna was fabricated by a standard printed circuit board (PCB) technology. The measured VSWR shows a good agreement with the simulation results. The radiation patterns are obtained from Ansoft HFSS simulations, which are based on the Finite Element Method (FEM), and verified by CST Microwave Studio based on the finite integration method. All of the results certify that the antenna is a promising candidate for UWB communication systems to avoid interference with other wireless systems.

2. ANTENNA CONFIGURATION

We first selected a normal printed circular disk monopole antenna, which can cover the frequency range from 3.1 GHz to 10.6 GHz for VSWR ≤ 2. The substrate has a relative permittivity of 2.65 and a thickness of 0.5 mm. We selected three frequency points 2.4 GHz, 3.5 GHz, and 5.5 GHz as center frequencies of the stopbands, so the antenna will not interfere with the other wireless communications systems, such as 2.4 GHz WLAN, 3.5 GHz WiMax, and 5.8 GHz WLAN systems.

The geometry of the proposed ultra-wideband antenna is depicted in Figure 1. We used a L-type band-stop filter, which was proposed in [27] and used in [25, 26], to produce the first notch at 2.4 GHz. Then a split ring resonator (SRR), first proposed by Pendry to construct the left-hand materials [28], was used to bring the second notch at 3.5 GHz. Finally, we proposed a structure that the L branches on the radiation disk to achieve the third notch at 5.5 GHz. The length of $L_3 + L_4$ is about a quarter of the wavelength of notch at 5.5 GHz. The geometry parameters of the antenna are $W_s = 42$ mm, $L_s = 48.7$ mm, $W_0 = 1.38$ mm, $W_1 = 1.3$ mm, $W_2 = 0.2$ mm, $g_0 = 0.33$ mm, $L_y = 27$ mm, $L_1 = 11.2$ mm, $L_2 = 9.5$ mm, $L_3 = 1$ mm, $L_4 = 9.77$ mm, $g = 1$ mm, $a = 10.07$ mm, $c = 1$ mm, $t = 1$ mm, $R_0 = 15$ mm, $R_1 = 15.8$ mm, $\theta = 150°$, $\phi = 80°$. The prototype photo of the proposed antenna is shown in Figure 2.

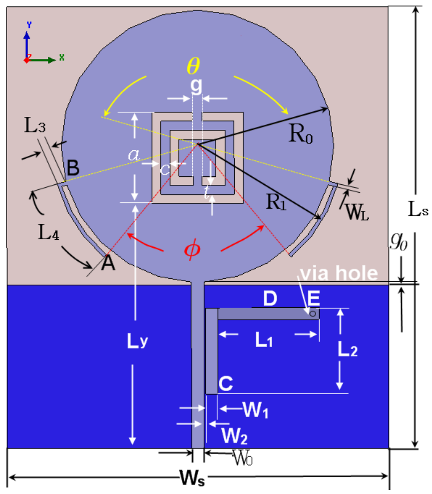
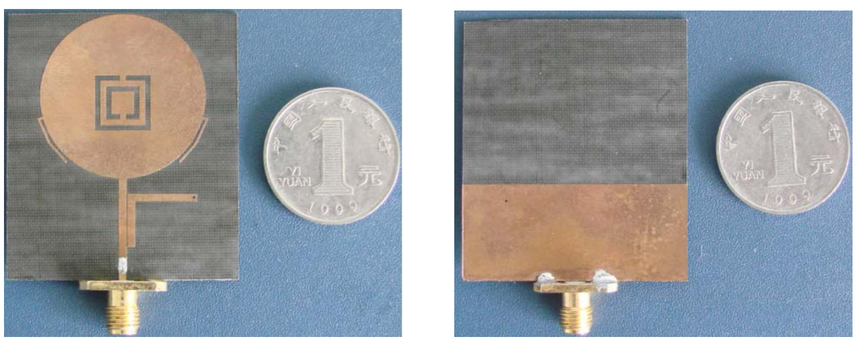


Figure 1. Schematic diagram of the proposed antenna.



(a) (b)

Figure 2. Fabricated sample of the proposed antenna. (a) top view, (b) bottom view.

3. BAND-STOP FILTER DESIGN

The first notch at 2.4 GHz was produced by the L-type band-stop filter, which was proposed in [27]. Figure 3 shows the typical configuration of the L-resonator. A main transmission line is electromagnetically couple to the open-circuited half wavelength resonator or the short-circuited quarter wavelength resonator [26]. In our design, we chose the short-circuited quarter wavelength resonator in order to reduce the size.

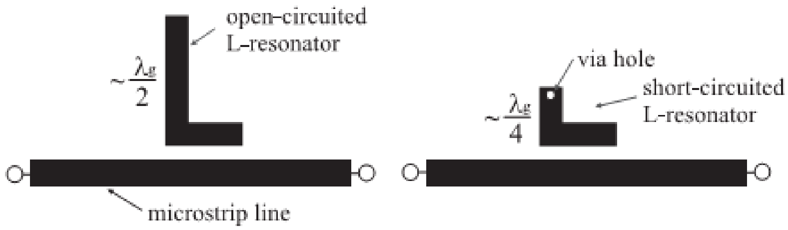


Figure 3. Configuration of the L-resonator.

The SRR can be considered as an electronically small resonator with a very high Q, it is a very useful structure in constructing filters requiring a sharp notch or pass of a certain frequency band. In this paper, we used the SRR to bring the second notch at 3.5 GHz. According to [29], the equivalent circuit can be described by a simple LC resonator and the resonance frequency can be postulated as Equation (1), which we can used to estimate the rough size of the SRR.

$$\omega_0 = \sqrt{\frac{2}{\pi r_a L_0 C}} \tag{1}$$

where L_0 is the per unit length inductance between the rings, C is the total capacitance of the SRR, and r_a is the average radius of the SRR. The average girth of the slotted rectangles is about shorter than a half wavelength at resonance.

Finally, we proposed a structure that the L branches on the radiation disk to achieve the third notch at 5.5 GHz. The length of $L_3 + L_4$ is about a quarter of the wavelength of notch at 5.5 GHz. The band notched frequency can be easily changed by the method we proposed.

After getting the initial size of the antenna by the method above, we adjust the geometry to achieve the accurate notches for the final design.

4. PERFORMANCES OF THE PROPOSED ANTENNA

Figure 4 shows the simulated and measured VSWR results of the proposed antenna with four notches. It shows that the proposed antenna provides a wide impedance bandwidth of 2.2–10.8 GHz (measured), and presents four sharp notched bands. The quantitive performances of the antenna are listed in Table 1. From the results we can know that the antenna will not bring interference with the other wireless communications systems. The fourth notched band is achieved

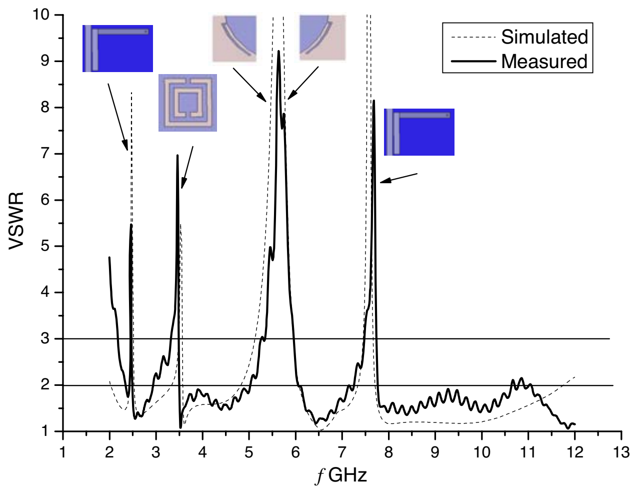


Figure 4. Simulated and measured results of VSWR.

Table 1. The quantitive performances of the antenna.

Simulated	VSWR ≥ 2			
	2.39 GHz ~2.53 GHz	3.35 GHz ~3.575 GHz	4.85 GHz ~6.05 GHz	7.35 GHz ~7.7 GHz
	2.42 GHz ~2.49 GHz	2.94 GHz ~3.5 GHz	5.03 GHz ~6.05 GHz	7.253 GHz ~7.762 GHz
Measured	VSWR ≥ 3			
	2.4 GHz ~2.51 GHz	3.48 GHz ~3.56 GHz	5.128 GHz ~5.94 GHz	7.45 GHz ~7.66 GHz
	2.45 GHz ~2.47 GHz	3.32 GHz ~3.49 GHz	5.25 GHz ~5.96 GHz	7.46 GHz ~7.74 GHz

by the L-type resonator. Because the lengths of CD and DE are about a half wavelength and quarter wavelength at the fourth resonance respectively, it just like that the point D is shorted. So the branch CD plays a role as another L-type resonator at the fourth resonance. Roughly say, the measured results are in agreement with the simulated results. The discrepancy between simulation and measurement maybe due to the reasons as below:

1. The joining of the SMA connector.
2. The indoor measurement environment.
3. The error of the Simulation and fabrication.
4. The error of the substrate's relative permittivity and thickness.

The simulated radiation patterns at 2.25 GHz, 4 GHz, 6.5 GHz, and 9 GHz are shown in Figure 5. In the H plane, the proposed antenna shows an omnidirectional radiation characteristic across the

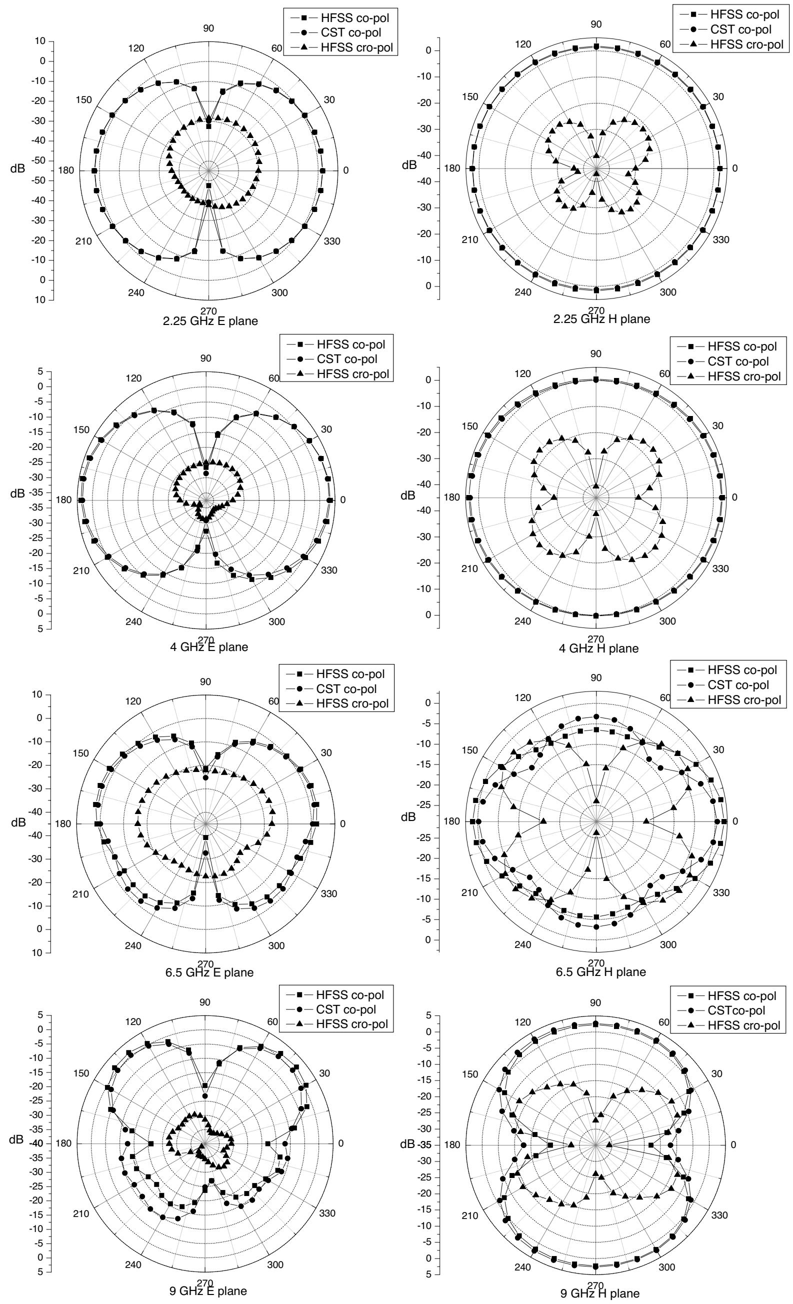


Figure 5. Simulated radiation pattern of the improved antenna at 2.25 GHz, 4 GHz, 6.5 GHz, and 9 GHz.

whole operating band, but larger fluctuations appears in the E plane. They deteriorate because the equivalent working area is different in the wide operation frequency. And the seriously unequal phase distribution and larger magnitude of high order mode at higher frequencies on the slot are not improved also play a part in the deterioration.

Figure 6 shows the HFSS simulated current distributions of the antenna at 2.42, 3.5, 5.6, and 7.6 GHz.

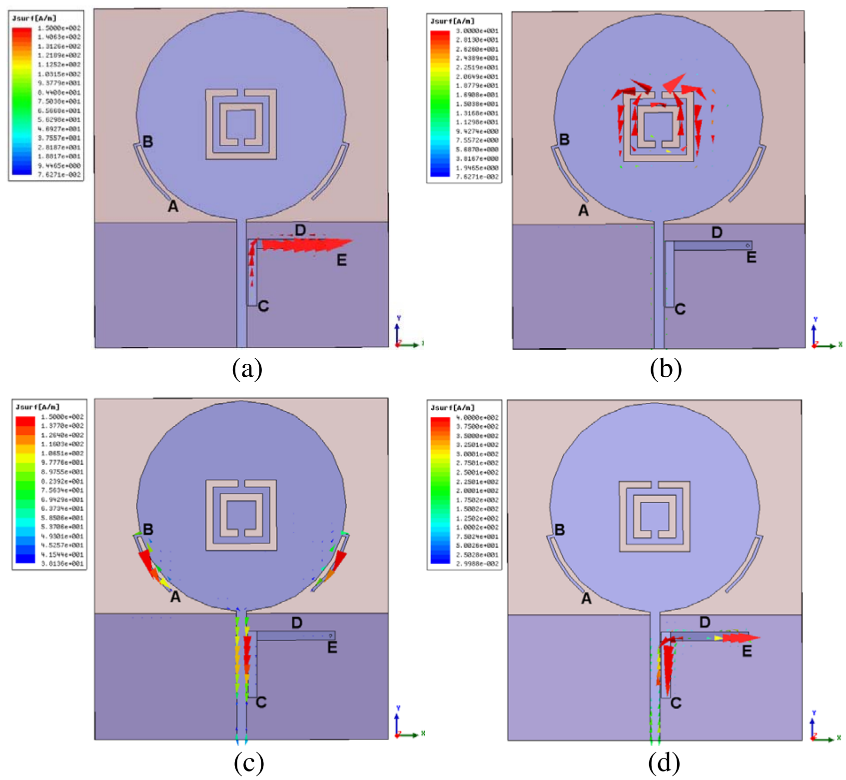


Figure 6. HFSS simulated current distributions at: (a) 2.42 GHz, (b) 3.5 GHz, (c) 5.5 GHz, (d) 7.6 GHz.

At the notch band of 2.42 GHz and 7.6 GHz the currents are concentrated at the L-type band-stop filter than any other area, then the antenna is not radiated. We can find that the current directions at 2.42 GHz are not changed from the open-circuited end to the short-circuited end. But at 7.6 GHz it inverted. This is also proves that the first and fourth notched band are both achieved by the L-type resonator. The length of CD is about a quarter of wavelength at the first resonance. And the length of CD and DE is about a half wavelength and quarter wavelength at the fourth resonance respectively, it just like that the point D is shorted. So the branch CD plays a role as another L-type resonator at the fourth resonance.

At 3.5 GHz for the WiMax, the strong current distributions were observed along the two slots of the SRR. It is observed that the currents directions near the edges of the two slots are oppositely directed. As a result, fields between the edges of the two slots are cancelled each other at the notch frequency.

At 5.5 GHz for the 5 GHz WLAN, the strong current distributions were observed along the L branches on the radiation disk. We can analyze it as follow. At point A, the L branch is opened, when transfer to point B at the notched frequency of 5.5 GHz, it just like about shorted. So the radiation current becomes ineffectively.

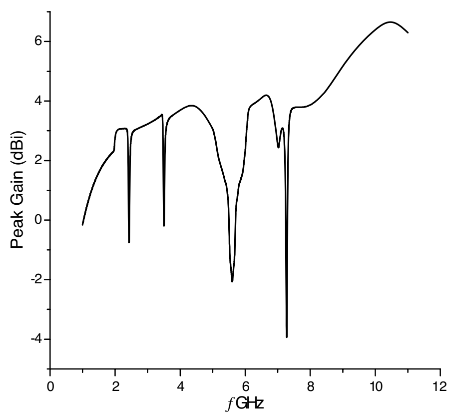


Figure 7. The peak gain of the proposed antenna.

Furthermore, Figure 7 shows the antenna's peak gain against frequency of the proposed antenna. The simulated peak gains within the operation frequency bands range from 1 dBi to 6.3 dBi. As expected, the peak gain is lowest in the vicinity of 5.5 GHz. Very sharp selectivity was observed from the experimental results of the band notch antenna.

5. PARAMETRIC STUDIES OF THE PROPOSED ANTENNA

Since the L-type band-stop filter has been reported exactly [25–27], and the resonance frequency of the SRR can be postulated as (1), so we only to discuss the structure that the L branches on the radiation disk. In the numerical simulation, only one absolute parameter was varied every time, whereas the others were kept constant. Noticed, L_3 and L_4 are not absolute parameters, they lie on the value of R_1 and WL.

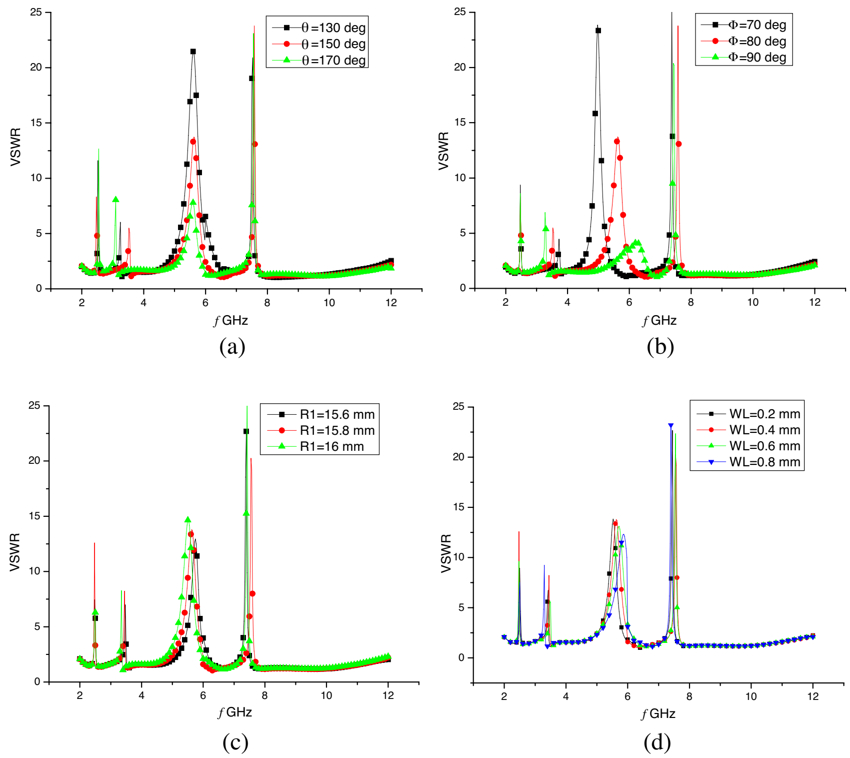


Figure 8. Simulated VSWR of the proposed antenna with different (a) θ (b) ϕ (c) R_1 (d) WL.

It is seen from Figure 8(a), with the increase of θ, the peak value of the third notch decrease. This is because more and stronger current distributions in the area, which near the feed point of the circular patch at 5.5 GHz. And it also can be used to explain for the phenomena in Figure 8(b), (c), (d). The simulated return losses curves in Figure 8(b) demonstrate that with the increase of ϕ, the third notch increase, but the peak value of the third notch decrease. It verifies the conclusions educed in Section 4 that, the length of $L_3 + L_4$ is about a quarter of the wavelength of the notch at 5.5 GHz. We can find that the changes of θ and ϕ also affect the second notch for they affect the current distributions.

From Figure 8(c) we can know that with the increase of R_1, the third notch decrease and the peak value increase slightly. It is seen from Figure 8(d), with the increase of WL, the third notch increase and the peak value decrease slightly. It is because that the changes of R_1 and WL make the length of $L_3 + L_4$ changes.

Directed by these conclusions, by carefully selecting the dimensions value of the antenna, the third notch can be achieved accurately.

6. CONCLUSION

In this paper, a new compact circular monopole ultrawide band (UWB) antenna with four narrow bands notched is proposed, which is implemented by using the existing techniques, such as loading a L-type band-stop filter, inserting a split ring resonator (SRR), and the method we proposed that connecting L branches on the radiation disk. All of the rules to select the notches are introduced detailed. The VSWR, radiation patterns, and gain of the antenna have been investigated intensively. From the above results, it may be concluded that the proposed antenna is a viable candidate for UWB wireless communications applications.

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