Progress In Electromagnetics Research, PIER 96, 141–154, 2009

STUDY OF A NOVEL WIDEBAND CIRCULAR SLOT ANTENNA HAVING FREQUENCY BAND-NOTCHED FUNCTION

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Abstract—In this paper, the design, simulation, and fabrication of a novel printed circular slot antenna with a band-notched function suitable for UWB application is presented and investigated. The band–notched characteristic is achieved and adjusted by inserting L-shaped branches into the ground plane. Experimental results show that the proposed antenna meets the requirement of wide working bandwidth of 3.1–10.6 GHz with return loss < -10 dB, while avoiding the interference with the 5-GHz WLAN band. The study of transfer function (amplitude of S_{21}/group delay) and time domain characteristic (fidelity/power spectrum density (PSD)) indicate a band-notched function of the antenna. The proposed antenna has a compact size, good radiation characteristics, ultra wide band-width, and good time-domain behaviors to satisfy the requirement of the current wireless communication systems.

1. INTRODUCTION

The ultra-wideband (UWB) communication systems have gained much attention due to their many advantages including the low-spectral-density radiated power and potential for accommodating higher data rate. Several slot antennas for UWB application have been reported so far [1–7]. To avoid the interference between the UWB system and the wireless local area network (WLAN) system with 5.15–5.825 GHz frequency band, a band-notched filter in the UWB system is necessary. However, the use of a filter will increase the complexity of the UWB

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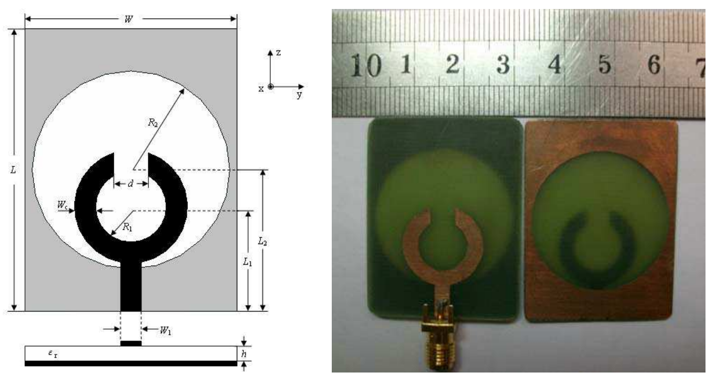
system. Therefore, a UWB antenna having frequency band-notched characteristic is an alternative choice to overcome this problem. Several antennas with band-notched characteristic have been reported [8–19].

In this paper, we propose a novel band-notched wideband circular slot UWB antenna. The band-notched characteristic is achieved by inserting L-shaped branches structure to the ground other than the feed line element. By adjusting the location and length of the branches, the band-notched function can be realized. Experimental and simulated results of the constructed prototype are presented, and the transfer function and time domain characteristics [20–23] are studied to evaluate the antenna.

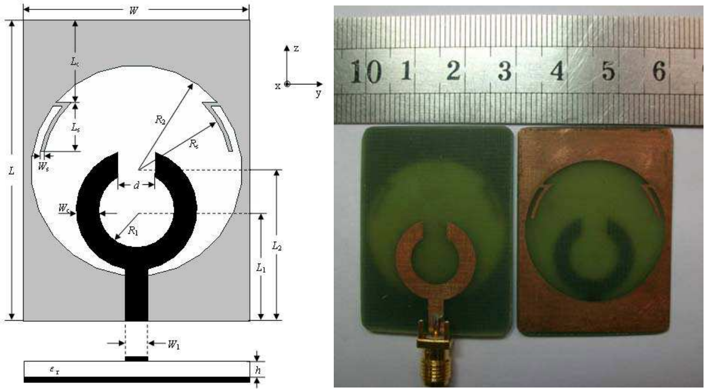
2. ANTENNA DESIGN AND RESULTS

Figures 1 and 2 show the proposed wideband circular slot antenna without/with band-notched function, respectively. As shown in Figure 1, the circular slot antenna is fabricated on a substrate with relative dielectric constant of $\varepsilon_r = 4.4$ and thickness of $h = 1.4$ mm with width and length of W and L. The radiation element is a circular arc which is fed by microstrip line. The circular arc has a width of W_c and inner radius of R_1. The width of microstrip feed line is fixed at W_1 to achieve $50\,\Omega$ characteristic impedance. The ground has a same size as the substrate and the inner profile of the ground is a circular cut with radius of R_2. The proposed slot antenna can cover all the 3.1–10.6 GHz UWB band. In order to achieve band-notched operation, two L-shaped branches with an inner radius of R_s, a width



(a) Geometry (b) Photograph

Figure 1. The geometry and photograph of the wideband circular slot antenna (Ant-1).



(a) Geometry (b) Photograph

Figure 2. The geometry and photograph of the notched wideband circular slot antenna (Ant-2).

Table 1. The dimensions of the proposed Ant-1 and Ant-2. All dimensions are in millimeters.

Parameter	W	L	W_1	L_1	L_2	R_1	R_2	W_c	d	R_s	L_c	L_s	W_s
Value	30	40	3	14.8	20	5	14	3	5	12.5	11	6.5	0.5

of W_s are inserted to the ground plane, as it is shown in Figure 2. The branches destroy the surface current on the ground, so that the antenna makes negative response at the notched frequency. Location and length of the branches is adjusted so that the proposed wideband circular slot antenna achieves a band-notched characteristic at the designed frequency.

The simulation of antenna is taken by using CST Microwave Studio software based on the method of finite integration technology (FIT), and the measurement is achieved by using Agilent E8363B Vector Network Analyzer. Table 1 shows the optimized dimensions of the antennas, and the prototype of Ant-1 and Ant-2 is constructed and investigated.

Figure 3 shows the measured and simulated return loss for the constructed prototype. It is clearly seen that band-notched characteristic of Ant-2 is obtained by inserting L-shaped branches into Ant-1. Simulation and measurement of the band-notched antenna agree well with each other. For Ant-2, the simulated return loss of lower than -10 dB is from 2.2 to 10.6 GHz, in which a frequency-notched band from 5.0 to 5.9 GHz has been achieved. The measured notched band for return loss > −10 dB is a little wider than the simulated one. This difference is mainly caused by the fabrication error, the SMA connector, and numerical error. Both the measured and simulated results are suitable for UWB antenna with 5-GHz notched band.

In order to study the notched characteristics of Ant-2. The parameters L_c, L_s and R_s which define the dimension of L-shaped branches are studied. The width of L-shaped branches W_s shows less influence on the return loss of the antenna, so the simulation is fixed

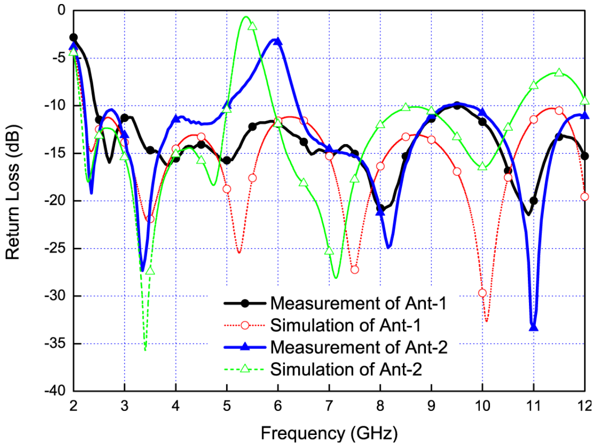


Figure 3. The measured and simulated return loss of the Ant-1 and Ant-2.

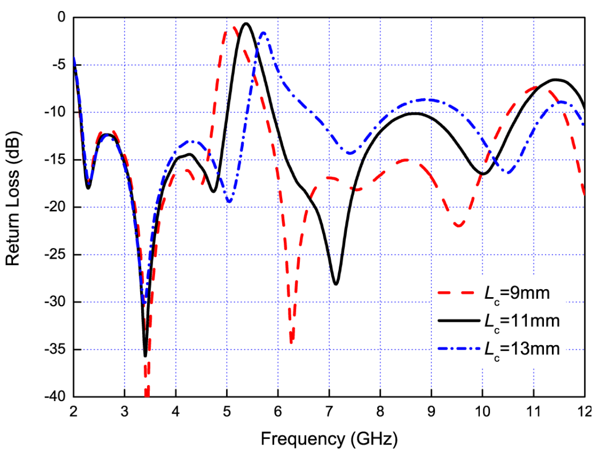


Figure 4. The effect of changing L_c on the return loss.

at $W_s = 0.5\,\mathrm{mm}$ in the parameter study.

The effect of branches location L_c on the band-notched characteristics is shown in Figure 4, as it is seen that the notched frequency of the proposed antenna increase by increasing the L_c. Figure 5 shows the simulated return loss against frequency for antennas with various branches length L_s. The center of notched frequency is about 5.4 GHz when $L_s = 6.5\,\mathrm{mm}$, and the notched frequency band decrease by increasing the branch length L_s.

Figure 6 indicates the simulated results for the proposed antenna

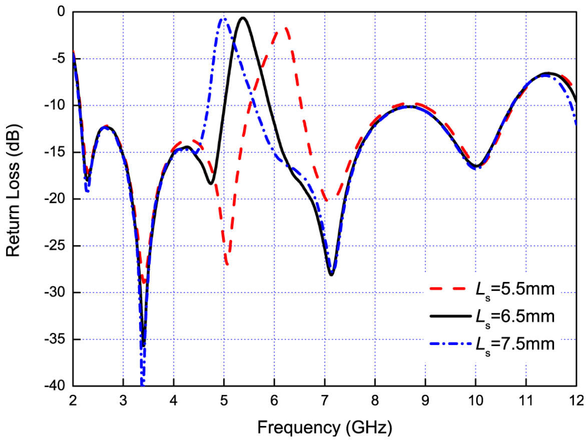


Figure 5. The effect of changing L_s on the return loss.

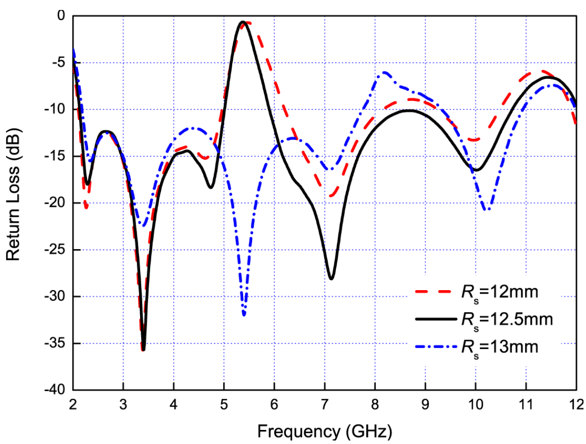
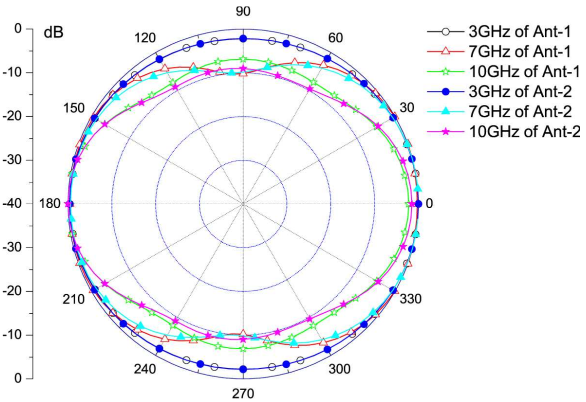


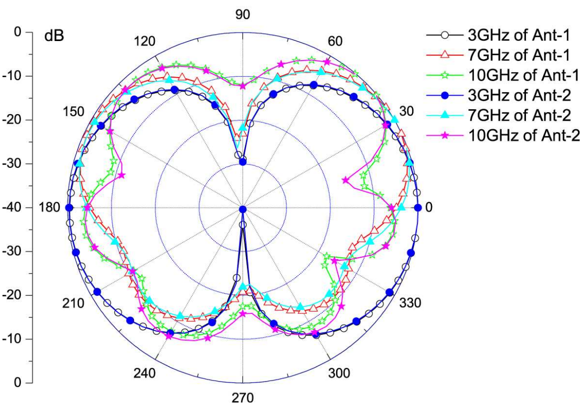
Figure 6. The effect of changing R_s on the return loss.

for $R_s = 12$, 12.5 and 13 mm with other fixed dimensions. The inner radius of the branches has a less influence on the center notched frequency band. But there is no notched frequency characteristics when $R_s = 13$ mm, so the gap between the branches and ground should not be too small in our design.

The simulated radiation patterns in the *H*-plane and *E*-plane of Ant-1 and Ant-2 are plotted in Figures 7(a) and 7(b), respectively. It can be seen that Ant-1 and Ant-2 have a similar radiation patterns at 3 GHz, 7 GHz and 10 GHz. The *H*-plane radiation patterns are approximately omni-directional over the entire operation frequencies,



(a)



(b)

Figure 7. The simulated radiation patterns at different frequencies. (a) *x*-*y* plane (*H*-plane); (b) *x*-*z* plane (*E*-plane).

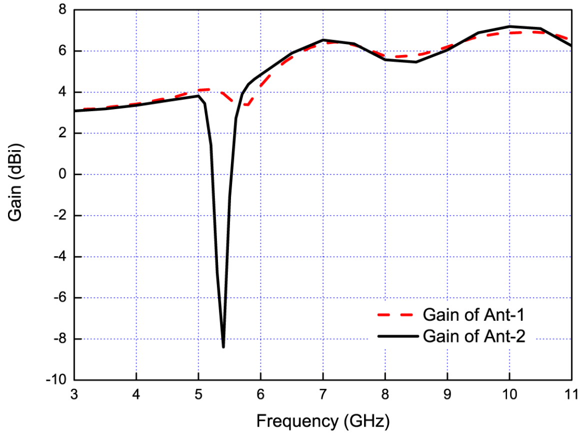


Figure 8. The gain against frequency for Ant-1 and Ant-2.

and the radiation is relatively stable. The E-plane radiation patterns at 3 GHz are about the same as that of a dipole antenna, while it become butterfly-shaped at 7 GHz and 10 GHz. So the E-plane pattern is monopole-like, and the number of lobes rises with the increase of frequency which means the antennas get more directional.

Figure 8 shows the peak gain of Ant-1 and Ant-2 against frequency. For Ant-1, the peak gain is relatively flat over the operation band and the variation is from 3.16 dBi to 6.91 dBi (3–11 GHz). The peak gain of Ant-2 is similar to Ant-1 in the operation band, while a large drop in the notch-frequency band is observed. The peak gain is the lowest in the vicinity of 5.4 GHz (-8.40 dBi). This result presents that the Ant-2 is successfully performed with the rejection in the 5–6 GHz WLAN band.

3. TRANSFER FUNCTION AND TIME DOMAIN STUDY

3.1. Transfer Function Measurement

Since UWB systems use short pulses to transmit signals, it is crucial to study the transfer function for evaluating the proposed antenna's performance and designing transmitted pulse signals. The UWB antenna can be viewed as a filter with some magnitude (antenna gain) and phase response. The phase response and group delay are related to the antenna gain response. The group delay is able to clearly show any nonlinearity that may be present in the phase response and indicates the degree of the distortion. For UWB applications, the magnitude of the transfer function should be as flat as possible in the operating band. The group delay is required to be constant over the entire band as well.

The transfer function measurement was taken out by using Agilent E8363B Vector Network Analyzer as shown in Figure 9. A pair of the proposed antenna is used as the transmitting and receiving antenna. The transmitter and receiver are positioned face to face (x directions opposite) with a distance of 10 cm. By considering the antenna system as a two-port network, the transmission scattering parameter S_{21} which indicates the transfer function is measured. It should be noted that the measurement was carried out in a real environment with reflecting objects in the surrounding area.

The measured amplitude of S_{21} is shown in Figure 10. The amplitude of S_{21} for Ant-1 is relatively flat from 3 GHz to 9 GHz

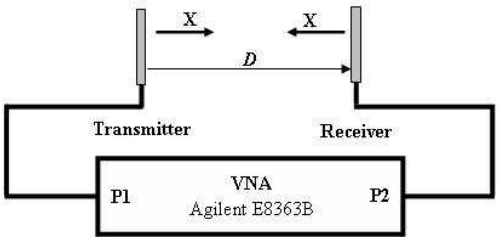


Figure 9. The transfer function measurement set up.

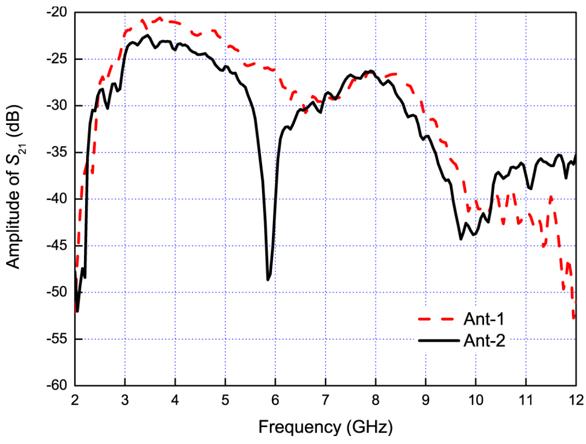


Figure 10. The measured Amplitude of S_{21} for the antenna systems.

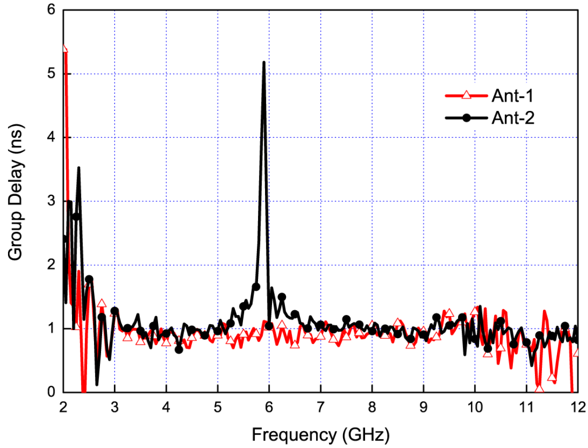


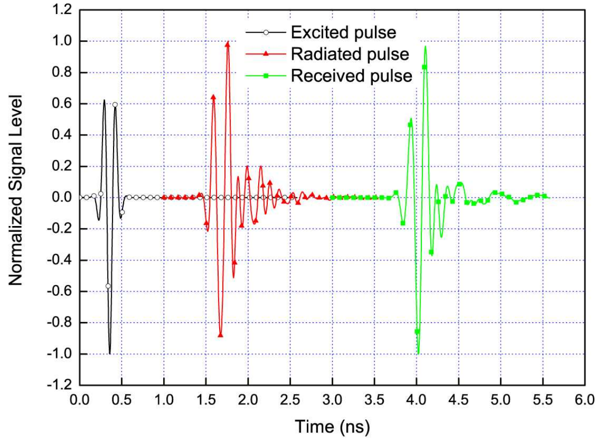
Figure 11. The measured group delay of the antenna systems.

(variation less than 10 dB). When the frequency is less than 3 GHz and more than 9 GHz, the measured results decrease rapidly. The measured results for Ant-2 have an attenuation of about 20 dB in the notched band, while a similar result as Ant-1 is obtained outside the notched band. Then it reveals the band-notched characteristic of the antenna.

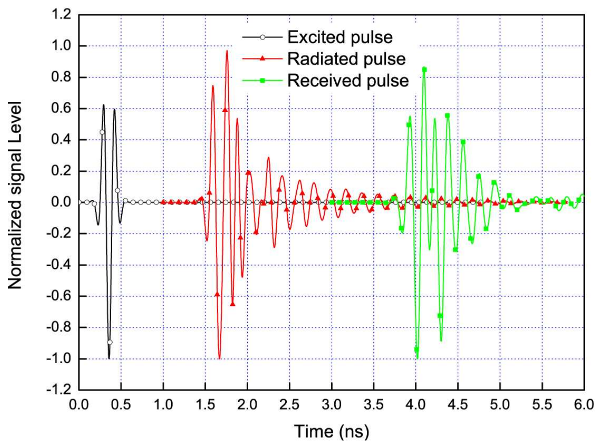
Figure 11 shows the measured group delay of the antenna systems. The Ant-1 shows a flat result in 3.1–10.6 GHz UWB band and the variation of group delay is less than 1 ns. The variation of the group delay for Ant-2 is within 1.5 ns across the whole UWB band except the notched band, in which the maximum group delay is more than 5 ns. The group delay corresponds well to the magnitude and phase of S_{21}, so it proves that the antenna has a good time-domain characteristic and a small pulse distortion as well.

3.2. Time Domain Study

Time domain study based on the measurement set up as shown in Figure 9, so the pulse in x direction can be evaluated. Figures 12(a) and 12(b) show the excited pulse, radiated pulse and received pulse of Ant-1 and Ant-2, respectively. In order to see clearly, the waveforms have been moved parallel along the abscissa. It can be seen that the radiated pulse and received pulse are distorted as compared to excited pulse, so we can study the fidelity and the normalized power spectrum density (PSD) to evaluate the characteristics of pulses.



(a)



(b)

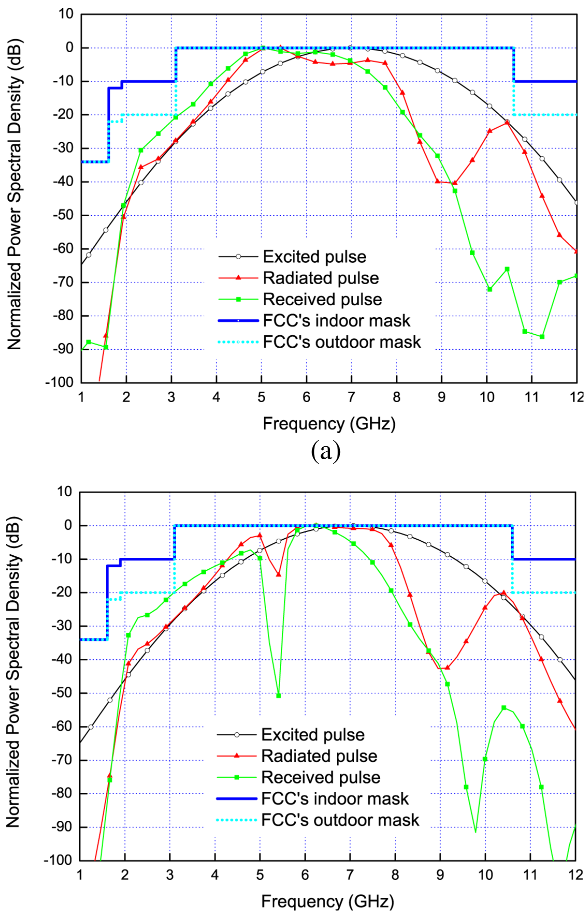
Figure 12. The pulse waveforms for the antenna system. (a) Ant-1; (b) Ant-2.

The fidelity is defined as

$$\rho = \max_{\tau} \left\{ \left| \frac{\int p(t)s(t-\tau)dt}{\sqrt{\int p^2(t)dt}\sqrt{\int s^2(t)dt}} \right| \right\} \quad (1)$$

where τ is a delay which is varied to make the numerator in Eq. (1) a maximum. It determines the correlation between the electric field signals $s(t)$ and $p(t)$. The excited pulses are chosen as the reference signal $p(t)$, while the radiated pulse and received pulse as signal $s(t)$.

The calculated fidelity is shown in Table 2. For Ant-1, the fidelity between excited and received pulse is 0.7909, which is a little smaller than the fidelity between excited and radiated pulse of 0.7968. So it indicate that the radiated and received pulse have the similar waveform. For Ant-2, the fidelity between excited and radiated pulse is 0.7290, it is less than the result of Ant-1 for 0.7968. This result can be explained by the band-notched characteristic of the Ant-2. The fidelity between excited and received pulse is 0.6322, it shows that the antenna have band-notched function in the received state as compared to 0.7290.



(a)

(b)

Figure 13. The normalized power spectrum density (PSD) of pulses for the antenna systems. (a) Ant-1; (b) Ant-2.

Table 2. Fidelity factor between excited pulse and radiated/received pulse.

	Radiated pulse	Received pulse
Ant-1	0.7968	0.7909
Ant-2	0.7290	0.6322

Figures 13(a) and 13(b) show the normalized power spectrum density (PSD) of the excited pulse, radiated pulse and received pulse for Ant-1 and Ant-2, respectively. It is seen that all the pulses comply with FCC's emission mask. In Figure 13(a), reduction of the bandwidth of the radiated and received pulse's PSD can be seen in comparison with PSD of the excited pulse. In Figure 13(b), The PSD of radiated and received pulse shows a similar result as compared to Figure 13(a), while the PSD decrease in the notched band, which confirms the transfer function results.

4. CONCLUSION

A novel band-notched UWB circular slot antenna with L-shape branches inserting to the ground is investigated in this paper. The study of return loss and gain show that the antenna has a band-notched characteristic at 5-GHz WLAN band. Monopole-like radiation patterns is observed for the antenna. Transfer function (amplitude of S_{21}/group delay) and time domain characteristic (fidelity/power spectrum density (PSD)) results show that the proposed notched antenna have band-notched characteristics in the WLAN band, which confirms the results of return loss and gain.

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