Compact Monopole Antenna With Band-Notched Characteristic for UWB Applications

Hsien-Wen Liu, *Student Member, IEEE*, Chia-Hao Ku, Te-Shun Wang, and Chang-Fa Yang, *Member, IEEE*

***Abstract*—A compact planar monopole antenna with standard band-notched characteristic suitable for ultrawideband (UWB) applications is presented. This microstrip-fed antenna, consisting of a square slot patch with a vertical coupling strip, only occupies a small size of 15 (L) $\times$ 15 (W) $\times$ 1.6 (H) mm^3. By properly designing the strip placed at the center of the patch, good frequency rejection performance of the antenna with a wide operating band from 3.05 to 11.15 GHz can be obtained. Compared to other designs, the antenna has a quite simple structure to make the band-notched property to reduce the effect caused by the frequency interference. Furthermore, fairly good omnidirectional radiation patterns and transmission responses both indicate that the proposed antenna is well suited to be integrated within various portable devices for UWB operation.**

***Index Terms*—Band-notched, monopole antenna, ultrawideband (UWB).**

I. Introduction

RECENTLY, ultrawideband (UWB) wireless communication techniques (3.1–10.6 GHz) have earned a lot of attention due to their merits such as high data rate, small emission power, and low cost. To tackle the effect caused by the frequency interference from WLAN (5.15–5.825 GHz) and WiMAX (5.25–5.85 GHz) systems, some UWB antennas with band-notched feature have been designed in [1]–[8]. One simple way is to etch thin slots on the antenna surface, such as L-shaped slot [1], U-shaped slot [2]–[4], and T-shaped slot [5]. By adding either a split-ring resonator (SRR) [6], [7] or a multiresonator load [8] in the antenna structure, the undesired frequencies can be rejected so that the system performance may be enhanced well. However, all of these designs need a complex structure to generate and control the stopband property, so that the cost in fabricating antenna will be increased for practical applications.

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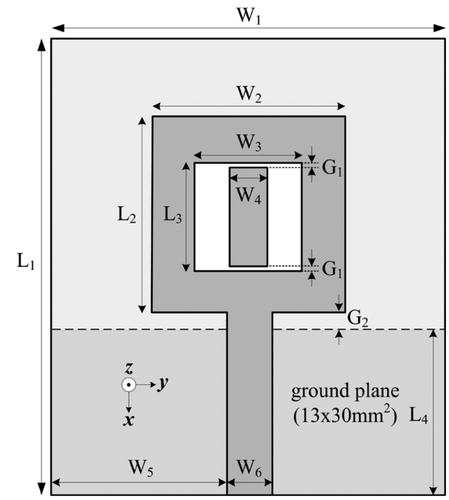

Fig. 1. Geometry of the proposed UWB band-notched antenna. ($L_1 = 35$ mm, $L_2 = 15$ mm, $L_3 = 8.3$ mm, $L_4 = 13$ mm, $W_1 = 30$ mm, $W_2 = 15$ mm, $W_3 = 8.3$ mm, $W_4 = 3$ mm, $W_5 = 13.3$ mm, $W_6 = 3.4$ mm, $G_1 = 0.2$ mm, and $G_2 = 1$ mm).

In this letter, we thus propose a printed monopole antenna that simply employs a vertical coupling strip to flexibly control the rejection frequency band for UWB system operation. Unlike those conventional designs, quite stable radiation performance of the antenna can be achieved as the major design parameters of the stopband are modified. This makes it possible for the proposed UWB band-notched antenna with a compact size of 15 (L) $\times$ 15 (W) $\times$ 1.6 (H) mm^3 to be integrated within different portable devices without the need for retuning the whole design structure. Details of the design concept of the antenna are then described in Section II, and a fabricated prototype of the proposed antenna is constructed and experimentally studied in Section III. Moreover, a number of design parameters in regard to the stopband feature are analyzed for the antenna, whose transmission characteristics including magnitude and group delay are further measured and discussed. Finally, this letter is concluded with a brief summary in Section IV.

II. Antenna Design

Fig. 1 shows the whole geometry with detailed design parameters of the proposed UWB band-notched antenna, which is fabricated on a 1.6-mm-thick FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and loss tangent $\tan\delta = 0.02$. This antenna is fed by a 50-Ω microstrip line with a width of 3.4 mm and is implemented using a square slot patch with a vertical coupling strip. Furthermore, the overall dimensions of the antenna were merely 15 (L) $\times$ 15 (W) mm^2, and a ground plane was selected with a length of 13 mm and a width of 30 mm.

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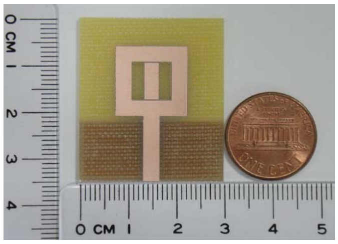


Fig. 2. Photograph of the proposed UWB band-notched antenna.

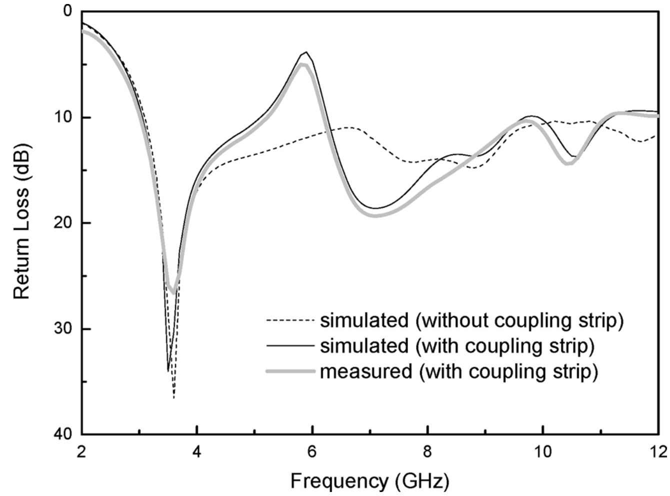


Fig. 3. Simulated and measured return loss of the proposed antenna.

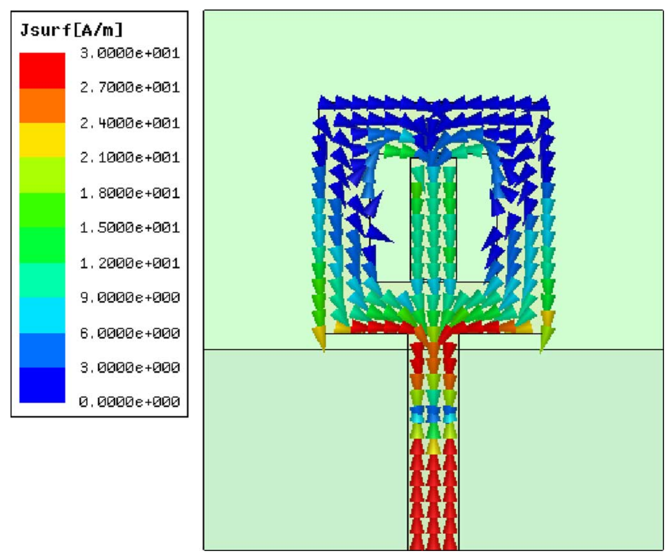


Fig. 4. Simulated surface current distribution at the center-rejected frequency of 5.6 GHz for the proposed antenna.

A longest resonant length of the antenna was designed about a quarter-guided-wavelength at 3.05 GHz, which was equal to $\mathrm{L}_2 = \mathrm{W}_2 = 15$ mm and also similar to that of the resonant monopole antenna. A spacing between the slot patch and the ground plane has been optimized to be about $\mathrm{G}_2 = 1$ mm, so that good impedance matching across the operating band can be obtained.

As shown, the coupling strip placed at the center of the slot patch can be devoted to generating desirable resonance for the stopband operation. In our antenna design, this coupling strip acts as a quarter-guided-wavelength resonator, and thus a center-rejected frequency f_r may be empirically approximated by

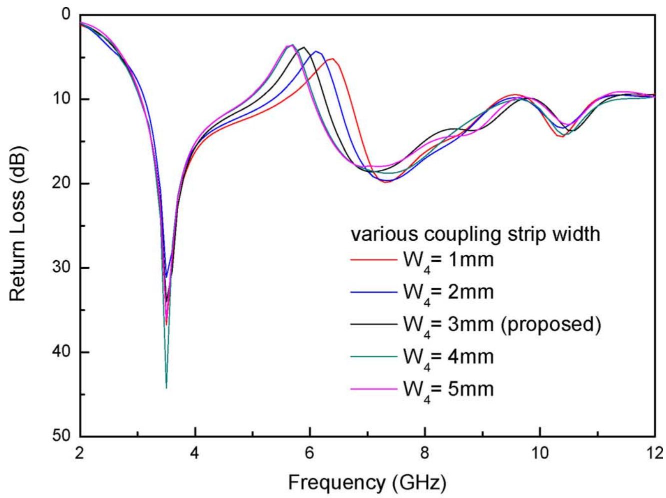
$$f_r \approx \frac{c}{4\sqrt{\frac{\varepsilon_r+1}{2}} \cdot (\mathrm{L}_3 - 2\mathrm{G}_1)} \tag{1}$$

where c is the speed of light in free space and ε_r is the dielectric constant. Since the center-rejected frequency is expected about 5.6 GHz, the strip length of the antenna can be calculated to be 7.9 mm, suitable for those optimum design parameters as listed below. Besides, to overcome the effects due to the frequency shifting for practical applications, the stopband property of the antenna can be controlled by flexibly tuning either the width (W_4) or the gap (G_1) for the strip. An electromagnetic software package, HFSS, has been utilized to simulate and analyze the electrical features and radiation performance of the proposed antenna. The design parameters optimized for the antenna were eventually determined with $\mathrm{L}_1 = 35$ mm, $\mathrm{L}_2 = 15$ mm, $\mathrm{L}_3 = 8.3$ mm, $\mathrm{L}_4 = 13$ mm, $\mathrm{W}_1 = 30$ mm, $\mathrm{W}_2 = 15$ mm, $\mathrm{W}_3 = 8.3$ mm, $\mathrm{W}_4 = 3$ mm, $\mathrm{W}_5 = 13.3$ mm, $\mathrm{W}_6 = 3.4$ mm, $\mathrm{G}_1 = 0.2$ mm, and $\mathrm{G}_2 = 1$ mm. A photograph of the implemented prototype of the proposed antenna is also shown in Fig. 2.

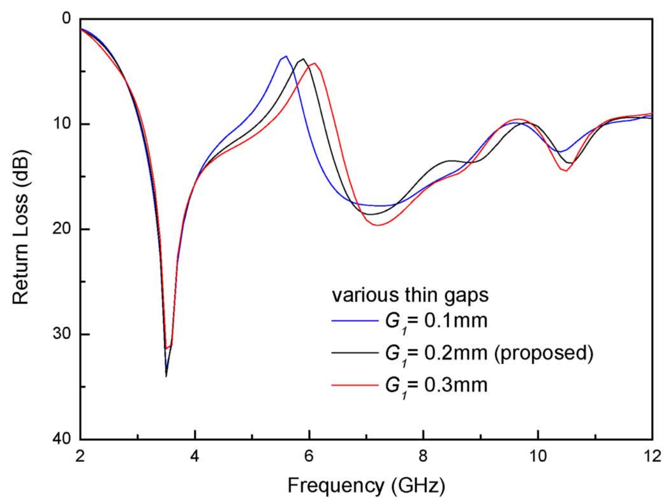
III. Results and Discussions

A fabricated prototype for the proposed UWB antenna was constructed and tested. A vector network analyzer (Agilent PNA 8362B) was utilized to measure and verify the antenna performance. Fig. 3 illustrates the simulated and experimental return losses against frequency of the antenna. Fairly good agreements between the simulations and measurements have been achieved. As observed, the measured impedance bandwidth with 10 dB return loss for the proposed antenna is from 3.05 to 11.15 GHz, rejecting the frequency band of about 5.12–6.08 GHz, so the effects due to the frequency interference can be avoided well. To further analyze the band-notched property, the surface current distribution of the antenna at the center-rejected frequency of 5.6 GHz has been simulated in Fig. 4. We can see that compared to the square slot patch, a stronger resonance surrounding the coupling strip has occurred apparently. This results in a good frequency rejection property for our design.

With the help of the simulator HFSS again, we can further study an operation range for the stopband with different strip widths (W_4) and gaps (G_1). Results given in Fig. 5(a) indicate that the stopband can be flexibly adjusted from 4.94 to 6.72 GHz, corresponding to the strip width from 1 to 5 mm. It should be noted that the stopband features for strip width equal to 4 and 5 mm are almost identical, so a proper width in designing the strip may be determined within 1–4 mm. On the other side, for different gaps from 0.1 to 0.3 mm, the antenna is also capable of achieving a tunable stopband range from 4.86 to 6.28 GHz, as shown in Fig. 5(b). We further see that the antenna performance in the operating band is less sensitive as the stopband varies, so that good radiation performance of the antenna can be maintained. According to this advantage of the antenna,

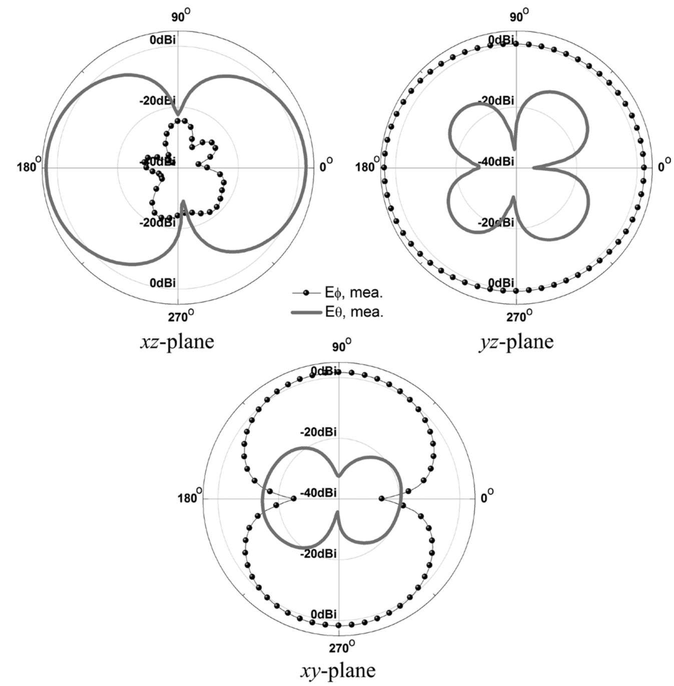


(a)

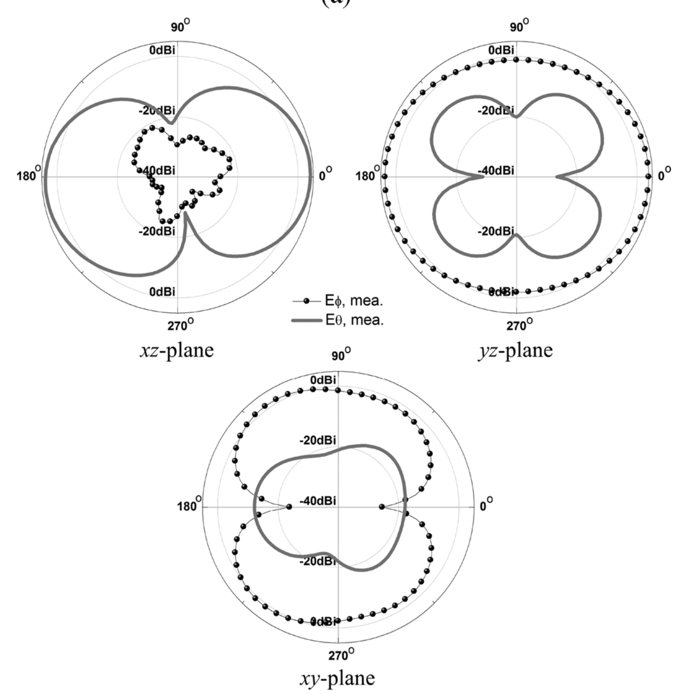


(b)

Fig. 5. Simulated return loss for different design parameters regarding the stopband property. (a) Strip width W_4. (b) Strip gap G_1.



(a)



(b)

Fig. 6. Measured radiation patterns of the proposed antenna. (a) 4 GHz. (b) 8 GHz.

a critical problem to the frequency shifting caused by the antenna to be integrated within the portable devices as an internal antenna may be addressed well.

Fig. 6(a) and (b) show the measured far-field radiation patterns in the xz, yz, and xy planes for the frequencies at 4 and 8 GHz, respectively. Nearly good omnidirectional patterns have been observed in the yz plane (H-plane), and the patterns in the xy plane (E-plane) are close to bidirectional. This also implies that a large and uniform coverage for UWB system operation can be attained with our design. Besides, the measured antenna gain and radiation efficiency versus the frequency are plotted in Fig. 7. At the passband, the antenna gain stably varies from 3.02 to 3.92 dBi, and also the radiation efficiency is larger than 82%. Lower performance for both gain and efficiency has been expected and received over the stopband. Better antenna performance for practical applications can be attained as a low-loss substrate is used for fabricating the antenna.

Fig. 8 reveals the measured magnitude and group delay in an anechoic chamber by using two identical fabricated prototypes for the proposed antenna with a distance of 1 m. As shown, significant reduction in magnitude has been obtained over the stopband for both orientations tested. Besides, nearly constant group delay and stable magnitude variation across the operating band can be achieved as well. Referring to these results, the proposed compact antenna is capable of offering good pulse-handling capability as demanded by modern UWB communication systems.

IV. Conclusion

A compact planar band-notched monopole antenna suitable for UWB operation has been presented and studied in this letter.

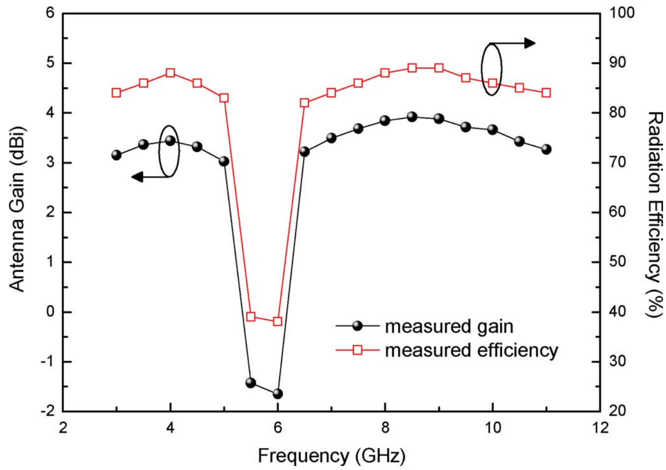


Fig. 7. Measured antenna gain and radiation efficiency of the proposed antenna.

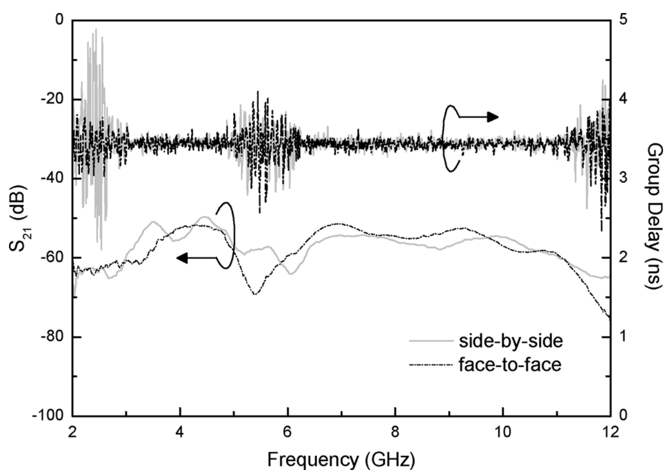


Fig. 8. Measured magnitude and group delay of the proposed antenna.

Compared to prior designs, the proposed antenna can easily and flexibly adjust its stopband property so that better radiation performance can be achieved. With the help of this tunable stopband, frequency interference issues may be better addressed as well. Furthermore, properties such as good omnidirectional coverage, stable transmission characteristics, and excellent pulse-handling capability indicate that the proposed compact antenna is well suitable for integration into UWB portable devices.

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