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DESIGN OF NOVEL UWB SLOT ANTENNA FOR BLUETOOTH AND UWB APPLICATIONS

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Abstract—In this article, a novel wideband planar monopole antenna for applications in 2.4 GHz Bluetooth and UWB bands is presented and investigated. The low-profile antenna comprises an approximate rectangle patch for covering the UWB band (3.1 $\sim$ 10.6 GHz). A lower pass band, 2.4 GHz Bluetooth band (2.4 $\sim$ 2.484 GHz), can be realized by adding a pair of U-shaped parasitic strips bilaterally beside the feed line without affecting its UWB behavior. The proposed antenna is designed and built on a FR-4 substrate, with overall size of 18 mm $\times$ 32 mm. The simulated and measured results are presented and show that the proposed compact antenna has a stable and good radiation patterns across all the relevant bands.

1. INTRODUCTION

In 2002, the Federal Communication Commission (FCC) authorized the frequency band from 3.1 to 10.6 GHz for commercial communication applications [1]. Since then, considerable research efforts have been put into ultra-wideband (UWB) communication technology worldwide. Compared with the traditional communication system, the UWB communication system has the advantages of high data transmission rate, good secrecy, low power consumption, low cost and ease of implementation. As the front-end equipment of the UWB communication systems, the UWB antenna is of course very vital. A suitable UWB antenna is supposed to fulfill many requirements such as small size, ominidirectional radiation patterns, constant group delay and gain across the whole band [2]. As a succeeded candidate of UWB antennas, printed monopole UWB antenna technology has attracted both academia and industrial's great attention [3–17].

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The increasing demands for wireless connectivity necessitates a single antenna to cover several allocate wireless frequency bands. Integrating both UWB and Bluetooth standards into single antenna has attracted many researchers' attention. Various integrating skills have been proposed [3–12]. In [3], a simple printed fork-shaped patch is employed to realize dual-band antenna for Bluetooth and UWB applications. In [4], by creating quarter-wavelength stubs in the ground plane of rectangle shaped printed slot antenna, this antenna can work at UWB and Bluetooth bands. In [5], a fan-shaped-patch antenna with added strips which are placed within the both sides of the base patch can achieve dual-band characteristics. In [6], a printed circular monopole antenna with a annular slot and fed by microstrip line is used to cover UWB and Bluetooth band, however, it has large profile of dimension $45\,\mathrm{mm} \times 32\,\mathrm{mm}$.

In this paper, a novel compact antenna for Bluetooth and UWB applications is presented. The motivation of integrating two technologies in one antenna is due to the current trend for short-range wireless systems of beyond 3G, which are envisioned to enable wireless connectivity for "everybody and everything at any place and any time." This ambitious goal requires a comprehensive integration of existing and future wireless systems that link devices as diverse as portable and fixed appliances, PCs, and entertainment equipment [12]. The proposed antenna is designed and built on a FR-4 substrate, with overall size of $18\,\mathrm{mm} \times 32\,\mathrm{mm}$. The simulated and measured results are presented and show that the proposed compact antenna has a stable and good radiation patterns across all the relevant bands. All simulations in this work were carried out by using Ansoft HFSS software package. Simulated results of the proposed antenna are presented along with the measured results of the fabricated antenna.

2. ANTENNA DESIGN

2.1. UWB Monopole Antenna

As shown in Fig. 1, the UWB antenna consists of an approximate rectangle radiating patch and a modified grounded plane with two bevels and a rectangle slot, which have a better impendence matching to cover UWB band. This antenna is built on an $h = 0.8\,\mathrm{mm}$ FR-4 substrate with a dimension of $W \times L = 18\,\mathrm{mm} \times 32\,\mathrm{mm}$, a relative permittivity of $\varepsilon_r = 4.4$ and a dielectric loss tangent of 0.02. In order to miniaturize the size of the antenna for the application of the portable devices, a $50\,\Omega$ microstrip line is used to excite the printed monopole antenna. The width of the microstrip feed line is 1.5 mm. The dimensions of the designed antenna after optimization are as

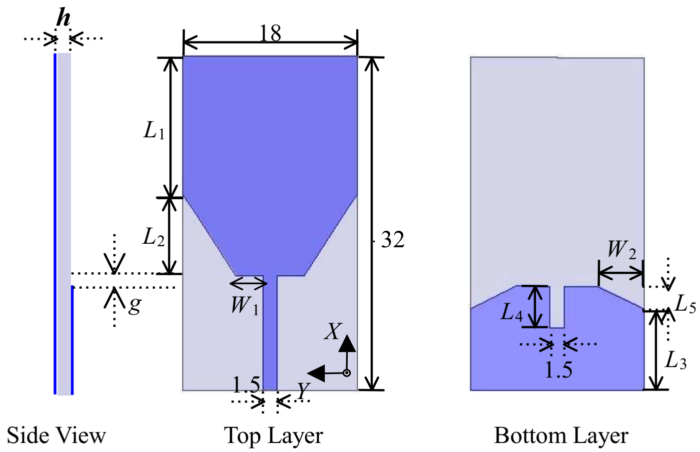


Figure 1. Configuration and parameters of the UWB antenna (unit: millimeters).

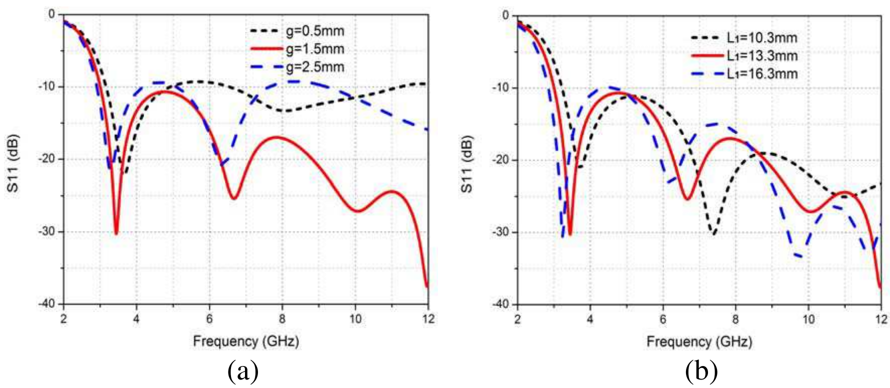


Figure 2. Simulated reflection coefficient of the primitive UWB antenna for (a) variance of g, (b) variance of L_1.

follow: $L_1 = 13.3\,\text{mm}$, $L_2 = 7.7\,\text{mm}$, $W_1 = 2.75\,\text{mm}$, $L_3 = 7.3\,\text{mm}$, $L_4 = 4\,\text{mm}$, $L_5 = 2.2\,\text{mm}$, $W_2 = 4.8\,\text{mm}$, $g = 1.5\,\text{mm}$.

In designing, the patch antenna is used to cover the UWB range, which is the higher frequency band of the dual-band antenna. As shown in Fig. 1, L_1 (the length of radiating patch), and g (the gap between the radiating patch and the ground plane) could affect the performance of the UWB antenna. The effects of these two parameters on antenna input reflection coefficient are studied and presented in Fig. 2. Fig. 3

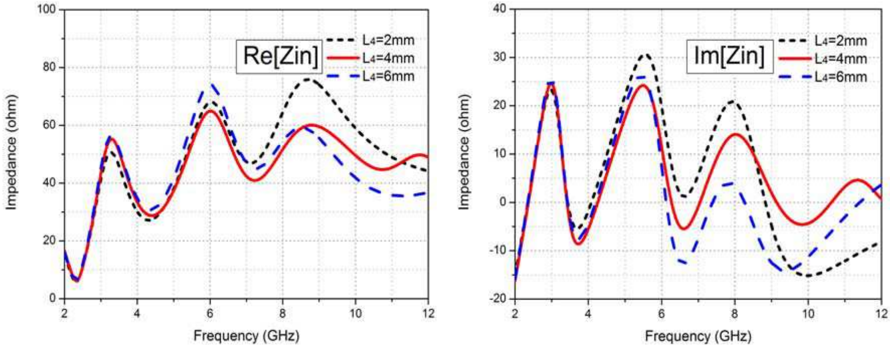


Figure 3. Simulated input impedance of the UWB antenna with variance of L_4.

shows the input impedance of the proposed antenna with variance of L_4. It is apparent that the input impedance of the proposed antenna with $L_4 = 4\,\mathrm{mm}$ is better than that $L_4 = 2\,\mathrm{mm}$ and $L_4 = 6\,\mathrm{mm}$.

2.2. Dual-band Antenna Configuration

Because the increasing demand for wireless connectivity necessitate a single antenna to cover several allocate wireless frequency bands. To create 2.4 GHz Bluetooth band without increasing the overall size of the antenna, a pair of U-shaped parasitic strips was added at both sides of the feed line, as shown in Fig. 4. Each of the length of the resonant strip L ($L = L_{s1} + 2*(L_{s2} + L_{s3} + L_{s4} + L_{s5})$) should be $\lambda_g/2$, where λ_g is the guided wavelength. So the length of each U-shaped stub can be obtained approximately from the following formula:

$$L \approx \lambda_g/2 = \frac{c}{2f\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where c is the velocity of light in free space, f the centric frequency of the adding resonant band, respectively. It can be calculated that $L = 37.3\,\mathrm{mm}$, for frequency of 2.45 GHz. All the widths of the U-shaped parasitic strips are 0.1 mm. The gap g_1 between U-shaped parasitic strips and feed line is $= 0.8\,\mathrm{mm}$. The gap L_6 between U-shaped parasitic strips and radiating patch is 2.8 mm. The adding operating frequency can be changed by adjusting the length L. Fig. 3 shows the geometry of the proposed antenna. The optimized U-shaped slot parameters are as follows: $L_{s1} = 8$, $L_{s2} = 7$, $L_{s3} = 1.5$, $L_{s4} = 5.2$ and $L_{s5} = 1.2$ (all in mm).

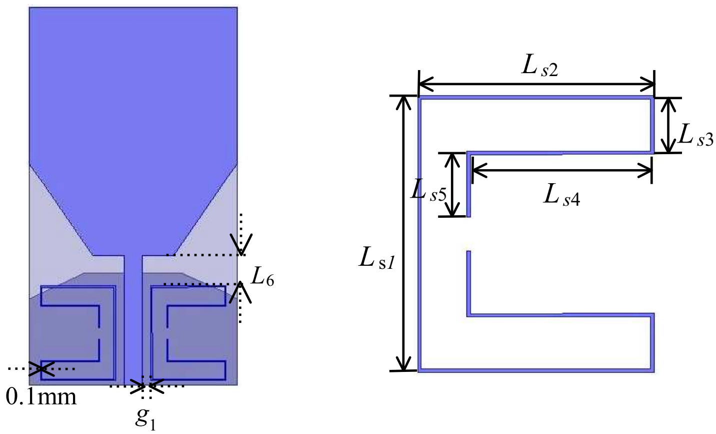


Figure 4. The dual-band antenna with adding U-shaped parasitic strips.

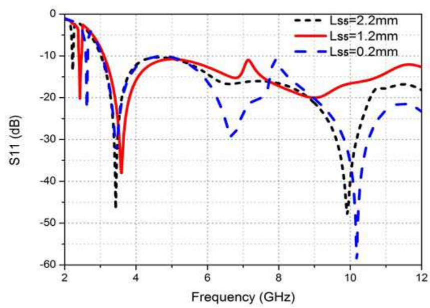
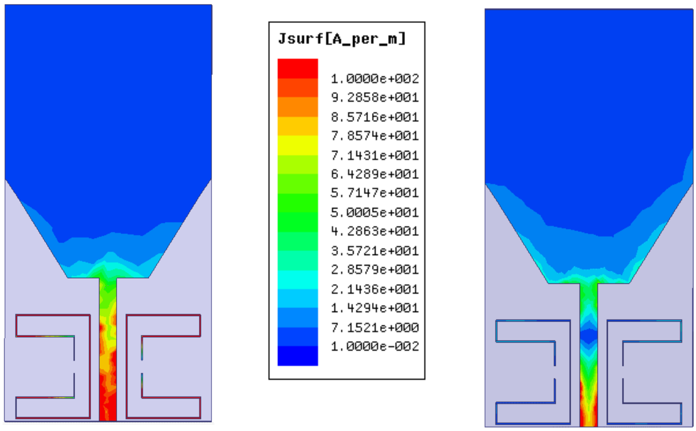


Figure 5. The simulated reflection coefficient of the dual-band antenna with varied L_{s5}.

The simulated reflection coefficient of the lower pass band is studied when the length of the parasitic strip L is varied, as shown in Fig. 5. By tuning the length of L_{s5}, the total length of L varies. From Fig. 5, it is seen that the increase in L_{s5} decreases the resonant frequency of the band and vice versa. So, by changing the length of the strips, the related frequency will be changed. These results are consistent with Eq. (1).

In order to better understand the antenna behavior, the current distributions of the dual-band antenna at frequencies of 2.45 GHz, 6 GHz are simulated and shown respectively in Figs. 6(a) and (b). As shown in Fig. 6(a), the current distribution at 2.45 GHz is drastically increased around the U-shaped parasitic strips, which are agreement with the half-wavelength behavior of the $\lambda_g/2$ strips.



(a) (b)

Figure 6. Current distributions on the proposed antenna at (a) 2.4 GHz, (b) 6 GHz.

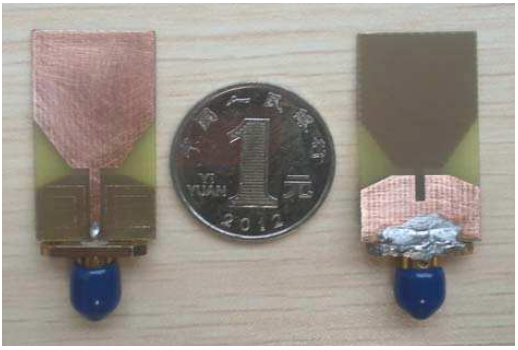


Figure 7. Photo of the proposed antenna: top view and bottom view.

3. EXPERIMENTAL RESULTS

Based on the design parameters, the proposed antenna structure was fabricated and tested. The prototype of the proposed antenna was fabricated on a FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with dimension of 18 mm $\times$ 32 mm and a thickness of 0.8 mm. Fig. 7 is a photo of the fabricated proposed antenna. Its performance was measured in an Anechoic Chamber with an Agilent E8363B.

The measured reflection coefficient is shown in Fig. 8 compared with the simulated one. It can be seem that these two results

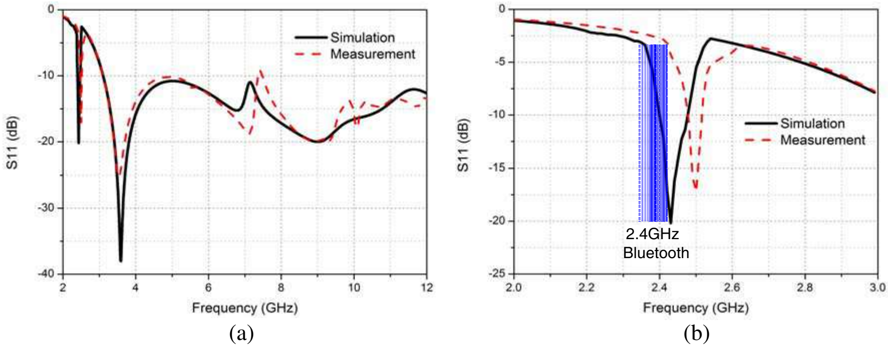


Figure 8. The reflection coefficient of the proposed antenna over (a) the whole band and (b) the Bluetooth pass bands.

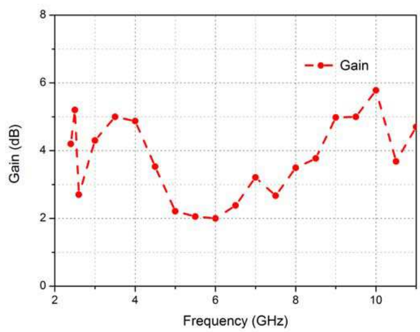


Figure 9. The measured gain of the proposed antenna.

are in good agreement. It is apparent that the proposed antenna successfully adds a lower pass band of 2.4 GHz Bluetooth band. The reflection coefficient of the lower pass band is well below -10 dB level, which mean good impedance matches at Bluetooth band. From the measured results, it can be seen that the lower pass band covers $2470 \sim 2520$ MHz.

The peak gain and radiation far field patterns are also measured for this antenna and shown in Figs. 9 and 10 respectively. From Fig. 10, it is seen that the antenna shows stable radiation patterns over both Bluetooth and UWB bands.

Figure 11 presents the measured the time-domain characteristics viz. group delay of the proposed antenna. If the group delay variation exceeds 1.0 ns, the phases are no longer linear in the far-field region, and pulse distortion is caused. This can be a serious problem in a

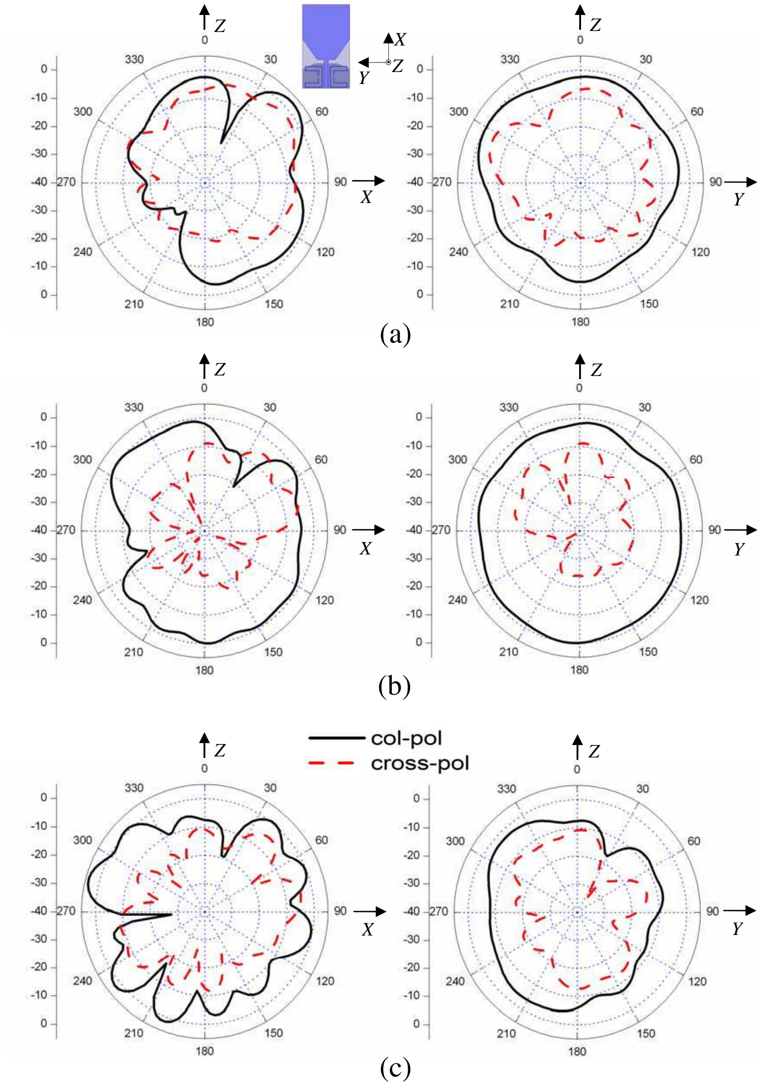


Figure 10. Measured E-plane and H-plane radiation patterns at (a) 2.45 GHz, (b) 6 GHz, and (c) 9 GHz.

UWB communication system [14]. In this study, a pair of identical antennas served as the transmitting and receiving antennas, which were connected to the double ports of the vector network analyzer indoors and they are placed face to face and side to side with a distance of 30 cm. It can be seen the variation of the group delay is almost within

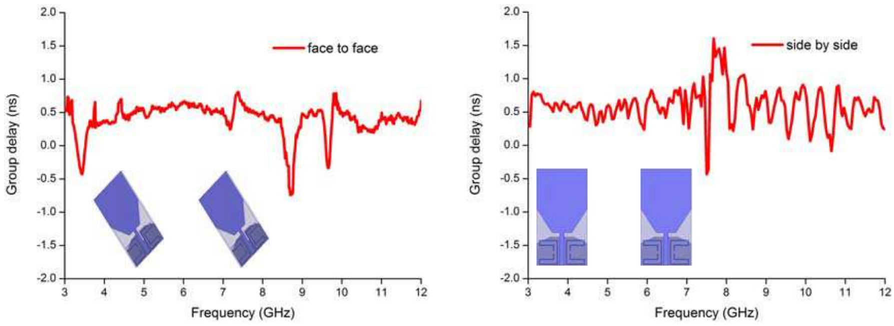


Figure 11. Measured group delay of the proposed antenna for both (a) face-to-face and (b) side by side configurations.

Table 1. Comparisons of the dual-band antenna to other dual-band antennas.

Performance compare	This work	Ref. [3]	Ref. [4]
Dielectric constant	4.4	4.4	3.38
Thickness (mm)	0.8	1.6	0.8
Size (mm)	$18 * 32$	$24 * 50$	$23 * 28$
Peak gain at Bluetooth band (dB)	5.1	1.9	-5
Performance compare	Ref. [5]	Ref. [6]	Ref. [7]
Dielectric constant	4.6	4.4	4.4
Thickness (mm)	1.6	1	1.6
Size (mm)	$30 * 35$	$32 * 45$	$35 * 35$
Peak gain at Bluetooth band (dB)	1.6	2.5	2.8

1 ns across the working band. It conforms that the proposed antenna exhibits phase linearity at desired UWB frequencies.

In addition, the comparisons for several different dual-band UWB antennas are illustrated in Table 1. Compared to these references [3–7], the proposed UWB antenna with compact size has higher gain at Bluetooth band. In references [3–7], by changing the shape of radiator or ground, these antennas can work at UWB and Bluetooth bands. The modification enlarged the dimension of the antenna more or less. In this work, by adding a pair of U-shaped parasitic strips bilaterally beside the feed line, a lower pass band can be realized for covering Bluetooth band without increasing the dimension of primitive UWB antenna.

4. CONCLUSION

The design of a compact microstrip-fed UWB patch antenna with Bluetooth pass band has been presented. By inserting a pair of U-shaped parasitic strips bilaterally beside the feed line, a lower pass band can be realized for covering Bluetooth band without affecting its UWB behavior. The proposed antenna have a stable radiation pattern, constant group delay and $S_{11} < -10\,\text{dB}$ over the whole desirable band. Compared to these references [3–7], the proposed UWB antenna with compact size has higher gain at Bluetooth band. It is a good antenna candidate for personal and mobile UWB applications due to the features described above.

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