Progress In Electromagnetics Research C, Vol. 35, 205–219, 2013

A COMPACT CPW-FED UWB ANTENNA WITH GSM, GPS, BLUETOOTH AND DUAL NOTCH BANDS APPLICATIONS

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Abstract—A novel compact ultrawideband (UWB) CPW-fed antenna with triple lower pass bands and dual notched bands for wireless applications is presented. The low-profile antenna comprises of an approximate hexagonal-shaped radiator for covering the UWB band ($3.1 \sim 10.8$ GHz). Triple lower pass bands, the 1.5 Gband, 1.8 GHz GSM band and 2.4 GHz Bluetooth band, can be realized by adding three handstand semielliptical-shaped stubs bilaterally at the upper part of antenna ground. A notched band of $3.3 \sim 3.7$ GHz for rejection of WiMAX radio signals can also be obtained by adjusting the geometry of the three stubs. In addition, an U-shaped slot on the radiating patch generates a notched band in $5.15 \sim 5.825$ GHz for rejection of WLAN radio signals. The proposed antenna is designed and built on a FR-4 substrate, with overall size of 25 mm $\times$ 24 mm. The simulated and measured results are presented and show that the proposed compact antenna has a stable and omnidirectional 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. The UWB communication systems can perform high-speed communication with speeds of more than 100 Mbps. Compared with the traditional communication system, the UWB communication system has the advantages of high data transmission rate, good secrecy,

Received 7 November 2012, Accepted 19 December 2012, Scheduled 26 December 2012
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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 a small size, omnidirectional radiation patterns, constant group delay and gain across whole band [2].

As a succeeded candidate of UWB antennas, printed monopole UWB antenna technology has attracted both academia and industrial's great attention [3–25]. There are two research hot points in UWB printed monopole antennas field. The first hot point is an antenna which can work in UWB band and other wireless narrow bands [3–7]. 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 fork shaped printed slot antenna, this antenna can work at UWB, GSM and GPS bands. In [5], a diamond-shaped-patch antenna with added strips which are placed within the notched region of the base patch can achieve quad-band characteristics. In [6], a printed elliptical monopole antenna with a trapezoid ground plane and fed by tapered CPW line is used to cover $1.02 \sim 24.1\,\text{GHz}$ frequency band, however, it has large profile of dimension $124\,\text{mm} \times 110\,\text{mm}$. Another hot point is band-notched UWB antenna technique. Many techniques have used create band-notched antennas [8–15]. In [8], the proposed antenna consists of two or three U-shaped slots to produce band-notched characteristics. In [9], the sharp band-notched characteristic of the UWB antenna is realized by inserting a half wavelength C-shaped slot in the radiating patch. In [10], a band-notched UWB planar monopole antenna with parasitic patches for achieving the band-rejected characteristics has been proposed. In [11], three electrically small resonators (capacitively-loaded loop (CLL)) are employed to achieve two tri-band-notched UWB antennas.

The increasing demands for wireless connectivity necessitates a single antenna to cover several allocate wireless frequency bands. Whilst, the communication devices are becoming smaller due to the great integration of electronics, it is a significant issue in communication systems to miniature the antenna while providing good performance over the bands. So the developments in the wireless communication system call for the more compact and multi-band antenna. And on other hand, for these indoor and hand held multiband users, the UWB radio frequency band of 3.1 to 10.6 GHz may be interfered by the $3.3 \sim 3.7\,\text{GHz}$ WiMAX (Worldwide Interoperability for Microwave Access) radio signals and $5.15 \sim 5.825\,\text{GHz}$ WLAN (Wireless Local Area Network) radio signals. Therefore, compact antennas for these communication systems are not only required to work in the multiband frequency band but also have notched bands in order to avoid being interfered by the WiMAX and WLAN radio signals.

In this paper, a novel compact UWB CPW-fed antenna with triple lower pass bands for multifunctional wireless applications and dual notched bands is presented. A hexagonal-shaped radiating patch is designed to cover UWB working frequency band. By inserting bilaterally three quarter-wavelength semielliptical-shaped stubs at the upper part of the ground, triple lower pass bands are obtained for covering GPS, GSM and Bluetooth bands, and an additional 3.3 ~ 3.7 GHz notched band is also realized to avoid being interfered by the WiMAX radio signals. By notching an inverted U-shape slot on the radiating patch, another notched frequency band of 5.15 ~ 5.825 GHz to reject the interfering of WLAN radio signals can be obtained. The three resonant strips and slot can be added to the hexagonal-shaped radiating patch structure without affecting its UWB behavior. Therefore the antenna size is kept compact. 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. MULTI-BAND ANTENNA DESIGN

2.1. The Primitive Antenna

As shown in Fig. 1, the primitive antenna consists of an approximate hexagonal-shaped radiating patch and an elliptical shaped etched plane, which have a better impendence matching to cover UWB band.

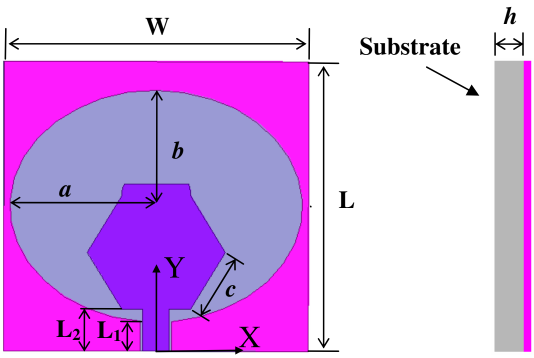


Figure 1. The front view of the primitive antenna, the side view of the primitive antenna.

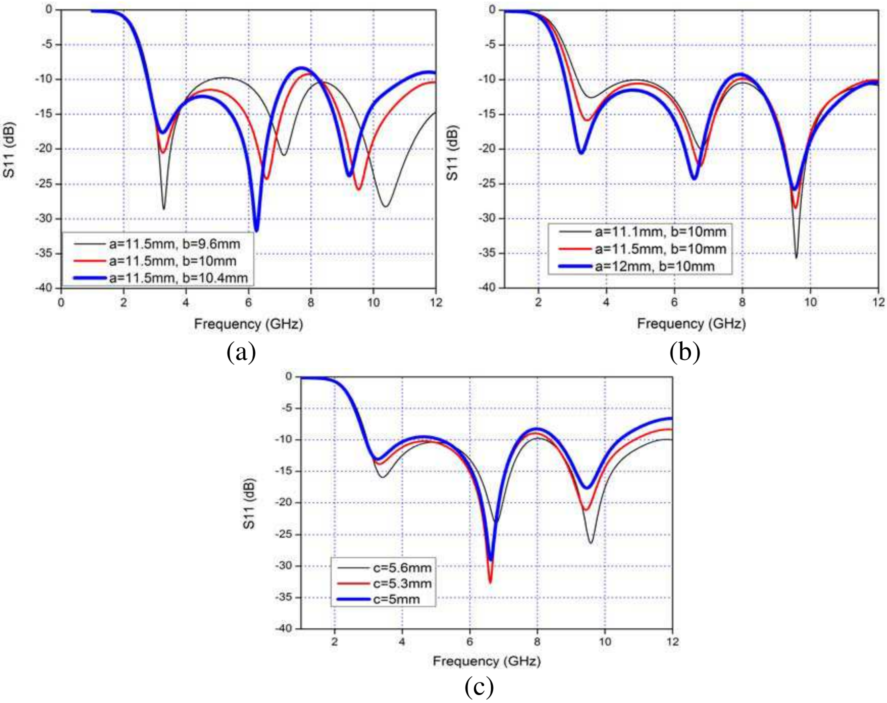


Figure 2. Simulated reflection coefficients of the primitive antenna for (a) variance of b ($a = 11.5\,\text{mm}$ and $c = 5.66\,\text{mm}$), (b) variance of a ($b = 10\,\text{mm}$ and $c = 5.6\,\text{mm}$), (c) variance of c ($a = 11.5\,\text{mm}$ and $b = 10\,\text{mm}$).

This antenna is built on an $h = 1.6\,\text{mm}$ FR-4 substrate with a dimension of $W \times L = 25\,\text{mm} \times 24\,\text{mm}$, a relative permittivity of $\varepsilon_r = 4.4$ and a dielectric loss tangent of 0.02. The length of the patch side is $c = 5.66\,\text{mm}$, the lengths of the two ellipse axles are $a = 11.5\,\text{mm}$ and $b = 10\,\text{mm}$. In order to miniaturize the size of the antenna for the application of the portable devices, a $50\,\Omega$ CPW-fed line is used to excite the printed monopole antenna. The width of the CPW feed line is 2.2 mm. Other geometry parameters are as follows: $L_1 = 2.56\,\text{mm}$, $L_2 = 3.6\,\text{mm}$.

In designing, the patch antenna is used to cover the UWB range, which is the highest frequency band of the multi-band antenna. As shown in Fig. 1(a), the lengths of the two ellipse axles and hexagonal-shaped radiating patch that could affect the performance of the UWB antenna. The effects of these three parameters on antenna input reflection coefficient are studied and presented in Fig. 2.

2.2. Quad-Band Antenna Configuration

Because the increasing demand for wireless connectivity necessitate a single antenna to cover several allocate wireless frequency bands. To create 1.5 GHz GSM band, 1.8 GHz GPS band and 2.45 GHz Bluetooth band without increasing the overall size of the antenna, three handstand stubs of quarter elliptical-shaped resonant L_{s1}, L_{s2}, L_{s3} been added at the upper part of the ground, as shown in Fig. 3. The stubs are symmetrically inserted to the ground notched region. Each of the length of the resonant stub should be $\lambda_g/4$, where λ_g is the guided wavelength. So the length of each semielliptical-shaped stub can be obtained approximately from the following formula:

$$L = \lambda_g/4 = \frac{c}{4f\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where ε_r is the dielectric constant, c the velocity of light in free space, f the centric frequency of the adding resonant band. It can be calculated that $L_{s1} = 26.6$ mm, $L_{s2} = 22.1$ mm and $L_{s3} = 16.1$ mm respectively for frequencies of 1.5 GHz, 1.8 GHz and 2.45 GHz. All the widths of these three stubs are 0.4 mm. The adding operating frequency can be changed by adjusting the length of corresponding stub.

The simulated reflection coefficients of the three lower pass bands is studied when the length of one stub is varied while other two are fixed, as shown in Fig. 4. From Fig. 4(a), it is seen that the increase in L_{s1} decreases the resonant frequency of the band and vice versa. So, by changing the length of one stub, the related frequency will be changed, while has slight effect on the other adding band. These results are consistent with Eq. (1).

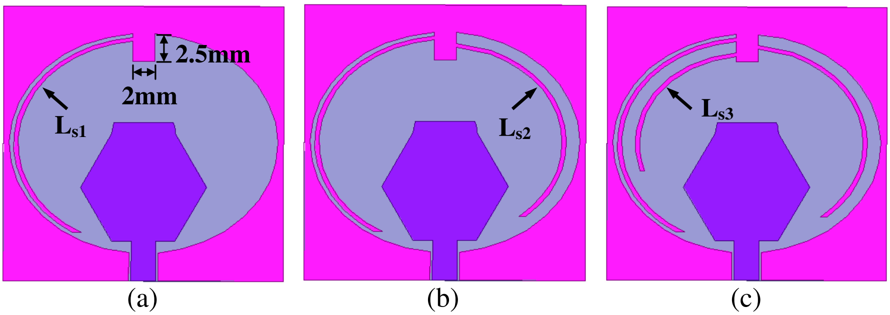


Figure 3. (a) The UWB antenna with adding stub L_{s1}. (b) The UWB antenna with adding stub L_{s1} and L_{s2}. (c) The UWB antenna with adding stub L_{s1}, L_{s2} and L_{s3}.

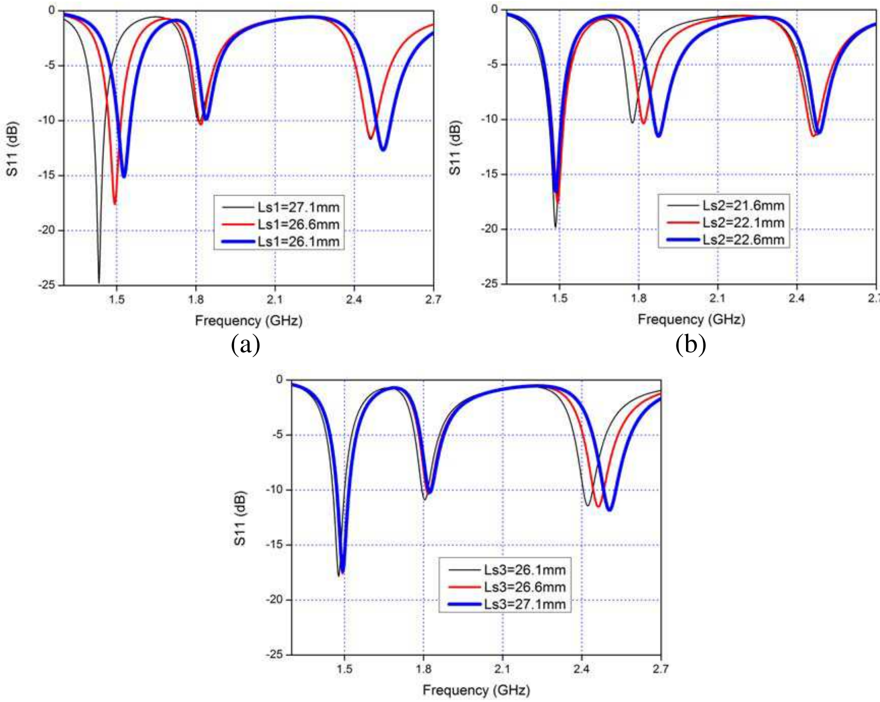


Figure 4. The simulated reflection coefficients of the multi-band antenna with (a) $L_{s2} = 22.1$ mm and $L_{s3} = 16.1$ mm for various L_{s1}, (b) $L_{s1} = 26.6$ mm and $L_{s3} = 16.1$ mm for various L_{s2}, (c) $L_{s1} = 26.6$ mm and $L_{s2} = 22.1$mm for various L_{s1}.

However, the stubs added as Fig. 3 are not symmetric in structure. To avoid no-symmetric far field patterns, bilateral stubs of L_{s1}, L_{s2} and L_{s3} are used and the final structure of the designed antenna is shown in Fig. 5. All space between any two stubs is 0.4 mm. The effects of bilateral stubs and unilateral stub are studied. For example, the reflection coefficients and 2.45 GHz radiation far field patterns of the antenna of Fig. 3(c) (with unilateral stubs) and antenna of Fig. 5 (with bilateral stubs) are simulated and shown in Figs. 6(a) and (b), respectively. It can be seen that the adding of stubs bilaterally on the opposite side of the patch improves impedance matching and guarantees the omnidirectional radiation patterns. As shown in Fig. 6(a), the reflection coefficient of the antenna with bilateral stubs is well below -10 dB compared with the one with unilateral stubs; in Fig. 6(b), the antenna with bilateral stubs has a symmetric

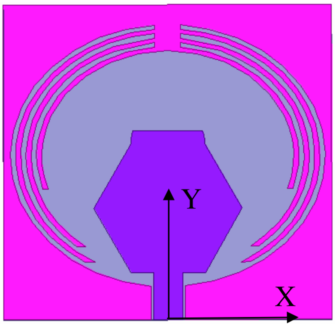


Figure 5. The structure of multiband antenna.

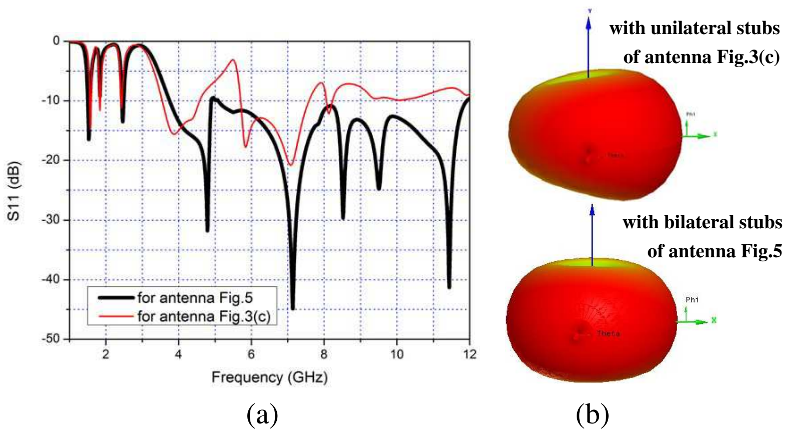


Figure 6. Comparison of unilateral and bilateral stubs: (a) The reflection coefficients, (b) the simulated radiation far field patterns at 2.45 GHz.

and omnidirectional radiation patterns compared with the one with unilateral stubs. And moreover, by optimizing the geometry of the three stubs and the space between stubs, a band-notched can be obtained in $3.3 \sim 3.7$ GHz for reduce the interference of WiMAX radio signals.

2.3. Notched Band Design

In order to create a notched band in $5.15 \sim 5.825$ GHz, a U-shaped slot L_{s4} is etched on the radiating patch. The length of the slot L_{s4} is about half of the guided wavelength $(\lambda_g/2)$ calculated at 5.45 GHz

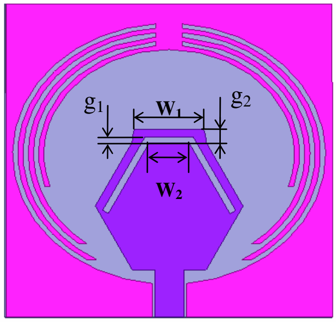


Figure 7. The configurations of the multiband antenna with two notch bands.

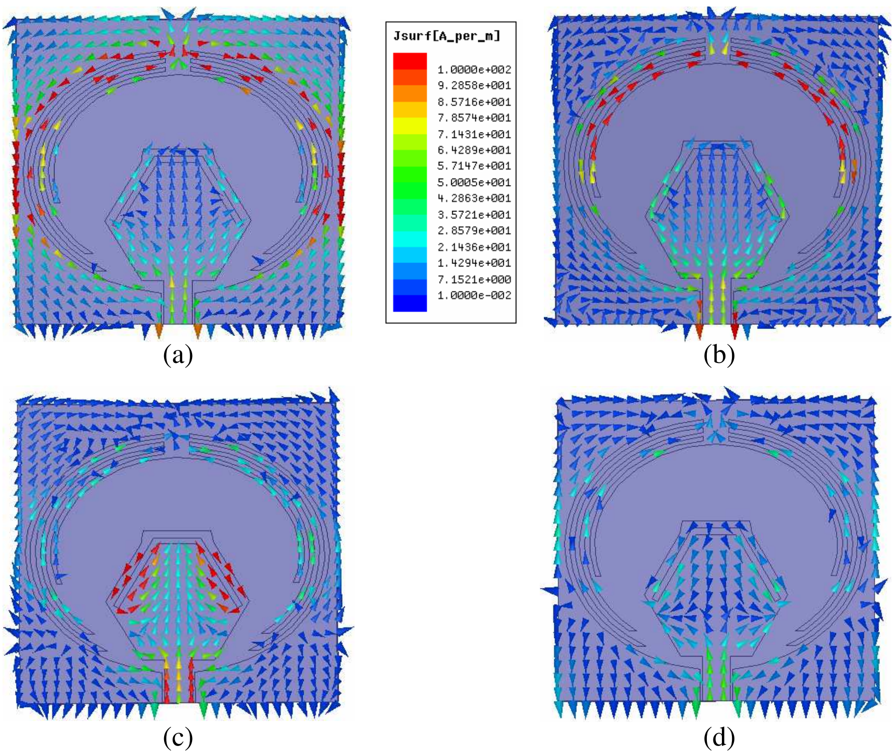


Figure 8. Current distributions on the proposed antenna at (a) 1.5 GHz, (b) 2.45 GHz, (c) 5.5 GHz, and (d) 7 GHz.

in the WLAN band. By adjusting the length and width of the slot, the centric frequency and range of the notched band will be changed. Fig. 7 shows the geometry of the proposed antenna. The optimized U-shaped slot parameters are as follows: $g_1 = 0.5$, $g_2 = 1$, $L_{s4} = 16.37$, $W_1 = 5.29$ and $W_2 = 3.11$ (all in mm).

In order to better understand the antenna behavior, the current distributions of the multiband antenna at frequencies of 1.5 GHz, 2.45 GHz, 5.5 GHz and 8 GHz are simulated and shown respectively in Figs. 8(a)–(d). As shown in Figs. 8(a) and (b), the current distributions at 1.5 and 2.45 GHz are strong around the stub L_{s1}, and L_{s3} respectively. And these surface current distributions on stubs L_{s1} and L_{s3} are maximum at the ends inserted to ground and minimum at the other open end, which are agreement with the quarter-wavelength behavior of the $\lambda_g/4$ stubs.

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 25 mm × 24 mm and a thickness of 1.6 mm. Fig. 9 is the 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. 10 compared with the simulated one. It can bee seem that these two results are in good agreement. It is apparent that the proposed antenna successfully adds three lower pass bands of 1.5 GHz GSM band, 1.8 GHz GPS band and 2.45 GHz Bluetooth band and two rejection bands of 3.5 GHz WiMAX and 5.5 GHz WLAN. The return losses of the three lower pass bands are well below −10 dB level, which mean good impedance matches at these bands. In Fig. 10(b), it can be seen that the first

Figure 9. Photo of the proposed antenna: Top view and bottom view.

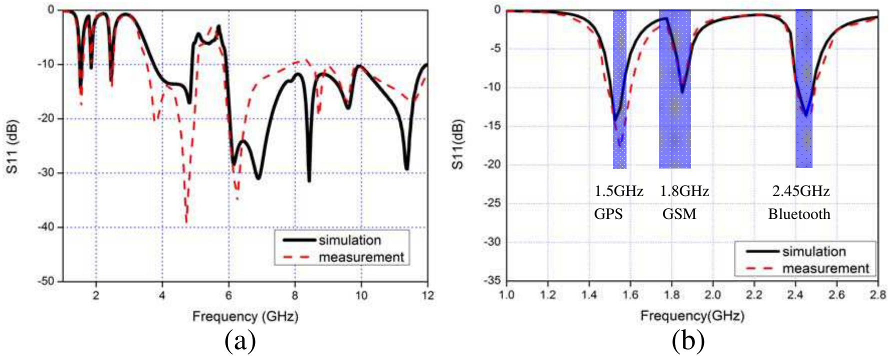


Figure 10. The reflection coefficients of the proposed antenna over (a) the whole band and (b) the three lower pass bands.

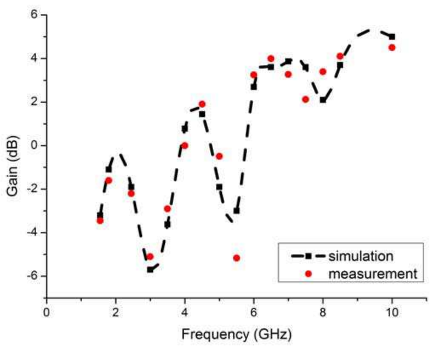


Figure 11. The measured and simulated gains of the proposed antenna.

pass band covers 1490 $\sim$ 1600 MHz, the second pass band covers 1835 $\sim$ 1865 MHz, and the third pass band covers 2400 $\sim$ 2490 MHz. Thus, the proposed antenna can cover the whole band of the GPS L1 and Bluetooth, and part of the GSM band (1710 $\sim$ 1880 MHz).

The gain and radiation far field patterns are also measured for this antenna and shown in Figs. 11 and 12 compared with the simulated ones respectively. From Fig. 11, the reduction of gain in the notch bands is significant and confirms the band-rejection behaviour of the proposed antenna. From Fig. 12, the antenna exhibits a symmetric and stable omnidirectional radiation over GPS, GSM, Bluetooth and UWB bands. The proposed antenna has nearly omnidirectional radiation characteristic in the H-plane and figure-eight radiation pattern in the E-plane over both Bluetooth and UWB bands.

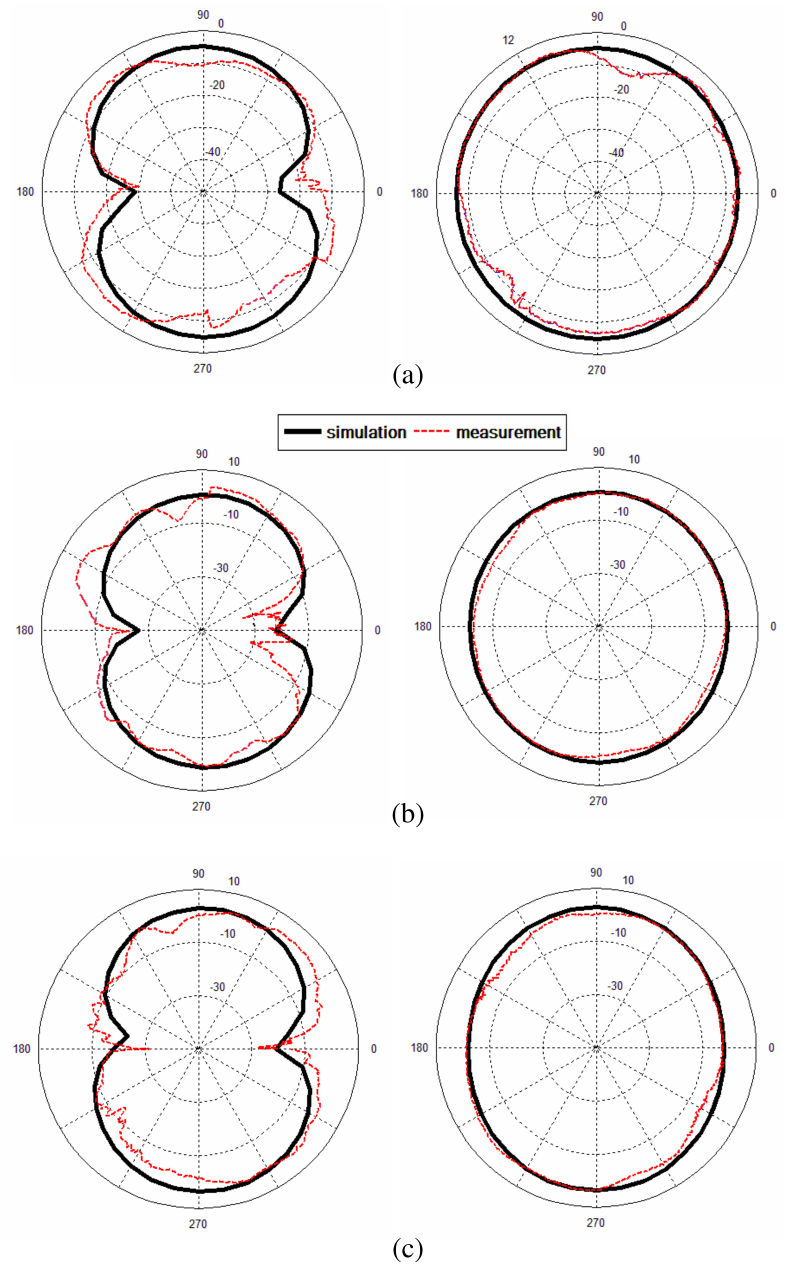
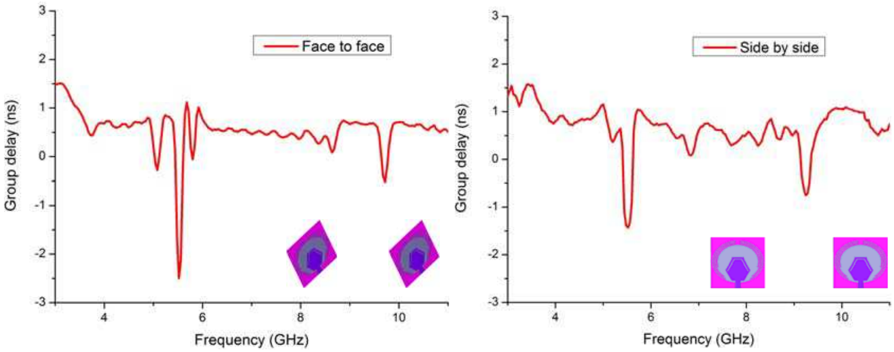


Figure 12. Measured and simulated E-plane and H-plane radiation patterns at (a) 2.45 GHz, (b) 4.5 GHz and (c) 7 GHz.



(a) (b)

Figure 13. Measured group delay of the proposed antenna for both (a) face-to-face and (b) side by side configurations.

Figure 13 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 UWB communication system [22]. 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 25 cm. It can be seen the variation of the group delay is almost within 1 ns across the working band except at 3.5 GHz and 5.5 GHz where the maximum group delay is more than 1 ns It conforms that the proposed antenna exhibits phase linearity at desired UWB frequencies.

4. CONCLUSION

The design of a compact CPW-fed UWB patch antenna with three lower pass bands and dual-notched bands has been presented. By using three handstand semielliptical-shaped stubs at the upper part of the ground, three lower pass bands can be realized for covering GPS, GSM and Bluetooth band, and a notched band generated in 3.3 $\sim$ 3.7 GHz for rejection of WiMAX signal interference. In addition, an inverted U-shape slot on the radiating patch generates another notched band in 5.15 $\sim$ 5.825 GHz for rejection of WLAN signal interference. The proposed antenna have a compact size, stable radiation pattern, constant group delay and return loss below -10 dB over the whole desirable band. It is a good antenna candidate for personal and mobile UWB applications due to the features described above.

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