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STUDY OF ELLPITICAL SLOT UWB ANTENNAS WITH A 5.0–6.0 GHz BAND-NOTCH CAPABILITY

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Abstract—Two microstrip fed ultra-wideband (UWB) antennas with different band rejection techniques are presented in this paper. The designed antennas consist of a defected ground plane with an elliptical slot and two different radiator shapes. The first design is composed of a half circular ring radiator element while the second one uses a crescent shaped radiator. The radiators are fed by a 50 Ω microstrip line with a tapered microstrip transition to ensure good impedance matching. The calculated impedance bandwidth of the proposed antenna ranges from 3 GHz to 14 GHz with relatively stable radiation patterns. To achieve band-notch characteristic in the 5.0–6.0 GHz WLAN frequency band, two different techniques have been implemented. The first technique uses a C-shaped slot etched in the ground plane while the other one uses another C-shaped slot in the feed line.

1. INTRODUCTION

Recently, there is a great attention in ultra-wideband (UWB) system design and its application in personal wireless communications especially since the Federal Communication Commission (FCC) released its report in 2002 [1]. There are significant demands for small size antenna elements with broader bandwidth for future high-speed, high data rate wireless communication systems. The antenna is considered to be a key component of UWB system and

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it affects its overall performance. There are many challenges for designing UWB antenna include the ultra-wideband performance of the impedance matching, i.e., 3.1–10.6 GHz, small size, good omni-directional radiation pattern, and stable gain. Unlike patch antennas, slot antennas [2–6] possess good characteristics such as wide impedance bandwidth, less copper losses, better isolation . . . etc. The main focus of these slot antenna designs is to enhance the impedance bandwidth using a widened slot and a fork like stub [3].

However, there are several narrowband communication systems operating in the same UWB frequency band such as IEEE 802.11a WLAN system or HIPERLAN/2 wireless system. These systems operate at 5.15–5.825 GHz which may cause interference with UWB system. To avoid potential interference with existing wireless systems, a filter with band rejection characteristics is connected to the UWB antenna to achieve a notch function at the interfering frequency band. Recently, many UWB antennas with different bandstop filter designs have been widely discussed [7–10].

In order to obtain a band rejection capability many techniques were introduced. Jahromi [7] used an H-shaped slot etched in the ground plane to destroy surface current at 5.8 GHz. Gao et al. [8] used a parasitic slots in the defected ground to stop radiation at the same frequency. A pi-shaped [9] or arc-shaped slot [10] in the radiating element have been used to obtain a band stop filter around the frequency of 5.8 GHz. Hong et al. [11] introduced a hybrid technique for having band notch ability by using a complex parasitic element in the radiator and a modified defected ground to obtain the band rejection in the middle of UWB range.

In this paper, two different elliptical slot UWB antenna prototypes are presented. The proposed antenna designs offer UWB radiation with compact size and simple feed structure and less optimization parameters. The proposed designs have a reduction in the antenna size compared with [2] and a better gain at lower frequencies than [4]. The calculated results show that the proposed antenna designs can achieve a reflection coefficient S_{11} less than -10 dB over an UWB range from 2.5 GHz to beyond 14 GHz. Detailed design and associated results are presented in Section 1. In Section 2, numerical investigation of band rejection capabilities of UWB elliptical slot antenna with circular and crescent shaped radiators are presented. The band rejection performance can be achieved either by a C-shaped slot in the ground plane design A or by cutting a C-shaped slot in the microstrip feedline design B. The calculated reflection coefficient of the both antenna designs show an impedance bandwidth starts from 2.5 GHz to beyond 14 GHz for $S_{11} < -10$ dB except in the 5.0–

6.0 GHz frequency range. Also, both designs show relatively stable radiation patterns over the whole UWB frequency band compared to the antennas in [4, 5]. The proposed designs are considered good candidates for UWB applications.

2. ANTENNA DESIGN AND RESULTS

The proposed structures are fabricated and simulated using two independent commercial software packages, i.e., Ansoft HFSS software [16] which utilizes the Finite Element Method (FEM) in frequency domain and CST MWS [17] that is based on the Finite Integration Technique (FIT) in time domain. The design goals are to achieve impedance bandwidth cover the whole UWB frequency spectrum (3.1–10.6 GHz) with good gain, stable radiation patterns, phase linearity, constant group delay characteristics across the whole desired band.

2.1. Proposed Antenna Prototype #A

Figure 1 shows the geometry and configuration of the proposed antenna prototype #A. The proposed antenna is designed and realized on RT5880 substrate ($\varepsilon_r = 3.38$, $\tan\delta = 0.0009$ and thickness $h = 1.575$ mm). The antenna consists of an elliptical aperture etched out

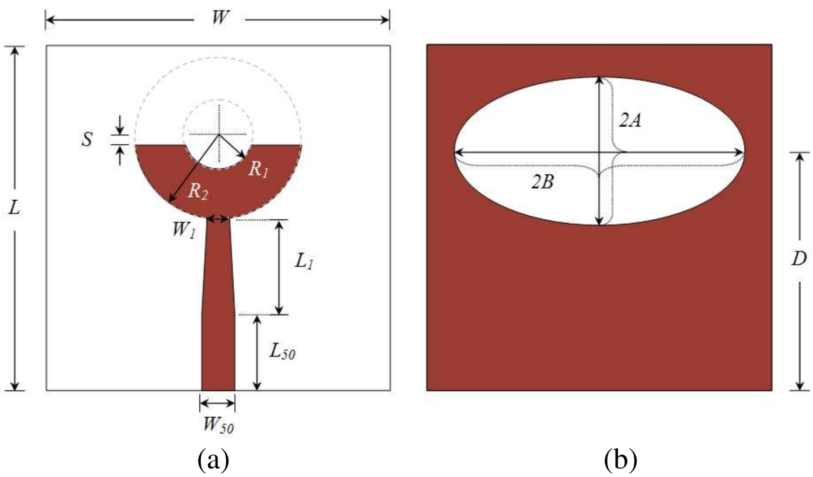


Figure 1. Geometry of the proposed antenna prototype #A design (a) top view, (b) bottom view.

from the ground plane of a PCB and a microstrip line with half circular shaped ring stub for excitation. Design of the elliptical aperture is determined by minimizing the aperture area while satisfying the input impedance matched for the entire UWB band. The proposed antenna has an approximated elliptical aperture area of $2A \times 2B\,\text{mm}^2$. The excitation of the antenna is formed by a $50\,\Omega$ microstrip line of width $W_{50} = 4.3\,\text{mm}$ and length $L_{50} = 10\,\text{mm}$ and a tapered line of width W_1 and length L_1 for impedance transformation to match with the radiator element. The radiator element is a half circular shaped ring stub of only three parameters: the inner radius R_1, the outer radius R_2, and the extrusion depth S, as shown in Figure 1. Due to the substrate's stable behavior at high frequency, an optimization process has been carried out using full-wave electromagnetic simulator. The optimization process led to the optimal parameters listed in Table 1.

All simulations are performed using two different commercial software programs. The first one is Ansoft High Frequency Structure Simulator (HFSS) software which is based on 3D full-wave Finite Element Method (FEM) [16]. It is considered one of the industry-standard software programs. The second software program is CST Microwave Studio (CST MWS) which is based on based on Finite Integration Technique (FIT) which is equivalent to FDTD [17].

The measured and calculated reflection coefficient S_{11} against the frequency for the designed antenna prototype #A is plotted in Figure 2.

Table 1. Antenna dimensions.

Parameter	W	L	W_1	L_1	S	R_1	R_2	A	B
Value	45	45	3	12.4	1.4	4.5	11	9.6	19

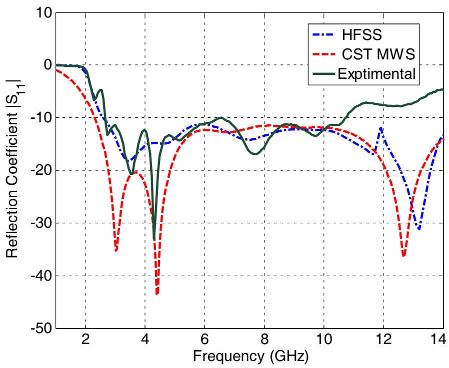


Figure 2. Simulated and experimental return loss S_{11} of the proposed antenna prototype #A design.

It is observed from the results that the calculated return loss using HFSS and CST MWS show some differences especially around 13 GHz because of different meshing schemes used by both programs. The designed antenna exhibits an impedance bandwidth of 11 GHz starts from 2.5 GHz to beyond 14 GHz theoretically but it around 9.5 GHz practically that is may accounted to the connector and cable effects at high frequency. Generally there are good agreement between the measured and the simulated results.

Figure 3 shows the calculated *E*-plane and *H*-plane radiation patterns at frequencies 3 GHz, 5 GHz, 7 GHz, and 9 GHz using Ansoft HFSS. As expected, the antenna exhibits a dipole-like radiation patterns in the *E*-plane and good omni-directional radiation patterns in the *H*-plane.

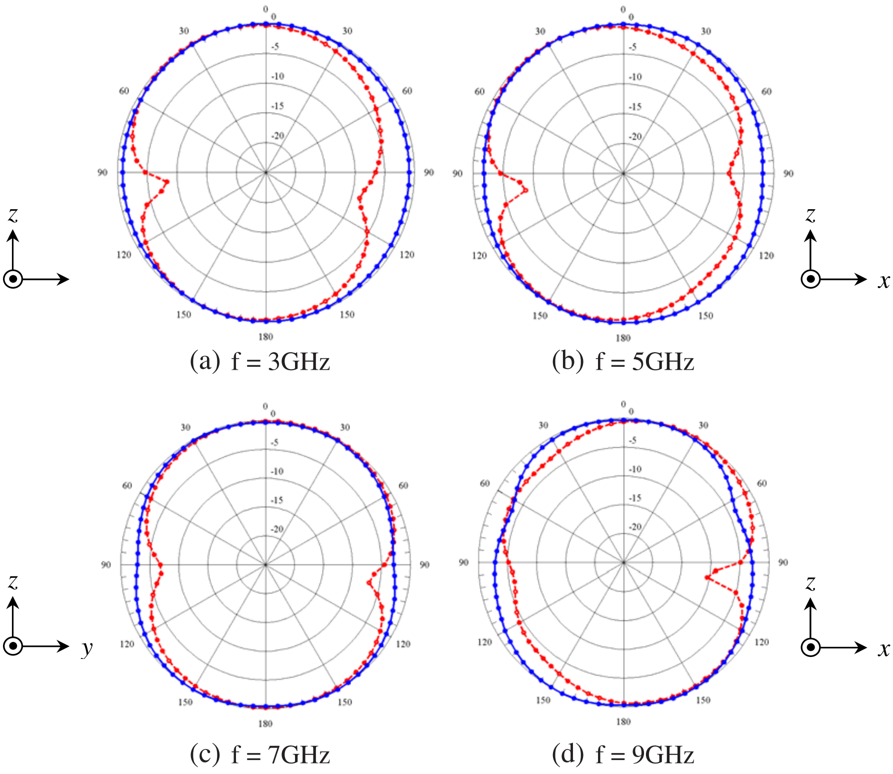


Figure 3. Calculated *E*-plane (red dashed) and *H*-plane (blue solid) radiation patterns for proposed antenna prototype #A at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz and (d) 9 GHz.

2.2. Proposed Antenna Prototype #B

In this section, a second antenna prototype design is introduced. The geometry and configuration of the proposed antenna prototype #B is shown in Figure 4. The proposed antenna has a crescent shaped ring stub for excitation. The excitation of the antenna is formed by a $50\,\Omega$ microstrip line with the same parameters as the one used in prototype #A. The radiator element is a crescent shaped ring stub of only three parameters: the inner radius R_1, the outer radius R_2,

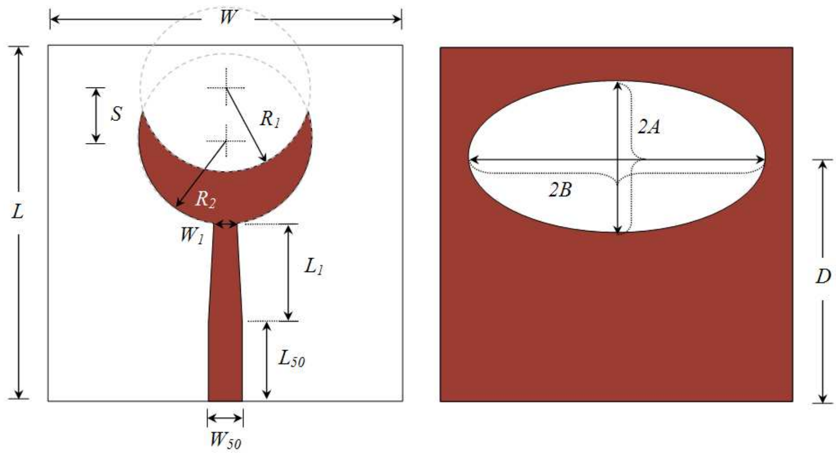


Figure 4. Geometry of the proposed antenna prototype #B design (a) top view, (b) bottom view.

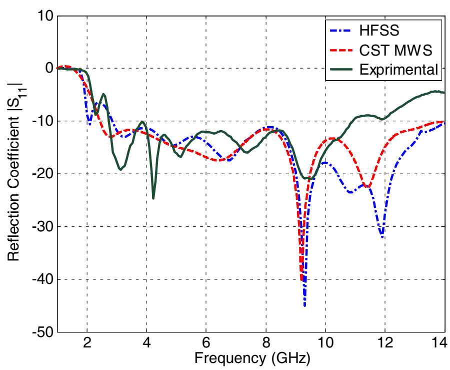


Figure 5. Simulated and experimental return loss S_{11} of the proposed antenna prototype #B design.

and the extrusion depth S, as shown in Figure 4. An optimization process has been carried by a full-wave electromagnetic simulator and the optimized parameters have been tabulated in Table 2.

The Experimental and simulated reflection coefficient S_{11} for the designed antenna prototype #C with frequency is shown in Figure 5.

Table 2. Antenna dimensions.

Parameter	W	L	W_1	L_1	S	R_1	R_2	A	B	D
Value	45	45	3	12.5	6.65	11	11	9.5	20	31.2

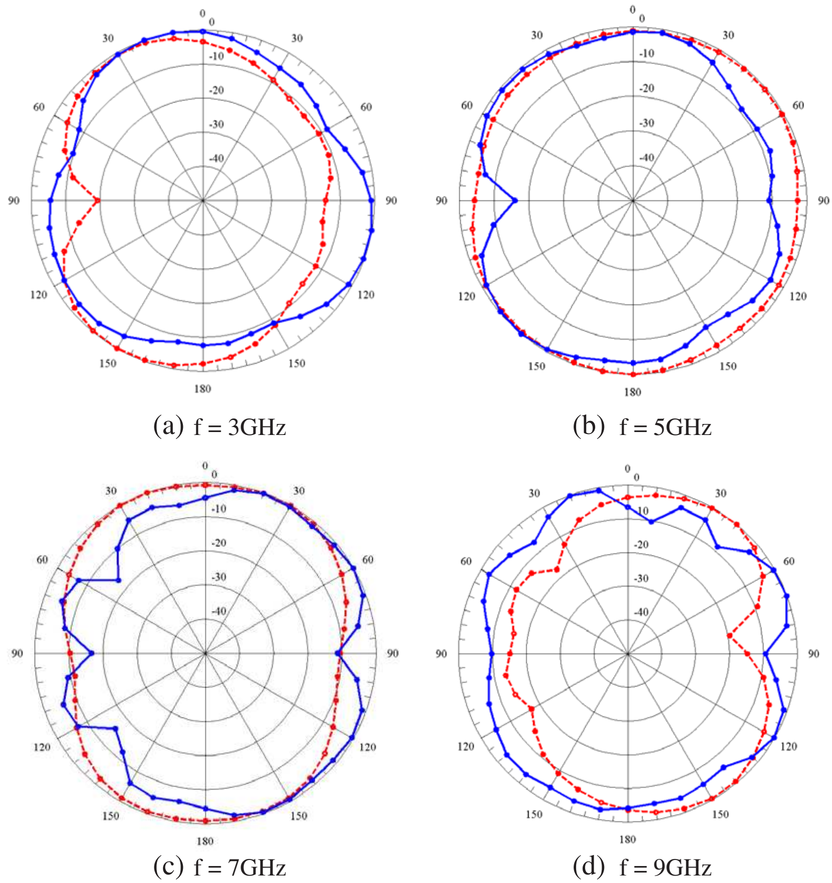


Figure 6. Calculated E-plane (red dashed) and H-plane (blue solid) radiation patterns for the proposed antenna prototype #B at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz and (d) 9 GHz.

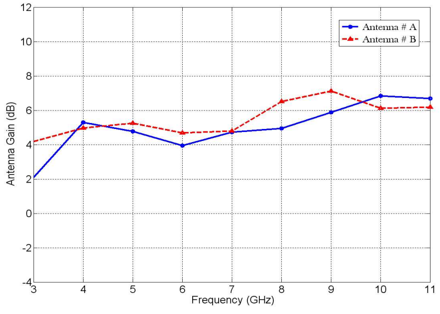


Figure 7. Calculated gain curves for the proposed antenna prototypes #A and B.

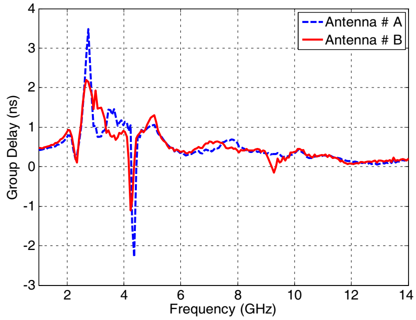


Figure 8. Measured group delay for the proposed antenna prototypes #A and B.

It can be seen from the results that the calculated return loss with both HFSS, CST MWS and experimentally are almost agree and the designed antenna exhibits an impedance bandwidth of 11 GHz starts from 3 GHz to 14 GHz theoretically but it around 9.5 GHz practically for the same reasons stated before, which covering the whole UWB frequency band.

Figure 6 shows the simulated E-plane and H-plane radiation patterns at frequencies 3 GHz, 5 GHz, 7 GHz, and 9 GHz. It can be noted that the antenna also exhibits good omni-directional radiation patterns in H-plane with a stable shape over the operated bandwidth.

The calculated gain curves in the boreside ($\theta = 180°$) direction for the proposed antennas A, and B are plotted in Figure 7. It can be noticed that the proposed antenna gain is almost stable over the whole frequency band. The measured group delay for both antennas is shown in Figure 8.

3. BAND-NOTCHED ANTENNA DESIGNS

The first band-notched prototype, shown in Figure 9, consists of the previously designed antenna prototype A with a C-shaped slot of width W_N, length L_N, thickness T and location D_N from the substrate edge etched from the ground plane. The other band-notched prototype shown in Figure 10 has the same geometry of prototype B with a C-shaped slot cut away from the feeding structure. The C-shaped slot in both designs works as a filtering element for stopping the surface currents at the frequency band of interference. All the optimized parameters for the band-notched antenna designs are tabulated in Table 3 and Table 4, respectively.

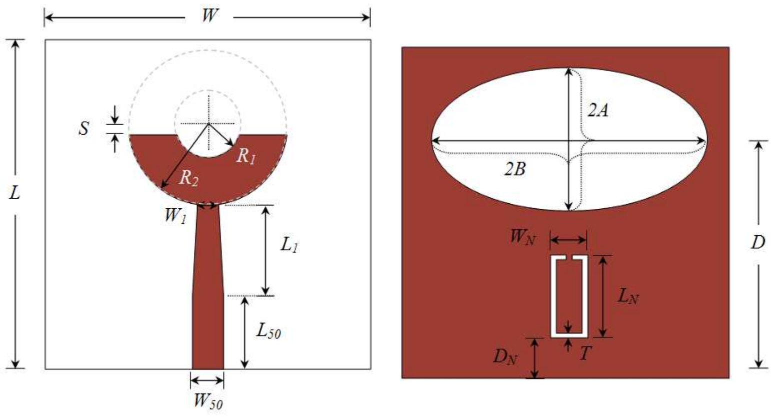


Figure 9. The geometry of the proposed antenna A (a) front view, (b) back view.

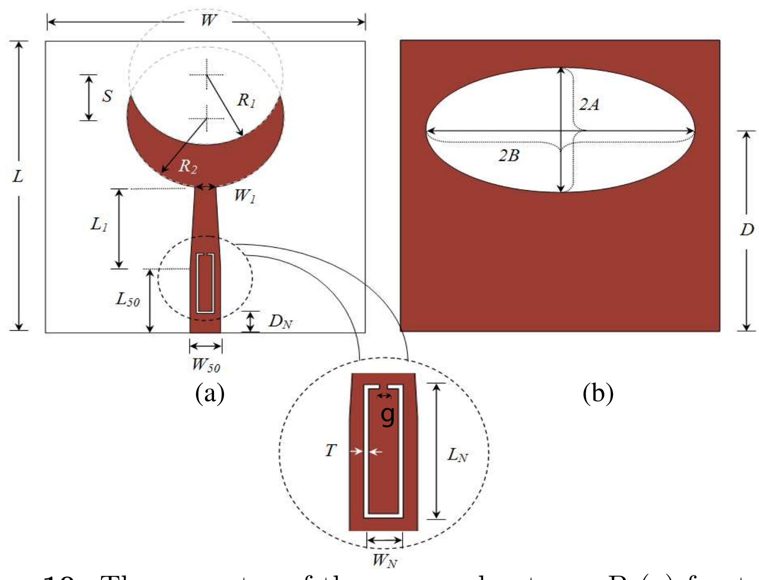


Figure 10. The geometry of the proposed antenna B (a) front view, (b) back view.

Table 3. Band-notched antenna #A dimensions.

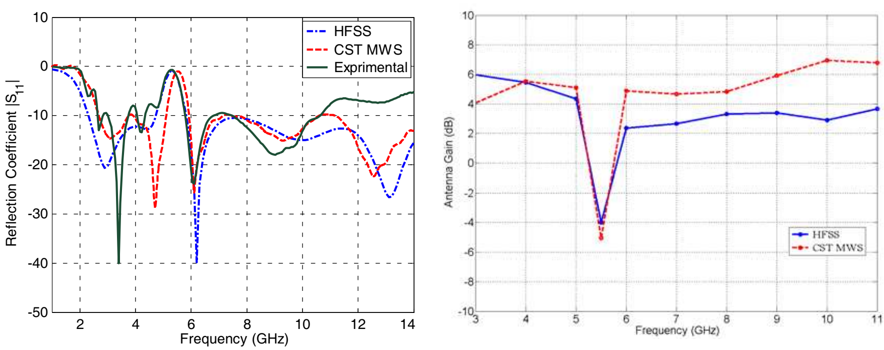
Band Rejection Filter Parameters	W_N	L_N	D_N	T	g
Value	3.2	8.8	4	0.2	0.4

Table 4. Band-notched antenna #B dimensions.

Band Rejection Filter Parameters	W_N	L_N	D_N	T	g
Value	2.5	9.3	3	0.3	0.4

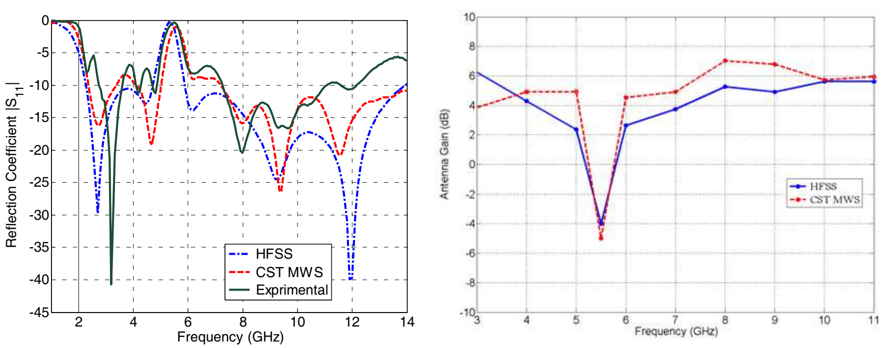
3.1. Results of Band-notched Prototype A and B

The reflection coefficient curves of the proposed antennas A and B using both Ansoft HFSS [16] and CST MWS [17] are illustrated in Figures 11(a) and 12(a), respectively, with a good agreement between them. A band-notched performance is noticeably achieved in the range from 5.0–6.0 GHz. Figures 11(b) and 12(b) present the



(a) (b)

Figure 11. Measured and simulated (a) reflection coefficient S_{11}, (b) gain curves of the proposed antenna A.



(a) (b)

Figure 12. Measured and simulated (a) reflection coefficient S_{11}, (b) gain curves of the proposed antenna B.

antenna gain curves in the entire operating frequency band for the proposed antennas A and B, respectively. For both antennas, it can be noticed that the proposed antenna gain is almost stable over the whole frequency band with a sharp gain decrease the in 5.0–6.0 GHz frequency band. The calculated E-plane and H-plane radiation patterns at 3, 5, 7 and 9 GHz for the proposed antennas A and B are plotted in Figures 13 and 14, respectively. It can be noticed that the H-plane pattern indicates a reasonable omni-directional patterns.

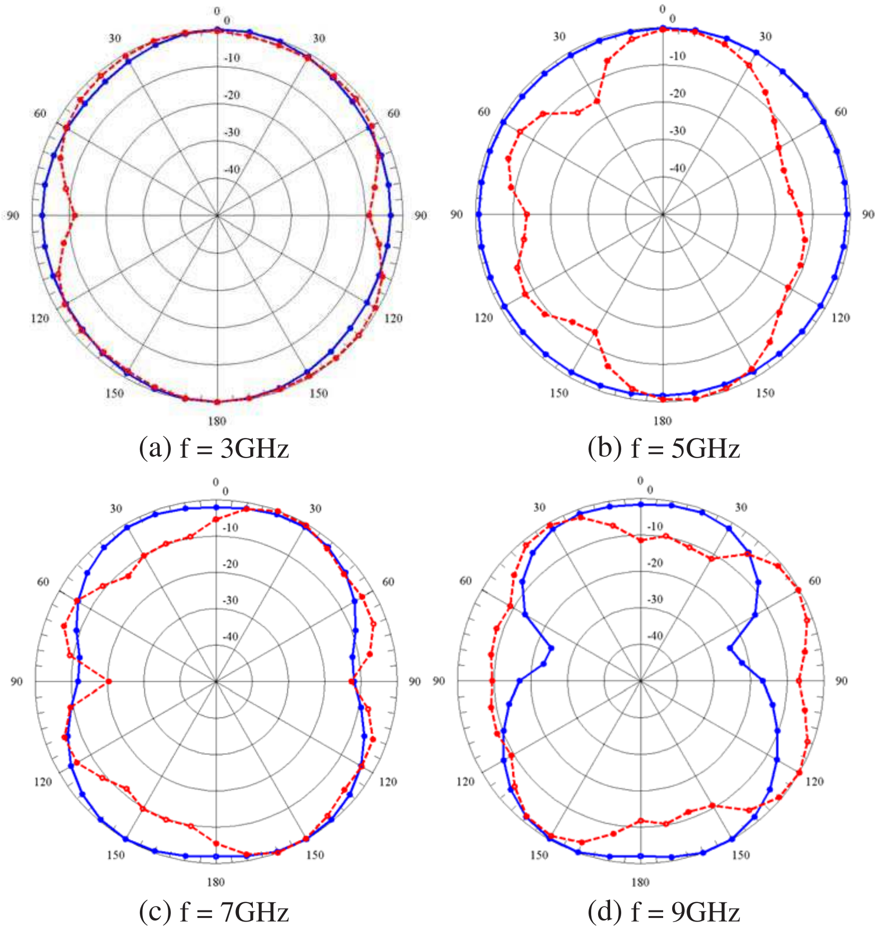


Figure 13. Calculated E-plane (red dashed) and H-plane (blue solid) radiation patterns for proposed antenna prototype #A at (a) 3 GHz (b) 5 GHz (c) 7 GHz and (d) 9 GHz.

It can be noticed that the antenna prototype B (Crescent) has sharp edges than prototype A (Half circular ring) which make the surface current variation near these discontinuities very high that will deteriorate the stability of the radiation pattern especially at high frequencies. To illustrate the effect of the C-shaped filtering element in both prototypes. Figures 15 and 16 show the surface current distribution over different frequencies (3 GHz, 5.5 GHz and 9 GHz) where nearly all the currents are trapped at the notched frequency

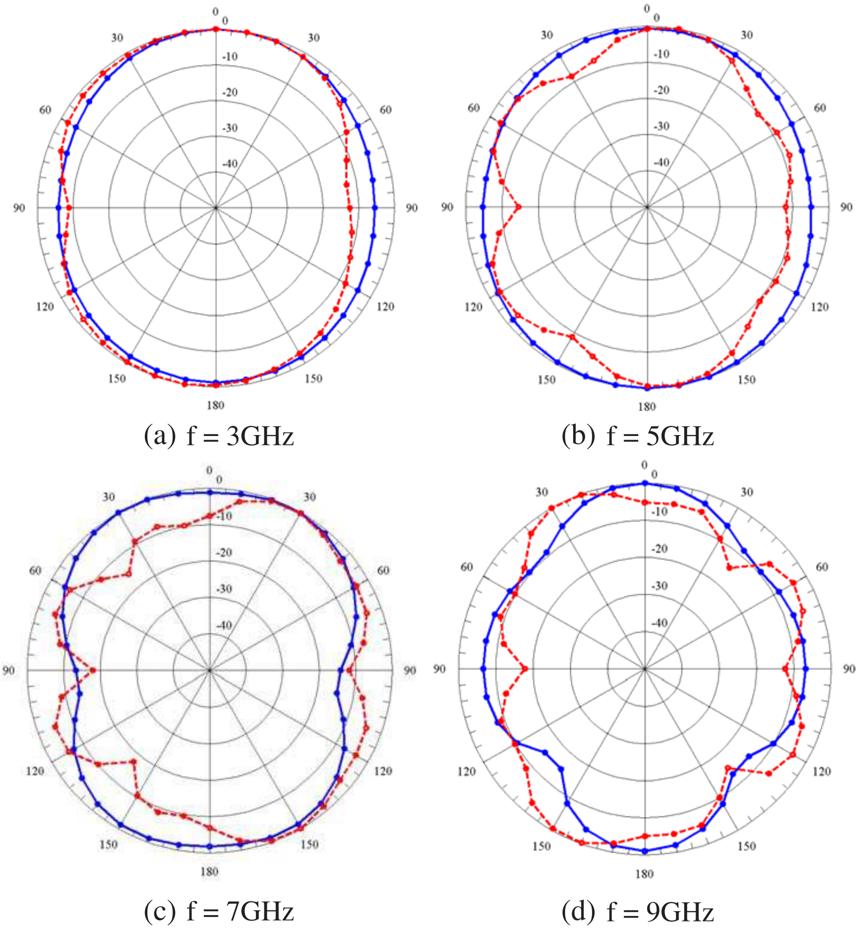
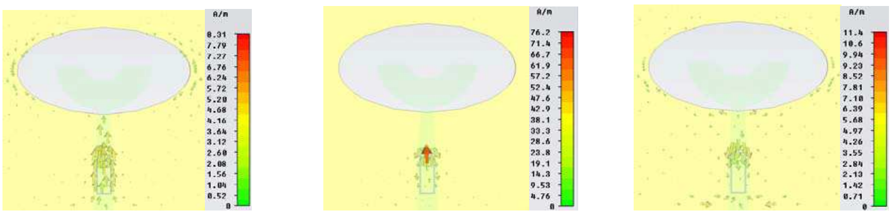


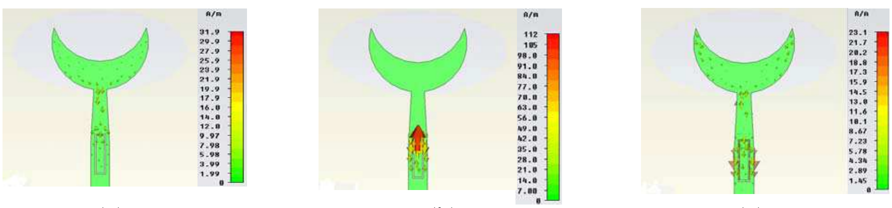
Figure 14. Calculated E-plane (red dashed) and H-plane (blue solid) radiation patterns for proposed antenna prototype #B at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz and (d) 9 GHz.

in both cases. Figure 17 illustrates the group delay for the band notched designs. It can be noticed that the measured group delay is within the acceptable range across the whole UWB band. A photo of the fabricated band-notched antenna prototypes A and B is shown in Figure 18.



(a) (b) (c)

Figure 15. Surface current for proposed antenna prototype #A at (a) 3 GHz, (b) 5.5 GHz and (d) 9 GHz.



(a) (b) (c)

Figure 16. Surface current for proposed antenna prototype #B at (a) 3 GHz, (b) 5.5 GHz and (d) 9 GHz.

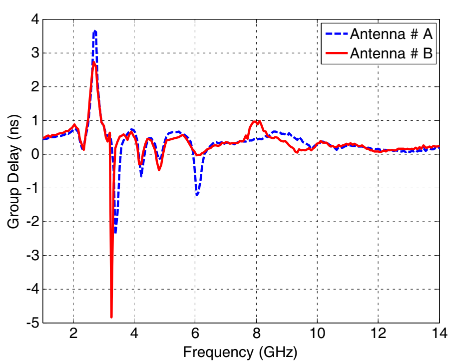
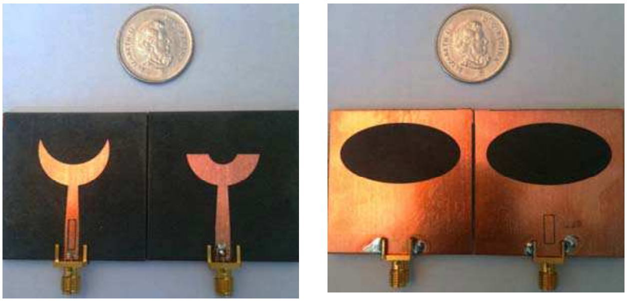


Figure 17. Measured group delay for the proposed band-notched antenna prototypes #A and B.



(a) (b)

Figure 18. Fabricated band-notched antenna prototypes A and B (a) top, (b) bottom.

4. CONCLUSION

In this paper, two different antenna design prototypes for UWB operation have been introduced. These antennas are proposed and designed with a standard PCB process. The calculated impedance bandwidth of proposed antenna designs ranges from 3 GHz to beyond 14 GHz for reflection coefficient (S_{11}) less than -10 dB. It can be noticed that the prototype A has a more stable radiation pattern compared with prototype B while prototype B has a better average gain over the whole frequency band of interest. So, the proposed antenna designs are considered good candidates for UWB applications. Two different band notched antennas are also presented. By introducing a C-shaped slot in the ground plane or by cutting a C-shaped slot in the microstrip feedline, a band rejection performance is achieved. The calculated reflection coefficient of both antennas show an impedance bandwidth starts from 2.5 GHz to beyond 14 GHz for VSWR < 2 except in the 5.0–6.0 GHz frequency range. Also, both prototypes have relatively stable radiation patterns over the whole frequency band of interest.

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