Planar Circular Monopole Antenna with Perforated Dielectric Resonator for Notched Ultra-Wide Band Applications

Saber H. Zainud-Deen[1], Ahmed Shaker [2], and K. R. Mahmoud[2]

[1] Faculty of Electronic Engineering, Menoufiya University, Menouf, Egypt
anssaber@yahoo.com

[2]Department of Electronics and Communications Engineering, Faculty of Engineering, Helwan University, Cairo, Egypt
shakerelhagar@yahoo.com,kurany_hameda@h-eng.helwan.edu.eg

Abstract -In this paper, a planar circular patch antenna is presented for UWB operating characteristics. The bandwidth of the proposed antenna is increased by inserting a perforated dielectric resonator (DR) material with the planar monopole. The design combines the advantages of a small size dielectric resonator (DR) and thin planar monopole antennas. Two antenna designs A and B are proposed. In design A, two layers of the same dielectric material are presented with the same radius and different thicknesses. While in antenna design B, only one dielectric material layer perforated by 11 holes drilled with the same radius is considered. The effects with respect to the geometric parameters of the proposed antennas on impedance bandwidth and radiation pattern are discussed. In addition, the two proposed antennas are designed to have a rejection frequency band from 5 to 6 GHz by inserting two U-shaped slots in the ground plane, where the WLAN service is allocated. The proposed antennas are completely designed and analyzed using the finite element method (FEM), and then the finite integral transform (FIT) technique is used to check the validity of the numerical results.

***Index Terms*-**Band notched, dielectric resonator antenna (DRA), FEM, FIT, ultra-wideband (UWB).

I. INTRODUCTION

Recently, ultra-wide band (UWB) technology has been attracting much attention for communication systems especially since the U.S. Federal Communications Commission (FCC) began allowing use of the band from 3.1 to 10.6 GHz for commercial applications [1]. UWB systems have widely been exploited in the wireless short-range high throughput communication operating over the same frequency range. To satisfy such requirement, various ultra-wide band antennas have been studied [2-3]. The UWB antennas have been designed with a specification of constant gain and linear phase response. Moreover, the antenna should have good impedance matching characteristics over the whole UWB frequency range. Planar monopole antennas are very suitable for UWB applications [4]. However, due to the overlap of currently allocated UWB frequency band with the existing wireless local area network (WLAN) (5.15 - 5.825GHz), special characteristics such as band notch are much desired for UWB antennas to reduce the interference between those two communication systems [5-6]. Accordingly, an ultra-wide band antenna with a band-notch characteristic can be an alternative choice to the use of a distinct stop-band filter in the system. One simple way is to etch thin slots in the antenna surface [7] to achieve the band-notched characteristic.

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A dielectric resonator antenna (DRA) has a minimum of metal parts and mainly consists of dielectric materials mounted over a metal ground plane. DRAs have been of interest for the last three decades due to its attractive features like high radiation efficiency, lightweight, small size, low loss, and ease of excitation [8]. DRAs found many applications in wireless communications such as cellular communications operating over a wide frequency band [9].An ultra-wide band DRAs are presented in [10]. A novel compact UWB dielectric resonator antenna for UWB short-range wireless communication systems has been presented in [11]. In [12], the UWB dielectric resonator antenna having consistent omnidirectional pattern and low cross-polarization is presented. Ultra wideband dielectric resonator antenna with band rejection is studied in [13].

In this paper, a simple compact monopole type dielectric resonator antenna is presented. The design combines the advantages of small size dielectric resonator antenna (DRA) and thin planar circular monopole antenna. The dielectric resonator is inserted with monopole antenna where it is shaped to house the excitation feed. Two proposed designs A and B are presented to operate in the UWB range. The coplanar waveguide (CPW) is used to feed the antennas. Then, U-shape slots etched on the ground plane is considered to achieve the notched band from 5 to 6 GHz, to prevent interference between the UWB communications and the WLAN systems. Simulations have been carried out with the finite element method (FEM) to determine the antenna return loss bandwidth, gain, and radiation pattern [14-15]. Numerical results are checked with those obtained by the finite integration technique (FIT) to validate the results [16].

The paper is organized as follows: In Section 2, the simulation and optimization for the two proposed UWB antennas A and B are demonstrated. In Section 3, the notched UWB antennas are presented. Finally, the conclusions are drawn in Section 4.

II. ANTENNAS DESIGN AND NUMERICAL RESULTS

Figure 1 shows the geometry of the planar circular monopole antenna. The antenna is printed on an RT6002 substrate with thickness of 0.762 mm and relative permittivity of 2.94. The antenna is composed of the radiation circular patch of radius R_p, and partial ground L_g x W. The coplanar waveguide is used to feed the antenna. The feed gap G_3 can be used to adjust the impedance matching. The antenna parameters are listed in Table 1.

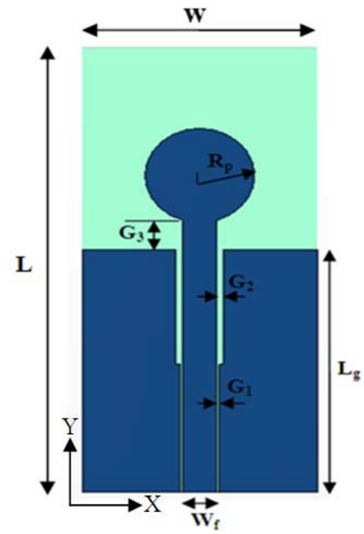
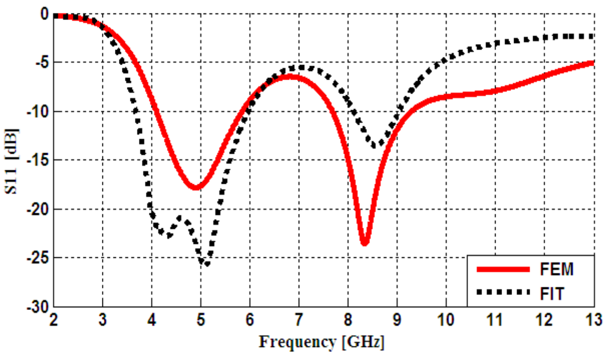


Fig. 1.The geometry of the planar circular monopole antenna.

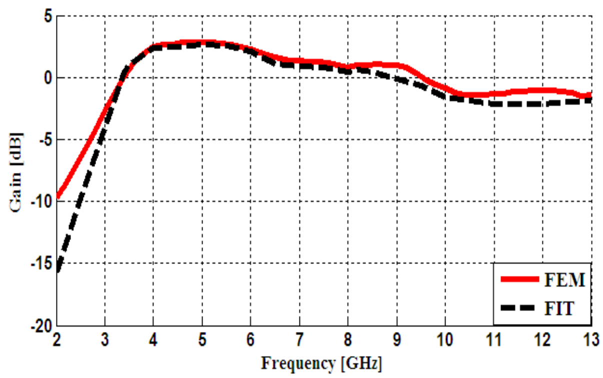
Table 1: Parameters of the planar circular monopole antenna (all dimensions are in mm)

L	W	L_g	G_1	G_2	G_3	R_p	W_f
33	15	2.54	0.15	0.45	2	3.5	2.16

Figure 2 shows the variation of the power reflection coefficient and the gain of the antenna versus the frequency. It is clearly shown that the return loss < -10 dB occurs over the frequency range from 4.1 to 5.9 GHz with gain variation from 2 to 3 dB and from 7.7 to 9.3 GHz with gain variation from 1 to 1.2 dB. The simulated radiation patterns of the antenna at frequencies 5 and 8.2 GHz in different planes are shown in Fig.3. Simulations have been carried out with FEM and compared with those calculated by the FIT method. It can be observed that, good agreement is obtained. The results show that the radiation pattern is nearly omnidirectional in the H-plane and monopole-like radiation pattern in the E-plane.

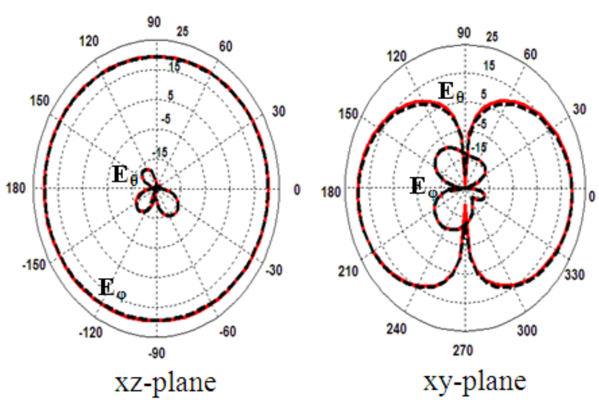


(a) Reflection coefficient frequency response.

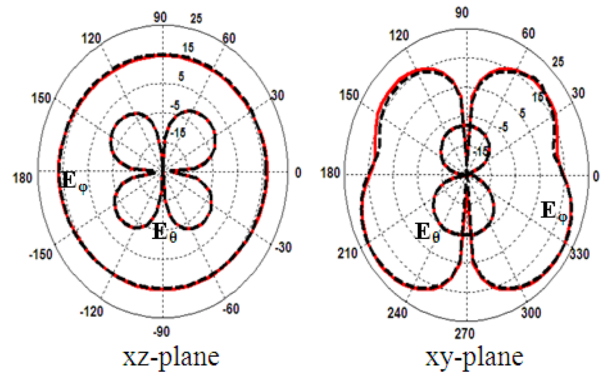


(b) Antenna gain frequency response.

Fig. 2. The simulated frequency response results of the planar circular monopole antenna using FEM and FIT methods.



(a) f = 5 GHz



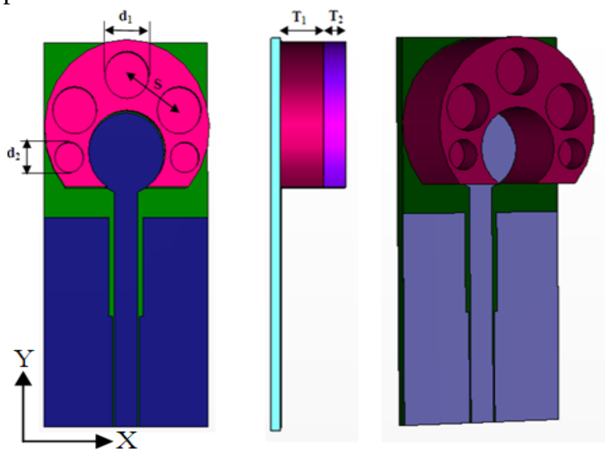
(b) f= 8.2 GHz

Fig. 3. The simulated radiation patterns of the planar circular monopole antenna in xz and xy-planes at different frequencies.

____ FEM --- FIT

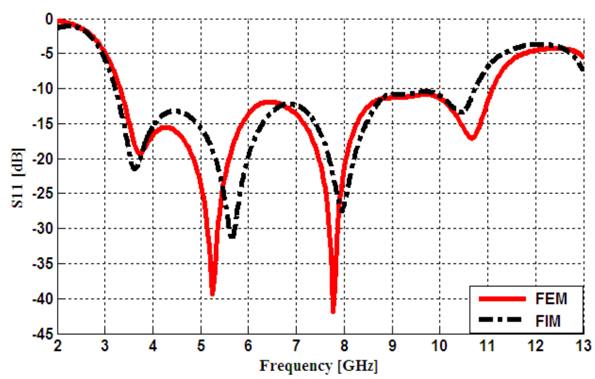
A. Antenna design A

In this antenna design, the circular monopole antenna is inserted within cylindrical DRA with two layers of the same dielectric material with a relative dielectric constant ε_r = 10.2. Both layers have the same radius of W/2 with different thicknesses of T_1 = 3.54 mm and $T_2 = T_1/2$ for lower and upper layers, respectively. The upper one is perforated by five holes drilled into the dielectric material to change its effective dielectric constant [17]. The radius of each hole and the separation between holes are optimized for wider antenna impedance bandwidth. Figure4 shows the construction of the proposed antenna where the diameter of wider holes is d_1 = 1.8 mm , the diameter of other holes is d_2 = 1.25 mm, and the separation between the holes is S= 5.41 mm. Figure5 depicts the simulated power reflection coefficient and antenna gain for the antenna design A. It obviously indicates that an UWB bandwidth covering from 3.2 GHz to 11.2 GHz with a ratio of about115% is achieved for the proposed antenna. The gain varies from 3 dB to 6 dB over the operating frequency range. It can be concluded that the gain variation is 3dB over the entire operating frequency range (3.2 to 11.2 GHz). The simulated radiation patterns of the proposed antenna at 3.4, 6.2, and 7.8 GHz in different planes are illustrated in Fig.6, respectively. The results show that the radiation pattern is quite stable as the frequency changes with a nearly omnidirectional radiation pattern in the H-plane and the monopole-like radiation patterns in the E-plane.

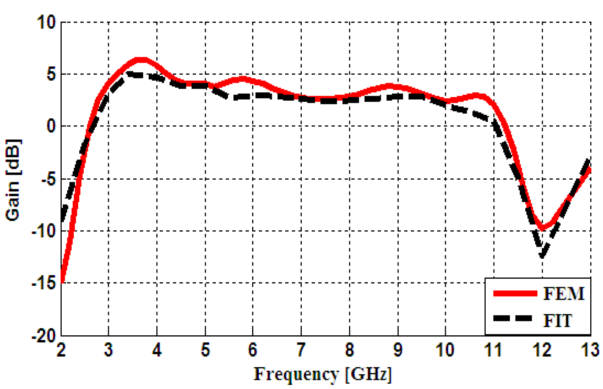


(a) Top view (b) Side view (c) Three dimension

Fig. 4.The geometry of the proposed antenna design A.

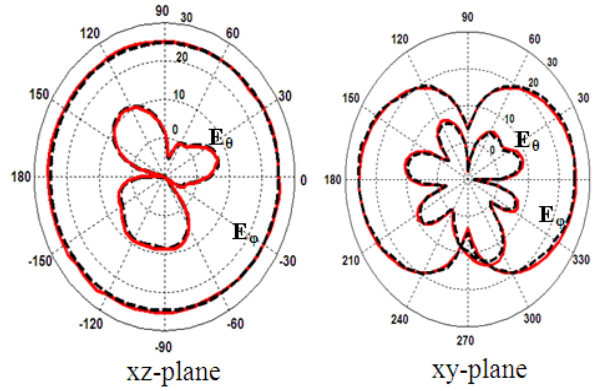


(a) Reflection coefficient frequency response.

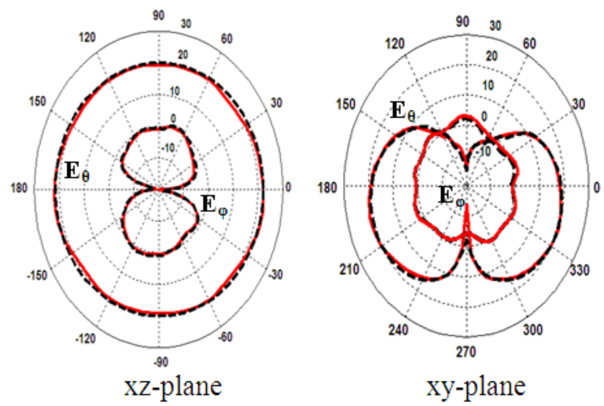


(b) Antenna gain frequency response

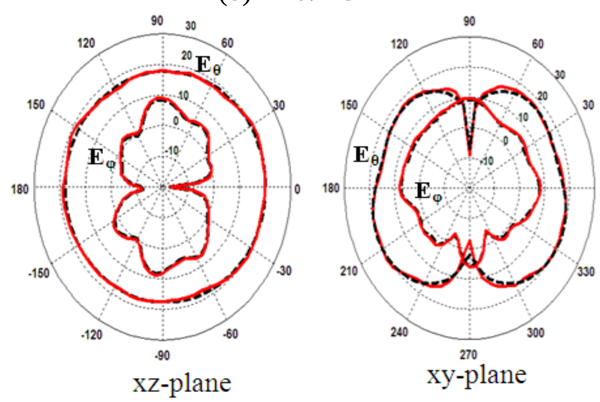
Fig. 5. The simulated frequency response results of proposed antenna design A using FEM and FIT.



(a) f= 3.4 GHz



(b) f= 6.2 GHz



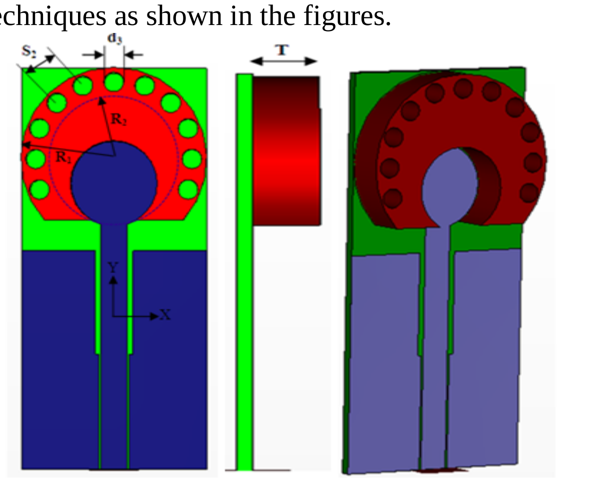
(c) f= 7.8 GHz

Fig. 6. The simulated radiation patterns of the proposed antenna A in xz and xy-planes at different frequencies.

____ FEM _ _ _ FIT

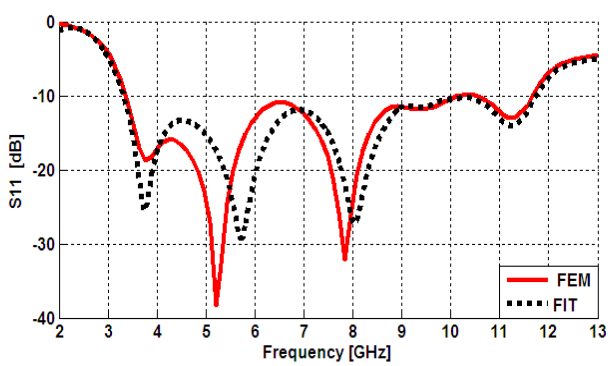
B. Antenna design B

In this proposed antenna design, the planar circular monopole antenna is inserted within only one layer of cylindrical DR with radius R_1 = 7.5 mm and thickness T = T_1+T_2 = 5.318 mm. The layer is perforated by 11 semi-holes drilled into the dielectric material with a hole diameter of d_3 = 1.4 mm and separation between each two holes S_2 = 2.52 mm. The center of the holes located at $\left(\frac{R_1+R_2}{2}\right)$,where R_2 = 5.5 mm. Based on several parametric studies, the optimized antenna is designed as depicted in Fig. 7. Using the FEM method, the power reflection coefficientand gain of the proposed antenna are calculated as shown in Fig.8. The gain of the proposed antenna in the boresight direction varies from 3dB to 6dB over the operating UWB frequency range. Simulation results show that the impedance bandwidth is about 8.4 GHz starting from 3.2 GHz to 11.6 GHz. The simulated radiation patterns of the proposed antenna at 3.4, 6.2, and 7.8 GHz along the different planes are illustrated in Fig. 9, respectively. The simulated H-plane retains omnidirectional over the entire bandwidth. The results are compared with that calculated with FIT with a good agreement between the two techniques as shown in the figures.

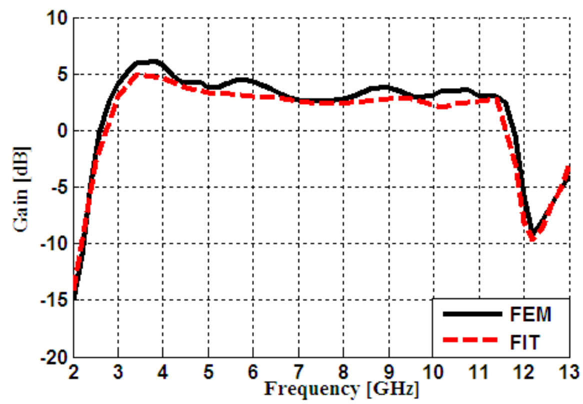


(a) Top view (b) Side view (c) Three dimensic

Fig. 7. The geometry of the proposed antenna design B.

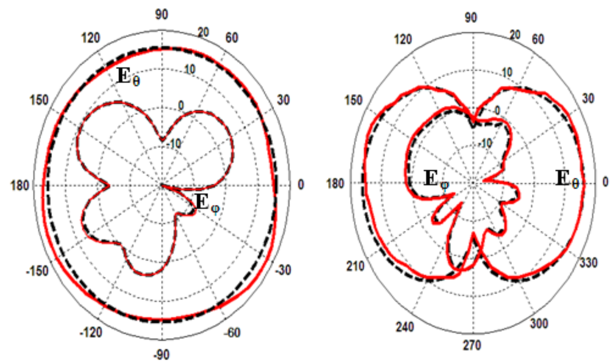


(a) Reflection coefficient frequency response.



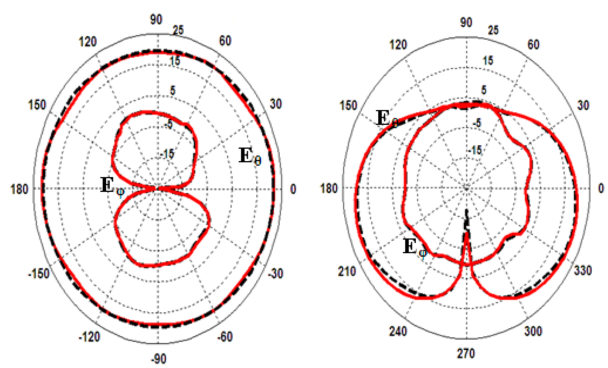
(b) Antenna gain frequency response

Fig. 8. The simulated frequency response results of proposed antenna design A using FEM and FIT.



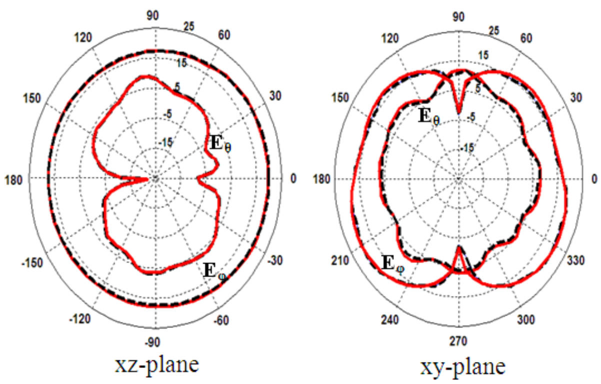
xz-plane xy-plane

(a) f= 3.4 GHz



xz-plane xy-plane

(b) f= 6.2 GHz



(c) f= 7.8 GHz

Fig. 9. The simulated radiation patterns of the proposed antenna B in xz and xy-planes at different frequencies.

___ FEM _ _ _ FIT

Figure 10 shows the effect of the parameters of the perforated DRA on the impedance bandwidth since the diameter of the holes is varying the bandwidth of the antenna affecting where the result effective permittivity is changing with respect to the holes diameter.

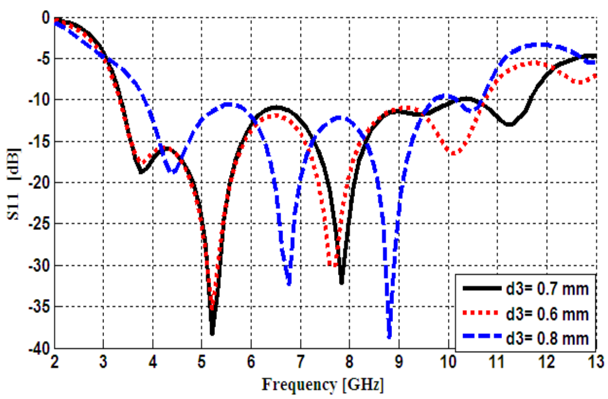
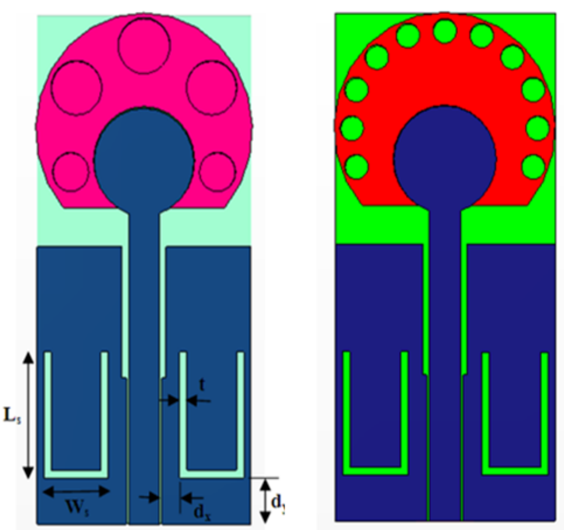


Fig. 10. The effect of the holes diameter on the antenna B bandwidth.

III. UWB ANTENNAS WITH A BAND-NOTCH STRUCTURES

In this section, the proposed antennas A and B are reconstructed to provide a stop-band notch from 5 to 6 GHz for WLAN communication system. Two U-shaped slots etched in the ground plane are used as shown in Fig. 11. The notch frequency can be adjusted by tuning the length and depth of the U-slot. The slots behave as resonant structures and are capable of preventing the energy from radiating to the free space. The dimensions of the slots are optimized to give the required stop band where the length of each slot is L_s= 8.2 mm and the width is W_s= 4 mm with thickness t = 0.5 mm with offsets d_x= 0.97 mm and d_y= 3 mm as depicted in Fig.11. It is seen that from Fig.12, the antennas in design A and design B provide sharp stop-band notch in the frequency range 5 - 6 GHz with a VSWR value of about 15 at 5.4 GHz for antenna design A and 12 at 5.5 GHz for design B by inserting the two slots. Figure 13 shows a minimum gain of -18dB at 5.4 GHz for design A while for design B the gain decreased to -15 dB at the frequency of 5.5 GHz. For other frequencies outside the notch frequency band, the antenna gain is about the same for both antennas with and without the U-slots. It is observed that the radiation patterns at other frequencies out of the notched frequency band are about the same as those of the antennas without adding the U-slots. The proposed antennas present omnidirectional patterns across the whole operating band in the H-plane an immediate sharp increase in VSWR is observed at the notch frequency band.

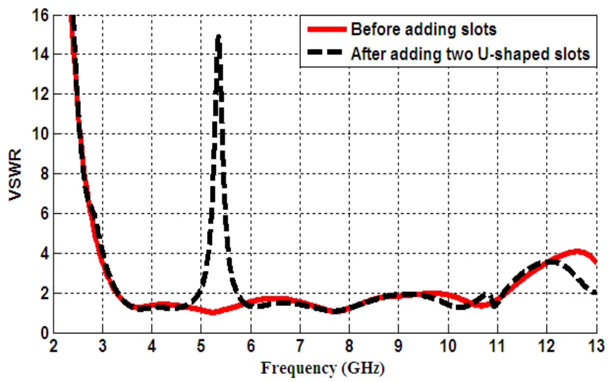


(a) Design A. (b) Design B.

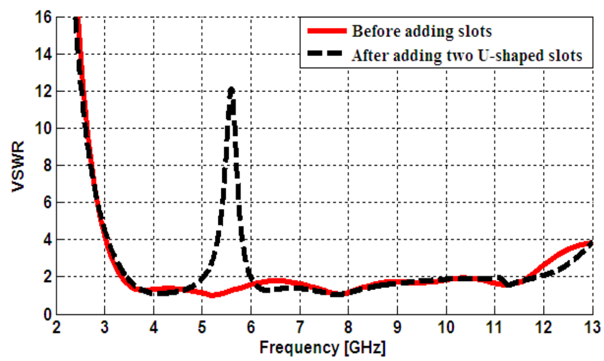
Fig. 11.The geometry of the proposed antennas A and B after adding two U-slots in the ground plane.

IV. CONCLUSIONS

In this paper, two antennas for notched-UWB applications are proposed. The antennas combine the planar circular monopole and dielectric resonator antennas. The antennas have demonstrated good performance in terms of return loss and gain. The antenna -10dB |s11|bandwidth covers the range of 3.2 to 11.6 GHz. The two U-slots embedded in the ground plane around the CPW feeding achieved an immediate sharp increase in VSWR at the notch band from 5 to 6 GHz for WLAN. The simulated radiation patterns are quite stable within UWB frequencies; it shows good monopole-like patterns and nearly omnidirectional patterns in the horizontal plane.

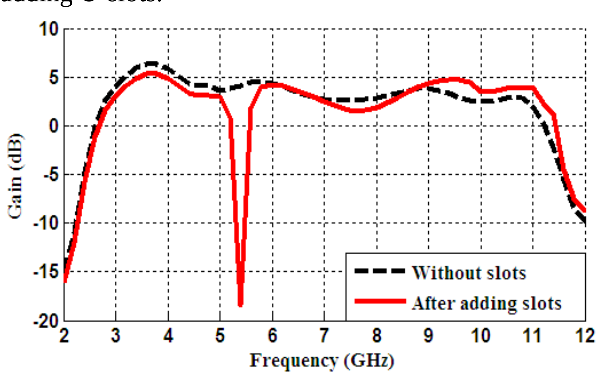


(a) Antenna design A.

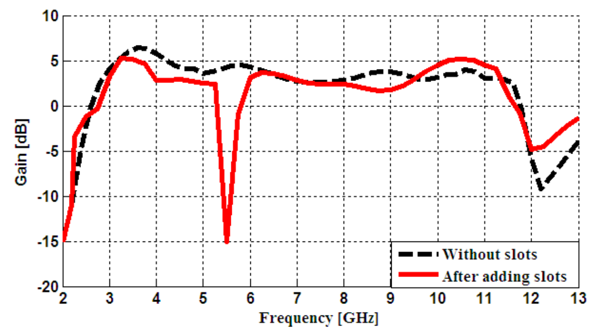


(b) Antenna design B.

Fig. 12. The simulated VSWR of proposed antennas A and B versus operating frequency before and after adding U-slots.



(a) Antenna design A.



(b) Antenna design B.

Fig. 13. The simulated gain of proposed antennas A and B versus operating frequency before and after adding U-slots.

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S. H. Zauind-Deen (S'81-M'88) was born in Menouf, Egypt, on November 15, 1955. He received the B.Sc. and M.Sc. degrees from Menoufia University in 1973 and 1982 respectively, and the Ph.D. degree in Antenna Engineering from Menoufia University, Egypt in 1988.He is currently a professor in the Department of Electrical And Electronic Engineering in the Faculty of Electronic Engineering, Menoufia University, Egypt. His research interests at present include microtrip and leaky wave antennas, DRA, RFID, UWB, and optimization techniques.

Ahmed Shaker was born in Cairo, Egypt, on February 10, 1976. He received the B.Sc. and M.Sc. degrees from Helwan University in 1999 and 2006 respectively. He is currently working for his Ph.D. in Antenna Engineering from Helwan University, Egypt. He is currently an assistance lecture in the Department of Electronics and Communications Engineering in the Faculty of Engineering, Helwan University, Egypt. His research interests at present include UWB antennas, and DRA.

Korany R. Mahmoud was born in Cairo, Egypt, on August 1975. He received his B.S. and M.S. degrees in Communications and Electronics Engineering from Helwan University in 1998 and 2003. His Ph.D. degree from Helwan University in collaboration with the University of Connecticut, USA in 2008. He is currently an assistant professor at the department of communications and electronics engineering in the same faculty. Dr. Mahmoud has served as an Editor/Reviewer of Int. J. RF & Microwave CAE. His current research interests include the areas of antenna design, array beamforming using optimization techniques.