A CPW Dual Band Notched UWB Antenna

M. Mighani [1], M. Akbari [2], and N. Felegari [2]

[1]Faculty of Eng., Department of Electrical Engineering
Aeronautical University, Tehran, Iran
mojtaba.mighani@gmail.com

[2]Faculty of Eng., Department of Electrical Engineering
Urmia University, Urmia, Iran
akbari.telecom@gmail.com, n.felegari@gmail.com

Abstract **─** In this paper, a coplanar waveguide (CPW)-fed microstrip antenna for ultra wideband application is presented. By using two branches of microstrip line and two slot lines on the antenna, two notches for interference bands has been created. The antenna has a rather compact structure; with total size of 25 × 25 × 1 mm^3. This antenna covers bandwidth of more than 137% from 2.96 GHz to 16 GHz for S_{11}< -10 dB.

Index Terms **─** Coplanar waveguide (CPW), microstrip antennas and dual band-notched, ultra wideband (UWB),

I. INTRODUCTION

After allocation of the frequency band of 3.1-10.6 GHz (UWB) for commercial use by the FCC (Federal Communication Commission) in 2002 [1], the requirements and attentions towards the UWB system are due to its inherent merits such as high data rate, small emission power, highly secure environment, low cost for short range access, and remote sensing applications. But there are many narrowband communication systems which severely interfere with the UWB communication system. Most notable among them are the Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX), which operate with the center frequencies of 5.2 GHz (5150-5350 MHz), 5.8 GHz (5725-5825 MHz) for WLAN and 3.5GHz (3400-3690 MHz), 5.5 GHz (5250-5850 MHz) bands for WiMAX. To mitigate this interference problem, various UWB antennas with band notched characteristics have been developed [2-7]. CPW monopole antennas have became popular due to wide operation bandwidth, good radiation pattern, simple structure, planar, light weight and easy integration of monolithic microwave integrated circuits (MMIC). In this paper, a CPW-Fed UWB antenna with dual band notched features is presented. The two notched bands minimize the potential interference between the UWB system and WLAN/WiMAX narrow band communication systems.

The proposed antenna can be used in UWB systems which need no filter to suppress dispensable bands. Both Ansoft high frequency simulation structure (HFSS) [8] and computer simulation technology (CST) [9] 3-D electromagnetic EM simulators are used to optimize the presented design. The proposed antenna with the dual-band notch is successfully implemented and the simulation results show reasonable agreement with the measurement results. Section II describes the antenna design, discussions on results is presented in Section III followed by conclusive comments and further scope in Section IV.

II. ANTENNA DESIGN

The geometry of the proposed CPW-fed antenna for UWB applications is depicted in Fig. 1; also the optimized parameter values are listed in Table 1.

Characteristic impedance of CPW feed line is approximately 50 ohm with the center line width W_f=3mm, and gap width W_{fg}=0.3mm. The CPW

Submitted On: Jan. 23, 2012
Accepted On: April 1, 2012

antenna has been designed based on the idea presented in [10]. Figure 2 exhibits the fabricated antenna.

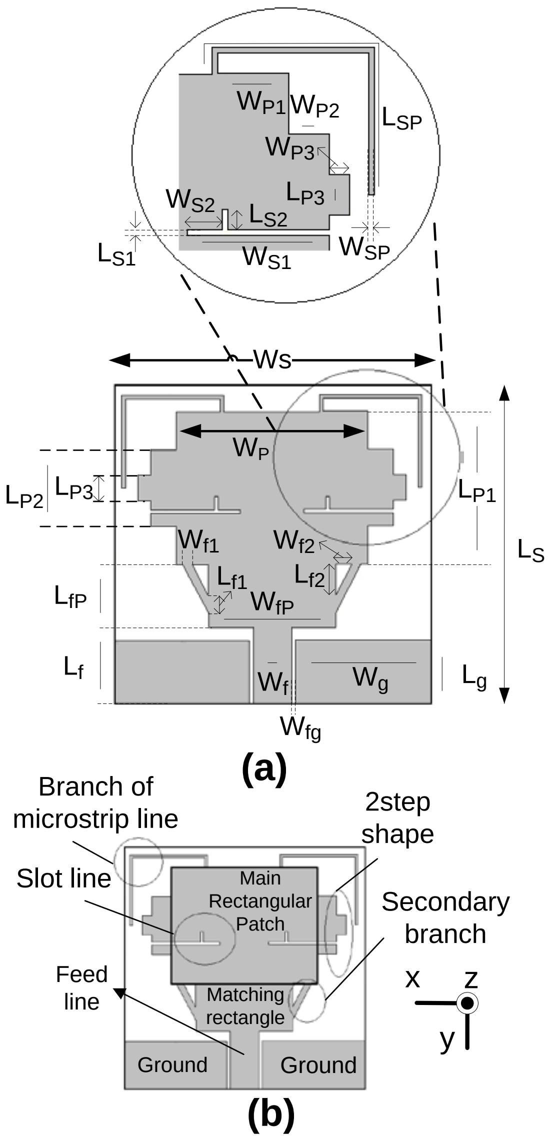

Fig. 1. The antenna geometry and its design parameters.

Table 1: Optimal parameter values of the antenna

L_S	W_S	L_f	W_f	L_g	W_g	W_{fg}
25	25	6	3	5	10.7	0.3
L_{P1}	W_P	W_{P1}	L_{P2}	W_{P2}	L_{P3}	W_{P3}
12	15	3.45	6	2	2	1
L_{fP}	W_{fP}	L_{SP}	W_{SP}	W_{S1}	W_{S2}	L_{S1}
5	10	16.6	0.3	7	1.7	0.3
L_{S2}	L_{f1}	W_{f1}	L_{f2}	W_{f2}	ε_r	h
1	1.25	0.75	2.5	1.25	4.4	1

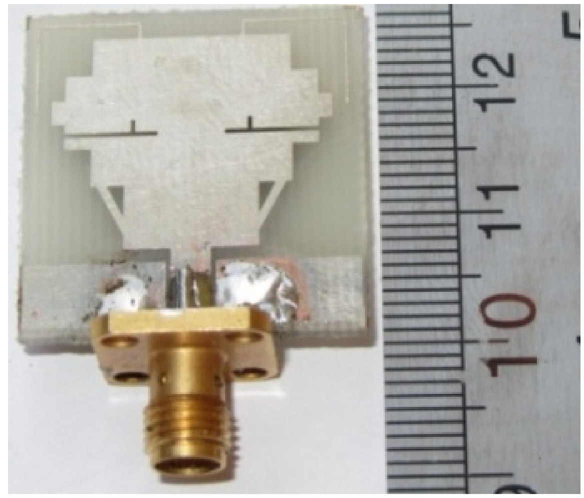

Fig. 2. Photograph of the fabricated antenna.

Total size of the referenced antenna is 30×26×1.6mm^3, and its bandwidth is from approximately 3 GHz up to 11 GHz (114%), but the size of the proposed antenna in this letter is 25×25×1mm^3 which its area 20% has been decreased while both of them have been printed on a low cost FR-4 substrate with dielectric constant of 4.4. Meanwhile, bandwidth of the proposed antenna is from 2.96 GHz up to 16 GHz (137%) which 23% has been increased. To increase bandwidth has been used the technique of step shape of [11] and also to create notch has been needed to a resonance, so the authors have designed two branch strip lines which this technique has been inserted from [12]. The modifications have been performed on the rectangular patch to improve its operating bandwidth and also to create two notches for WiMAX and WLAN bands. After obtaining values of W_f and W_{fg}, it is needed to match between the patch and the feed line, there for used a rectangle with length of L_{fP} and width of W_{fP} respectively with values 5, 10mm respectively has been used. In the next stage, to improve the impedance bandwidth has been applied from the two step shapes in the both sides of rectangular patch with lengths and widths respectively L_{P2}, L_{P3} and W_{P2}, W_{P3} and the optimized values are summarized in Table 1. Also, the Trident feed technique has been applied for further improvement of bandwidth, where two branches have been used to connect the matching rectangle into the main patch. Physical dimensions of the trident as L_{f1} and W_{f1} are illustrated in Fig. 1.

In order to create two resonant frequency centers at 3.4 GHz and 5.5 GHz, there have been used two techniques as follow:

1- Using two slot lines on both sides of the patch with lengths of λ/4.

2- Using two branch strip lines over the main patch.

In the next section, the antenna design procedure will be dealt, and the effect of various parameters on reflection coefficient will be discussed.

III. ANTENNA PERFORMANCE AND DISCUSSION

A. Full-band design

In this section, the design procedure of the CPW fed UWB antenna with reflection coefficient curves are demonstrated. Note, that the simulated reflection coefficient results are obtained using the HFSS and CST software. At first, the effect of width variation of the matching rectangle (W_{fP}), which has connected the feed line into the radiated (radiation) patch, on bandwidth was studied. With regard to Fig. 3, it is clear that the best value for W_{fP} is 10mm.

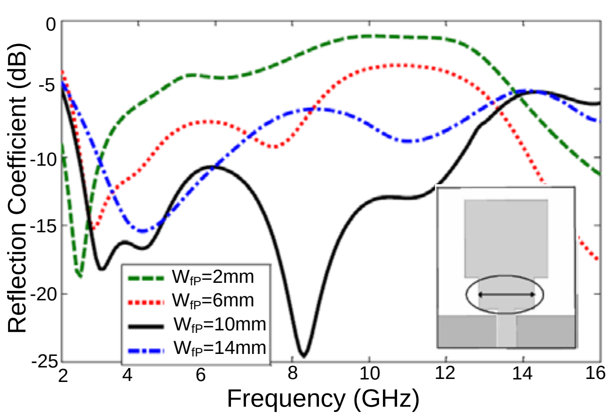

Fig. 3. Reflection coefficients for different values of W_{fP}.

Here, the proposed methods result in bandwidth enhancement of the impedance. The first, secondary branches are added on both of sides of the rectangle and effect of them on reflection coefficients is visible in Fig. 4. From this figure, it can be seen that the secondary branches improve the bandwidth more than 1 GHz on the upper band.

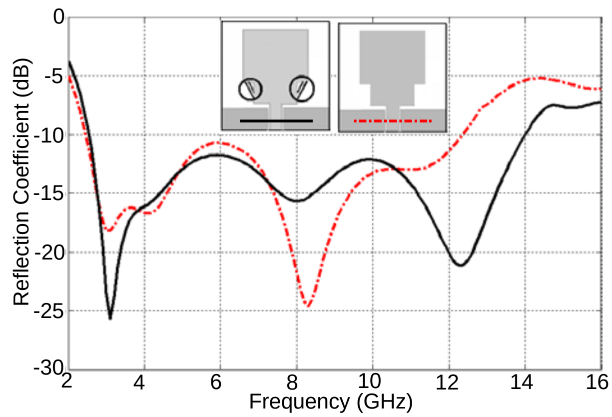

Fig. 4. Reflection coefficients for the antenna with and without the secondary branches.

Figures 5 and 6 show the effects of Step 1 and Step 2 on the reflection coefficient, respectively. Figure 5 exhibits that, the result of Step 1 is an improvement in the middle and upper bands. Likewise, from Fig. 6, it is clear that, effect of Step 2 is the expansion of the lower band of the antenna's bandwidth.

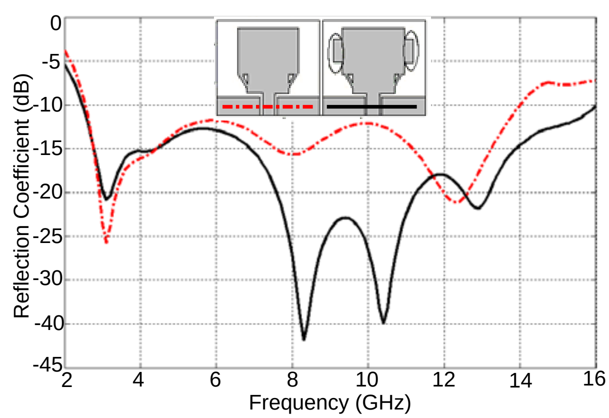

Fig. 5. Simulated reflection coefficients for the antenna with and without Step 1.

Although the bandwidth of the middle band is decreased, but the antenna designer's main goal is to cover the defined UWB bandwidth by FCC, so it can be concluded that being the Step 2 for the proposed antenna is useful. With the accomplished modifications on the antenna, as Fig. 6 depicts, the simulated bandwidth of the antenna has been enhanced more than FCC defined frequency range and has been obtained from 2.29 to 16 GHz.

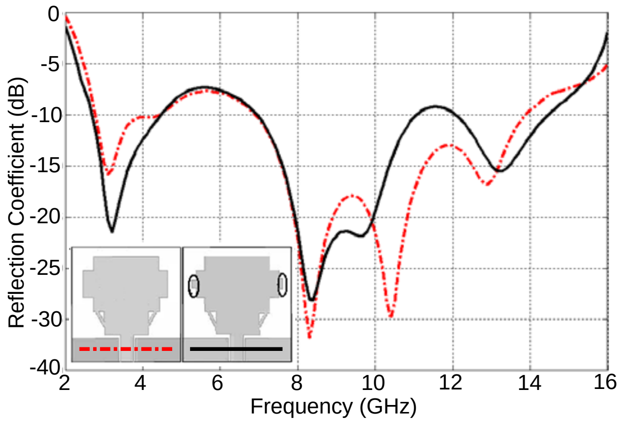

Fig. 6. Simulated reflection coefficients for the antenna with and without Step 2.

B. Single-notch design

In the next stage, the antenna designer's aim is to create the notches on the bandwidth by using various techniques such as slotting in the patch and adding microstrip lines over the patch. For this, it is better to be looked at Fig. 1 once again. For the proposed antenna are used two techniques to create notches at the center frequencies of 3.4 and 5.5 GHz. In other words, the antenna has the capability of filtering the interference bands of WLAN and WiMAX. In general, the length of the slot has the inverse relationship with frequency and type of substrate.

$$\varepsilon_{re} = \frac{1+\varepsilon_r}{2} \quad (1)$$

$$L = \frac{\lambda_g}{4} = \frac{300}{4f(GHz)\sqrt{\varepsilon_{re}}} \quad (mm) \quad (2)$$

$$L = \frac{\lambda_g}{2} = \frac{300}{2f(GHz)\sqrt{\varepsilon_{re}}} \quad (mm) \quad (3)$$

By simulations, it can be found when slots are inside of the patch, like the U-shaped slot, the length of slots is $\lambda_g/2$, but there is another way to decrease the length of slots down to $\lambda_g/4$ like the used slot in the proposed antenna, on the other hand, the using of slots in which a side of them are not insight of patch. It means that the slot is started from the outer edges of patch. To understand more, the function of the slots in the design, the characteristics of three designs of without strip lines are compared with each other. The simulated results have been plotted in Fig. 7.

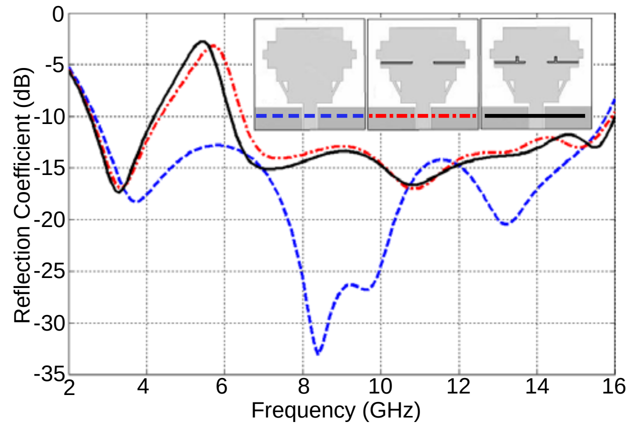

Fig. 7. Simulated reflection coefficients for the antennas with and without slots.

As shown in Fig. 7, it is found that by using slots, the notch can be created in the impedance bandwidth. To adjust the notch bandwidth at the frequency band from 5150 MHz to 5850MHz (WiMAX and WLAN) is used from the two sub slots. With regard to Fig. 7, by the sub slots can be shifted the central frequency of notch and also can be increased the amplitude of notch. There is the other point in a way that to enhance magnitude of notch is applied from the two slots on the both sides of the patch instead of one slot.

C. Another single-notch design

In this antenna to create the other notch at frequency band of 3.3 to 3.69 GHz (WiMAX) has been used the two strip lines over the patch. Figure 8 illustrates simulated reflection coefficient characteristics for the antenna with and without strip lines. To increase the magnitude on the notched band two strip lines has been used instead of one strip line. The proposed antenna has been implemented based on the dimensions presented in Table 1.

The VSWR of the proposed antenna has been measured using an Agilent E8362B network analyzer in its full operational span (10 MHz–20 GHz). The simulated and measured VSWR of the fabricated antenna are depicted in Fig. 9.

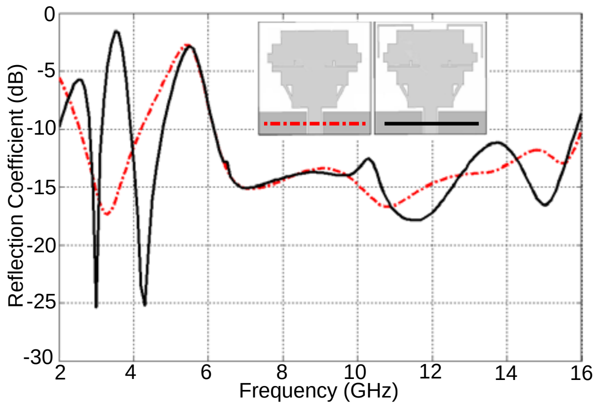

Fig. 8. Simulated reflection coefficients for the antennas with and without the strip lines.

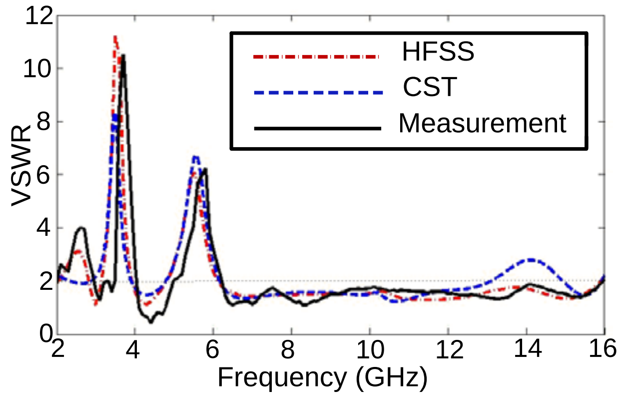

Fig. 9. Simulated and measured VSWR for the proposed antenna.

The results show that the antenna impedance bandwidth extends from 2.96 up to 16 GHz, as high as 137%. It is apparent that the presented antenna can be used for higher frequencies above the FCC band. This behavior almost was predicted from HFSS and CST simulators. Good agreement between simulated and measured results is observed and a bit of difference between them is attributed to factors such as SMA connector effects, fabrication imperfections, and inappropriate quality of the microwave substrate.

D. Time domain analysis

In ultra wideband systems, the information is transmitted using short pulses. Hence, it is important to study the temporal behavior of the transmitted pulse. The communication system for UWB pulse transmission must limit distortion, spreading, and disturbance as much as possible. Group delay is an important parameter in UWB communication, which represents the degree of distortion of pulse signal. The key in UWB antenna design is to obtain a good linearity of the phase of the radiated field because the antenna should be able to transmit the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency. Ideally, when the phase response is strictly linear, the group delay is constant.

$$\text{group delay} = -\frac{d\theta(w)}{dw} \quad (4)$$

As depicted in Fig. 10, the group delay variation is less than 0.8ns over the frequency UWB without notched bands which ensure that the pulse transmitted or received by the antenna will not distort seriously and will retain its shape. As expected before, the groups delay variation at notches from 3.3GHz up to 3.69GHz and 5.15GHz up to 5.85GHz, WiMAX and WLAN, with respect to other frequencies is more. Therefore, the proposed antenna is suitable for modern UWB communication systems.

Transient response of the antenna is studied by modeling the antenna by its transfer function. The transmission coefficient S21 was simulated in the frequency domain for the face-to-face orientation. Figure 11 shows the magnitude of measured S21 for the face-to-face orientation and plot of S21 is almost flat with variation less than 15dB in the operating band. The reason of two intense resonances in plot of S21 is because of two notches WiMAX and WLAN at frequencies 3.5 and 5.5 GHz.

Phase of S_{21} for the face to face orientation has been also plotted and is shown in the Fig. 12. As previously expected, the plot shows a linear variation of phase in the total operating band except notched bands.

The transfer function is transformed to time domain by performing the inverse Fourier transform. Fourth derivative of a Rayleigh function is selected as the transmitted pulse. The output waveform at the receiving antenna terminal can therefore be expressed by convoluting the input signal and the transfer function. The input and received wave forms for the face-to-face and side-by-side orientations of the antenna are shown in Fig. 13. It can be seen that the shape of the pulse is preserved very well in all the cases. Using the reference and received signals, it becomes possible to quantify the level of similarity between signals.

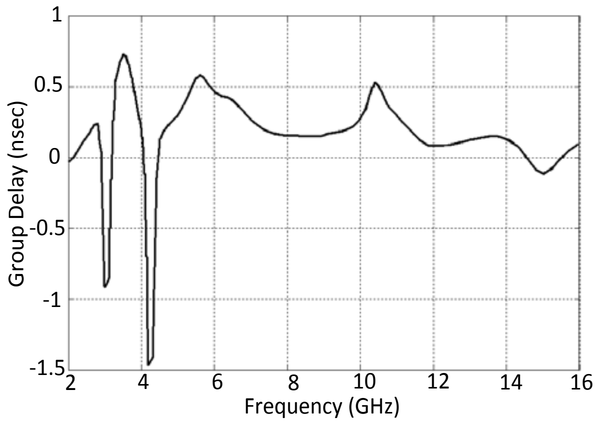

Fig. 10. Simulated group delay versus frequency for the proposed antenna.

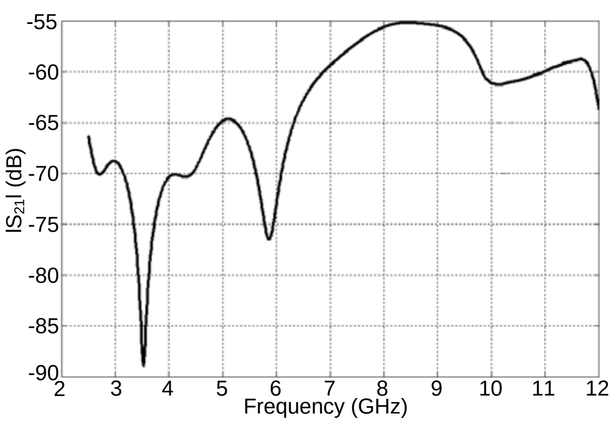

Fig. 11. Simulated S_{21} with a pair of identical UWB antennas for face to face orientation.

In telecommunications systems, the correlation between the transmitted (TX) and received (RX) signals is evaluated using the fidelity factor [21]

$$F = max_{\tau}\left|\frac{\int_{-\infty}^{+\infty} S(t)r(t-\tau)dt}{\sqrt{\int_{-\infty}^{+\infty} S(t)^2 \cdot \int_{-\infty}^{+\infty} r(t)^2\, dt}}\right|, \qquad (5)$$

where S(t) and r(t) are the TX and RX signals, respectively. For impulse radio in UWB communications, it is necessary to have a high degree of correlation between the TX and RX signals to avoid losing the modulated information. However, for most other telecommunication systems, the fidelity parameter is not that relevant. In order to evaluate the pulse transmission characteristics of the proposed double band-notched antenna, two configurations (side by side and face to face orientations) were chosen. The transmitting and receiving antennas were placed in a d=0.5 m distance from each other. As shown in Fig. 13, although the received pulses in each of two orientations are broadened, a relatively good similarity exists between the RX and TX pulses. Using (4), the fidelity factor for the face to face and side by side configurations was obtained equal to 0.94 and 0.89, respectively. These values for the fidelity factor show that the antenna imposes negligible effects on the transmitted pulses. The pulse transmission results are obtained using CST.

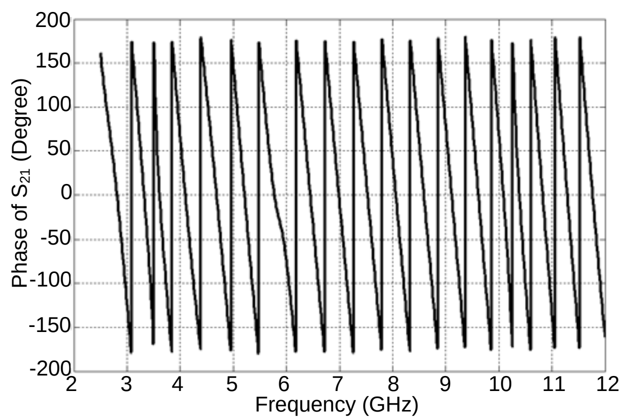

Fig. 12. Simulated Phase of S_{21} for face to face orientation.

E. Radiation characteristics

The y–z plane and the x–z plane are selected to show the antenna radiation patterns referred to as E-plane and H-plane, respectively. Figures 14 and 15 respectively show the antenna normalized radiation pattern at E-plane and H-plane.

According to Fig. 14, it is clear that the proposed antenna has a nearly bidirectional pattern and Fig. 15 also depicts that the antenna has a non directional pattern required to receive information signals from all directions. In addition, the gain curve of the proposed antenna is illustrated in Fig. 16.

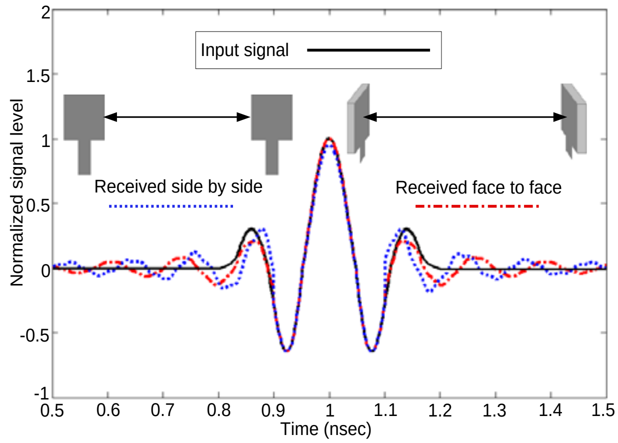

Fig. 13. Transmitted and received pulses.

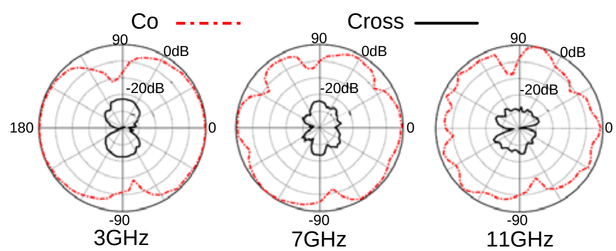

Fig. 14. Measured normalized radiation pattern of the antenna at E-plane.

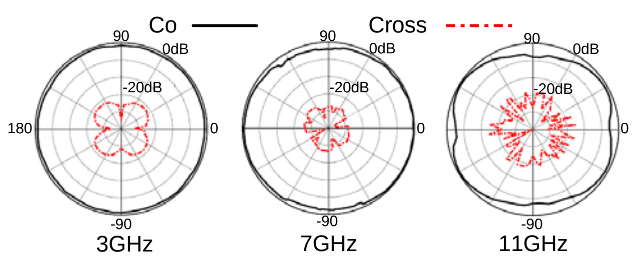

Fig. 15. Measured normalized radiation pattern of the antenna at H-plane.

From these curves it is obvious that the antenna has rather acceptable gain and on the frequency bands of 3.3 to 3.69 GHz and 5.15 to 5.825 GHz, in spite of having compact size of 25×25 mm^2. Using two techniques of strip lines and slots, the antenna has filtered the interference bands of WiMAX and WLAN. The last point from Fig. 16 is that the maximum values of gain for the antenna has been earned at the higher frequencies with values of 5.5 to 6 dB, and also the minimum values of gain is for a dual band notch with values of -4 to -5 dB.

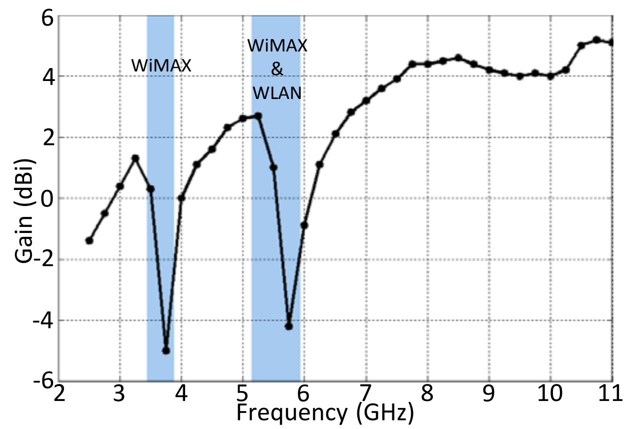

Fig. 16. Measured gain versus frequency for the proposed antenna.

IV. CONCLUSION

A CPW antenna to cover UWB band and to reject interference bands has been presented. The measured bandwidth of the antenna is from 2.96 to 16 GHz. The simulation and measurement results of the proposed antenna show a good agreement in term of the reflection coefficient, and radiation patterns.

REFERENCES

[1] Federal Communications Commission, First report and order on ultra-wideband technology, FCC 02-48, compact UWB planar antenna with band-notch characterization, Washington, DC, 22nd April, 2002.

[2] T. D. Nguyen, D. H. Lee, and H. C. Park, “Design and Analysis of Compact Printed Triple Band-Notched UWB Antenna,” *Antennas and Wireless Propagation Letters, IEEE*, vol. 10, pp. 403-406, 2011.

[3] H.-W. Liu, C.-H. Ku, T.-S. Wang, and C.-F. Yang, “Compact Monopole Antenna with Band-Notched Characteristic for UWB Applications,” *Antennas and Wireless Propagation Letters, IEEE*, vol. 9, pp. 397-400, 2010.

[4] R. Azim, M. T. Islam, and N. Misran, “Design of a Planar UWB Antenna with New Band Enhancement Technique,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 26, no. 10, pp. 856-862, October 2011.

[5] J. William and R. Nakkeeran, “A New UWB Slot Antenna with Rejection of WiMax and WLAN Bands,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 9, pp. 787-793, September 2010.

[6] D. S. Javan and O. H. Ghouchani, “Cross Slot Antenna with U-Shaped Tuning Stub for Ultra Wideband Applications,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 24, no. 4, pp. 427-432, August 2009.

[7] M. Naghshvarian-Jahromi and N. Komjani-Barchloui, “Analysis of the Behavior of Sierpinski Carpet Monopole Antenna,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 24, no. 1, pp. 32-36, February 2009.

[8] Ansoft HFSS User’s manual, Ansoft Corporation, Beta Release 11.0, April 2007.

[9] CST Microwave studio, ver. 2008. Computer Simulation Technology, Framingham, MA, 2008.

[10] Q.-X. Chu and Y.-Y. Yang, “A Compact Ultra wideband Antenna With 3.4/5.5 GHz Dual Band-Notched Characteristics,” *Antennas and Propagation, IEEE Transactions*, vol. 56, no. 12, pp. 3637-3644, 2008.

[11] M. Akbari, M. Koohestani, C. H. Ghobadi, and J. Nourinia, “A New Compact Planar UWB Monopole Antenna,” *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 21, no. 2, pp. 216-220, March 2011.

[12] M. Akbari, C. H. Ghobadi, and J. Nourinia, “Internal Multiband PIFA Antenna for GPS/DCS/PCS/UMTS/WLAN Operation in the Mobile Device,” *IEICE Electronics Express*, vol. 6, no. 24, pp. 1752-1756, 2010.

Mojtaba Mighani was born in Mashhad, Iran, in September 23, 1983. He received B.Sc. degree in Electrical and Electronic Engineering from Aeronautical University, Tehran, Iran, in 2005 and M.Sc. degrees in Electrical and Telecommunication Engineering from K. N. Toosi University, Tehran, Iran. He is currently working toward the Ph.D. degree in Communication Engineering. Since 2007, he has taught courses in communication circuits, microwave engineering, antenna theory, RADAR, and Fields & Waves in Aeronautical University, Tehran, Iran. His research interests include antenna theory, microwave active circuits, and RF communication links.

Mohammad Akbari was born on February 3, 1983 in Tehran, Iran. He received his B.Sc. degree in Engineering-Telecommunication from University of Bahonar, Kerman, Iran, in 2007 and M.Sc. degrees in Electrical Engineering-Telecommunication from University of Urmia, Urmia, Iran, in 2011. His primary research interests are in antenna design, filters, and microwave components. Since 2011, he has taught courses in microwave engineering, antenna theory, and Fields & Waves, and electromagnetic in Aeronautical University, Tehran, Iran.

Nader Felegari was born in Songhor, Iran 1984. He received his B.S. degree of Electrical Engineering and his M.S. degree of Communication Engineering from the Urmia University, Iran. His primary research interests are in antenna design.