Square Monopole Antenna with Band-Notched Characteristic for UWB Communications

Nasser Ojaroudi [1], Mohammad Ojaroudi [2], and Noradin Ghadimi [2]

[1] Department of Electrical Engineering,
Germi Branch, Islamic Azad University, Germi, Iran
n.ojaroudi@iaugermi.ac.ir

[2] Young Researchers Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir and noradin.ghadimi@gmail.com

Abstract ─ In this paper, a novel ultra wideband monopole antenna with frequency band-stop performance is designed and manufactured. The proposed antenna consists of a square radiating patch, and a ground plane with a cross-shaped slit and an inverted π-shaped conductor-backed plane. The cross-shaped slit, increases the bandwidth that provides a wide usable fractional bandwidth of more than 125 % (2.86 GHz – 12.91 GHz). In order to create band-notched function we use an inverted π-shaped parasitic structure in the ground plane, a frequency notch band of 5.11 GHz – 6.02 GHz has been achieved. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

Index Terms ─ Band-notched function, inverted π-shaped conductor-backed plane, printed monopole antenna (PMA), and ultra wideband (UWB).

I. INTRODUCTION

Communication systems usually require smaller antenna size in order to meet the miniaturization requirements of radio-frequency (RF) units [1]. It is a well-known fact that planar monopole antennas present really appealing physical features, such as simple structure, small size, and low cost. Due to all these interesting characteristics, planar monopoles are extremely attractive to be used in emerging UWB applications, and growing research activity is being focused on them. Consequently, a number of planar monopoles with different geometries have been experimentally characterized [2, 3].

The frequency range for UWB systems is between 3.1 GHz – 10.6 GHz, which will cause interference to the existing wireless communication systems for example the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15 GHz – 5.35 GHz and 5.725 GHz – 5.825 GHz bands, so the UWB antenna with a band-notched function is required. Lately, to generate the frequency band-notched function, several modified planar antennas with band-notch characteristic have been reported [4-8]. In references [4-6], different shapes of the slots (i.e., square ring, W-shaped, and folded trapezoid) are used to obtain the desired band-notched characteristics. Also reconfigurable structures integrated with diodes can be used to generate band-notched performances [7]. In [8] single and multiple half-wavelength U-shaped is used to generate the frequency band-notched function, modified planar slits are embedded in the radiation patch to generate the band-notched functions.

All of the above methods are used for rejecting a single band of frequencies. However, to effectively utilize the UWB spectrum and to improve the performance of the UWB system, it is desirable to design the UWB antenna with dual band rejection. It will help to minimize the interference between the narrow band systems

Submitted On: Aug. 8, 2012
Accepted On: April 24, 2013

with the UWB system. Some methods are used to obtain the dual band rejection in the literature [9-11].

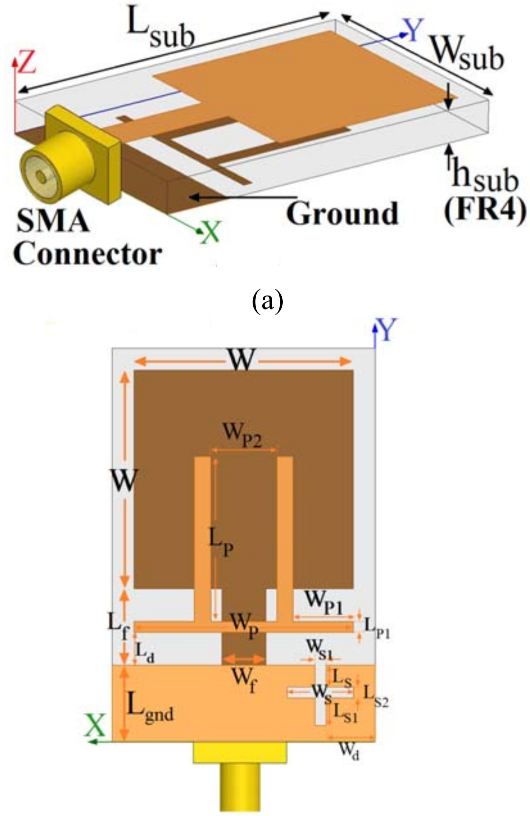
In this paper, a simple method for designing a novel and compact microstrip-fed monopole antenna with band-notched characteristic for UWB applications has been presented. In the proposed antenna, for bandwidth enhancement we use cross-shaped slit in the ground plane and by using an inverted π-shaped parasitic structure with variable dimensions on the other side of the substrate a band-stop performance can be created. The presented monopole antenna has a small size of 12×18×1.6 mm^3. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

II. ANTENNA DESIGN

The presented small monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on an FR4 substrate of thickness 1.6 mm, permittivity 4.4, and loss tangent 0.018. The basic monopole antenna structure consists of a square patch, a feed line, and a ground plane. The square patch has a width W. The patch is connected to a feed line of width W_f and length $L_f + L_{gnd}$. The width of the microstrip feed line is fixed at 2 mm, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane is placed. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission.

In this study, based on defected ground structure (DGS), the cross-shaped slit in the ground plane is used to perturb an additional resonance at higher frequencies and increase the bandwidth [5]. Also, based on electromagnetic coupling theory (ECT), for generating band-stop performance we use an inverted π-shaped parasitic structure in the ground plane. In this structure, by inserting the inverted π-shaped parasitic structure, the desired high attenuation near the notch frequency can be produced.

In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, are $W_{sub} \times L_{sub}$ = 12 mm × 18 mm or about 0.15 λ × 0.25 λ at 4.2 GHz (the first resonance frequency). We have a lot of flexibility in choosing the width of the radiating patch. This parameter mostly affects the antenna bandwidth. As W_X decreases, so does the antenna bandwidth, and vice versa. Next step, we have to determine the length of the radiating patch L_X. This parameter is approximately $\lambda_{lower}/4$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the radiating patch width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated [9]. The important step in the design is to choose $L_{resonance}$ (the length of the resonator), L_{notch} (the length of the filter). $L_{resonance}$ is set to resonate at 0.25 λ_g, where $L_{resonance3} = 0.5 (W_S - W_{S1}) + L_{S1} + L_{S2}$, corresponds to resonance frequency wavelength (12 GHz is the third resonance frequency). L_{notch} is set to band-stop resonate at 0.5 λ_g, where $L_{notch} = L_P + W_{P1}$, λ_g corresponds to the notched band frequency wavelength (5.5 GHz is the notched frequency).



(a)

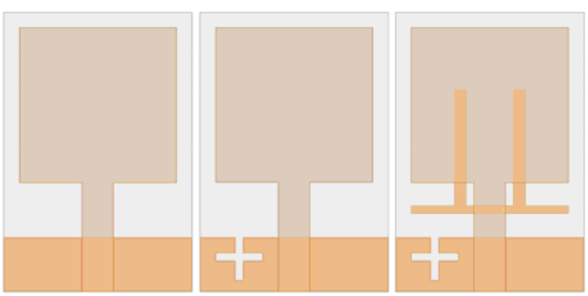
(b)

Fig. 1. Geometry of the proposed monopole antenna, (a) side view, (b) bottom view.

The optimized values of the proposed antenna design parameters are as follows: W_{sub} = 12 mm, L_{sub} = 18 mm, h_{sub} = 1.6 mm, W_f = 2 mm, L_f = 3.5 mm, W = 10 mm, W_s = 3.5 mm, L_s = 0.5 mm, W_{s1} = 0.5 mm, L_{s1} = 1 mm, L_{s2} = 0.5 mm, W_d = 2.25 mm, L_d = 1.5 mm, W_p = 8 mm, L_p = 9.5 mm, W_{p1} = 2.5 mm, L_{p1} = 0.5 mm, W_{p2} = 2 mm, and L_{gnd} = 3.5 mm.

III. RESULTS AND DISCUSSIONS

The proposed microstrip monopole antenna with various design parameters were constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The proposed microstrip-fed monopole antenna was fabricated and tested. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement is obtained [12]. The configuration of the presented monopole antenna was shown in Fig. 1. The geometry of the ordinary square patch antenna (Fig. 2 (a)), with a cross-shaped slit in the ground plane (Fig. 2 (b)), and the proposed antenna (Fig. 2 (c)) structures are compared in Fig. 2.



(a) (b) (c)

Fig. 2. (a) basic structure (ordinary monopole antenna), (b) antenna with a cross-shaped slit in the ground plane, and (c) the proposed antenna.

The VSWR characteristics of the structures that were shown in Fig. 2 are compared in Fig. 3. As shown in Fig. 3, it is observed that the upper frequency bandwidth is affected by using the cross-shaped slit in the ground plane and the notch frequency bandwidth is sensitive to the inverted π-shaped parasitic structure. Also the input impedance of the various monopole antenna structures that were studied in Fig. 3, are shown on a Smith chart in Fig. 4.

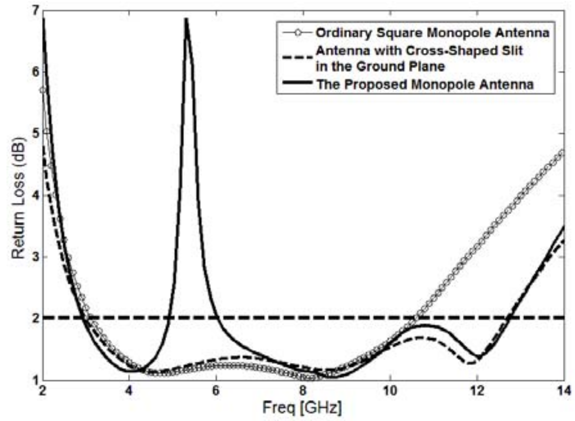


Fig. 3. Simulated VSWR characteristics for the antennas shown in Fig. 2.

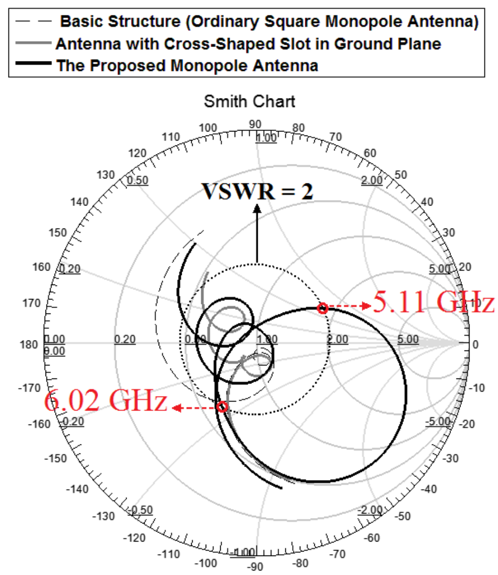
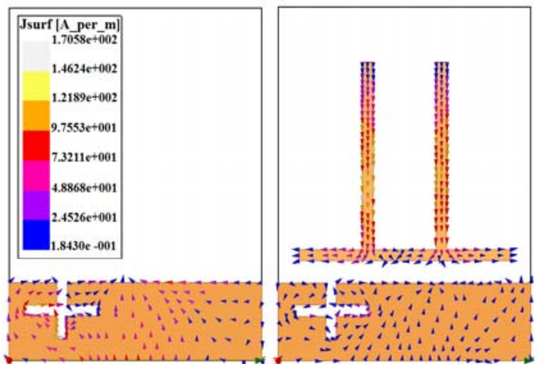


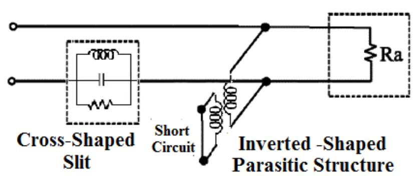
Fig. 4. The simulated input impedance on a Smith chart for the various antenna structures shown in Fig. 2.

In order to understand the phenomenon behind this additional resonance performance, the simulated current distributions on the ground plane for the square antenna with a cross-shaped slit in the ground plane at 12 GHz are presented in Fig. 5 (a). It is found that, based on the defected ground structure (DGS), by using the cross-shaped slit in the ground plane; third resonance at 12 GHz can be achieved. Other important design parameters of this structure is the use of an inverted π-shaped parasitic structure on the ground plane. Figure 5 (b) presents the simulated current distributions on the ground plane at the notch frequency (5.5 GHz). As shown in Fig. 5 (b), at the notch frequency the current flows are more dominant around the inverted π-shaped parasitic structure.

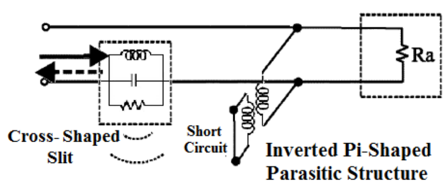


(a) (b)

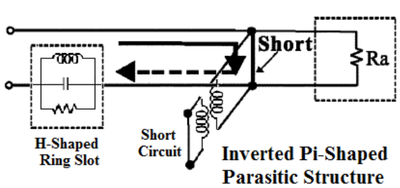
Fig. 5. Simulated surface current distributions for the proposed antenna on the ground plane (a) at the extra resonance frequency at 12 GHz and (b) at the notch frequency at 5.5 GHz.



(a)



(b)



(c)

Fig. 6. (a) Conceptual equivalent-circuit model for the proposed antenna, and the equivalent circuits at (b) the new resonance frequency, and (c) at the first notch frequency.

Figure 6 shows the conceptual equivalent circuit model for the proposed antenna, which has an RLC resonator and a shunt stub. When the current path in the inverted π-shaped ring conductor backed plane is equal to a half-wavelength at 5.5 GHz in Fig. 6 (c), the input impedance at the feeding point is zero (short circuit). Figure 7 shows the simulated VSWR curves with different values of L_p. As shown in Fig. 7, when the exterior length of the inverted π-shaped parasitic structure increases from 9.5 mm to 12.25 mm, the center of the notch frequency decreases from 6.6 GHz to 4.8 GHz. From these results, we can conclude that the notch frequency is controllable by changing the exterior length of the inverted π-shaped parasitic structure [13].

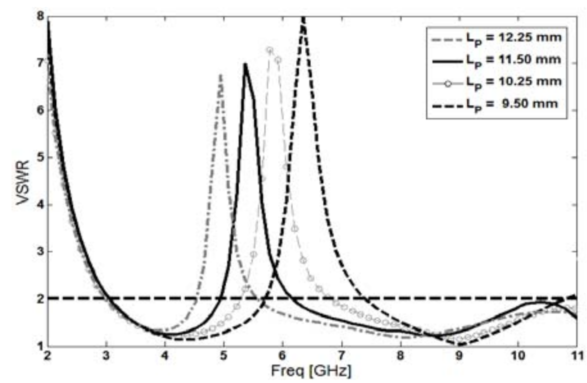


Fig. 7. Simulated VSWR characteristics for the proposed antenna with different values of W_X.

Another main effect of the inverted π-shaped conductor-backed plane occurs on the filter bandwidth. In this structure, the width W_{p2}, is the critical parameter to control the filter bandwidth. Figure 8 illustrates the simulated VSWR characteristics with various length of W_{p2}. As the interior width of the W_{p2} increases from 0.4 mm to 1.4 mm, the filter bandwidth varies from 0.7 GHz to 1.5 GHz. Therefore the bandwidth of the notch frequency is controllable by changing the width of W_{p2}.

The proposed antenna with optimal design was built and tested. The measured and simulated VSWR characteristic of the proposed antenna are shown in Fig. 9. The fabricated antenna has the frequency band of 2.86 GHz to 12.91 GHz with WLAN rejection band around 5.11 GHz – 6.02 GHz.

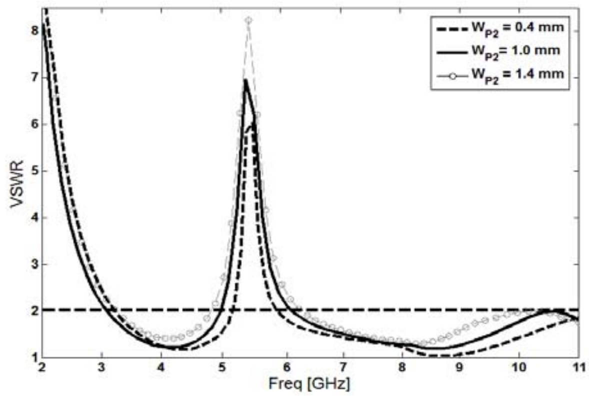


Fig. 8. Simulated VSWR characteristics for the proposed antenna with different values of W_{X1}.

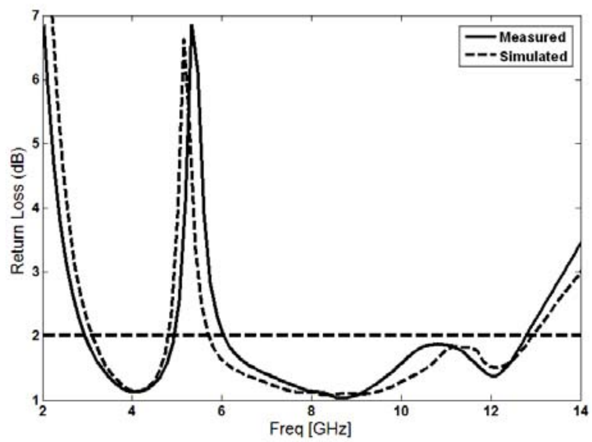


Fig. 9. Measured and simulated VSWR for the proposed antenna.

Figure 10 illustrates the measured radiation patterns, including the co–polarization and cross–polarization, in the H– (x–z plane) and E–planes (y–z plane). It can be seen that the radiation patterns in x–z plane are nearly omni-directional for the three frequencies. Figure 11 shows the effects of the cross-shaped slit and the inverted π-shaped parasitic structure, on the maximum gain in comparison to the same antenna without them. As shown in Fig. 11, the ordinary square antenna has a gain that is low at 3 GHz and increases with frequency. It can be observed in Fig. 11 that by using a cross-shaped slit and the inverted π-shaped parasitic structure, a sharp decrease of maximum gain in the notched frequency band at 5.5 GHz is shown. For other frequencies outside the notched frequency band, the antenna gain with the filter is similar to those without it.

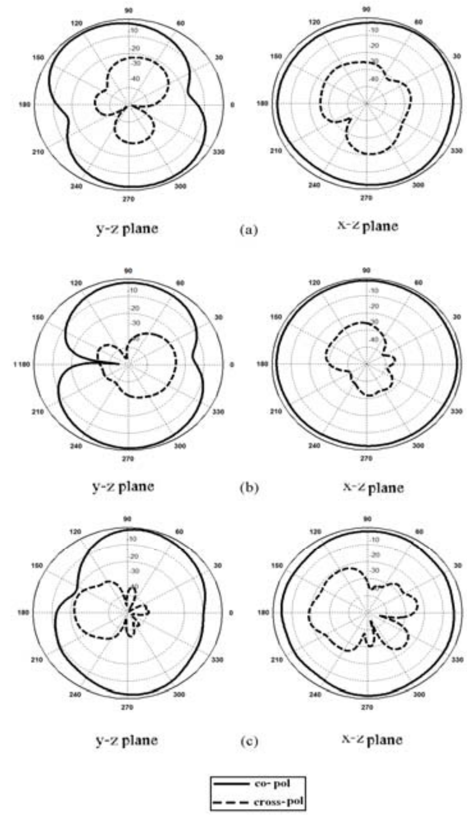


Fig. 10. Measured radiation patterns of the proposed antenna at (a) 4 GHz, (b) 7 GHz, and (c) 10 GHz.

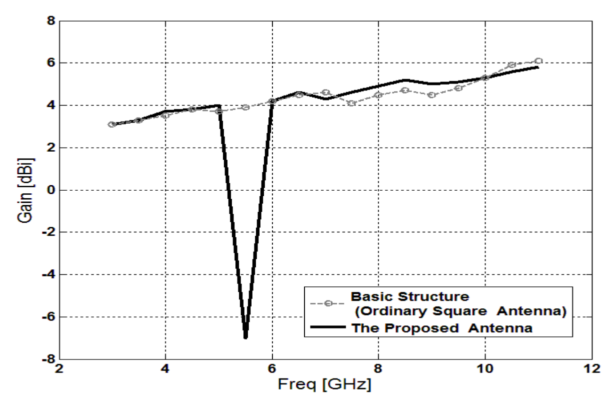


Fig. 11. Measured maximum gain comparisons for the ordinary square antenna and the proposed antenna.

IV. CONCLUSION

A new small monopole antenna with band-notched function for UWB applications is presented in this paper. The proposed antenna can operate from 2.86 GHz to 12.91 GHz with WLAN rejection band around 5.11 GHz – 6.02 GHz. In order to enhance the bandwidth we cut a cross-shaped slit in the ground plane, and also by using an inverted π-shaped parasitic structure at the ground plane, a frequency band-notched function can be achieved and improved. The designed antenna has a small size of 12×18 mm^2. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB applications.

ACKNOWLEDGMENT

The authors are thankful to Microwave Technology (MWT) Company staff for their beneficial and professional help (www.microwave-technology.com).

REFERENCES

[1] H. Schantz, "The art and science of ultra wideband antennas," *Artech House* 2005.

[2] M. Ojaroudi, Sh. Yzdanifard, N. Ojaroudi, and M. Nasser-Moghaddasi, "Small square monopole antenna enhanced by using inverted T-shaped slot and conductor-backed plane," *IEEE Transactions on Antenna and Propagation*, vol. 59, no. 2, pp. 670-674, February 2011.

[3] A. Ghazi, M. N. Azarmanesh, and M. Ojaroudi, "Muti-resonance square monopole antenna for ultra-wideband applications," *Progress In Electromagnetics Research C*, vol. 14, pp. 103-113, 2010.

[4] M. Ojaroudi, Sh. Yzdanifard, N. Ojaroudi, and R. A. Sadeghzadeh, "Band-notched small square-ring antenna with a pair of T-shaped strips protruded inside the square ring for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 227-230, 2011.

[5] M. Ojaroudi, "Printed monopole antenna with a novel band-notched folded trapezoid for ultra-wideband applications," *Journal of Electromagnetic Waves and Application (JEMWA)*, vol. 23, pp. 2513–2522, 2009.

[6] Sh. Yazdanifard, R. A. Sadeghzadeh, and M. Ojaroudi, "Ultra-wideband small square monopole antenna with variable frequency band-notch," *Progress In Electromagnetics Research C*, vol. 15, pp. 133-144, 2010.

[7] G. Zhang, J. S. Hong, B. Z. Wang, and G. Song, "Switched band-notched UWB/WLAN monopole antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 3, pp. 256-260, March 2012.

[8] M. Ojaroudi, Gh. Ghanbari, N. Ojaroudi, and Ch. Ghobadi, "Small square monopole antenna for UWB Applications with variable frequency band-notch function," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 1061-1064, 2009.

[9] M. Ojaroudi, N. Ojaroudi, and Y. Ebazadeh, "Dual band-notch small square monopole antenna with enhanced bandwidth characteristics for UWB applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 5, pp. 420-426, May 2012.

[10] M. Mighani, M. Akbari, and N. Felegari, "A CPW dual band notched UWB antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 4, pp. 352-359, April 2012.

[11] 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.

[12] Ansoft High Frequency Structure Simulation (HFSS), ver. 13, Ansoft Corporation, 2010.

[13] Y. Li, W. Li, and W. Yu, "A switchable UWB slot antenna using SIS-HSIR and SIS-SIR for multi-mode wireless communications applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 4, pp. 340-351, April 2012.

Nasser Ojaroudi was born on 1986 in Germi, Iran. He received his B.Sc. degree in Electrical Engineering from Islamic Azad University, Ardabil Branch. From 2011, he is working toward the M.Sc. degree in Telecommunication Engineering at Shahid Rajaee Teacher Training University. Since March 2008, he has been a Research Fellow in the Microwave Technology (MWT) Company, Tehran, Iran. His research interests include ultra-wideband (UWB) microstrip antennas and band-pass filters (BPF), reconfigurable structure, design and modeling of microwave device, and electromagnetic wave propagation.

Mohammad Ojaroudi was born on 1984 in Germi, Iran. He received his B.Sc. degree in Electrical Engineering from Azad University, Ardabil Branch and M.Sc. degree in Telecommunication Engineering from Urmia University. From 2010, he is working toward the Ph.D. degree at Shahid Beheshti University. From 2007 until now, he is a Teaching Assistant with the Department of Electrical Engineering, Islamic Azad University, Ardabil Branch, Iran. Since March 2009, he has been a Research Fellow (Chief Executive Officer) in the Microwave Technology Company (MWT), Tehran, Iran. From 2012, Mr. Ojaroudi is a member of the IEEE Transaction on Antennas and Propagation (APS) reviewer group and the Applied Computational Electromagnetic Society (ACES). From 2013 he is a student member of the IEEE. His research interests include analysis and design of microstrip antennas, design and modeling of microwave structures, radar systems, and electromagnetic theory. He is author and coauthor of more than 100 journal and international conferences papers. His papers have more than 400 citations with 10 h-index.

Noradin Ghadimi was born in ardabil-Iran in 1985, and received the B.Sc. degree in Electrical Engineering from the Islamic Azad University, Ardabil Branch, Ardabil, Iran, in 2009 and the M.Sc. degree in Electrical Engineering from the Islamic Azad University Ahar Branch, Ahar, Iran , in 2011. His research interests include power system protection, modeling and analysis of distributed generations, renewable energy and communications systems.