UWB Monopole Antenna with WLAN Frequency Band-Notched Performance by using a Pair of E-Shaped Slits

N. Ojaroudi, M. Ojaroudi, and N. Ghadimi

Young Researchers Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
n.ojaroudi@yahoo.com, m.ojaroudi@iauardabil.ac.ir, noradin.ghadimi@gmail.com

Abstract ─ In this paper an ultra-wideband monopole antenna with frequency band-stop performance is designed and manufactured. The proposed antenna consists of square radiating patch with two E-shaped slits and a ground plane with a protruded T-shaped strip inside the rectangular slot. In the proposed structure, by inserting a rectangular slot with a T-shaped strip protruded inside the slot on the ground plane, additional resonance is excited and hence, much wider impedance bandwidth can be produced, especially at the higher band. In order to create band-rejected function we use two E-shaped slits in the square radiating patch. The fabricated antenna has the frequency band of 3 GHz to over 12.7 GHz with a rejection band around 5 GHz – 6 GHz. 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, E-shaped slit, microstrip-fed monopole antenna, protruded T-shaped strip, and ultra-wideband (UWB) communications.

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 between 3.1GHz–10.6 GHz will cause interference to the existing wireless communication systems for example the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15GHz–5.35 GHz and 5.725GHz–5.825 GHz bands, so the UWB antenna with a band-notch function is required. Lately to generate the frequency band-notch function, modified planar monopoles several antennas with band-notch characteristic have been reported [4-10]. In [6-8], different shapes of the slots (i.e., W-shaped, L-shaped, and folded trapezoid) are used to obtain the desired band notched characteristics. Single and multiple [9] half-wavelength U-shaped slots are embedded in the radiation patch to generate the single and multiple band-notched functions, respectively. and automatic design methods have been developed to achieve band-notch performance [10].

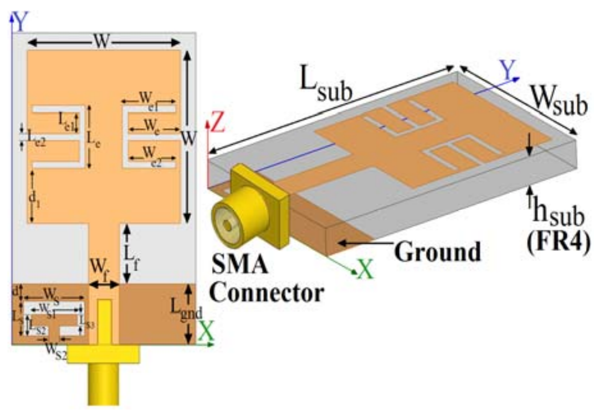
In this paper, a simple method for designing a novel and compact microstrip-fed monopole antenna with band-notched characteristic for UWB applications has been presented. In the proposed antenna, for bandwidth enhancement we use a rectangular slot with a T-shaped strip protruded inside the rectangular slot on the ground plane. Also by using two E-shaped slits with variable dimensions beside the square radiating patch a band-stop performance can be created. The presented monopole antenna has a small size of 12×18 mm^2. The size of the designed antenna is smaller than the UWB antennas with band-notched function reported recently, which has at least a

Submitted On: Sept. 25, 2012
Accepted On: Jan. 19, 2014

size reduction of 15 % with respect to the previous similar antenna [7-10]. Good return loss 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 cross-shaped radiating patch, a feed line, and a ground plane. The patch is connected to a feed line of width W_f and length L_f. 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.



(a) (b)

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

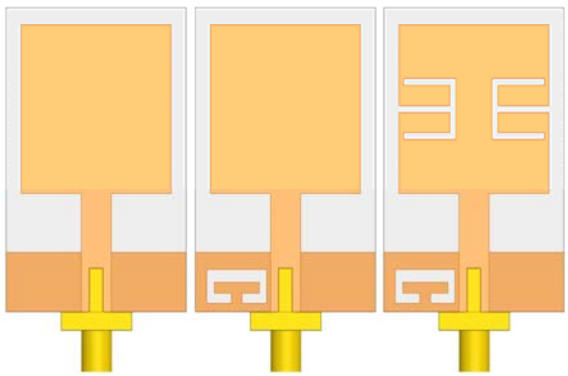
Regarding defected ground structures (DGS), creating slots in the ground plane provides an additional current path. Moreover, this structure changes the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth. The DGS applied to a microstrip line causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slot [2]. Therefore, by cutting a rectangular slot with a T-shaped strip protruded inside the rectangular slot on the ground plane and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. As illustrated in Fig. 1, the E-shaped slits are placed in the radiating patch and is also symmetrical with respect to the longitudinal direction. This structure can perturb the resonant response and also acts as a half-wave resonant structure [3]. At the notched frequency, the current flows are more dominant around the slits, and they are oppositely directed between the slit edges [3]. As a result, the desired high attenuation near the notch frequency can be produced.

The optimized values of presented monopole 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 = 4 mm, L_S = 2 mm, W_{S1} = 1 mm, L_{S1}= 1 mm, W_{S2} = 3 mm, L_{S2} = 11.5 mm, W_{S3} = 1 mm, W_e = 12 mm, L_e = 0.5 mm, W_{e1} = 0.25 mm, L_{e1} = 0.5 mm, W_{e2} = 3 mm, L_{e2} = 3.5 mm, d = 1.5 mm, d_1 = 3.5 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 [11].

The configuration of the presented monopole antenna was shown in Fig. 1. Geometry for the ordinary square patch antenna (Fig. 2 (a)), with a rectangular slot with a T-shaped strip protruded inside the rectangular slot on the ground plane (Fig. 2 (b)), and the proposed antenna (Fig. 2 (c)) structures are compared in Fig. 2. The VSWR characteristics for 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 rectangular slot with a T-shaped strip protruded inside the rectangular slot on the ground plane and the notch frequency bandwidth is sensitive to the E-shaped slits on the radiating patch [12]. Also it is found that by using the T-shaped strip protruded inside the rectangular slot on the ground plane, the third resonance occur at around 12 GHz in the simulation. The input impedance of the proposed slot antenna structure that studied in Fig. 1, on a Smith chart is shown in Fig. 4.



(a) (b) (c)

Fig. 2. (a) Basic structure (ordinary square monopole antenna), (b) antenna with a pair of H-shaped slots in the ground plane, and (c) the proposed antenna.

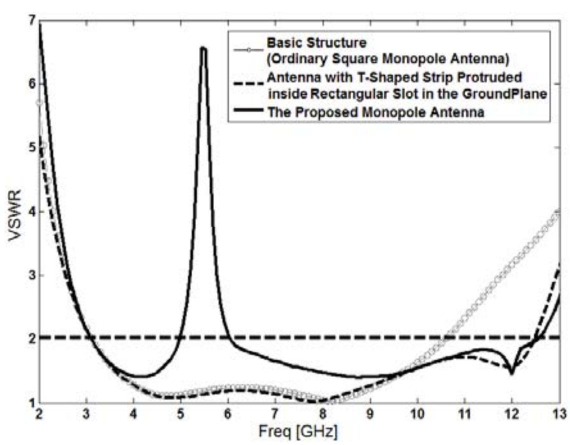


Fig. 3. Simulated VSWR characteristics for the monopole antennas shown in Fig. 2.

In order to understand the phenomenon behind this additional resonance and band notch performance, the simulated current distribution on the ground plane for the square antenna with a T-shaped strip protruded inside the rectangular slot on the ground plane at the new resonance frequency of 12 GHz are presented in Fig. 5 (a). It can be observed that in Fig. 5 (a), the current concentrated on the edges of the interior and exterior of T-shaped strip protruded inside the rectangular slot at 12 GHz [13].

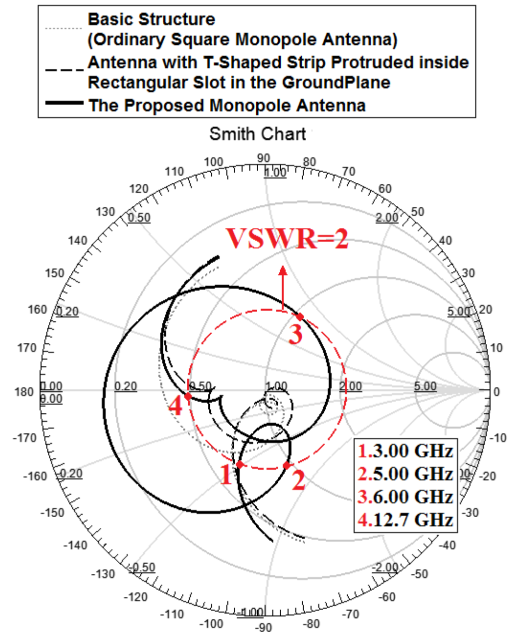
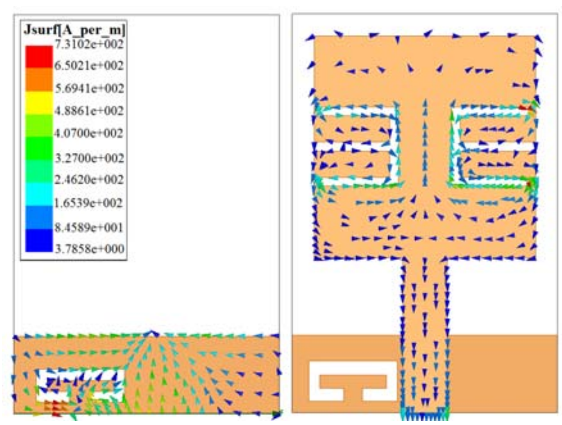


Fig. 4. The simulated input impedance on a Smith chart of the proposed antenna structure shown in Fig. 1.



(a) (b)

Fig. 5. Simulated surface current distributions on the ground plane (a) for the square monopole antenna with two H-shaped slot at 11.2 GHz and (b) for the proposed antenna at 5.5 GHz.

Therefore the antenna impedance changes at this frequency due to the resonance properties of the proposed structure. Also, to understand the phenomenon behind this band-notch performance, the simulated current distribution on the radiating patch for the proposed antenna at the notch frequency (5.5 GHz) is presented in Fig. 5 (b). It can be observed that in Fig. 5 (b), the current is concentrated on the edges of the interior and exterior of the E-shaped slits at 5.5 GHz. Therefore the antenna impedance changes at this frequency due to the band-notch properties of the proposed structure.

Figure 6 shows the simulated VSWR curves with different values of W_e. As shown in Fig. 6, when the interior width of the E-shaped slits increases from 3.0 mm to 4.5 mm, the center of the notched frequency decreases from 6.7 GHz to 4.1 GHz. From these results, we can conclude that the notched frequency is controllable by changing the interior width of the E-shaped slits in the radiating patch.

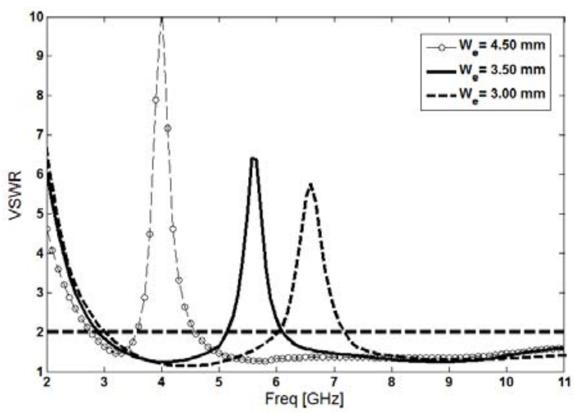


Fig. 6. Simulated VSWR characteristics for the proposed antenna with different values of L_P.

The proposed antenna with optimal design was built and tested. The measured and simulated VSWR characteristic of the proposed antenna was shown in Fig. 7. The fabricated antenna has the frequency band of 3 GHz to over 12.7 GHz with a rejection band around 5 GHz–6 GHz. However, as shown in Fig. 7, there exists a discrepancy between measured data and the simulated results. This discrepancy between measured and simulated results is mostly due to a number of parameters such as the fabricated antenna dimensions as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated, the wide range of simulation frequencies and also the effect of SMA and its connector, because in the simulation the mismatch, which is made by the adapter and connector, are not considered, but in practice the effect of the coaxial cable, which is connected to the SMA at the input of the antenna is considerable, especially the additional inductance which is produced by the length of its inner conductor, is not negligible [8]. In other words, in a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of an SMA connector and a microstrip line (the microstrip feed-line is excited by an SMA connector), which are connected to network analyzer through a coaxial cable, whereas the simulated results are obtained by using the Ansoft simulation software high-frequency structure simulator (HFSS), in which by default, the antenna is excited by a wave port that it is renormalized to a 50 Ω full port impedance at all frequencies, therefore this discrepancy between measured data and the simulated results could be due to the effect of the SMA port [8]. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully, besides, SMA soldering accuracy and FR4 substrate quality needs to be taken into consideration.

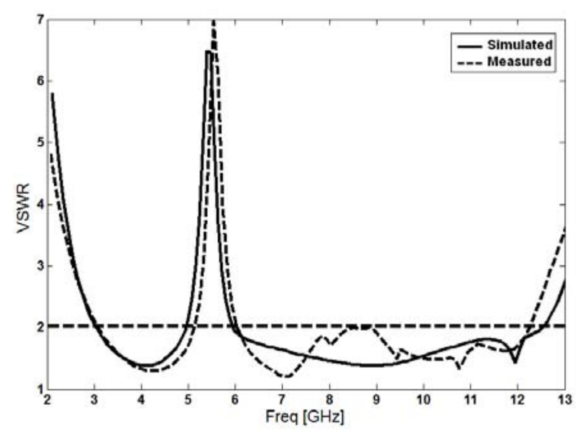


Fig. 7. Measured and simulated VSWR characteristics for the proposed antenna.

Figure 8 illustrates the measured radiation patterns, including the co-polarization and cross-polarization, in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that the radiation patterns in the x-z plane are nearly omni-directional for the three frequencies [14-15].

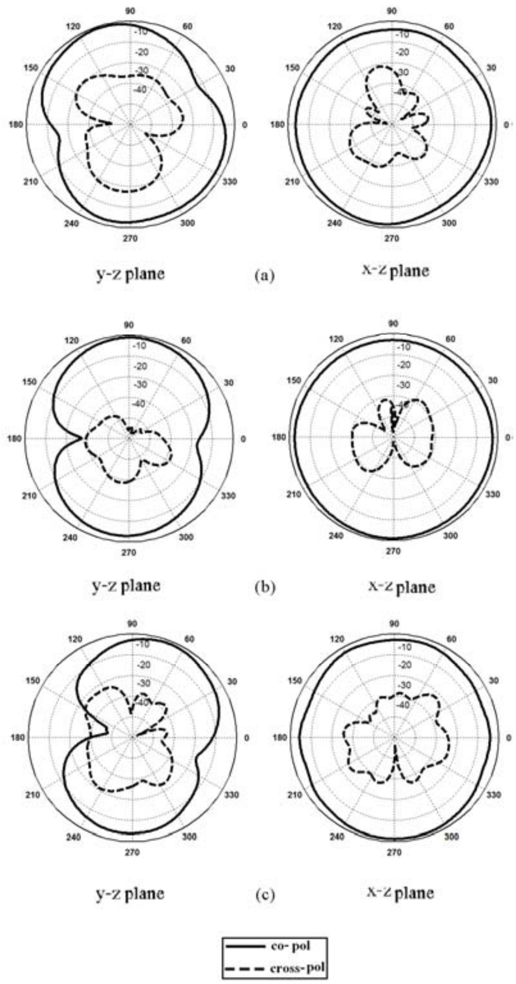


Fig. 8. Measured radiation patterns of the proposed antenna at (a) 4 GHz, (b) 7 GHz, and (c) 10 GHz.

Figure 9 shows the effects of the E-shaped slits and the protruded T-shaped strip on the maximum gain in comparison to the same antenna without them. It can be observed in Fig. 9 that by these structures, 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 [16].

IV. CONCLUSION

A new small printed monopole antenna (PMA) with frequency-notch function for UWB applications is presented, in this paper. The proposed antenna can operate from 3 GHz to 12.7 GHz with WLAN rejection band around 5 GHz–6 GHz. In order to enhance the bandwidth we cut a rectangular slot with a T-shaped strip protruded inside the rectangular slot in the ground plane and also by using two E-shaped slits in the radiating patch, a frequency band-notch function can be achieved. 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.

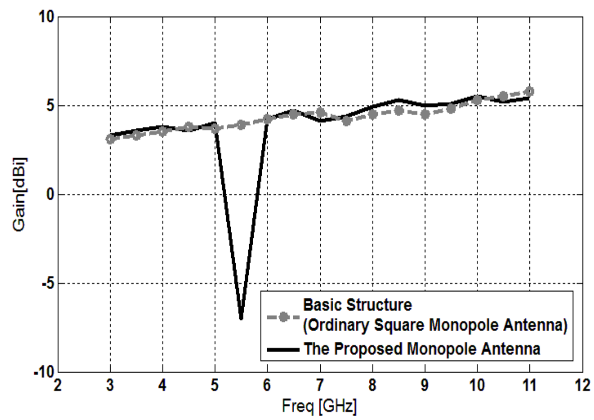


Fig. 9. Maximum gain comparisons for the ordinary square monopole antenna (simulated), and the proposed antenna (measured).

ACKNOWLEDGMENT

The authors are thankful from Microwave Technology (MWT) company staffs 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] J. Jung, W. Choi, and J. Choi, “A compact broadband antenna with an L-shaped notch,” *IEICE Trans. Commun.*, vol. E89-B, no. 6, pp. 1968-1971, June 2006.

[3] A. Ghazi, M. 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] L. Lizzi, G. Oliveri, and A. Massa, “Planar monopole UWB antenna with WLAN-band notched characteristics,” *Progress In Electromagnetic Research B*, vol. 25, pp. 277-292, 2010.

[5] M. Tang, S. Xiao, T. Deng, D. Wang, J. Guan, B. Wang, and G. Ge, “Compact UWB antenna with multiple band-notches for WiMAX and WLAN,”

IEEE Trans. Antennas and Propag., vol. 59, no. 4, pp. 1372-1376, 2011.
[6] N. Ojaroudi and M. Ojaroudi, "Dual band-notched monopole antenna with multi-resonance characteristic for UWB wireless communications," *Progress In Electromagnetics Research C*, vol. 40, pp. 188-199, 2013.
[7] M. Abdollahvad, G. Dadashzadeh, and D. Mostafa, "Compact dual band-notched printed monopole antenna for UWB 2 application," *IEEE Antennas Wireless Propag. Let t.*, vol. 9, pp. 1148-1151, 2010.
[8] M. Ojaroudi, M., "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.
[9] 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.
[10] T. Dissanayake and K. Esselle, "Prediction of the notch frequency of slot loaded printed UWB antennas," *IEEE Trans. Antennas and Propag.*, vol. 55, no. 11, pp. 3320-3325, 2007.
[11] Ansoft High Frequency Structure Simulation (HFSS), Ver. 13, Ansoft Corporation, 2010.
[12] T.-G. Ma and S.-J. Wu, "Ultrawideband band-notched folded strip monopole antenna," *IEEE Trans. Antennas Propag.*, vol. 55, no. 9, pp. 2473-2479, 2007.
[13] N. Ojaroudi and M. Ojaroudi, "An UWB slot antenna with band-stop notch," *ICET Microw. Antennas Propag.*, vol. 10. pp. 831-835, 2013.
[14] M. Ojaroudi and N. Ojaroudi, "Ultra-wideband small rectangular slot antenna with variable band-stop function," *IEEE Trans. Antennas Propag*., vol. 62, pp. 490-494, 2014.
[15] M. Ojaroudi and N .Ojaroudi, "Ultra-wideband slot antenna with frequency band-stop operation," *Microw. Opt. Technol. Lett* ., vol. 55, pp. 2020-2023, 2013.
[16] N. Ojaroudi and M. Ojaroudi, "Novel design of dual band-notched monopole antenna with bandwidth enhancement for UWB applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 698-701, 2013.

Nasser Ojaroudi was born in 1986 in Germi, Iran. He received his B.Sc. degree in Electrical Engineering from 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 Company (MWT), Tehran, Iran. His research interests include monopole antenna, slot antennas, microstrip antennas for radar systems, ultra-wideband (UWB) and small antennas for wireless communications, microwave passive devices and circuits, and microwave/millimeter systems.

Mohammad Ojaroudi was born in 1984 in Germi, Iran. He received his B.Sc. degree in Power 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. Also from July 2013 he has been working, as a research visitor in University of Tennessee, Knoxville, USA. 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 the Chief Executive Officer (CEO) in the Microwave Technology Company (MWT), Tehran, Iran. From 2012, Dr. Ojaroudi is a member of the IEEE Transaction on Antennas and Propagation (APS) reviewer group and the Applied Computational Electromagnetic Society. 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 150 journal and international conferences papers. His papers have more than 600 citations with 13 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.