Enhanced Bandwidth Ultra-Wideband Small Monopole Antenna with Variable Band-Stop Function

M. T. Partovi [1], N. Ojaroudi [2], M. Ojaroudi [3], and N. Ghadimi [3]

[1] Department of Electrical Engineering,
Aeronautical University of Science and Technology, Tehran, Iran.
partovimt@gmail.com

[2] Department of Electrical Engineering
Ardabil Branch, Islamic Azad University, Ardabil, Iran
n_ojaroudi@srttu.edu

[3] Young Researchers Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir, 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 square radiating patch with a T-shaped ring slot and ground plane with two G-shaped slots. In the proposed structure, by cutting two G-shaped slots in 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 a T-shaped ring slot in the radiating patch. The fabricated antenna has the frequency band of 2.95 to over 15.65 GHz with a rejection band around 5.13-5.91 GHz. 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.

Index Terms **─** Frequency Band-Notch Function, G-Shaped Slot, T-Ring Slot, 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 between 3.1-10.6 GHz will cause interference to the existing wireless communication systems for example the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15-5.35 GHz and 5.725-5.825 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 [4-8]. In [4], [5] and [6], 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 [7] half wavelength U-shaped slots are embedded in the radiation patch to generate the single and multiple

Submitted On: Mar. 8, 2012
Accepted On: Aug. 22, 2012

band-notched functions, respectively. Other automatic design methods have been developed to achieve band-notch performance [8].

In this paper, a simple method for designing a novel and compact microstrip-fed monopole antenna with band-notch characteristic for UWB applications has been presented. In the proposed antenna, based on defected ground structure, for bandwidth enhancement we use two G-shaped slots on the ground plane. Also by using a T-shaped ring slot with variable dimensions on 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 size reduction of 15% with respect to the previous similar antenna [4-8]. 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.

In the proposed structure, by cutting the modified T-shaped ring slot of suitable dimensions at the monopole's patch a double fed structure can be constructed. This structure has a novel feeding configuration that consists of a splitting network connected to two symmetrical ports on its base. Using the Theory of Characteristic Modes it has been demonstrated that the insertion of two symmetric feed ports prevents the excitation of horizontal currents and assures that only the dominant vertical current mode is present in the structure [2]. As a result, unlike other antennas reported in the literature to date [5]-[9], the proposed antenna displays a good omni-directional with low cross-polarization level radiation pattern even at higher frequencies.

II. ANTENNA DESIGN

The presented small square 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 of W_f and length of L_f .The width of the microstrip feed line is fixed at 2 mm. On the other side of the substrate, a conducting ground plane is placed. The proposed antenna is connected to a 50- SMA connector for signal transmission.

Regarding defected ground structures (DGS), the creating slots in the ground plane provide 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 [8]. Therefore, by cutting two G-shaped slots at the ground plane and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. In addition, as illustrated in Fig. 1, a T-shaped ring slot in the radiating patch can perturb the resonant response and also acts as a half-wave resonant structure [3]-[5]. At the notch frequency, the current concentrated on the edges of the interior and exterior of the T-shaped ring slot. As a result, the desired high attenuation near the notch frequency can be produced. The final dimensions of the designed antenna are specified in Table I.

Table I: The final dimensions of the designed antenna

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	10	L_{Sub}	16	L_f	6
L_V	1.5	L_S	7	L_{S2}	7
W_P	9	L	0.5	W	0.5
W_{S1}	2	L_{S1}	0.5	W_{S2}	3
W_{S3}	1	L_{S3}	2.5	W_V	2
W_{V1}	1	W_{V2}	1	L_{gnd}	1

III. RESULTS AND DISCUSSIONS

In this Section, the 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 parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [9].

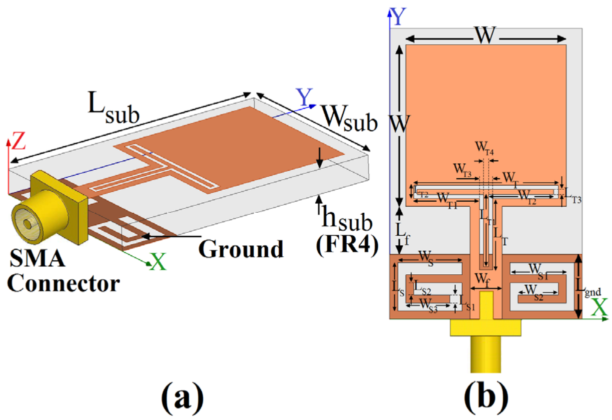

Fig. 1. Geometry of the proposed antenna, (a) side view, (b) top view.

Figure 2 shows the structure of the various monopole antennas used for new additional resonance and band notch performance simulation studies. VSWR characteristics for ordinary square monopole antenna (Fig. 2(a)), with a pair of G-shaped slots in the ground plane (Fig. 2(b)), and the proposed antenna structure (Fig. 2(c)) are compared in Fig. 3. Fig. As shown in Fig. 3, it is found that by inserting a pair of G-shaped slots in the ground plane, the antenna can create the third resonant frequency at 13 GHz. Also as shown in Fig. 3, in this structure, Also as shown in Fig. 3, in this structure, a modified T-shaped ring slot in the square radiating patch with variable dimensions is used in order to generate the frequency band stop performance. [6]-[7]. Also the input impedance of the various monopole antenna structures that shown in Fig. 2, on a Smith Chart is shown in Fig. 4.

To understand the phenomenon behind this new additional resonance performance, the simulated current distributions on the ground plane for the proposed antenna with two G-shaped slots at 13 GHz are presented in Fig. 5 (a). It can be observed in Fig. 5 (a) that the current concentrated on the edges of the interior and exterior of the two G-shaped slots at 13 GHz. Therefore, the antenna impedance changes at these frequencies due to the resonant properties of the G-shaped slots [8]. It is found that by using these slots, third resonance at 13 GHz. Another important design parameter of this structure is the T-shaped ring slot in radiating patch. 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 of the T-shaped ring slot. As a result, the desired high attenuation near the notch frequency can be produced [6]-[7].

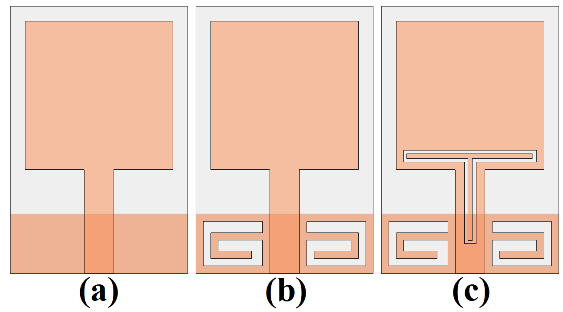

Fig. 2. (a) The basic structure (ordinary square antenna), (b) square antenna with two G-shaped slots, (c) the proposed antenna.

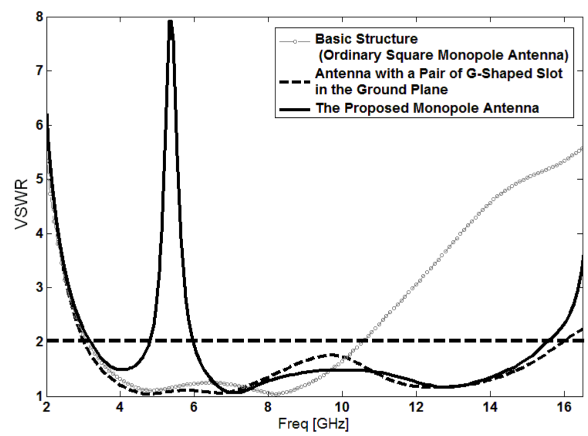

Fig. 3. Simulated VSWR characteristics for the antennas shown in Fig. 2.

In this study, the T-shaped ring slot is used in order to generate the frequency band-stop performance as displayed in Fig. 1. The simulated VSWR curves with different values of W_1 are plotted in Fig. 6. As shown in Fig. 6, when the interior width of the T-shaped ring slot increases from 1 to 2.5 mm, the center of notch frequency is increases from 4. 3 to 6.7 GHz. From these results, we can conclude that the notch frequency is controllable by changing the interior width of the T-shaped ring slot.

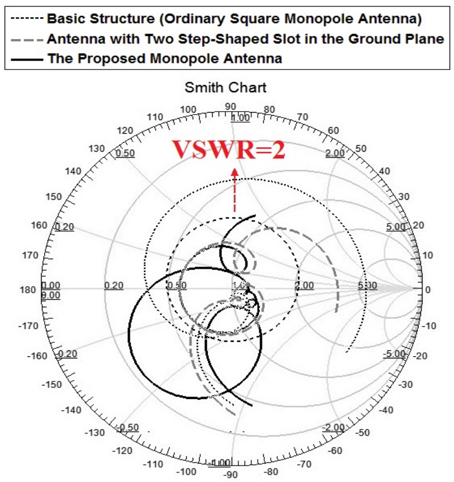

Fig. 4. The simulated input impedance on a Smith chart of the various monopole antenna structures shown in Fig. 2.

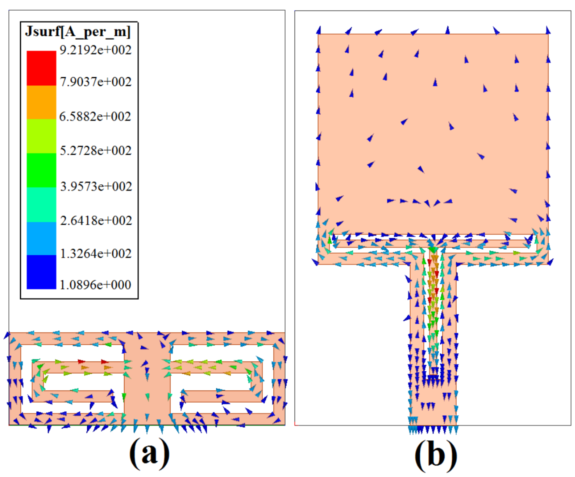

Fig. 5. Simulated surface current distributions for the proposed antenna, (a) on the ground plane at 13 GHz (third resonance frequency), (b) on the radiating patch at 5.5 GHz (notch frequency).

Another main effect of the T-shaped ring slot occurs on the filter bandwidth. In this structure, the width L_1, is the critical parameter to control the filter bandwidth. Figure 7 illustrates the simulated VSWR characteristics with various length of L_1. As the gap distance between the T-shaped ring slot increases from 0.4 to 1.2 mm, the filter bandwidth is varied from 0.5 to 1.7 GHz. Therefore the bandwidth of notch frequency is controllable by changing the width of L_1.

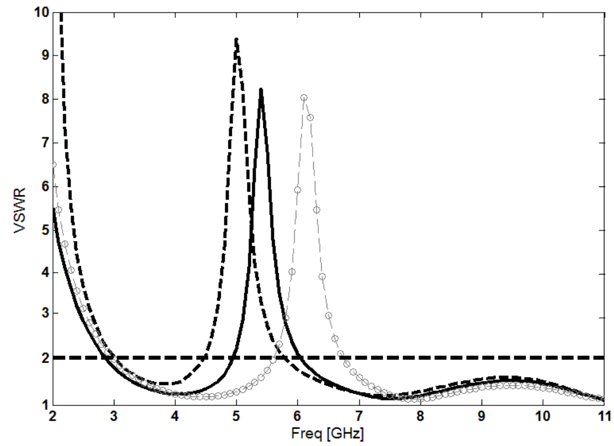

Fig. 6. Simulated VSWR characteristic with different values of W_1.

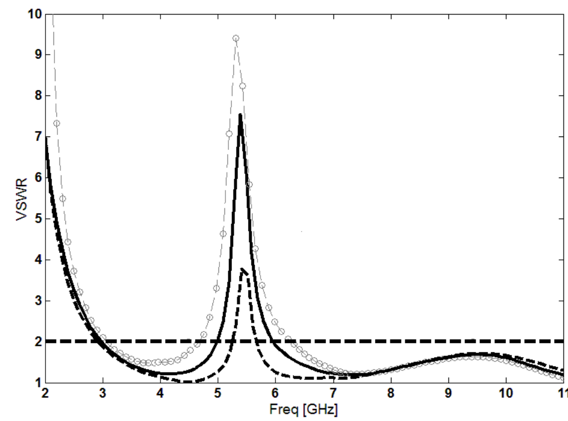

Fig. 7. Simulated VSWR characteristics for the proposed antenna with different values of L_1.

Figure 8 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna has the frequency band of 2.95 to over 15.65 GHz with a rejection band around 5.13 to 5.91 GHz. Also in order to clear show the resonance frequencies the measured and simulated return loss characteristics of the proposed antenna shown in Fig. 9. As shown in Figs. 8 and 9, there exists a discrepancy between measured data and the simulated results this could be due to the effect of the SMA port, and also the accuracy of the simulation due to the wide range of simulation frequencies. 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.

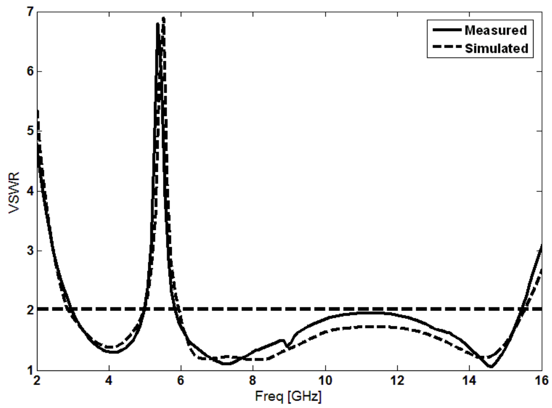

Fig. 8. Measured and simulated VSWR for the proposed antenna.

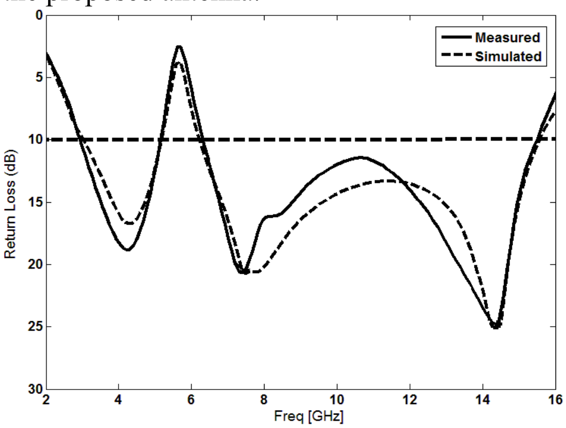

Fig. 9. Measured and simulated return loss characteristics for the proposed antenna.

Figure 10 shows 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 *x-z* plane are nearly omnidirectional for the three frequencies.

Figure 11 shows the effects of the G-shaped slots and a T-shaped ring slot on the maximum gain in comparison to the ordinary square 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 is found that the gain of the square antenna is decreased with the use of the G-shaped slots in the ground plane and the T-shaped ring slot the square radiating patch of the antenna. It can be observed in Fig. 11 that by using 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 frequencies band, the antenna gain with the filter is similar to those without it.

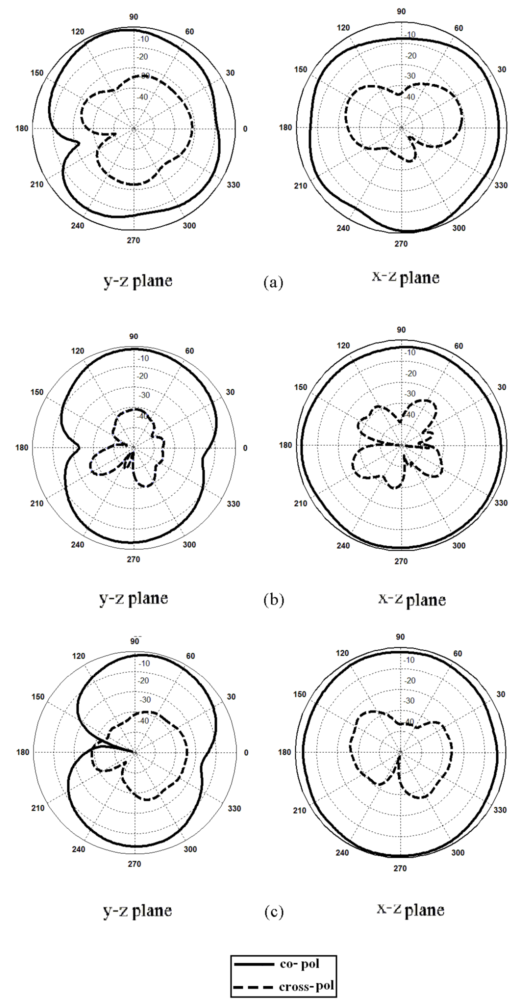

Fig. 10. Measured radiation patterns of the proposed antenna. (a) 4GHz, (b) 7 GHz, and (c) 10 GHz.

V. CONCLUSION

In this paper, a novel small square slot antenna with variable band-stop characteristic for UWB applications has been proposed. In this design, the proposed antenna can operate from 2.95 to 15.65 GHz with VSWR < 2 with a rejection band around 5.13 to 5.91 GHz. and unlike other antennas reported in the literature to date, the proposed antenna displays a good omni-directional radiation pattern even at higher frequencies. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. The designed antenna has a small size. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB application.

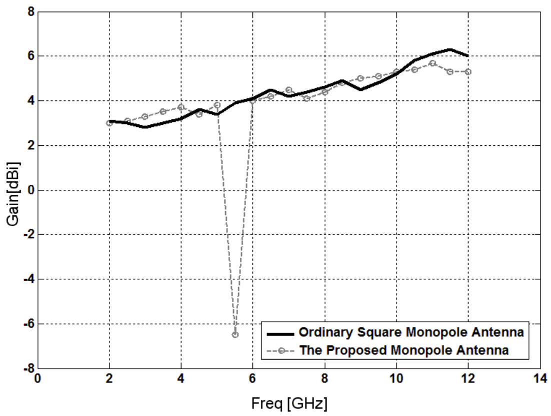

Fig. 11. Maximum gain comparisons for the ordinary square antenna (simulated), and the proposed antenna (measured).

ACKNOWLEDGMENT

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

REFERENCES

[1] Schantz H., 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 with 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] R. Azim, M. T. Islam, 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.

[4] D. S. Javan, 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.

[5] D. S. Javan, 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.

[6] 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.

[7] R. Rouhi, Ch. Ghobadi, J. Nourinia and M. Ojaroudi, "Ultra-Wideband Small Square Monopole Antenna with Band Notched Function, Accepted on *Microwave and Optical Tech. Letters*, vol. 52, no. 9, pp. 2065-2069, September 2010.

[8] J. William, 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.

[9] M. Naghshvarian-Jahromi, 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.

[10] Ansoft High Frequency Structure Simulation (HFSS), Ver. 13, Ansoft Corporation, 2010.

Mohammad-Taghi Partovi was born on 1973 in Mianeh Iran. He received his B.Sc. degree in Control Engineering from University of Science and Technology, and M.Sc. degree in Industrial Engineering from University of Science and Technology, Mazandaran, Iran. Since March 2001, he has been a Research Fellow and a Teaching Assistant with the Department of Electrical Engineering, Aeronautical University of Science and Technology, Tehran, Iran. His research interests include design and modeling of microwave structures, radar systems, and RFID systems.

Nasser Ojaroudi was born on 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 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 an Teaching Assistant with the Department of Electrical Engineering, Islamic Azad University, Ardabil Branch, Iran. Since March 2008, he has been a Research Fellow (Chief Executive Officer) in the Microwave Technology Company (MWT), Tehran, Iran. 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 80 journal and international conference papers.

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.