Bandwidth Enhancement of Small Square Monopole Antenna with Dual Band-Notched Characterestics Using H-Ring Slot and Conductor Backed Plane for UWB Applications

Mohammad Ojaroudi [1], Nasser Ojaroudi [2], and Seyed Amin Mirhashemi [3]

[1] Young Researchers Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir

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

[3] Department of Electrical Engineering
South Tehran Branch, Islamic Azad University, Tehran, Iran
mirhashemi_amin@yahoo.com

Abstract **─** This article proposes a novel printed monopole antenna for ultra wideband applications with dual band-notch function. The antenna consists of a square radiating patch and a ground plane with H-ring slot and conductor backed plane, which provides a wide usable fractional bandwidth of more than 125% (2.89-13.43 GHz). In order to generate single band-notched characteristic, we use an H-shaped conductor backed plane on the other side of the substrate. By converting this H-shaped conductor backed plane to H-ring form, a dual band-notched function is achieved and also by inserting an H- ring slot in the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band. The measured results reveal that the presented dual band-notched monopole antenna offers a wide bandwidth with two notched bands, covering all the 5.2/5.8GHz WLAN, 3.5/5.5 GHz WiMAX and 4-GHz C bands. The designed antenna has a small size of 12×18 mm^2.

Index Terms **─** H-ring parasitic structure, H-ring slot, microstrip-fed monopole antenna, and ultra-wideband (UWB) applications.

I. INTRODUCTION

In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized. Moreover, other strategies to improve the impedance bandwidth, which do not involve a modification of the geometry of the planar antenna, have been investigated [1-4].

In UWB systems, the frequency range of 3.1 GHz to 10.6 GHz will cause interference to the existing wireless communication systems, such as, 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, WiMAX (3.3 GHz – 3.6 GHz), and C-band (3.7 GHz – 4.2 GHz); thus UWB antenna with a single and dual band-stop performance is required. In order to generate the frequency band-notch function antenna, modified planar monopole antennas have been recently proposed [5-8]. In [5] and [6], different shapes of the slits (i.e., W-shaped and folded trapezoid) are used to obtain the desired band-notched characteristics. Single and multiple [7] half-wavelength U-shaped slits are embedded in the radiation patch to generate the single and

Submitted On: Apr. 28, 2012
Accepted On: Dec. 26, 2012

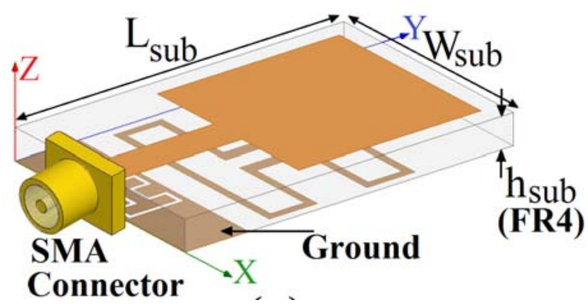
multiple band-notched functions, respectively. In [8], band-notch function is achieved by using a T-shaped coupled-parasitic element in the ground plane.

In this paper, a new dual band-notch printed monopole antenna with multi resonance performance is presented. In the proposed structure, based on defected ground structure (DGS), by cutting an H-ring slot on the ground plane, additional resonances are excited and the bandwidth is improved to achieve a fractional bandwidth with multi resonance performance of more than 125 %. Also, based on electromagnetic coupling theory (ECT), single band-notched function is provided by inserting an H-shaped conductor backed plane and dual band-notch characteristic is obtained by using an H-ring conductor backed plane. The size of the designed antenna is smaller than the UWB antennas with band-notched function reported recently in [6-7]. 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.

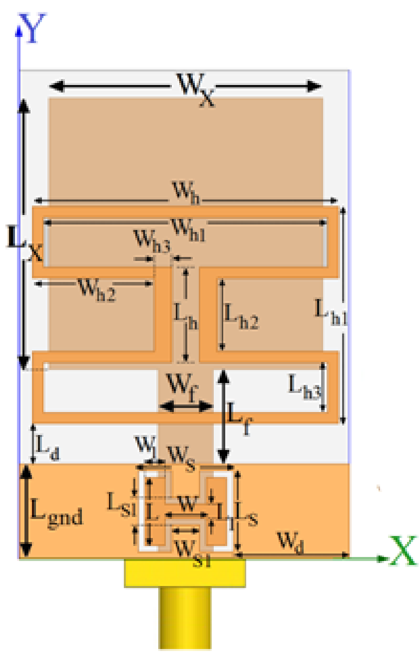
II. ANTENNA DESIGN

The proposed square monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on a FR4 substrate of thickness 1.6 mm, and permittivity 4.4. The width of the microstrip feed line is fixed at 2 mm. The basic antenna structure consists of a square radiating patch, a feed line, and a ground plane. The patch is connected to a feed line, 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 50Ω SMA connector for signal transmission.

Regarding 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 [2]. Therefore, by cutting an H-ring slot at the ground plane and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. As illustrated in Fig. 1, the H-shaped ring conductor backed plane is placed under the radiating patch and is also symmetrical with respect to the longitudinal direction. Based on ECT, the conductor backed plane perturbs the resonant response and also acts as a parasitic half-wave resonant structure electrically coupled to the rectangular monopole [3]. At the notched frequency, the current flows are more dominant around the parasitic element, and they are oppositely directed between the parasitic element and the radiation [3]. As a result, the desired high attenuation near the notch frequency can be produced.



(a)



(b)

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

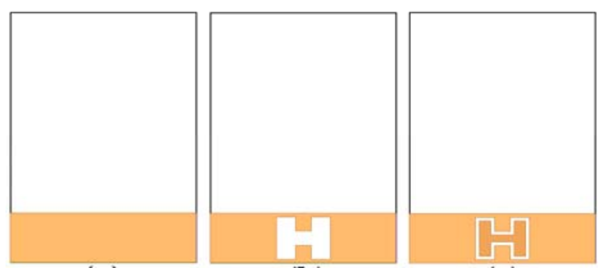
In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, are $W_{sub} \times L_{sub} = 12\ mm \times 18\ mm$ or about $0.15\lambda \times 0.25\lambda$ at 4.2 GHz (the first resonance frequency). We have a lot of flexibility in choosing the 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 (λ_{lower} / 4), where λ_{lower} is the lower bandwidth frequency wavelength. The 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 [8]. The important step in the design is to choose $L_{resonance}$ (the length of the resonator) and L_{notch} (the length of the filters). $L_{resonance}$ is set to resonate at $0.25\lambda_g$, where $L_{resonance} = 2L_S - L_{S1} + 2W_1 + 0.5W_{S1}$, and λ_g corresponds to a new resonance frequency wavelength at 11.2 GHz. L_{notch} is set to band-stop resonance at $0.5\lambda_g$, where $L_{first\ notch} = L_{h2} + 2L_{h3} + W_{h1} + 2W_{h2}$, $L_{second\ notch} = 0.5L_h + L_{h3} + 0.5W_{h1} + W_{h2}$, and λ_g corresponds to notched band frequencies wavelength (3.9 GHz is the first notched frequency and 5.5 GHz is the second notched frequency). The optimized values of the proposed antenna design parameters are as follow:

$W_{sub} = 12\ mm$, $L_{sub} = 18\ mm$, $h_{sub} = 1.6\ mm$, $W_f = 2\ mm$, $L_f = 3.5\ mm$, $L_x = 10\ mm$, $W_x = 10\ mm$, $W_s = 3\ mm$, $L_s = 3\ mm$, $W_{s1} = 0.5\ mm$, $L_{s1} = 1\ mm$, $W = 1\ mm$, $L = 2.5\ mm$, $W_1 = 0.75\ mm$, $L_1 = 0.5\ mm$, $W_d = 4.5\ mm$, L_d, $1.5\ mm$, $W_h = 11.5\ mm$, $L_h = 3.5\ mm$, $W_{h1} = 11\ mm$, $L_{h1} = 8\ mm$, $W_{h2} = 4.75\ mm$, $L_{h2} = 3\ mm$, $W_{h3} = 0.5\ mm$, $L_{h3} = 2\ mm$, and $L_{gnd} = 3.5\ mm$.

III. RESULTS AND DISCUSSIONS

The microstrip-fed monopole antenna were constructed and studied to demonstrate the effect of the proposed dual band-notch function and bandwidth enhancement technique. 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 or two parameters at a time and fixing the others. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS^{TM}) [9].

Figure 2 shows the structure of the various antennas used for simulation studies. VSWR characteristics for ordinary square patch antennas (Fig. 2(a)), with an H-shaped slot in the ground plane (Fig. 2(b)), and with an H-ring slot in the ground plane (Fig. 2(c)) are compared in Fig 3. As shown in Fig. 3, for the proposed antenna configuration, the ordinary square monopole can provide the fundamental and next higher resonant radiation band at 4.6 GHz and 8.3 GHz, respectively. As illustrated in Fig. 3, the H-shaped slot is playing an important role in the broadband characteristics and in determining the sensitivity of impedance matching of this type of antenna. This is because it can adjust the electromagnetic coupling effects between the patch and the ground plane, and improve its impedance bandwidth without any cost of size or expense [10, 11]. It is found that by inserting the H-shaped ring slot at the ground plane additional resonance (third resonance at 11.2 GHz) is excited and hence much wider impedance bandwidth with multi-resonance characteristics can be produced, especially at the higher band.



(a) (b) (c)

Fig. 2. (a) Ordinary square monopole antenna, (b) antenna with an H-shaped slot in the ground plane, and (c) antenna with an H-shaped ring slot in the ground plane.

To understand the phenomenon behind this new exited resonance performance, the simulated current distributions on the ground plane for the antennas studied in Fig. 2 (b) at 10 GHz and Fig. 2 (c) at 11.2 GHz are presented in Fig. 4 (a) and (b), respectively. It can be observed in Fig. 4 that the current concentrated on the edges of the interior and exterior of the slots. Therefore, the antenna impedance changes at this frequency due to the resonant properties of these slots inserted in the ground plane [3].

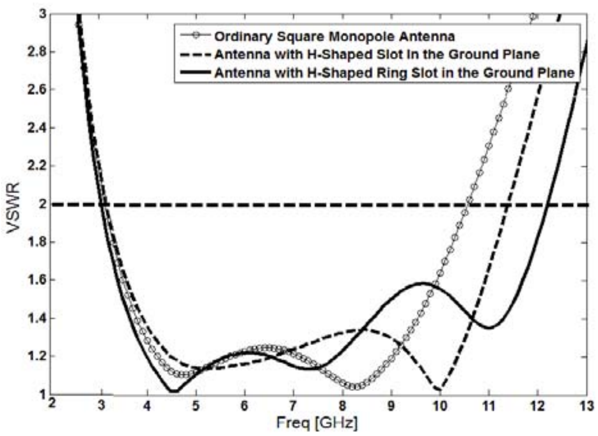
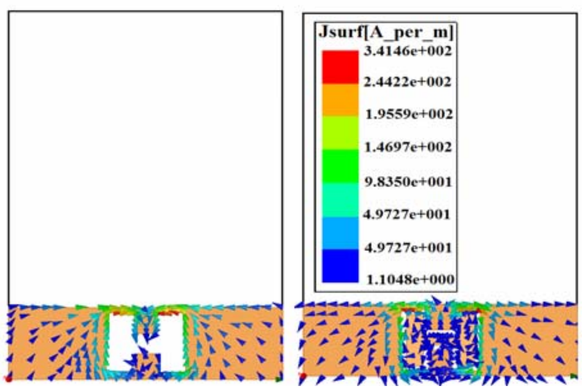


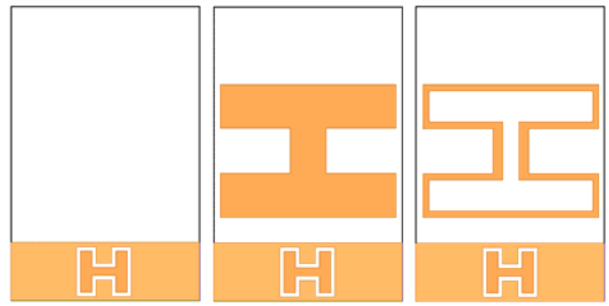
Fig. 3. Simulated VSWR characteristics for the various antenna structures shown in Fig. 2.



(a) (b)

Fig. 4. Simulated surface current distributions in the ground plane for (a) the square monopole antenna with an H-shaped slot at 10 GHz and (b) the square monopole antenna with an H-shaped ring slot at 11.2 GHz.

Figure 5 shows the structure of various basic structures (square antenna with an H-shaped slot ring in the ground plane) used for band-notched function simulation studies. The VSWR characteristics for the basic structure (Fig. 5 (a)), with an H-shaped conductor backed plane (Fig. 5 (b)), and the proposed antenna ((Fig. 5(c)) are compared in Fig 6. As shown in Fig. 6, for the proposed antenna configuration, in order to generate single band-notch characteristics, we use an H-shaped conductor backed plane on the other side of the substrate. By inserting an H-ring conductor backed plane, a dual band-notched function is achieved that covers all the 5.2 GHz / 5.8 GHz WLAN, 3.5 GHz / 5.5 GHz WiMAX and 4 GHz C bands.



(a) (b) (c)

Fig. 5. (a) The basic structure (ordinary square monopole antenna with an H-ring slot in the ground plane), (b) basic structure with an H-shaped conductor backed plane, and (c) basic structure with an H-ring conductor backed plane**.**

To understand the phenomenon behind this dual band-notch performance, the simulated current distribution on the ground plane for the proposed antenna at the notch frequencies of 3.9 GHz and 5.5 GHz is presented in Fig. 7 (a) and (b), respectively. It can be observed from Fig. 7 (a) and (b) that the current is concentrated on the edges of the interior and exterior of the H-shaped ring conductor backed plane at frequencies 3.9 GHz and 5.5 GHz. Therefore, the antenna impedance changes at these frequencies due to the band-notch properties of the proposed structure.

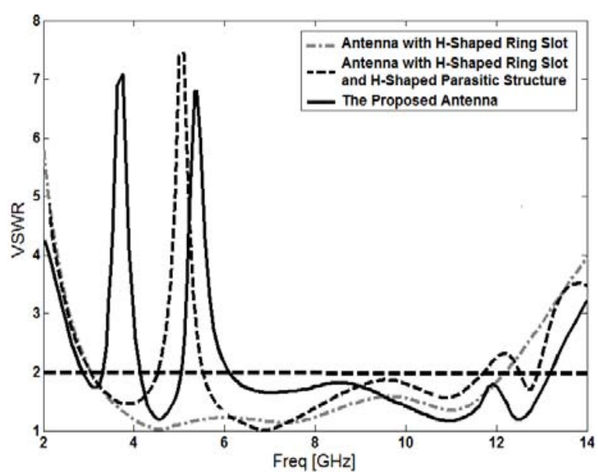
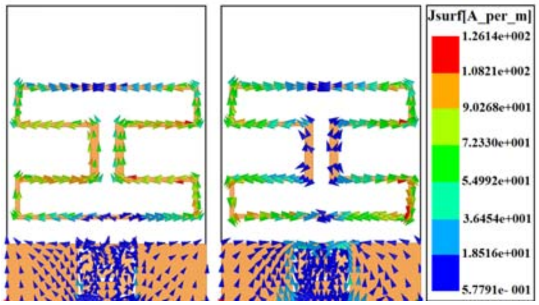


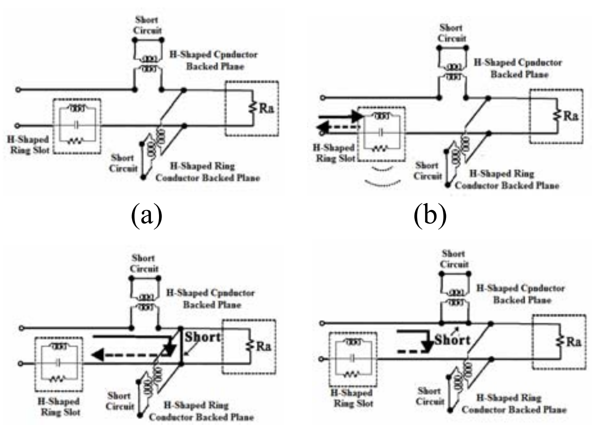
Fig. 6. Simulated VSWR characteristics for the various antenna structures shown in Fig. 5.



(a) (b)

Fig. 7. Simulated surface current distributions on ground plane for the proposed antenna at (a) 3.9 GHz and (b) 5.5 GHz.

Figure 8 shows the conceptual equivalent circuit model for the proposed antenna, which has an RLC resonator and two shunt stubs. When the current path in the H-shaped ring conductor backed plane is equal to a half-wavelength at 3.9 GHz, as shown in Fig. 8 (c), the input impedance at the feeding point is zero (short circuit). Moreover, when the current path in the H-shaped ring conductor backed plane is equal to a half-wavelength at 5.5 GHz, as shown in Fig. 8(d), the input impedance at the feeding point is zero (short circuit).



(a) (b)
(c) (d)

Fig. 8. (a) The conceptual equivalent-circuit model for the proposed antenna, (b) for the new resonance frequency, (c) for the first notched frequency, and (d) for the second notched frequency.

Figure 9 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna has the frequency band of 2.89 GHz to over than 13.43 GHz with two rejection bands around 3.45 GHz – 4.23 GHz and 5.07 GHz – 5.89 GHz. As shown in Fig. 9, there exists a discrepancy between the measured data and the simulated results. 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 exited by an SMA connector), whereas the simulated results are obtained using the Ansoft simulation software (HFSS^{TM}), where the antenna is exited by a wave port that is renormalized to a 50-Ohm full port impedance. Therefore this discrepancy between the measured data and the simulated results could be due to the effect of the SMA port [6]. In order to verify the accuracy of the VSWR characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully. In conclusion, since the slot antenna is a short radiator, the SMA connector can modify its impedance matching.

Figure 10 shows the measured radiation patterns including both, the co-polarized and cross-polarized, *E*-plane (*x-z* plane) and *H*-plane (*y-z* plane), respectively. The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. It can be seen that the radiation patterns in *x-z* plane are nearly omnidirectional for the three frequencies.

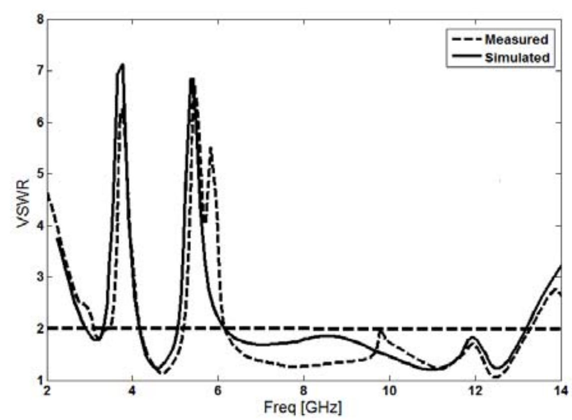


Fig. 9. Measured and simulated VSWR characteristic for the proposed antenna.

Figure 11 shows the effects of the ordinary H-shaped and H-shaped ring conductor backed plane, on the maximum gain in comparison to the same antenna without them. As shown in Fig. 11, the basic structure (ordinary square monopole antenna with an H-shaped ring slot in the ground plane) has a gain that is low at 3 GHz and increases with frequency [12]. It is found that the gain of the basic structure is decreased with the use of the H-shaped conductor backed plane structures. It can be observed in Fig. 11 that by using the H-ring conductor backed plane, two sharp decrease of maximum gain in the notched frequencies band at 3.9 GHz and 5.5 GHz are shown. For other frequencies outside the notched frequencies' band, the antenna gain with the filter is similar to those without it.

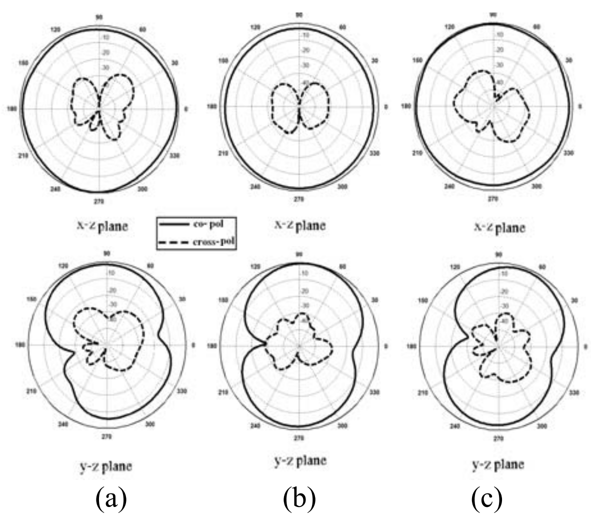


Fig. 10. Measured radiation patterns of the proposed antenna at frequency (a) 4.7 GHz, (b) 7.5 GHz, and (c) 9.8 GHz.

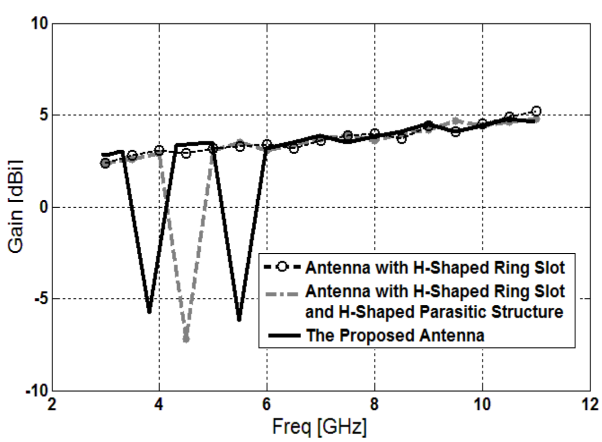


Fig. 11. Maximum gain comparisons for the basic structure (simulated), basic structure with H-shaped parasitic structure (simulated), and the proposed antenna (measured).

IV. CONCLUSIONS

In this paper, a novel compact wideband planar monopole antenna with single and dual band-notched characteristics has been proposed for various UWB applications. The fabricated antenna has the frequency band of 2.89 GHz to over than 13.43 GHz with two rejection bands around 3.45 GHz – 4.23 GHz and 5.07 GHz – 5.89 GHz. By cutting an H-ring slot in the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band. Furthermore, by inserting an H-ring conductor backed plane on the other side of the substrate, dual band-notch characteristics are generated. The proposed antenna has a simple configuration and is easy to fabricate. 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).

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Mohammad Ojaroudi was born on 1984 in Germi, Iran. He received his B.Sc. degree in Electrical Engineering from Ardabil Branch, Islamic Azad University, 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, Ardabil Branch, Islamic Azad University, Ardabil, 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 100 journal and international conference papers.

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.

Seyed Amin Mirhashemi was born on 1983 in Khalkhal, Iran. He received his B.Sc. degree in Electrical Engineering from Ardabil Branch, Islamic Azad University. From 2011, he is working toward the M.Sc. degree in Control Engineering at South Tehran Branch, Islamic Azad University, Tehran, Iran. Since March 2009, he has been a Research Fellow in the Microwave Technology Company (MWT), Tehran, Iran. His research interests include modeling of microstrip structures using neural networks and system identification methods.