Enhanced Bandwidth of Small Square Monopole Antenna by using Inverted U-shaped Slot and Conductor-Backed Plane

N. Ojaroudi [1], M. Ojaroudi [2], and Sh. Amiri [3]

[1] Faculty of Electrical & Computer Engineering
Shahid Rajaee Teacher Training University, Tehran, Iran
n_ojaroudi@srttu.edu

[2]Young Research Group
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir

[3] Scientific Member of Electrical Engineering, Department of Iranian Research Organization for Science and Technology (IROST), Tehran, Iran
amiri@irost.org

Abstract **─**This paper, presents a novel multi-resonance monopole antenna for ultra wideband applications. The proposed antenna consists of a square radiating patch with an inverted U-shaped slot and a ground plane with an inverted U-shaped conductor-backed plane, which leads to a wide usable fractional bandwidth of more than 135% (2.9-15.1 GHz). By cutting a modified inverted U-shaped slot with variable dimensions on the radiating patch and also by inserting an inverted U-shaped conductor-backed plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band. The designed antenna has a small size of 12×18 mm^2, or about $0.15\lambda \times 0.25\lambda$ at 4.2 GHz (the first resonance frequency). Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

Index Terms- Square Monopole Antenna, Inverted U-Shaped Structure, Ultra Wide-Band Systems.

I. INTRODUCTION

Commercial UWB systems require small low-cost antennas with omnidirectional radiation patterns and large bandwidth [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.

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, several planar monopoles with different geometries have been experimentally characterized [2]-[3] and automatic design methods have been developed to achieve the optimum planar shape [4]-[5]. Moreover, other strategies to improve the impedance bandwidth have been investigated [6]-[8].

This paper focuses on a square monopole antenna for UWB applications, which combines the square-patch approach with an inverted U-shaped slot, and the ground plane with an inverted U-shaped conductor backed plane that achieves a fractional bandwidth of more than 135%. Three new small wideband printed monopole antennas were proposed in [6-8], in

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

1054-4887 © 2012 ACES

which in order to achieve the maximum impedance bandwidth, inverted T-shaped, rectangular, and trapezoid notches were etched on the upper edge of the ground plane, respectively, where as in this letter to achieve the same goal, for the first time, an inverted U-shaped conductor backed plane is inserted in the feed gap distance and there is no notch on the ground plane (this structure has an ordinary rectangular ground plane configuration). Moreover, by cutting a modified inverted U-shaped slot with variable dimensions on the radiating patch, additional resonances (third and fourth resonances) are excited, which results in an increase in the usable upper frequency of the monopole and extends it from 10.3 GHz to 15.1 GHz. The designed antenna has a small size of 12×18 mm^2, and the impedance bandwidth of the designed antenna is higher than the UWB antennas reported recently [2-8].

II. ANTENNA DESIGN

The 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, permittivity 4.4, and loss tangent 0.018. The width W_f of the microstrip feedline is fixed at 2 mm. The basic antenna structure consists of a square patch, a feedline, and a ground plane. The square patch has a width of W. The patch is connected to a feed line with the width of W_f and the length of L_f. 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.

To design a novel antenna, an inverted U-shaped slot and an inverted U-shaped conductor-backed plane are embedded on the basic antenna structure, mentioned above. Based on the current distribution analysis, in UWB frequency band, it is observed that the currents on the bottom edge of the monopole's radiating patch, are distributed vertically at lower frequencies, while at higher frequencies this currents are distributed horizontally [9]. By cutting the inverted U-shaped notch of suitable dimensions (W_C, L_C, W_{C1} and L_{C1}) on the square radiating patch, it is found that much enhanced impedance bandwidth can be achieved for the proposed antenna.

In addition, the conductor-backed plane is playing an important role in the broadband characteristics of this antenna, because it can adjust the electromagnetic coupling effects between the patch and the ground plane, and improves its impedance bandwidth without any cost of size or expense [10]-[11]. This phenomenon occurs because, with the use of a conductor-backed plane structure in air gap distance, additional coupling is introduced between the bottom edge of the square patch and the ground plane [5].

In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, is $L_{Sub}\times W_{Sub} = 12mm\times18mm$, or about $0.15\lambda\times0.25\lambda$ 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 decreases, so does the antenna bandwidth, and vice versa. Next step, we have to determine the The length of the radiating patch L. This parameter is approximately $\frac{\lambda_{lower}}{4}$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_S depends on a number of parameters such as the slot width as well as the thickness and dielectric constant of the substrate on which the slot is fabricated. The last and final step in the design is to choose the length of the resonator (slot and conductor backed plane). L_r is set to resonate at $0.25\lambda_g$, where $L_r = W_C + 2L_C$ for slot, and $L_r = W_C + 2L_C$ for conductor backed plane, λ_g corresponds to resonance frequency wavelength.

The final dimensions of the designed antenna are as follows: $W_{sub} = 12mm$, $L_{sub} = 18mm$, $h_{sub} = 1.6mm$, $W = 10mm$, $L = 10mm$, $W_f = 2mm$, $L_f = 7mm$, $W_C = 4mm$, $L_C = 3mm$, $W_{C1} = 1mm$, $L_{C1} = 2mm$, $W_P = 9mm$, $L_P = 3.75mm$, $W_{P1} = 2.5mm$, $L_{P1} = 2.5mm$,

$L_{d1} = 0.75mm$, $W_{d1} = 1.5mm$, $d_{PS} = 2.75mm$ and $L_{gnd} = 3.5mm$.

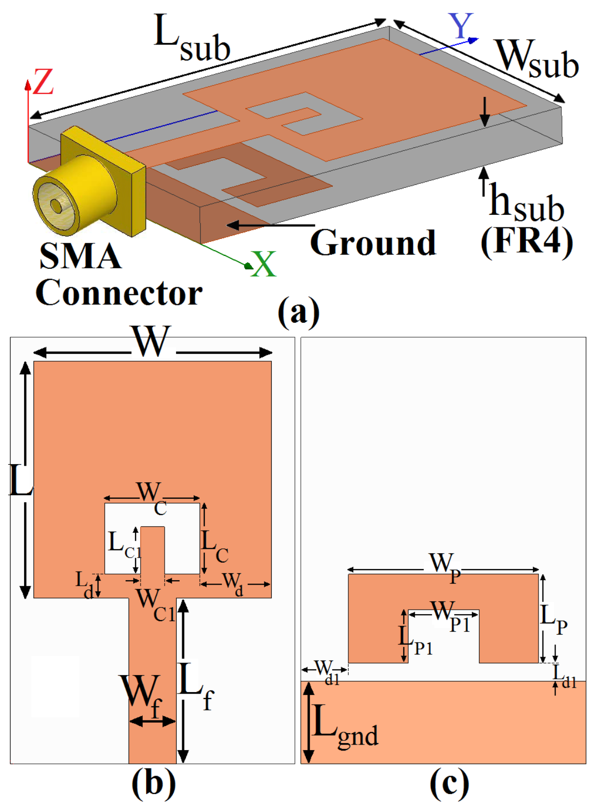

Fig. 1. Geometry of proposed antenna with inverted U-shaped slot and conductor-backed plane, (a) side view, (b) square radiating patch, and (c) ground plane structure.

III. RESULTS AND DISCUSSIONS

In this Section, the planar 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, while others are fixed. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [12].

Figure 2 shows the structure of various antennas used for simulation studies. Return loss characteristics for ordinary square patch antennas (Fig. 2(a)), with an inverted U-shaped slot (Fig. 2(b)), and with inverted U-shaped slot and conductor-backed plane (Fig. 2(c)) are compared in Fig 3. As shown in Figure 3, it is observed that by using these modified elements including an inverted U-shaped slot etched on the radiating patch and inserting an inverted U-shaped conductor-backed plane on the other side of substrate, additional third and fourth resonances are excited respectively, and hence the bandwidth is increased.

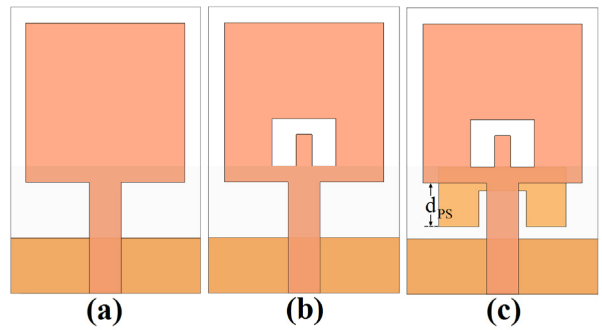

Fig. 2. (a) The ordinary square antenna, (b) the square antenna with inverted U-shaped slot (c) the square antenna with inverted U-shaped slot and parasitic structures.

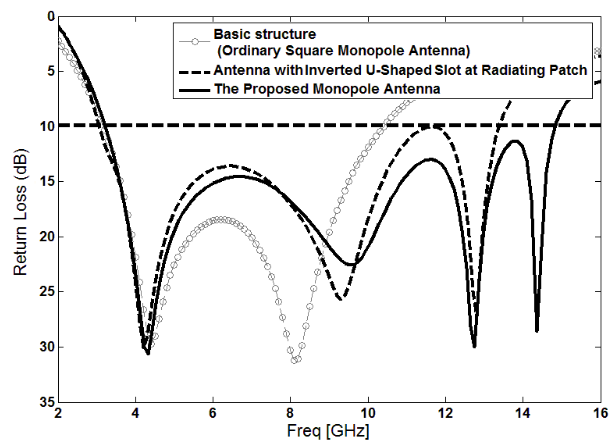

Fig. 3. Simulated return loss characteristics for the antennas shown in Fig. 2.

As shown in Fig. 3, in the proposed antenna configuration, the ordinary square monopole can provide the fundamental and next higher resonant radiation band at 4 and 8 GHz, respectively, in the absence of the inverted U-shaped slot and conductor-backed plane. Also Smith Chart demonstration of the input impedance of various monopole antenna structures, which were studied as Fig. 3, is shown in Fig. 4.

The upper frequency bandwidth is significantly affected by the use of the inverted U-shaped slot on the radiating patch. This behavior is mainly due to the change of surface

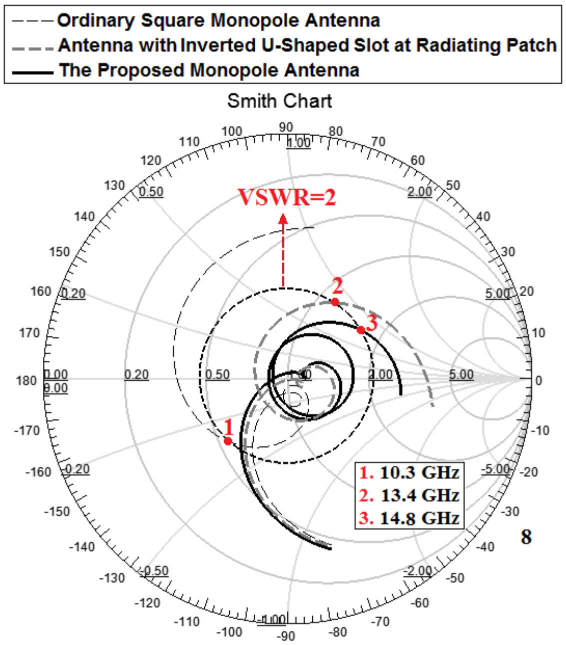

Fig. 4. Smith chart demonstration of the simulated input impedance of various monopole antenna structures, shown in Fig. 2.

current path which depends on the dimensions of inverted U-shaped slot as shown in Fig. 5 (a). In addition, by inserting the inverted U-shaped conductor-backed plane on the other side of substrate, the impedance bandwidth is effectively improved at the upper frequency [6]. The inverted U-shaped conductor backed plane can be regarded as a parasitic resonator that is electrically coupled to the square monopole.

As shown in Fig. 5(b), at fourth resonance frequency (14.3 GHz), the current is mainly concentrated on the interior and exterior edges of the inverted U-shaped conductor-backed plane. This figure shows that the electrical current for the fourth resonance frequency (Fig. 5 (b)) does change direction along the bottom edge of the square radiating patch and changes the antenna impedance at this frequency, as leads to an increase in the radiating power and bandwidth. Also there will be an increase in radiation efficiency. However, the resonant resistance is decreased [9].

By properly tuning the dimensions and spacing d_{PS} to semi-ground plane for the inverted U-shaped conductor backed plane, the antenna can create the fourth resonant frequency in individual resonant radiation band based on an over-coupling condition. Figure 6 shows the effects of the feed gap distance d_{PS} (as shown Fig. 2, $d_{PS} = L_f - L_{gnd} - L_{d1}$) of the square patch and dimension of the inverted U-shaped conductor-backed plane on the impedance. As illustrated in Fig. 6, the feed gap distance d_{PS} is an important parameter in determining the sensitivity of impedance matching. By adjusting d_{PS}, the electromagnetic coupling between the bottom edge of the square patch and the ground plane can be properly controlled [6].

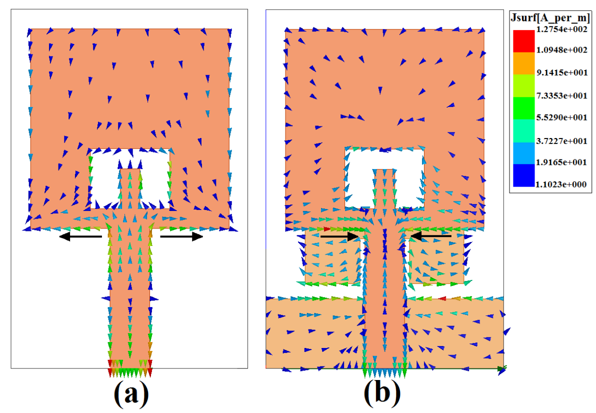

Fig. 5. Simulated surface current distributions on the radiating patch and ground plane for (a) the square antenna with inverted U-shaped slot at third resonance frequency (12.5 GHz), (b) the square antenna with inverted U-shaped slot and parasitic structure at fourth resonance frequency (14.3 GHz).

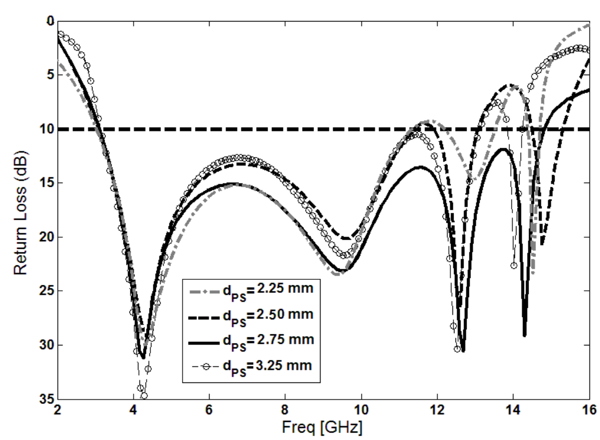

Fig. 6. Simulated return loss characteristics for various values of d_{PS}.

Figure 7 shows the measured and simulated return loss characteristics of the proposed antenna. The fabricated antenna satisfies the 10-dB return loss requirement from 2.91 to 15.1 GHz. As shown in Fig. 7, there exists a discrepancy between measured data and the simulated results this could be due to the effect of the SMA port. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement processes need to be performed carefully.

Figure 8 shows the measured radiation patterns at resonances frequencies including the co-polarization and cross-polarization in the *H*-plane (*x*-*z* plane) and *E*-plane (*y*-*z* plane). 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 all the four frequencies.

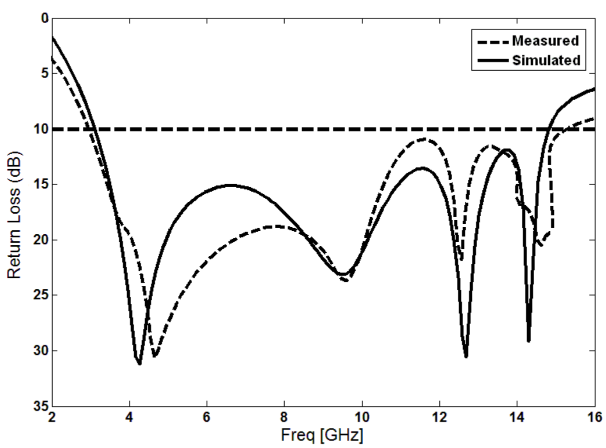

Fig. 7. Measured and simulated return loss characteristics for the proposed antenna.

V. CONCLUSION

In this letter, a novel compact Printed Monopole Antenna (PMA) has been proposed for UWB applications. The fabricated antenna satisfies the 10-dB return loss requirement from 2.9 to 15.1 GHz. By cutting a modified inverted U-shaped slot with variable dimensions on the radiating patch and also by inserting an inverted U-shaped conductor-backed plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band. 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 application.

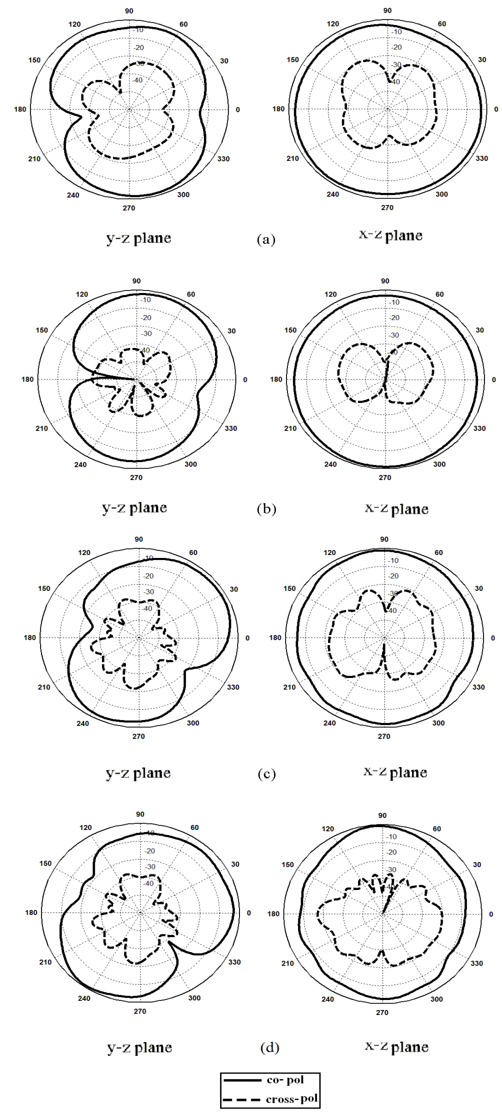

Fig. 8. Measured radiation patterns of the proposed antenna, (a) 4GHz, (b) 8GHz, (c) 12.7 GHz, and (c) 14.5 GHz.

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] Ammann M. J., Impedance bandwidth of the square planar monopole, *Microwave and Optical Tech. Letters*, vol. 24, no. 3, February 2000.

[3] R. Azim, M. T. Islam, N. Misran, "Design of a Planar UWB Antenna with New Band Enhancement Technique," *Applied Computational Electromagnetic 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 Electromagnetic Society (ACES) Journal*, vol. 24, no. 4, pp. 427-432, August 2009.

[5] Suh S. Y., Stutzman W. L., Davis W. A., A new ultrawideband printed monopole antenna: the planar inverted cone antenna (PICA), *IEEE Trans. Antennas Propagat.*, vol. 52, no. 5, pp. 1361-1364, May 2004.

[6] Kerkhoff A. J., Rogers R. L., Ling H., Design and Analysis of Planar Monopole Antennas Using a Genetic Algorithm Approach, *IEEE Trans. Antennas Propagat.,* vol. 2, pp. 1768-1771, June 2004.

[7] M. Ojaroudi, G. Kohneshahri, and Ja. Noory, "small modified monopole antenna for UWB application," *IET Microw, Antennas Propag*, vol. 3, no. 5, pp. 863-869, August. 2009.

[8] M. Ojaroudi, Ch. Ghobadi, and J. Nourinia, "Small Square Monopole Antenna With Inverted T-Shaped Notch in the Ground Plane for UWB Application," *IEEE* Antennas and Wireless Propagation *Letters*, vol. 8, no. 1, pp. 728-731, 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] J. William, R. Nakkeeran, "A New UWB Slot Antenna with Rejection of WiMax and WLAN Bands," *Applied Computational Electromagnetic Society (ACES) Journal*, vol. 25, no. 9, pp. 787-793, September 2010.

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

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

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 a 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 60 journal and international conference papers.

Shervin Amiri was born in Tehran, Iran, in 1966. He received his B.Sc., M.Sc. and Ph.D. from Iran University of Science & Technology (IUST) in communication systems. Now he is a Scientific Member of Electrical Engineering Department in Iranian Research Organization for Science and Technology (IROST). His research interest fields are Antenna and RF subsystems in Microwave and mm-wave Bands and Radar systems. He is supervisor of many Ph.D. and M.Sc. students in the fields of communication system and subsystems.