Compact Microstrip-fed Monopole Antenna with Modified Slot Ground Plane for UWB Applications

Maryam Majidzadeh[1] and Changiz Ghobadi[2]

[1] Department of Electrical Engineering
Urmia University, Urmia, Iran
Maryam_majidzadeh37@yahoo.com

[2] Department of Electrical Engineering
Urmia University, Urmia, Iran
Ch.Ghobadi@urmia.ac.ir

Abstract **─** A novel UWB microstrip-fed monopole antenna with modified structure has been designed and analyzed. The main body of the antenna under consideration consists of a quasi square radiating patch with tapered steps and a modified slotted ground plane. Due to the repeatedly cutting of three notches on the radiating patch and also inserting a rectangular slot and three tapered steps on the ground plane, a new resonance is excited and a wide bandwidth is obtained. By applying two sleeves with proper sizes to the antenna structure, an even wider impedance bandwidth is achieved. The antenna has a compact size of $18\times12\times1.6\text{mm}^3$ and operates over the frequency range of 2.34 – 21.43 GHz (9.15:1; 160%). The impedance bandwidth improvement process of the proposed antenna is presented and discussed in detail.

Index Terms **─** Microstrip feed line, UWB antenna, wide impedance bandwidth.

I. INTRODUCTION

Printed monopole antennas, although known for many years, are still at the center of the attention of the communication experts. Interest in these antennas is basically due to their marvelous merits such as low profile, easy and cost-effective fabrication process and good radiation properties. Equipped with such admirable characteristics, printed monopole antennas have provided a challenging opportunity for antenna designers in designing novel antennas satisfying UWB requirements. The main drawback to be considered in the antenna design realm is the problem of inherent narrow bandwidth. There has been a vast variety of literature conducted on the design of antennas operating over the UWB frequency range. Different combinations of radiating patch, feed line, and ground plane structures have been introduced to widen the antenna impedance bandwidth. For instance in [1], a square radiating patch with rectangular slots and a ground plane with an inverted T-shaped notch is introduced. A new band enhancement technique, chosen to design an antenna with UWB characteristics is proposed in [2]. An UWB antenna with an inverted T-shaped slot on its radiating patch and an inverted T-shaped conductor on the back plane of the substrate is proposed in [3]. The antenna presented in [4] is a hook shaped antenna with multi branch radiator. An antenna with elliptical/circular slots with U-shaped tuning stub and tapered microstrip feed line, is the structure adopted in [5] to reach the UWB characteristics. The antenna in [6] is a cross slot antenna with U-shaped tuning stub which is designed for UWB applications. In [7], a simple rectangular radiating patch with a ladder shaped conductor on the back plane is excited by a microstrip feed line. By introducing a tapered slot to the antenna structure in [8], UWB performance is obtained. Another antenna with elliptic patch and a hexagonal slot etched from the ground plane on the other side of the substrate is presented in [9]

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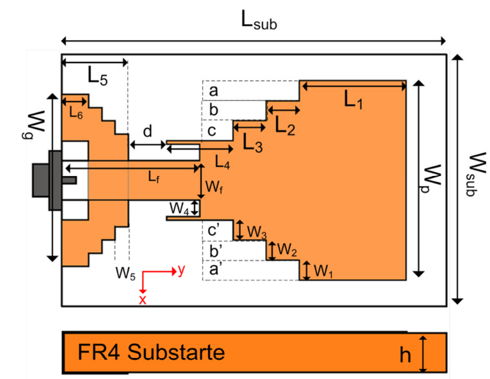
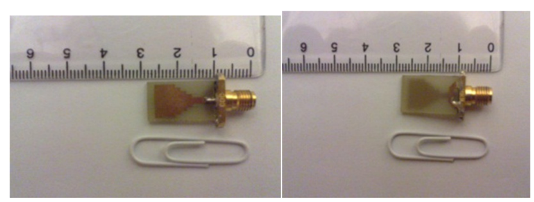
and provides an impedance bandwidth of 145%. An antenna with tapered-shaped slot and a rectangular tuning stub for UWB systems is offered in [10]. Fractal geometries are also used in the design of UWB antennas. Behavior of a Sierpinski carpet monopole antenna in analyzed in [11]. Also, in [12] a novel UWB antenna is offered which rejects WiMAX and WLAN bands. In this paper, a novel compact microstrip-fed monopole antenna is presented. The proposed antenna has a very compact size of 18×12×1.6mm^3 and operates over the frequency range of 2.34-21.43GHz (160%). The antenna benefits from a novel shape of ground plane structure and radiating patch. Omnidirectional radiation pattern and constant gain is observed over the UWB frequency range. As mentioned earlier, the proposed antenna, besides covering the UWB frequency range, has a good performance at higher frequencies ranging from 11-21.43GHz. This feature is a salient merit which makes this antenna to be a good candidate in satellite communications [13]. The remainder of the paper is outlined as follows: The structure and design process of the antenna are discussed in Section II. The simulation results of parametric study, measured results and the comparison of the antenna performance with some of the recently published antennas are presented in Section III. Eventually, Section IV concludes the paper.

II. ANTENNA DESIGN

The schematic of the proposed monopole antenna is shown in Fig. 1.a. The fabricated antenna is shown in Fig. 1.b. The proposed antenna is printed on a cheap FR4-epoxy substrate with permittivity of 4.4, loss tangent of 0.002 and thickness of 1.6 mm. A microstrip feed line with the length and width of 6mm and 2mm, respectively, is adopted to feed the study antenna. What makes this antenna distinctive from the conventional printed monopole antennas is the modified structure of its ground plane and the inclusion of two sleeves on the lowest edges of the radiating patch. The radiating element is basically a 10×10 mm^2 square on which three notches named as (a, a'), (b, b'), and (c, c') are cut. In the main square patch without notches, the sudden discontinuity between the feed line and the patch, leads to narrow bandwidth and degraded radiation pattern. To overcome the mentioned problem, the notches are embedded on the radiating patch. As it will be shown later, due to the removing of the mentioned rectangular symmetrical notches from the patch, the bandwidth of the antenna is remarkably enhanced. Two sleeves with dimensions of 1.5×0.1 mm^2 are added to the edges of the lowest steps of the radiating patch to further widen the bandwidth. The proposed antenna benefits from a new shape of ground plane. A rectangular slot with length and width of 4×1.5 mm^2 is removed from the lowest part of the ground plane. This slot, along with three tapered steps, plays an important role in the antenna performance. The values of all the antenna parameters are given in detail in Fig. 1.



(a)



(b)

Fig. 1(a). The schematic geometry of the proposed antenna, (b) The fabricated antenna. W_{sub}=12, L_{sub}=18, W_f=2, L_f=6, L_1=5.5, L_2=1.5, L_3=1.5, L_4=3, L_5=3, L_6=1.5, W_1=1, W_2=1, W_3=1, W_4=0.9, W_5=0.5, W_g=8, h=1.6 (Unit: mm).

III. RESULTS AND DISCUSSIONS

The performance of the monopole antenna has been investigated using the Ansoft High Frequency Structure Simulator (HFSS v. 11). The impedance bandwidth, VSWR, gain and radiation patterns of the proposed antenna are measured and analyzed. All the measured results are obtained using the Agilent 8722ES network analyzer. An exhaustive parametric study is conducted to verify the effect of different parameters on the performance of the proposed antenna.

A. Ground plane effect

At first, for explaining the effect of the ground plane, four prototypes of proposed antenna (Ant. 1- Ant. 4), with different shapes of ground planes are defined as follows: Antenna 1, includes only a ground plane without any slots on it, with the width and length of $W_{sub} = W_g = 12\text{mm}$ and $L_5 = 3mm$ respectively; in Antenna 2, two rectangular slots are cut from both sides of the conventional rectangular ground plane. In Antenna 2, the ground width is reduced to $W_g = 8\text{mm}$ while its length is kept at $L_5 = 3mm$. Antenna 3, contains a rectangular slot with dimensions of $4\text{mm} \times 1.5\text{mm}$ inserted on the ground (π-shape); and finally the Antenna 4, exhibits the modified ground plane proposed in this paper. The VSWR curves for the Antenna 1 to Antenna 4 are depicted in Fig. 3. These results confirm that both lower and upper band edge frequencies are sensitive to the ground plane shape and have shifted toward lower and higher frequencies respectively, which results in bandwidth improvement, especially at higher frequencies.

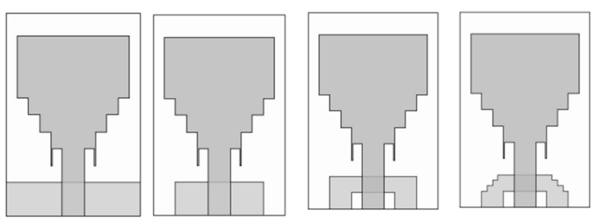


Fig. 2. The geometry of the four prototypes of the proposed antennas. (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, a (d) Antenna 4 (proposed antenna).

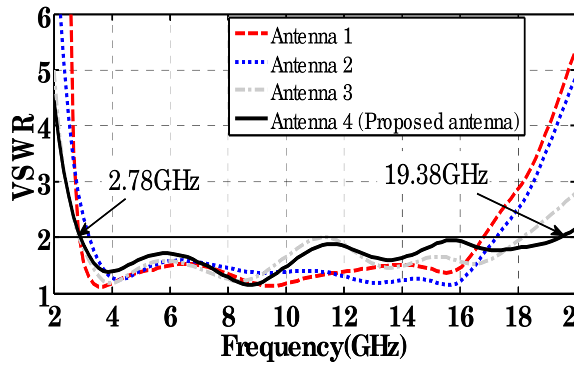


Fig. 3. Simulated VSWR curves for the antennas presented in Fig. 2.

B. Rectangular notches on the radiating patch

As it was mentioned earlier, three symmetrical rectangular slots on the patch are the other elements affect the antenna impedance bandwidth. When there is no notch on the radiating patch, the current encounters a sharp point on its path, but when the current flow path is smoothed by the notches, the impedance matching and the bandwidth are enhanced. Three pairs of notches named as (a, a'), (b, b'), and (c, c') are repeatedly applied to the antenna structure. Figure 4 shows the embedding of notches on the patch. Antenna in Fig. 4.a includes only a pair of notch named as (a, a'). In Fig. 4.b, notches (a, a'), (b, b') are added to the antenna structure. In Fig. 4.c, the antenna has three pair of rectangular notches, and finally in Fig. 4.d, the sleeves are also applied to the antenna and the final configuration is obtained. VSWR curves for the antennas presented in Fig. 4 are plotted in Fig. 5. The simulated results show that repeatedly embedded notches on the patch directly influence both the upper and lower band edge frequencies. The impedance bandwidth enhancement process is clearly seen in Fig. 5. Due to the adding of two sleeves to the lowest steps of the radiating patch, a new resonance is excited. By the appearance of this resonance, at the frequency of about 17.5GHz even wider frequency band is covered by the proposed antenna.

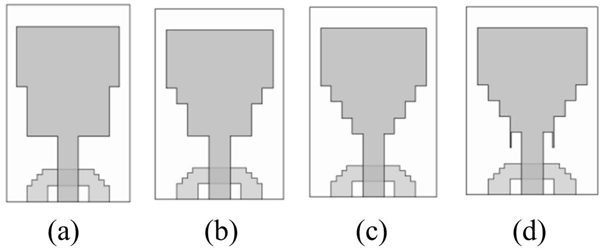


Fig. 4. (a): Antenna with notches (a, a'). (b): Antenna with notches (a, a'), (b, b'). (c): Antenna with notches (a, a'), (b, b'), (c, c'). (d): Proposed antenna.

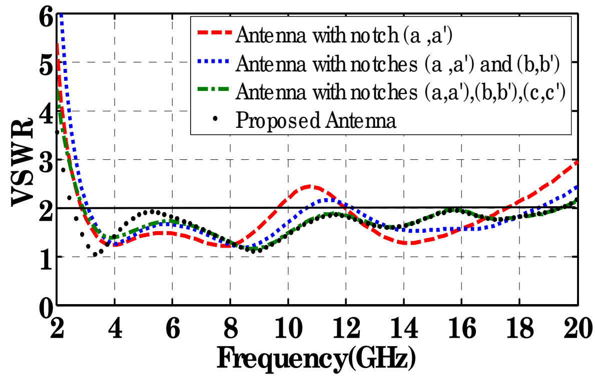


Fig. 5. Simulated VSWR curves for the effect of the notches on the patch.

C. Feed gap distance (d)

The other parameter to be studied is the distance between the upper edge of the ground plane and lower edge of the radiating patch which is named as 'd'. The antenna is analyzed with three different values for d and the results are shown in Fig. 6. It is seen that when d is decreased from the initial value of 2.5 mm, by a step of 1mm, the impedance matching becomes poor and results in bandwidth reduction. From the VSWR curves, for d=1.5 mm, the widest bandwidth is achieved.

The measured VSWR curve for the proposed antenna is depicted in Fig. 7 and is compared to the simulated results. The measured results indicate that the impedance bandwidth is stretched from 2.34 to 21.43 GHz (160%) for VSWR<2. As it is seen, four resonances are excited in the VSWR curve of the proposed antenna, which are shown in Fig. 7. To provide a better understanding of the antenna performance, Fig. 8 shows the surface current distribution at the resonance frequencies of 3.7, 8.7, 13.5, and 17 GHz.

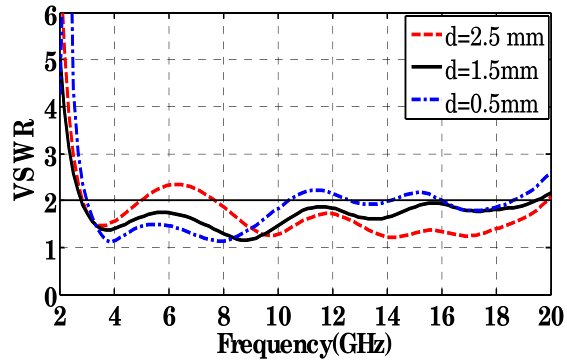


Fig. 6. Simulated VSWR curves for different parameters of 'd'.

As it is seen from Fig. 8. a, at 3.7 GHz, where the first resonance is excited, the majority of the current is concentrated around the edges of the rectangular slot on the ground plane, sleeves, and the lowest step of the patch. It shows that the sleeves and the steps on the patch are important elements in determining the antenna performance at this frequency. In Fig. 8.b, the current distribution at 8.7 GHz is shown. Strong current distribution on the edges of the rectangular slot shows that this part of the ground plane can be considered as a part of the radiating element. It is observed from Fig. 8.c that at 13.5 GHz, the current concentration is stronger on the edges of the two lower steps of the radiating patch and also on the edges of the rectangular ground plane slot which confirms that the rectangular notch significantly affects the bandwidth. The surface current distribution around the fourth resonance frequency (17 GHz), is shown in Fig. 8.d. Here, most of the current is concentrated at the lowest steps and sleeves. From the current distribution at resonance frequencies, it can be deduced that the sleeves and rectangular slot on the ground plane, have the most influence on the antenna bandwidth.

A comparison of the performance of the proposed antenna and some of the recently published antennas is done in Table 1. According to the results, the antenna in this work has the same size in [1] and [3] but it covers 40% and 30% wider bandwidth, respectively. The proposed antenna in this paper occupies a smaller area than the antennas in [5] and the antennas in [7] to [10]. Although having a smaller size, it covers a larger frequency band which make it a very suitable choice to be used in communication systems. The antenna in [4] has a smaller size respect to the present work, but it has 47.6% narrower bandwidth than the antenna presented in this work.

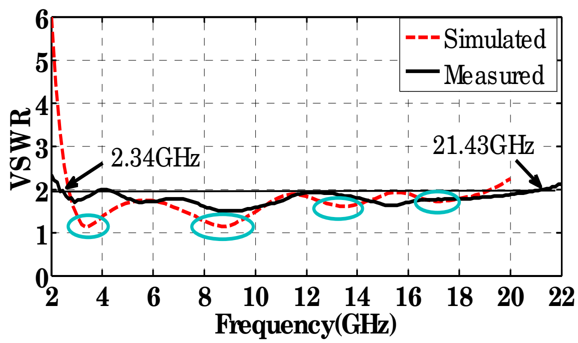


Fig. 7. Simulated and measured VSWR curves for the proposed antenna.

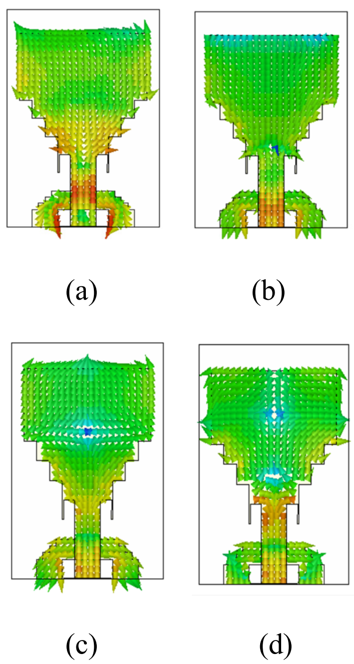


Fig. 8. Current distributions at (a)3.7 GHz, (b)8.7 GHz , (c) 13.5 GHz, (d) 17 GHz.

For the fabricated antenna, a low level group delay is obtained in the measurement process that is shown in Fig. 9, which makes the proposed antenna a suitable candidate for UWB applications.

Apart from the VSWR curves, the gain and radiation efficiency of the proposed antenna are measured and analyzed. The measured peak gain in dB is plotted in Fig. 10. A nearly constant gain is observed for the antenna over the operating frequency range. Gain values are between 1 and 2.3 dBi over the wide operating band of 2.34-21.43 GHz.

Table 1: Comparison of the performance of the proposed antenna and some of the recently published antennas

Ant.	Size	BW	Area Reduction	BW Increment
Ant in [1]	18×12×1.6	3.2-12.73	0	40%
Ant in [3]	18×12×1.6	2.91-14.1	0	30%
Ant in [4]	10×10×1.6	3-10.7	-53.7%	47.6%
Ant in [5]: circular	50×43×1.5	3.46-10.9	8%	56.4%
Ant in [5]: elliptical	42×42×1.5	2.6-10.22	86.9%	41%
Ant in [7]	22×22×1.6	2.7-20	55.37%	7.57%
Ant in [8]	29×26×1	2.91-12	54.1%	38%
Ant in [9]	30×30×1.6	2.9-18	76%	15%
Ant in [10]	24×22×1.6	3-11.2	59%	44.5%
Ant in this work	18×12×1.6	2.34-21.43	------	--------

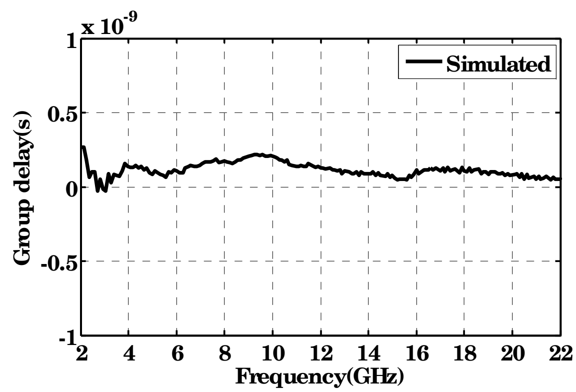


Fig. 9. Simulated group delay of the proposed antenna.

Simulated and measured radiation efficiency are plotted in Fig. 11. As it is seen a radiation efficiency of around 80% is obtained for the fabricated antenna.

Simulated and measured radiation patterns at H-plane (xz plane) and E plane (yz plane) are also plotted in Fig. 12. 3GHz, 8GHz, 11GHz, and 20 GHz are selected as sample frequencies over the operating frequency range. Good agreement is observed between the simulated and measured results. As it is expected an omnidirectional pattern is obtained on H-plane and two nulls are appeared in the radiation patterns of E-plane, which is suitable for UWB applications.

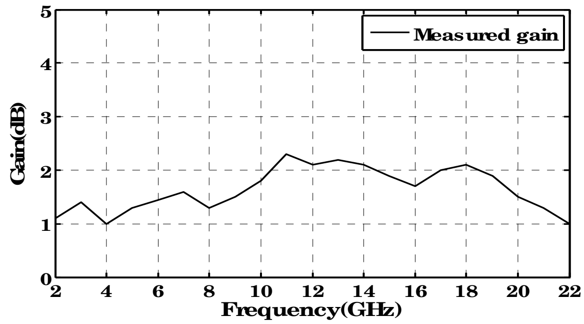


Fig. 10. Measured gain of the proposed antenna.

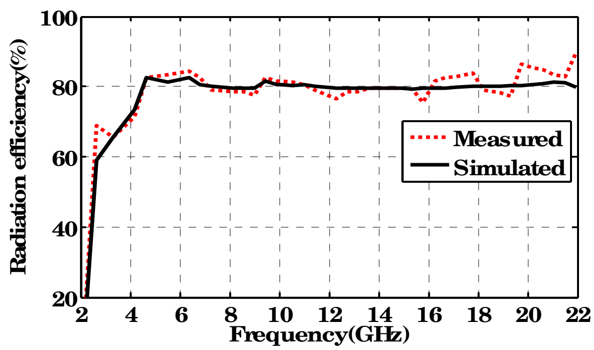


Fig. 11. Measured and simulated radiation efficiency for the proposed antenna.

IV. CONCLUSION

A novel microstrip-fed monopole antenna with modified structure is presented for UWB applications. The antenna is printed on a $18\times12\times1.6mm^3$ cheap FR4 substrate. The bandwidth of the antenna is stretched from 2.34 to 21.43GHz (160%). The novel ground plane shape along with the modified radiating patch makes this antenna distinctive from the other microstrip antennas. Characteristics such as compact size, low profile, low cost, good impedance matching, omnidirectional pattern, and wider bandwidth respect to the previously designed antennas, make this antenna a beneficial choice for UWB applications.

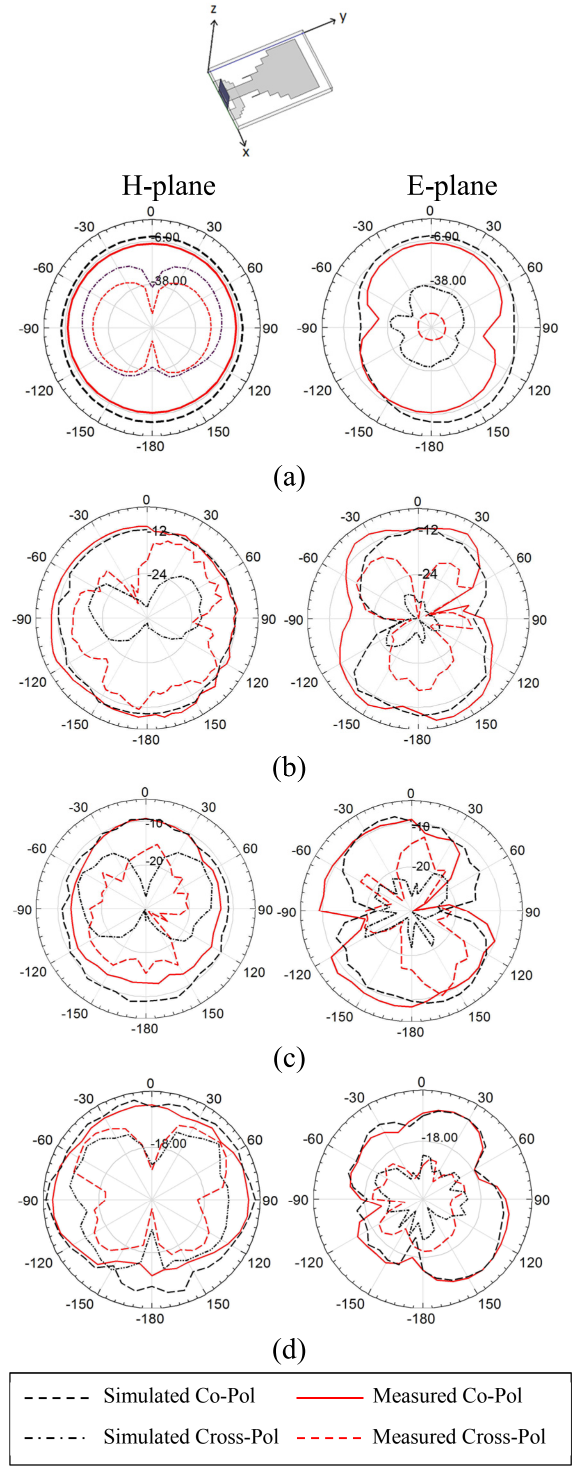


Fig. 12. Measured radiation patterns for the proposed antenna: (a) 3 GHz, (b) 8 GHz, (c) 11 GHz, (d) 20 GHz at H-plane (xz plane) and E-plane (yz plane).

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Maryam Majidzadeh was born on 18 September, 1987 in Urmia, Iran. She received her B.S. degree in Electrical Engineering from Urmia University, Iran in 2009 and is currently an M.Sc. student in Electrical Communication Engineering at the same university. Her research interests are in designing of UWB antenna, antenna miniaturization, and impedance bandwidth enhancement techniques.

Changiz Ghobadi was born on 1 June, 1960 in Iran. He received the B.S. degree in Electrical and Electronic Engineering and M.S. degree in Electrical and Telecommunication Engineering from Isfahan University of Technology, Isfahan, Iran and Ph.D. degree in Electrical-Telecommunication from University of Bath, Bath, UK in 1998. From 1998 he was an Assistant Professor and now is Associated Professor in the Department of Electrical Engineering, of Urmia University, Urmia, Iran. His primary research interests are in antenna design, radar and adaptive filters.