A Novel Design of Reconfigurable Monopole Antenna for UWB Applications

Nasser Ojaroudi [1], Shervin Amiri [2], and Fatemeh Geran [1]

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

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

Abstract ─ In this paper, a kind of reconfigurable monopole antenna with multi-resonance and switchable band-notched function is designed and manufactured whose frequency characteristics can be reconfigured electronically to have a single-band notch function in order to block interfering signals from 5.15 GHz - 5.35 GHz HiperLAN, 5 GHz - 6 GHz WLAN or 7.25 GHz - 7.75 GHz for downlink of X-band satellite communication systems. The proposed antenna consists of a square radiating patch, feed-line, and a ground plane with a Fork-shaped conductor-backed plane. By adding an inverted T-shaped and a pair of L-shaped parasitic structures in the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the higher band, which provides a wide usable fractional bandwidth of more than 135% (3.05 GHz-16.51 GHz). In order to generate reconfigurable band-stop performance, we use a pair of PIN diodes within the antenna configuration. By changing the ON/OFF conditions of the PIN diodes, the antenna can be used to generate a single notch band to isolate and block any interference in the UWB frequency range. The proposed antenna has a small dimension of $12 \times 18 \times 1.6$ mm^3.

Index Terms ─ Band-notched performance, conductor-backed plane, PIN diode, reconfigurable monopole antenna, and UWB wireless communication.

I. INTRODUCTION

An ultra-wideband (UWB) system requires small low-cost antenna with omni-directional radiation patterns and large bandwidth [1]. 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 and automatic design methods have been developed to achieve the optimum planar shape [2-3]. Moreover, other strategies to improve the impedance bandwidth have been investigated [4-6]. In [7] and [8], a coupled T-shaped strip in the bottom side of the FR-4 substrate acts as a conductor-backed plane, and it is created to enhance the gain of the monopole antenna at the lower and middle of the frequency band such that the gain of the proposed antenna over the complete bandwidth remains nearly constant.

The frequency range for UWB systems between 3.1 GHz – 10.6 GHz will cause interference to the existing wireless communication systems for example C-band (3.7 GHz – 4.2 GHz) systems or the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15 GHz – 5.35 GHz or 7.25 GHz – 7.75 GHz for downlink of X-band satellite communication systems, so the UWB antenna with a band-notched function is required. Lately, to generate the frequency band-notched function,

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modified several planar monopole antennas with band-notched characteristic have been reported [4-7]. In [4], [5] and [6], different shapes of the slots (i.e., square ring, W-shaped, and folded trapezoid) are used to obtain the desired band notched characteristics. Single and multiple [7] half-wavelength U-shaped to generate the frequency band-notch function, modified planar slits are embedded in the radiation patch to generate the single and multiple band-notched functions, respectively. In order to effectively and fully utilize the UWB spectrum and to improve the performance of the UWB system, it is desirable to design the UWB antenna with reconfigurable notch band [9-10]. It will help to minimize the interference between the systems and whenever there is no coexistence system, the structure of the antenna can be transformed in a way that leads to a whole coverage of UWB spectrum. In [9] for reconfigurable performance of rejection band, which is between 5 GHz to 6 GHz, RF MEMS is utilized while in [10] diodes are used for the same reason. That demands the use of 'smart' reconfigurable antennas capable of cancelling in-band interference. Hence, an UWB antenna with reconfigurable band-rejection characteristics at the WLAN or C-band satellite frequencies is highly desirable.

This paper focuses on a multi-resonance square monopole antenna with reconfigurable band-notched performance for UWB applications. In the proposed structure, multi-resonance characteristic is provided by using a pair of L-shaped and an inverted T-shaped conductor-backed plane. By implementing two PIN diodes across the parasitic structures and biasing these active elements, variable frequency band-notched function can be achieved. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest.

II. ANTENNA DESIGN

The 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 width W_f of the microstrip feed-line is fixed at 2 mm. The basic 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 W_f and length L_f, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane of width W_{sub} and length L_{gnd} is placed. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission.

To design a novel reconfigurable antenna, the modified fork-shaped conductor-backed plane is 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 [11].

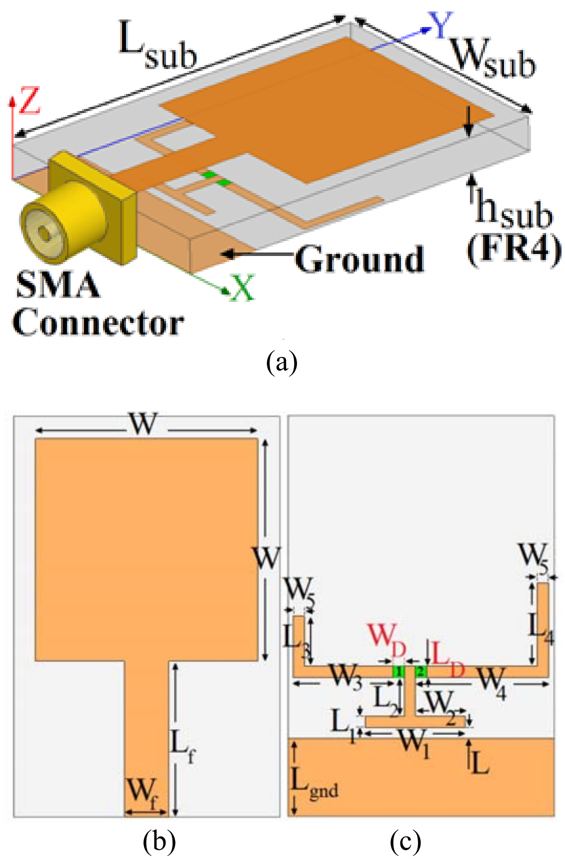


Fig. 1. Geometry of the proposed antenna; (a) side view, (b) square radiating patch, and (c) ground plane structure.

The modified T- and L-shaped parasitic structures are playing important roles in the broadband characteristics of this antenna, because these 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 [7-10]. This phenomenon occurs because, with the use of conductor-backed plane structures in air gap distance, additional couplings are introduced between the bottom edge of the square patch and the ground plane [2]. The final dimensions of the designed antenna are specified in Table 1.

Table 1: Final dimensions of the proposed antenna.

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	12	L_{Sub}	18	L_{gnd}	3.5
W	10	L	0.5	W_f	2
L_f	7	W_1	4.5	L_1	0.5
W_2	2	L_2	12	W_3	4.75
L_3	2.75	W_4	5.75	L_4	3.5
W_5	0.5	L_D	0.5	W_D	0.5

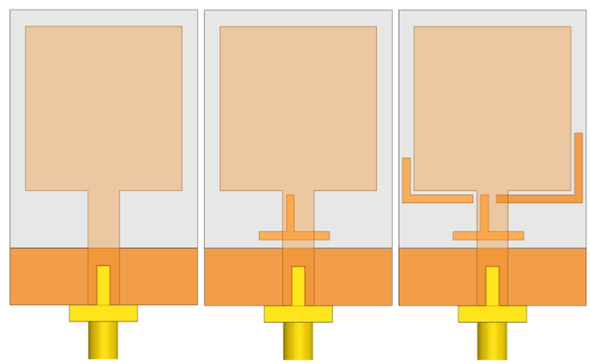
III. RESULTS AND DISCUSSIONS

In this section, the planar monopole antenna with various design parameters was 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) [12].

A. UWB monopole antenna with multi-resonance characteristic

Figure 2 shows the structure of the various antennas used for simulation studies. VSWR characteristics for ordinary square monopole antenna (Fig. 2 (a)), with an inverted T-shaped conductor-backed plane (Fig. 2 (b)), and with inverted T-shaped and a pair of L-shaped conductor-backed plane structures (Fig. 2 (c)) are compared in Fig. 3. As shown in Fig. 3, it is observed that by using these modified parasitic structures, additional third and fourth resonances are excited respectively, and hence the bandwidth is increased.

In the proposed antenna configuration, the ordinary square monopole can provide the fundamental and next higher resonant radiation band at 4 GHz and 8 GHz, respectively, in the absence of parasitic structures in the ground plane. The upper frequency bandwidth is significantly affected by using the inverted T-shaped conductor-backed plane in the ground plane. This behavior is mainly due to the change of surface current path by the dimensions of the inverted T-shaped structure as shown in Fig. 4 (a). In addition, by adding a pair of modified L-shaped conductor-backed plane on the other side of the substrate, the impedance bandwidth is effectively improved at the upper frequency [6]. The L-shaped structures can be regarded as a parasitic resonator electrically coupled to the square monopole.



(a) (b) (c)

Fig. 2. (a) Ordinary square antenna, (b) the square antenna with an inverted T-shaped parasitic structure, and (c) the square antenna with inverted T-shaped and a pair of L-shaped conductor-backed plane.

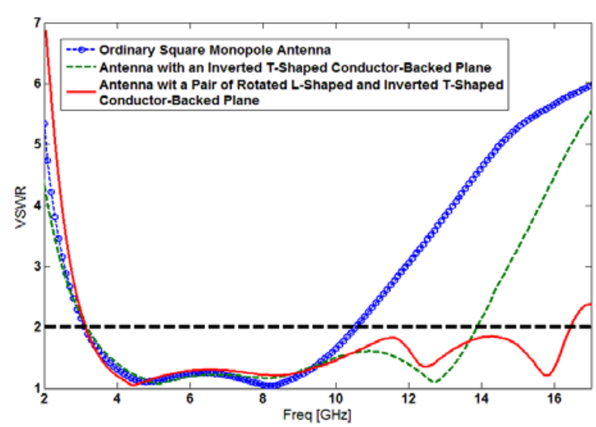
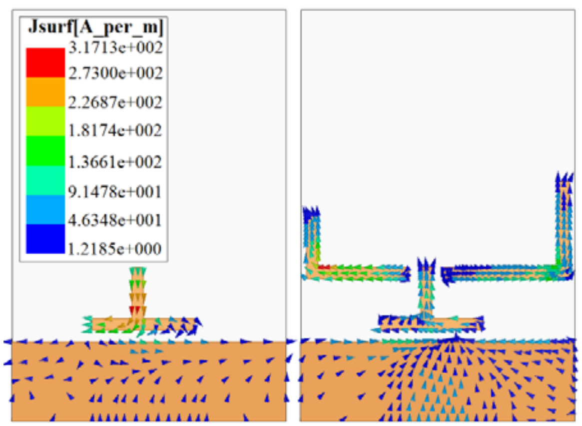


Fig. 3. Simulated VSWR characteristics for the antennas shown in Fig. 2.

As shown in Fig. 4 (b), the currents concentrated on the edges of the interior and exterior of the pair of L-shaped conductor-backed plane at fourth resonance frequency (14.3 GHz). This figure shows that the electrical current for the fourth resonance frequency (Fig. 4 (b)) does change the direction along the bottom edge of the square radiating patch. Therefore, the antenna impedance changes at this frequency, the radiating power and bandwidth will increases. Furthermore, the radiation efficiency will increase. However, the resonant resistance is decreased [9].



(a) (b)

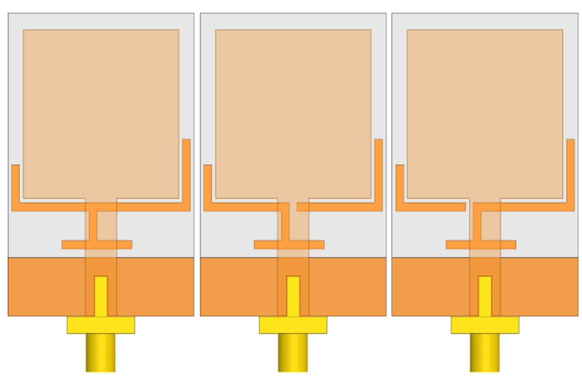
Fig. 4. Simulated surface current distribution in the ground plane for (a) the square antenna with inverted T-shaped conductor-backed plane at third resonance frequency (12.5 GHz) and (b) the proposed antenna at fourth resonance frequency (14.3 GHz).

B. UWB monopole antenna with reconfigurable band-notched performance

Geometry of the proposed reconfigurable monopole antenna for D_1 and D_2 = ON (Fig. 5 (a)), D_1 = ON and D_2 = OFF (Fig. 5 (b)), and D_1 = OFF and D_2 = ON (Fig. 5 (c)) were shown in Fig. 5. VSWR characteristics for the various reconfigurable structures of the proposed antenna were shown in Fig. 6. By implementing two PIN diodes across the parasitic structures and biasing these active elements, variable frequency band-notched function can be achieved.

For applying the DC voltage to PIN diodes, metal strips with dimensions of 1.5 mm × 0.6 mm were used inside the main slot. In the introduced design, HPND-4005 beam lead PIN diodes [13] with extremely low capacitance were used. For biasing PIN diodes a 0.7 volts supply is applied to metal strips. The PIN diodes exhibit an ohmic resistance of 4.6 Ω and capacitance of 0.017 pF in the ON and OFF states, respectively. By turning diodes ON, the metal protruded L-shaped strips are connected to the inverted T-shaped strip and become a part of it. The desired notched frequency band can be selected by varying the states of the PIN diodes, which changes the total equivalent length of the strip.

In order to understand the phenomenon behind switching electronically between band-notched function, the simulated current distributions on the ground plane for the proposed reconfigurable antenna at notched frequencies for ON and OFF statuses of the p-i-n diodes, are presented in Fig. 7. Figure 7 (a) presents the simulated current distributions on the ground plane for D_1 and D_2 = ON at the second notched frequency (5.5 GHz). As shown in Fig. 7 (a), at the notched frequency the current flows are more dominant around of the fork-shaped conductor-backed plane structure. It is found that by changing the ON/OFF conditions of the PIN diodes the antenna can be used to generate a single notch band to isolate and block any interference in the frequency bands.



(a) (b) (c)

Fig. 5. Configuration of the proposed square antenna, (a) D_1 and D_2 = ON, (b) D_1 = ON and D_2 = OFF, and (c) D_1 = OFF and D_2 = ON.

Figures 7 (b) and (c) show the simulated current distributions on the ground plane for D_1 = OFF and D_2 = ON and D_1 = ON and D_2 = OFF at the notched frequencies (5.25 GHz and 7.5 GHz).

As shown in Fig. 7 (b), at the first notched frequency (5.25 GHz), the current mainly concentrates on the left hand L-shaped strip, and also it can be seen that the electrical current does change its direction along the left hand L-shaped strip. Finally, the current mainly concentrates on the interior and exterior edges of the right hand L-shaped strip at the third notched frequency (7.5 GHz), as shown in Fig. 7 (c). It is found that by changing the conditions of the PIN diodes we can give a variable frequency band-notched function.

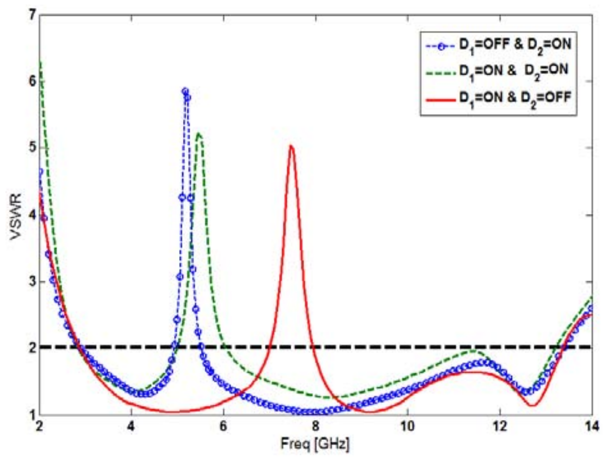
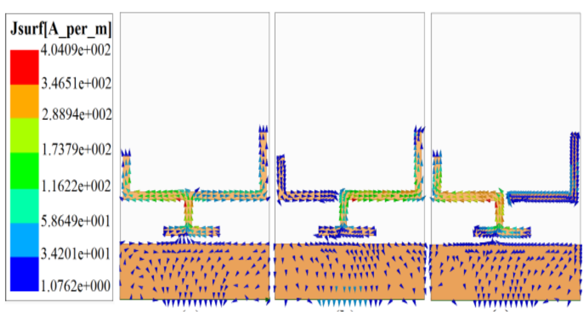


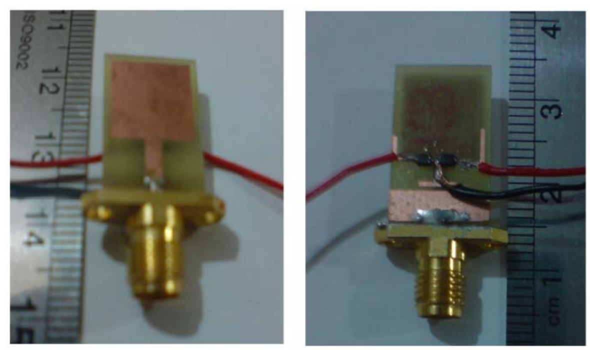
Fig. 6. Simulated VSWR characteristics for the proposed antenna with various structures shown in Fig. 5.



(a) (b) (c)

Fig. 7. Simulated surface current distribution in the ground plane for the proposed antenna (a) at 5.5 GHz (D_1 and D_4 = ON), (b) at 5.25 GHz (D_1 = ON and D_2 = OFF), and (c) 7.5 GHz (D_1 = OFF and D_2 = ON).

The proposed antenna with final design, as shown in Fig. 8 was built and tested. Measured VSWR characteristic of the proposed antenna with multi-resonance and reconfigurable band notched function was shown in Fig .9. The fabricated antenna has the frequency band of 3.05 GHz to 11.5 GHz with a bad-stop function around of 5 GHz - 6 GHz. However, as shown in Fig. 8, there exists a discrepancy between measured data and the simulated results. This discrepancy 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 the p-i-n diode and its biasing circuit. 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. Moreover, SMA soldering accuracy and FR4 substrate quality need to be taken into consideration.



(a) (b)

Fig 8. Photograph of the realized printed monopole antenna, (a) top view and (b) bottom view.

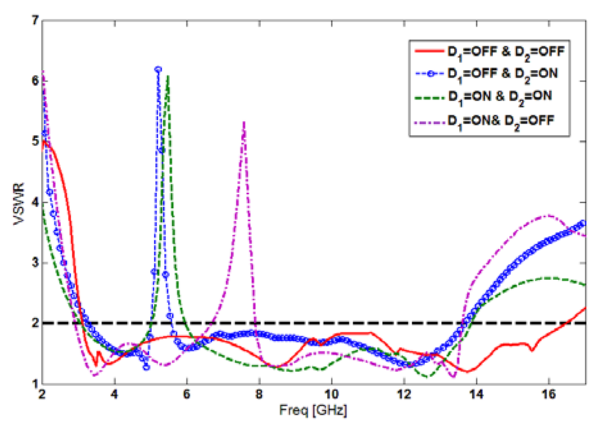


Fig. 9. Measured VSWR characteristics for the proposed antenna with reconfigurable function.

Figure 10 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 the *x-z* plane are nearly omni-directional for the four frequencies.

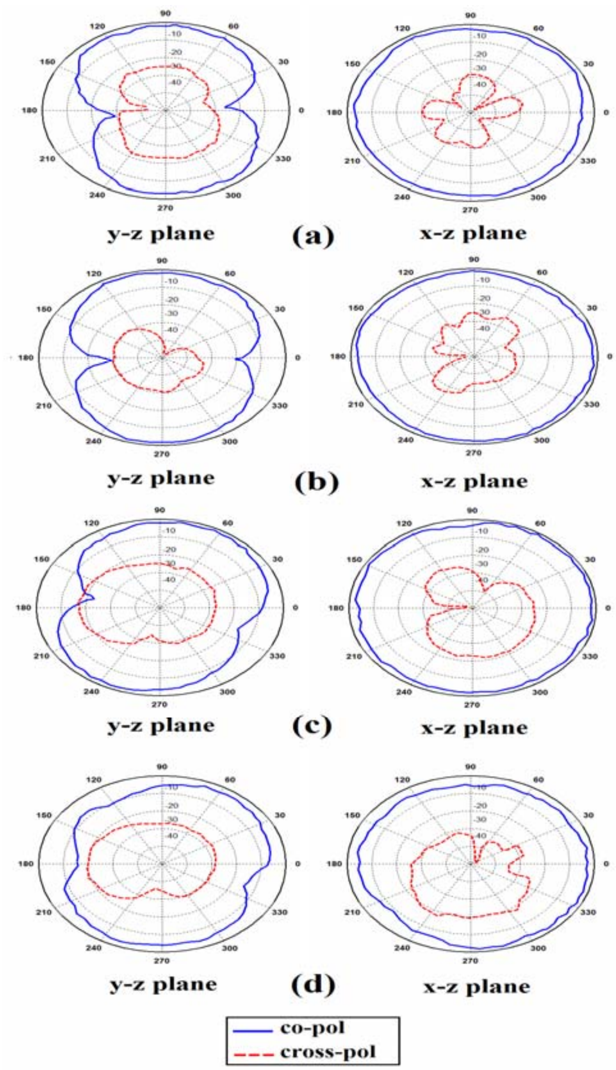


Fig. 10. Measured radiation patterns of the proposed antenna for D_1 and D_2 = OFF, (a) 4 GHz, (b) 7 GHz, (c) 11 GHz, and (d) 14.5 GHz.

IV. CONCLUSION

In this letter, a novel compact printed monopole antenna (PMA) with reconfigurable function has been proposed for UWB applications. In the proposed structure, multi-resonance characteristic is provided by using a pair of L-shaped and an inverted T-shaped conductor-backed plane. By implementing two PIN diodes across the parasitic structures and biasing these active elements, variable frequency band-notched function can be achieved. The fabricated antenna satisfies the 10 dB return loss requirement from 3.05 GHz to 16.51 GHz with variable band-notched function to block interfering signals from 5.15 GHz - 5.35 GHz HiperLAN, 5 GHz - 6 GHz WLAN or 7.25 GHz - 7.75 GHz for downlink of X-band satellite communication systems. The proposed antenna has a simple configuration and is easy to fabricate. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. Experimental results show that the proposed antenna could be a good candidate for UWB application.

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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. His research interests include ultra-wideband (UWB) microstrip antennas wireless communications, reconfigurable structures, and electromagnetic theory.

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.

Fatemeh Geran was born in Ghaemshar, Iran in 1977. She received her B.Sc. degree in Electrical Engineering (Telecommunication) from Tehran University, Tehran, Iran in 1999. Also, she received her M.Sc. and PHD degrees in Electrical Engineering (Telecommunication) from Tarbiat Modares University, Tehran, Iran, in 2003 and 2009, respectively. She is currently as an Assistant Professor in Electrical Engineering at Shahid Rajaee Teacher Training University, Tehran, Iran. Her research interest fields are antenna and RF subsystems in microwave and mm-wave Bands.