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Design and Implementation of An Aperture Coupled Microstrip IFF Antenna

Mahmood Niroo Jazi
Isfahan University of Technology (IUT)
Information and Communication Technology Institute
Isfahan 84156, IRAN
njazi@emt.inrs.ca

Gholamreza Askari
Isfahan University of Technology (IUT)
Information and Communication Technology Institute
Isfahan 84156, IRAN
askarigh@cc.iut.ac.ir

Hamidreza Eskandari
Isfahan University of Technology (IUT)
Information and Communication Technology Institute
Isfahan 84156, IRAN
hamid.r.eskandari@gmail.com

Hamid Mirmohammad-Sadeghi
Isfahan University of Technology (IUT)
Information and Communication Technology Institute
Isfahan 84156, IRAN
sadegi_m@cc.iut.ac.ir

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Abstract- **Design and implementation procedure of a wideband aperture coupled microstrip antenna in L-band frequency is introduced. To improve radiation performance of the microstrip antenna four structures are proposed. The measurement and simulation results show better performance in terms of matching bandwidth for the structure constructed with air substrate. Experimental results of frequency bandwidth and radiation patterns of the optimum structure are in agreement with the simulation results. The proposed patch antenna creates a directive radiation pattern with a gain of 8.5dB. In addition, it provides a quite large frequency bandwidth of greater than 25%, and F/B better than 15dB as well. This aperture coupled microstrip antenna has been used as an element of 8×1 microstrip array antenna for SSR systems. The array antenna gain, SLL and azimuth HPBW are: 17.5dB, less than 24dB and 10°, respectively.**

Keywords- Aperture Coupled Microstrip Antenna; Wide Frequency Bandwidth; Second Surveillance Radar (SSR)

چکیده- در این مقاله مراحل طراحی و پیاده سازی یک آنتن پچ با تغذیه روزنه ای با پهنای باند زیاد در باند L ارایه میگردد. برای بهبود کارایی آنتن پچ میکرواستریپ، چهار ساختار متفاوت پیشنهاد میشود. نتایج شبیه سازی و اندازه گیری نشان میدهد که آنتن با زیرلایه هوا دارای کارایی بهتری نسبت به سایر ساختارها از جهت پهنای باند میباشد. همچنین آنتن پیشنهادی قابلیت ایجاد یک پترن تشعشعی جهت دار با بهره ۸,۵ دسی بل را دارد. علاوه بر این، آنتن پیشنهادی دارای پهنای باند ۲۵ درصد بوده و نسبت میزان تشعشع به عقب برای این آنتن بهتر از ۱۵ دسی بل میباشد. این آنتن به عنوان المانهای یک آرایه ۸×۱ برای طراحی آنتن مورد نیاز در یک سیستم IFF در نظر گرفته شده است. نتایج بدست آمده نشان دهنده یک آنتن با قابلیت ایجاد پترنهای مجموع و تفاضل با بهره ۱۷,۵ دسی بل برای پترن مجموع، سطح لوبهای کناری کمتر از ۲۴ دسی بل و پهنای بیم در امتداد افقی حدود °۱۰ میباشد.

I. INTRODUCTION

Microstrip antennas (MA) are simple planar structures that have advantages such as low profile, conformal availability, simple fabrication using printed circuit technology, low cost and compatibility with integrated circuits. In spite of limitations such as small bandwidth, low gain and low power handling capability [1], MA is more preferable than other type of antennas due to their advantages and increasingly used in a variety applications such as military, industry and wireless communication [2]. Different techniques have been used to increase bandwidth such as using thick substrate [3]. This technique can improve antenna bandwidth up to 5 percent. Alternatively, aperture coupled stacked patch microstrip antenna can enhance the matching bandwidth more than 50 percent at the expense of increasing in back lobe radiation level. In order to reduce the back radiation, metallic rods or resonance planes are used in the rear of the antenna or appropriate cavities are designed next to the coupling aperture [5-8]. Aperture coupled microstrip antenna has been used for IFF (or Secondary Surveillance Radar) systems with 6 percent bandwidth of VSWR<1.5. However, Front to Back (F/B) ratio has been reported 10dB which is not enough for IFF application [9].

In this paper, both techniques have been applied to increase the bandwidth and decrease the back radiation. The design process of the proposed structure is organized as followed. First of all, an aperture coupled microstrip antenna will be designed according to the system requirements. Then, four structures will be introduced and compared to each other. After simulation, the best structure will be optimized and used in designing an 8×1 patch array which is adequate for SSR applications. Finally, the measurements and conclusion will be reported.

II. DESIGN AND SIMULATION

A. *Single Patch*

The structure of the aperture coupled microstrip antenna has been depicted in Figure 1. This antenna is designed to use as an element in the microstrip array antenna for SSR systems. The central frequency is 1060MHz and the bandwidth is at least 250MHz. Because of desired bandwidth, the thickness of h_3 is chosen 20mm. Patch antenna is etched on FR4 substrate and inversely stacked on the other layers benefiting FR4 substrate as a cover for patch antenna. FR4 substrate has a thickness of $h_4 = 1mm$ and $\varepsilon_{r4} = 4.3$. The feed substrate is RT/Duroid 5880 with thickness of $h_2 = 0.787mm$ and relative dielectric constant of 2.2.

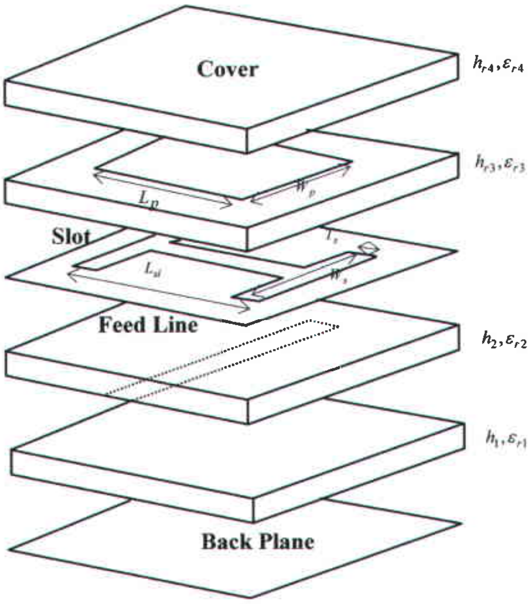

Figure 1. Aperture coupled microstrip antenna structure.

According to [1], the preliminary antenna dimensions are designed and calculated at the central frequency of 1060MHz. [4] recommends that aperture width W_s is the one half of its length L_{sl} and T_s is the one-tenth of L_{sl}. The length of the stub, L_{st} is $0.22\lambda_g$, in which λ_g is the wavelength in the feed substrate.

The antenna parameters such as patch dimensions, aperture length, length of stub, and the distance between feed line and back plane are optimized using software package based on full wave method until frequency bandwidth greater than 25% and Front to Back (F/B) ratio better than 20dB obtained at the center frequency of 1060MHz. Four different structures as shown in Figure 2 have been designed, simulated and compared to evaluate the structure with best performance.

Aperture has been designed to resonate near the resonance frequency of the patch. Aperture shape is very important to control the maximum coupling between the feed line, the patch and also the level of back radiation. A metallic plane is placed behind of the antenna to reduce back radiation power to -20dB. Actually, this plane acts as a resonator and generates appropriate current distribution to eliminate undesired radiation fields in the rear of the antenna. The distance between the back plane and the feed line influences on the amplitude of the current distribution but the phase of the current distribution is controlled by the size of the back plane.

(a) Air substrate

(b) Foam substrate

(c) Foam-Teflon substrate

(d) Teflon-Foam substrate

Figure 2. Four different structures of aperture coupled microstrip antenna.

The four structures have been simulated and optimized by IE3D software. The graph of their return losses has been depicted in Figure 3. According to Figure 2, structure (a) has the maximum bandwidth. The simulation results indicate that the smallest bandwidth will be achieved when Teflon dielectric is directly beneath the patch. In addition, the frequency center of structure (d) is lower than other structures. The simulation results have been summarized in Table 1 in which f_u and f_l are the low and high frequency corresponding to -10dB return loss, respectively.

E- and H-plane radiation patterns at 1030MHz and 1090MHz have been represented for structure (a) in Figures 4 and 5, respectively. The Front to Back ratio is greater than 20dB. E- and H-plane Half Power Beam Width (HPBW) at 1030 MHz are 65° and 75°, respectively. At 1090 MHz, E-plane HPBW is 63° and H-plane HPBW is 74°. Figure 6 shows simulated results for gain of four structures. The gain difference between 1030MHz and 1090MHz is less than 0.5dB for four structures. For example, the gain of structure (a) at 1030 MHz and 1090MHz is 8.5dB and 8.8dB, respectively.

Achieved results for four structures show that structure (a) i.e. the antenna with air substrate has the best performance. Consequently, this structure is selected to be fabricated and measured its radiation parameters.

TABLE I. SIMULATION RESULTS OF FOUR DIFFERENT STRUCTURES AS SHOWN IN FIGURE 2.

Structure	Central Frequency (MHz) $(f_u + f_l)/2$	Bandwidth (MHz) $f_u - f_l$
(a)	1038	279
(b)	1030	260
(c)	1018	224
(d)	1000	195

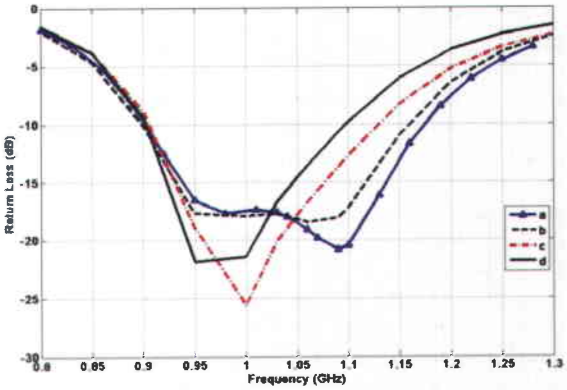

Figure 2 Return losses of four structures simulated by IE3D.

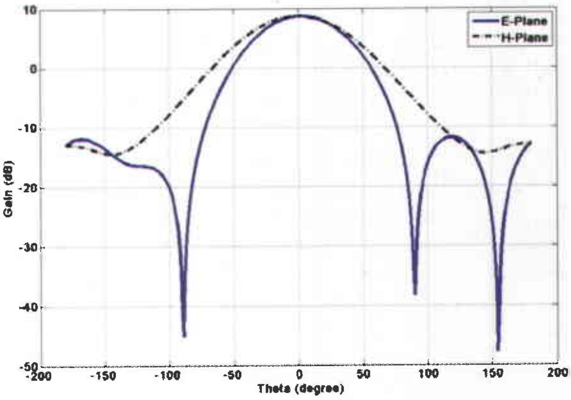

Figure 3. E- and H-plane radiation patterns at 1030MHz simulated by IE3D.

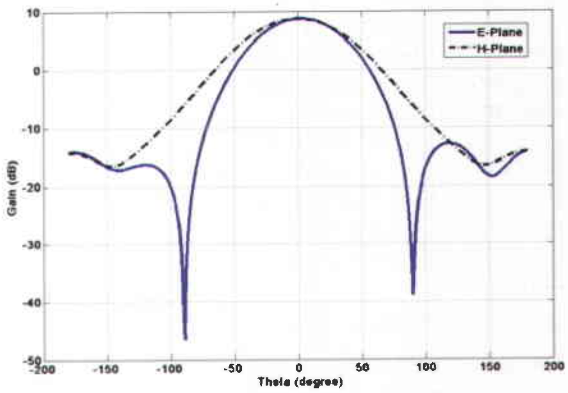

Figure 4. E- and H-plane radiation patterns at 1090MHz simulated by IE3D.

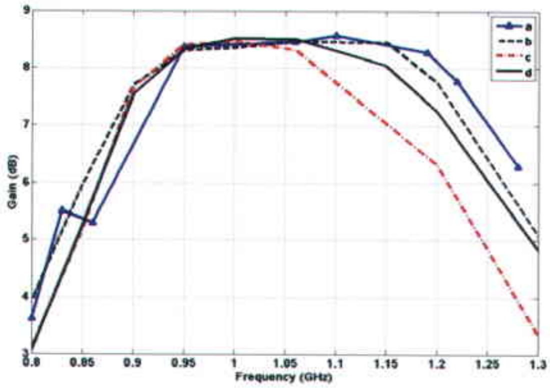

Figure 5. Comparison the gain of four different structures simulated by IE3D.

B. *Array antenna*

The optimized structure is used as the element of an 8×1 array antenna for SSR applications. The specifications of a currently used SSR antenna, AA75 model is presented in Table 2.

SSR transmitter systems interrogate with transponder of the targets at the frequency of 1030MHz and receive their responses at the frequency of 1090MHz. For monopulse operation, the antenna requires to simultaneously produce sum and difference patterns. Therefore, a specific feed configuration is demanded to provide this requirement along with precisely amplitude/phase excitation for each antenna element. A feed network based on the T-junction power dividers has been designed to provide the required amplitude distribution for each antenna displaced 235mm from each other. In order to realize monopulse requirement, a rat-race power divider/combiner utilized to achieve sum/difference radiation pattern.

In order to assess the mutual coupling between eight elements, antenna array has been simulated with the aid of FEKO software without considering the effect of feed network. Each element is excited using an ideal Chebycheff distribution to achieve low side lobe level (SLL) radiation pattern of 28dB. As depicted in Figure 7, coupling between all antenna elements are lower than -20 dB even for the elements in the middle of the array which are excited with larger power amplitude compared to the other neighbor elements. Therefore, feed network are designed for load impedance of 50 Ω at each port without considering mutual coupling effect. Figure 8 shows the overall view of the proposed feed configuration. The simulated power distribution of the proposed feed network has been depicted in Figure 9.

Scattering parameter of proposed patch antenna simulated by HFSS simulator has been applied as a load in the feed network to evaluate the matching of the antenna array. As it can be observed in Figure 10, the proposed structure introduce a good matching over the desired frequency bandwidth for both sum and difference ports.

Radiation pattern of the 8×1 array structure is obtained by FEKO for the distribution provided by the desinged feed network. Figure 11 shows the simulated radiation pattern of the array antenna in sum mode in which antenna elements have been excited in two different cases of using designed feed network and an ideal 28dB SLL Chebycheff distrubution. A summary of the antenna performances have been documented in Table 2 which shows a good agreement to the orginal antenna of AA75.

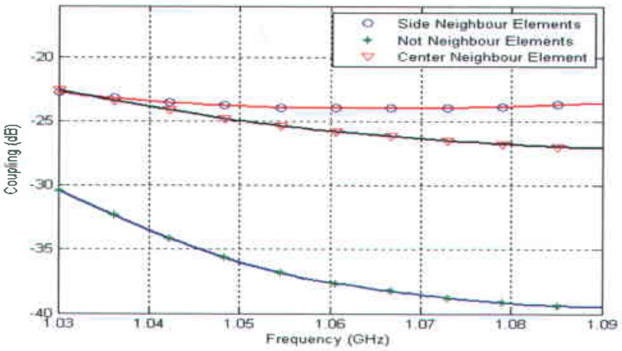

Figure 6. Coupling between center and side elements in an 8×1 array.

Figure 7. Overall view of feed structure.

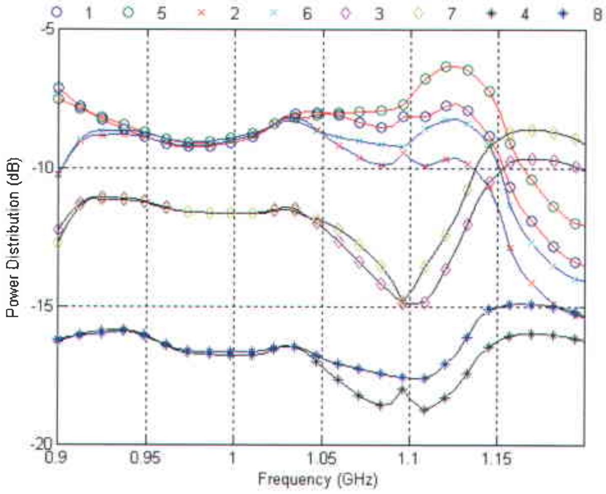

Figure 8. Sum mode element powers.

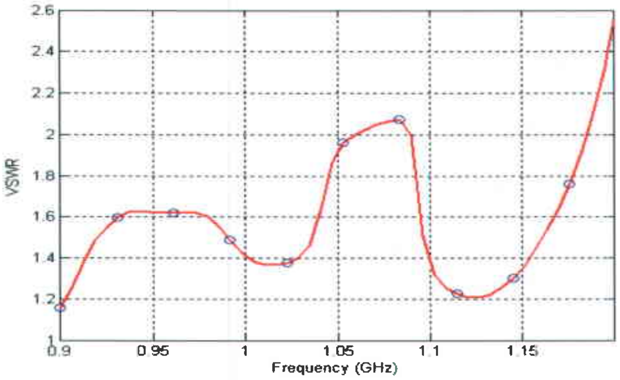

Figure 9. VSWR of sum and difference ports.

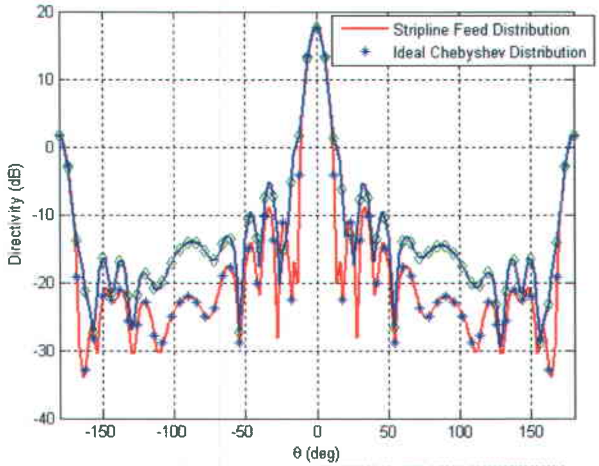

Figure 10. Sum pattern at 1030MHz for two simulations.

TABLE II. OVERALL VIEW OF FEED STRUCTURE.

Structure	AA75	Ideal distribution	Feed+ Antenna
Azimuth HPBW (deg)	11	10.0	9.6
Elev. HPBW (deg)	47	57	58
SLL (dB)	-24	-26.6	-23
Gain (dB)	16	17.7	17.7
VSWR	1.6:1	—	2.1:1
F/B (dB)	-26	-20	-20

III. MEASUREMENT

Fig. 12 shows photo of the fabricated aperture coupled microstrip antenna. Return loss of the antenna has been measured and compared with simulation result in Fig. 13. A little frequency difference between two curves is observed because of simulation accuracy, simulation settings and measurement accuracy and fabrication tolerance.

Figure 14 and 15 show co- and cross-polarization radiation patterns at 1030MHz and 1090MHz. F/B of E- and H-plane radiation patterns are greater than 15dB and 12dB at 1030MHz, respectively. As it can be noticed in these results, F/B of E-plane radiation pattern is better than 20dB but that of H-plane radiation pattern is greater than 15dB. The preceding difference is due to the low accurate measurement of anechoic chamber for this frequency bandwidth. The gain difference of both planes is less than 0.5dB. This antenna has better performance in terms of bandwidth and F/B than the antenna reported in [9].

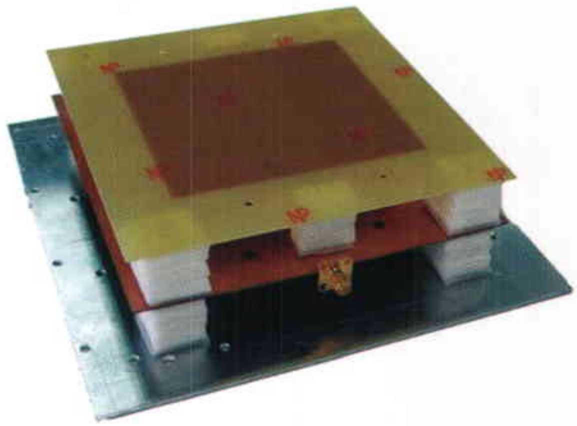

Figure 11. The photo of the fabricated aperture coupled microstrip antenna with air substrate.

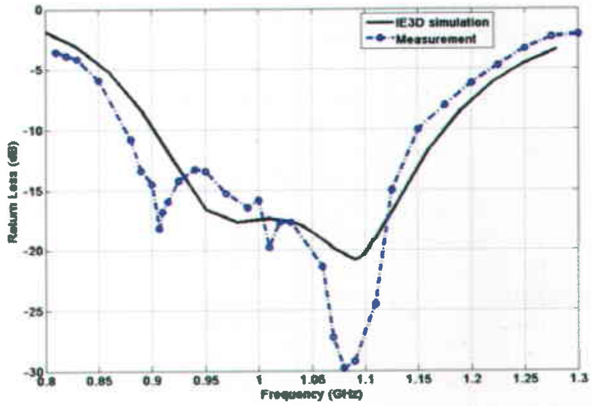

Figure 12. Simulation and measurement results of return loss of the antenna.

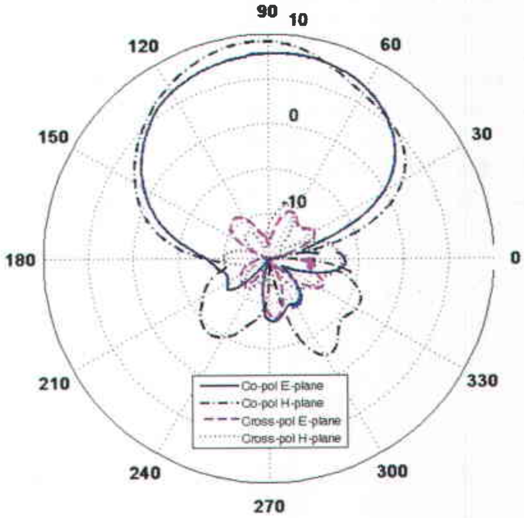

Figure 13. Measurement of co- and cross-polarization radiation patterns at 1030MHz.

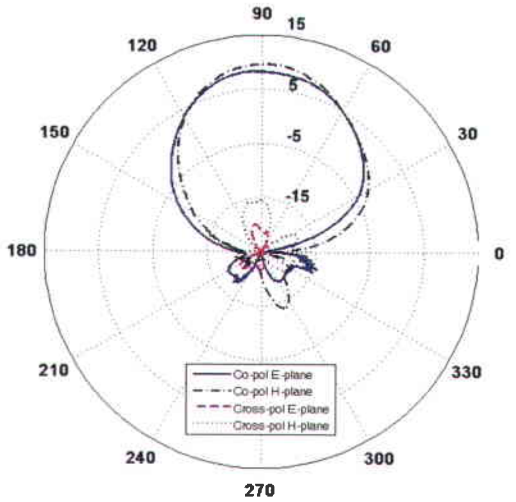

Figure 14. Measurement of co- and cross-polarization radiation patterns at 1090MHz.

IV. CONCLUSION

In this paper, four different structures of aperture coupled microstrip antenna have been considered to achieve the maximum bandwidth with good radiation performance in this bandwidth. The air substrate antenna was selected and optimized by IE3D simulator. The simulation and measurement results are in good agreement with each other. The antenna has the gain of 8.5dB, the bandwidth of greater than 25%, and F/B better than 15dB. This aperture coupled microstrip antenna was used as an element for designing microstrip array antennas in SSR systems. This array antenna has remarkable results compared with commercial SSR antennas. Optimization of antenna feed and implementation of whole antenna are under development and will be presented in future works.

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M. Niroo Jazi was born in Isfahan, Iran, in 1977. He received the B. Sc. degree from Azad University of Najafabad, and M. S degree from Urmia University, Urmia, Iran both in electrical engineering in 2000 and 2004, respectively.

He joined to the Information Communication Institute & Technology (ICTI) as a research engineer since April 2004 to May 2007. He was involved in the Antenna & RF/Microwave research group to develop and implement some practical projects in communication systems.

He is currently working toward the PhD degree at the University of Quebec, INRS-EMT, Montreal, Canada.

His research interests are in the area of antennas & microwave, numerical methods in electromagnetic and radar systems. He is currently working on DR antennas, UWB antennas, and particularly on periodic structures & artificial materials in the application of reconfigurable antennas.

Gholamreza Askari was born in Iran in 1971. He received his B.Sc. and M.Sc. degrees in communication and electronic engineering from Isfahan University of Technology (IUT) in 1994 and 1997, Isfahan, Iran.He was senior researcher in Information and Communication Technology Institute (ICTI) and from 1997, he joined Isfahan University of Technology as a faculty member. He has been technical assistant in communication group of ICTI since 1998. His research activities are in Communications, RF and Microwave Circuits and Systems.

Hamidreza Eskandari was born in Shahrood, Iran, in 1981. He received the B. Sc. degree from Isfahan University of Technology, and M. S degree from Science and Technology University, Tehran, Iran, both in electrical engineering in 2003 and 2006 respectively. He joined to the Information and Communication Institute & Technology (ICTI) as a research engineer since September 2006 to December 2008. He was involved in Antenna & RF/Microwave research group to develop and implement some practical projects in communication systems.

H. Mirmohammad-Sadeghi was born in Iran in 1964. He received the B.Sc. degree in electrical engineering from Isfahan University of Technology (IUT), Isfahan, Iran in 1987, and also the M.Sc in communication engineering in 1991. He was a Graduate Teaching Assistant in Dept. of Elec. & Comp. Eng. of IUT from 1987-1990, Research Engineer in Information and Communication Technology Institute (ICTI) of IUT from 1987-1992, and Lecturer of Comp. Dept. of Sharif University of Technology from 1992-1994. In 1994, he joined to Isfahan University of Technology as a faculty member. Mr. Mirmohammad-Sadeghi was the General Director of Information and Communication Technology Institute from 1994 to 2006. He has been the Director of Communications Group of ICTI since 2004. His current research interests deal with Radar Technology, Communication Circuits & Systems Design, and Robotics. Mr. Mirmohammad-Sadeghi has been the recipient of numerous awards. His team was the 3rd place winner of Rescue Robot League, Robocup 2003 in Italy. Also, he was honored the 2nd award of 16th International Kwarizmi Award 2003, Iran.