Compact Triple-Band S-Shaped Monopole Diversity Antenna for MIMO Applications

Jalil Mazloum [1], Seyed Ali Ghorashi [2], Mohammad Ojaroudi [3], and Nasser Ojaroudi [3]

[1] Electrical Engineering Department
Shahid Sattari Aeronautical University of Science and Technology, Tehran, Iran
jalil9898@yahoo.com

[2] Cognitive Telecommunication Research Group, Faculty of Electrical & Computer Engineering
Shahid Beheshti University, G. C., 1983693113, Tehran, Iran
a_ghorashi@sbu.ac.ir

[3] Young Researchers and Elite Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir, n.ojaroudi@yahoo.com

Abstract **─** In this paper, a novel WLAN frequency range monopole antenna is designed and manufactured for MIMO applications. The proposed antenna consists of two L-shaped slots in the S-shaped radiating patch. In this structure, the S-shaped monopole antenna can create dual resonances within the WLAN frequency range. The placement of two L-shaped slots within the S-shaped monopole antenna creates an extra resonance and the desired resonant frequencies are obtained by adjusting the dimension of the S-shaped monopole and the L-shaped slots. The operating frequencies of the proposed antenna are 2.4/5.2/5.8 GHz, which covers WLAN systems. Also, the two elements array configuration of this S-shaped monopole antenna which can be used in MIMO with a very high isolation over three operational bands is studied. The prototypes of the proposed antenna have been constructed and studied experimentally. Good diversity performance, return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of this small proposed antenna structure for MIMO applications.

Index Terms **─** Diversity antenna, Multi-Output Multi-Input (MIMO) applications, triple-band S-shaped monopole.

I. INTRODUCTION

In wireless systems, signals may combine destructively at a receiver, causing fading to occur. With the rapid growth of wireless communication, it is important to attain sufficient channel capacity and combat multi-path fading and co-channel interferences [1]. In order to improve the quality of wireless downlink signal, more than one antenna is necessary for the terminal side. In this kind of mobile terminal, two or more antenna elements are envisaged and the restricted space available for antenna is an open issue [2]-[3]. Antenna diversity is a well-known technique to enhance the performance of wireless communication systems by reducing the short term fading and co-channel interference effects of the channel [1]. The reliability of the system can be improved with the use of diversity technology, which is achieved by using the information from the different branches available to the receiver so as to increase the signal-to-noise ratio (SNR) at the decoding stage.

In the last few years, there have been rapid developments in wireless local area networks (WLAN). The 2.4/5.2/5.8 GHz (2.4-2.84 GHz/5.15-5.35 GHz/ 5.725-5.825 GHz) bands are demanded in practical WLAN applications. During the last years, there are various antenna designs, which enable antennas with low-profile, lightweight, flush mounted and WLAN devices. These antennas include the planar inverted-F antennas [4], and the slot antennas [5]. Planar monopoles are extremely attractive to be used in WLAN applications, and growing research activities are being focused on them in MIMO application systems, because of its advantages, such as simple structure, small size and low cost. Consequently, a number of planar monopoles with different geometries have been experimentally characterized [6]-[9].

In this paper, we propose a printed omni-directional antenna using S-shaped radiating patch. An S-shaped radiating patch with a pair of L-shaped slots which are printed on a dielectric substrate to generate triple-band operation at 2.4, 5.2, and 5.8 GHz is reported. This

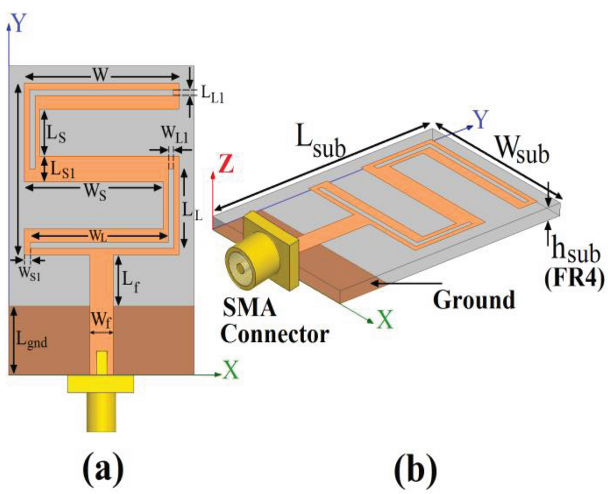
Submitted On: May 13, 2013
Accepted On: May 25, 2015

structure is suitable particularly for WLAN applications. Two-element arrays of such antennas for MIMO applications are analyzed and the results of the pair that provides the lowest mutual coupling and better omni-directional radiation pattern are given. The proposed structure is designed based on the antenna presented in [10], but with a lower mutual coupling and higher isolation. In this paper we present a structure for the MIMO antenna elements, in which the identical two antenna elements are orthogonally placed. Then the two antenna elements have orthogonal polarization which can reduce the mutual coupling between the two antennas. The proposed antenna shows advantages of small size, low cost and good omni-directional radiation characteristics. The presented monopole antenna has a small size of 12×18 mm².

II. ANTENNA DESIGN

The presented small monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on an FR4 substrate of thickness 0.8 mm, permittivity 4.4, and loss tangent 0.018. The basic monopole antenna structure consists of a square patch, a feed line, 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+L_{gnd}. 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.

In this study, two L-shaped slots in the S-shaped radiating patch is used to perturb an additional resonance at higher frequencies of WLAN frequency range. In other words, in this structure two L-shaped slots are playing an important role in the triple-band characteristics of this antenna. The final dimensions of the designed antenna are specified in Table 1.



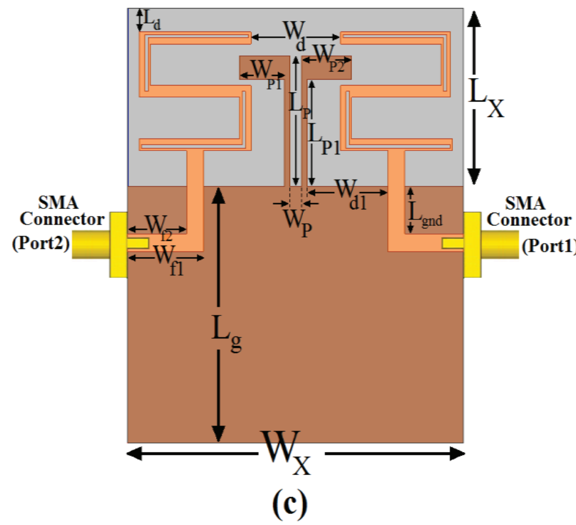


Fig. 1. Geometry of the proposed S-shaped monopole antenna with a pair of L-shaped slots on the radiating patch: (a) top view, (b) side view, and (c) geometry of the proposed diversity antenna.

Table 1: The final dimensions of the designed antenna

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	12	L_{Sub}	18	W_f	1.5
L_f	3	W	10	L_{gnd}	4
W_S	9.25	L_S	3.5	W_{S1}	0.25
L_{S1}	1	W_L	9.5	L_L	4.75
W_{L1}	0.25	L_{L1}	0.25	L_X	15
W_X	30	L_g	25	W_d	8
L_d	2	W_{d1}	7	L_P	11
W_P	1	W_{P1}	4	L_{P1}	9
W_{P2}	4.5	W_{f1}	7	W_{f2}	5

III. RESULTS AND DISCUSSIONS

A. Monopole antenna for WLAN applications

The proposed microstrip monopole antenna with various design parameters as 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. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement is obtained [11].

Return loss characteristics for ordinary square patch antenna with a rectangular slit (Fig. 2 (a)), S-shaped monopole antenna (Fig. 2 (b)), and the proposed antenna (Fig. 2 (c)) are compared in Fig. 3. As shown in Fig. 3, in order to generate dual-band characteristics (2.4/5.2 GHz), we use S-shaped radiating patch. By adding two

L-shaped slots in the S-shaped radiating patch, a triple-band is achieved that covers all the 2.4/5.2/5.8 GHz WLAN.

In order to understand the phenomenon behind this additional resonance performance, the simulated current distributions on the radiating patch for the ordinary square antenna with a rectangular slit and the S-shaped radiating patch at 2.4 GHz and 5.2 GHz are presented in Figs. 4 (a) and (b), respectively. It is found that by using this S-shaped radiating patch, the second resonance at 5.2 GHz can be achieved. Other important design parameters of this structure are L-shaped slots on the S-shaped radiating patch. Figures 5 (a) and (b) present the simulated current distributions on the radiating patch of the proposed antenna at the second resonance (5.2 GHz), and the third resonance (5.8 GHz), respectively. As shown in Figs. 5 (a) and (b), at the second and third resonances, the current flows are more dominant around of the L-shaped slots [12].

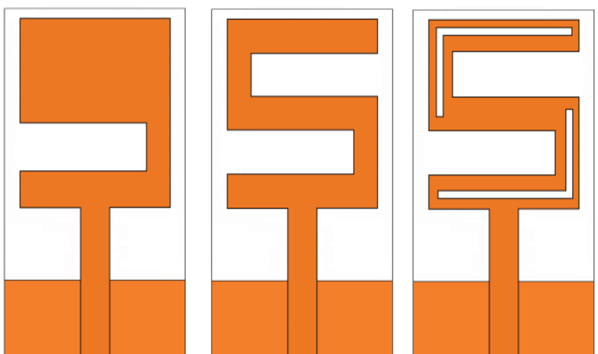


Fig. 2. (a) Ordinary square monopole antenna with a rectangular slit, (b) ordinary S-shaped monopole antenna, and (c) the proposed antenna.

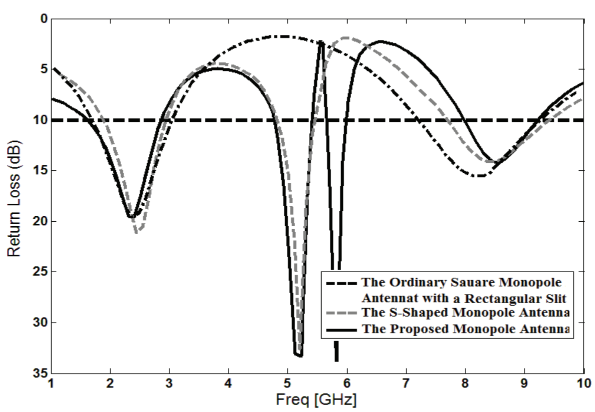


Fig. 3. Simulated return loss characteristics for the various square monopole antenna structures shown in Fig. 2.

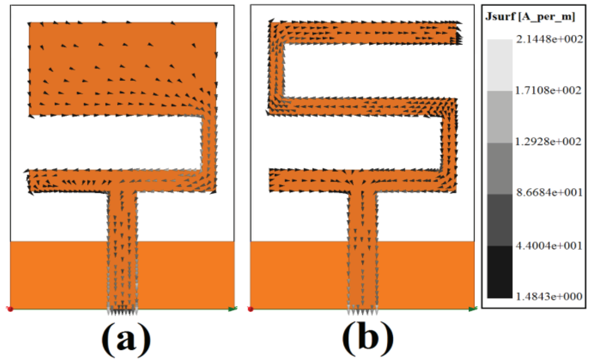


Fig. 4. Simulated surface current distributions on radiating patch for the proposed antenna without L-shaped slots: (a) at the first resonance frequency (2.4 GHz), (b) at the second resonance (5.2 GHz).

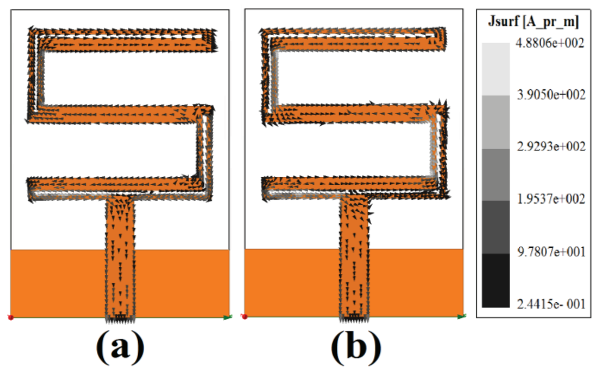


Fig. 5. Simulated surface current distributions on radiating patch for the proposed antenna: (a) at second resonance frequency (5.2 GHz), (b) at third resonance frequency (5.8 GHz).

B. Monopole antenna array structures for MIMO applications

This antenna element can be arrayed for MIMO applications. The performance of an antenna array suitable for MIMO applications is based on various parameters such as mutual coupling, and radiation pattern. As shown in Fig. 1 (c), two such monopole antennas can be arranged back to back with symmetric configuration and is printed on a printed circuit board (PCB). As shown in Fig. 1 (c), in order to increase the isolation and reduce the mutual coupling between the two monopoles, the L-shaped sleeves are introduced in the ground plane of this design. These sleeves on ground plane act as parasitic elements which help to adjust the resonant frequency and improve bandwidth [4]. Each antenna is directly fed by a 50 Ω microstrip line with 1.5 mm in width.

The antenna configuration with detailed dimensions and the effects of some important parameters of the proposed antenna have been fabricated as shown in Fig. 6, and discussed to show how this diversity antenna works. The measured and simulated return loss and mutual coupling characteristic of the proposed antenna were shown in Figs. 7 and 8, respectively. The operating frequencies of the proposed antenna are 2.4/5.2/5.8 GHz, which covers WLAN system. Figure 8, in which the antenna elements are orthogonal, show lower mutual coupling than those structures in which the elements are parallel. For such orthogonal elements, the pattern of each element lies on a plane. As shown in Figs. 7 and 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 SMA. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully, besides, SMA soldering accuracy and FR4 substrate quality needs to be taken into consideration [13].

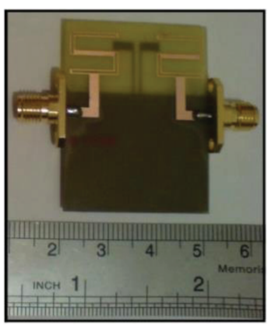


Fig. 6. Photograph of the realized diversity antenna.

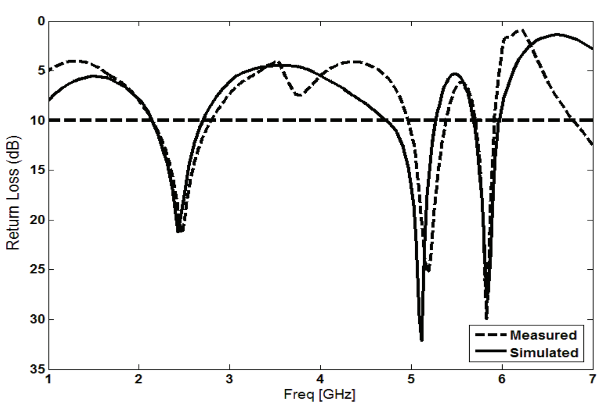


Fig. 7. Measured and simulated return loss of the MIMO configured proposed antenna for arrangement of two elements beside.

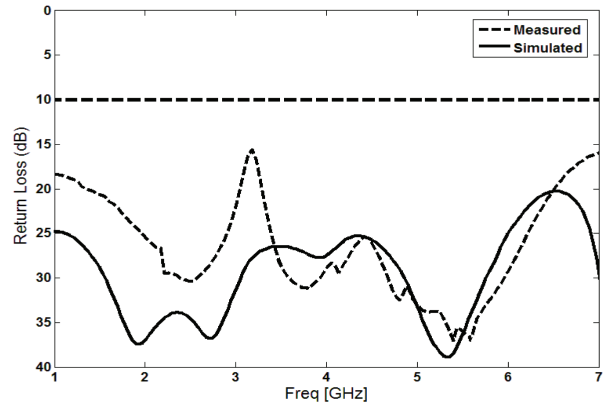


Fig. 8. Measured and simulated insertion loss (mutual coupling) of the MIMO configured proposed antenna for arrangement of two elements beside.

Figures 9, 10 and 11 illustrate the measured radiation patterns at resonance frequencies, including the co-polarization and cross-polarization, in the H-plane (x-z plane) and E-plane (y-z plane) of the two antenna elements. It can be seen that the two antenna elements have orthogonal polarizations, and also the radiation patterns in *x-z* plane are nearly omni-directional for the three frequencies.

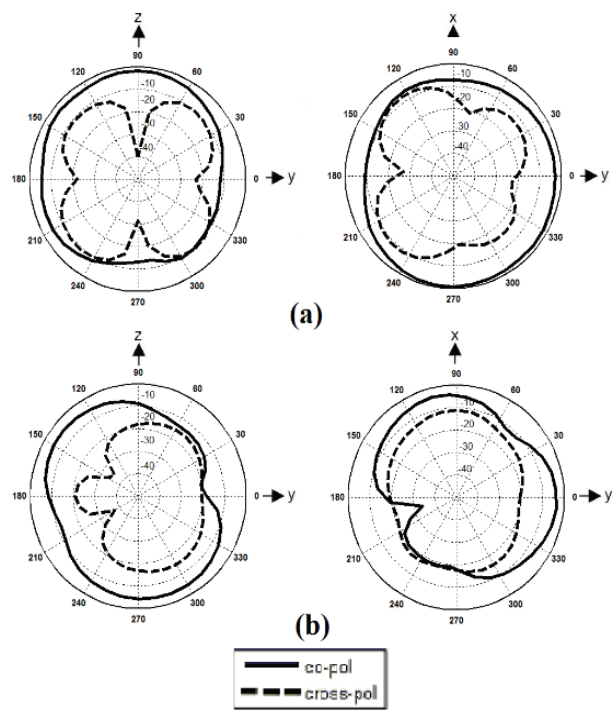


Fig. 9. Measured radiation patterns for monopole 1 (left) and monopole 2 (right) excitations at 2.4 GHz (first resonance frequency).

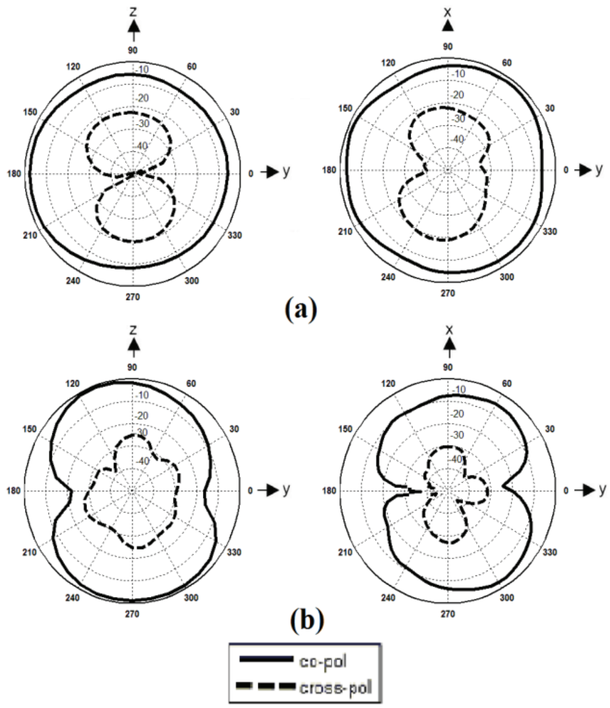


Fig. 10. Measured radiation patterns for monopole 1 (left) and monopole 2 (right) excitations at 5.2 GHz (second resonance frequency).

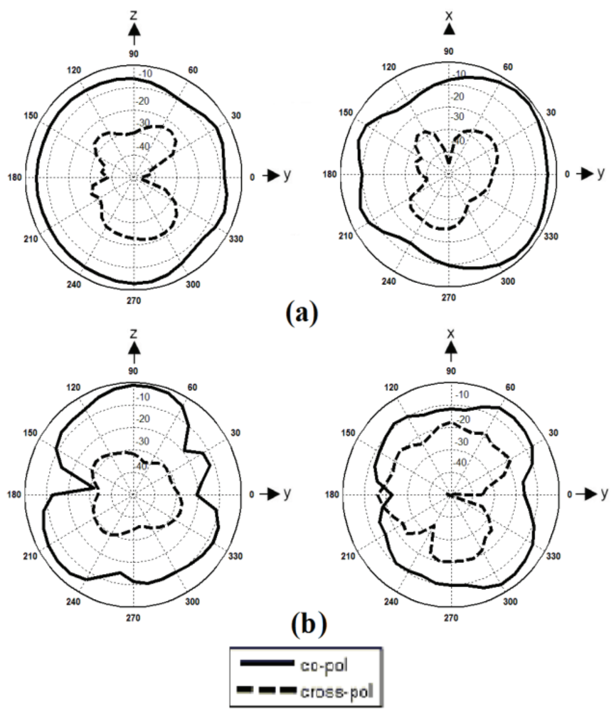


Fig. 11. Measured radiation patterns for monopole 1 (left) and monopole 2 (right) excitations at 5.8 GHz (third resonance frequency).

The envelope correlation can be computed from the S-parameters using the following formula [14]:

$$\rho_e = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^2}{\left(1 - \left|S_{11}\right|^2 - \left|S_{12}\right|^2\right)\left(1 - \left|S_{22}\right|^2 - \left|S_{21}\right|^2\right)}.$$

Figure 12 shows the simulated envelope correlation of the array structure of Fig. 1 (c). For the antenna diversity, the practically acceptable envelope correlation is less than 0.5. The calculated envelope correlation of the proposed antenna array structure of Fig. 1 (c) can be shown to be less than 0.002. The evaluation of results shows that the antenna is a good candidate for diversity system for MIMO application.

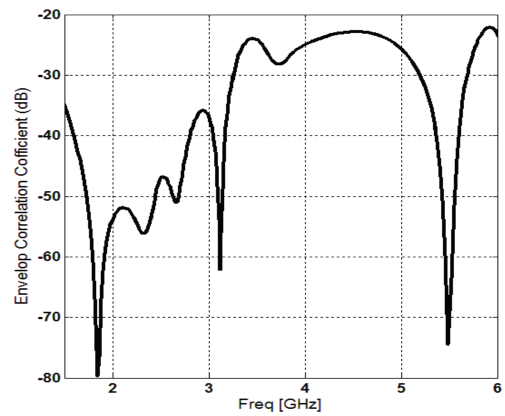


Fig. 12. Simulated envelope correlation coefficient against frequency using HFSS.

IV. CONCLUSION

A new triple-band diversity small printed monopole antenna (PMA) with triple-band performance for WLAN applications, presented in this paper. The operating frequencies of the proposed antenna are 2.4/5.2/5.8 GHz which covers WLAN system. In order to generate a triple-band performance, we insert two L-shaped slots in the S-shaped radiating patch. Also two-element arrays of such antennas in MIMO applications are analyzed. To evaluate the diversity performance, the envelope correlation coefficient of the antenna elements from measured results is calculated. It is proved that the proposed antenna can provide pattern diversity to mitigate multi-path fading problem for WLAN operations. The designed antenna has a small size of 12×18 mm^2. Simulated and experimental results show that the proposed antenna could be a good candidate for MIMO applications.

REFERENCES

[1] R. G. Vaghan and J. B. Andersen, "Antenna diversity in mobile communications," *IEEE Trans. on Veh. Techn.*, vol. 36, no. 4, pp. 149 172, Nov.

1987.

[2] Y. S. Li, W. Li, and W. Yu, "A multi-band/UWB MIMO/diversity antenna with an enhanced isolation using radial stub loaded resonator," Applied Computational Electromagnetics Society (ACES) Journal, vol. 28, no. 1, pp. 8-20, Jan. 2013.

[3] H. Oraizi and B. Rezaei, "Application of inductive loadings for the dual and broad banding of CPW-fed ring antennas," Applied Computational Electromagnetics Society (ACES) Journal, vol. 27, no. 7, pp. 587-595, July 2012.

[4] P. Wang, G. J. Wen, and Y. Huang, "Compact CPW-fed planar monopole antenna with triple-band operation for WLAN/WiMAX applications," Applied Computational Electromagnetics Society (ACES) Journal, vol. 27, no. 8, pp. 691-696, Aug. 2012.

[5] R. Rouhi, Ch. Ghobadi, J. Nourinia, and M. Ojaroudi, "Ultra-wideband small square monopole antenna with band notched function," *Microwave and Optical Tech. Letters*, vol. 52, no. 8, Aug. 2010.

[6] G. Chi, B. Li, and D. Qi, "Dual-band printed diversity antenna for 2.4/5.2 GHz WLAN application," *Microw. Opt. Technol. Lett*., vol. 45, no. 6, pp. 561-563, June 2005.

[7] S. A. Mohammad Nezhad and H. R. Hassani, "A novel triband E-shaped printed monopole antenna for MIMO application," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 576-579, 2010.

[8] M. Ojaroudi, H. Ebrahimian, Ch. Ghobadi, and J. Nourinia, "Small microstrip-fed monopole printed monopole antenna for UWB applications," *Microwave and Optical Tech. Letters*, vol. 52, no. 8, Aug. 2010.

[9] M. P. Karaboikis, V. C. Papamichael, G. F. Tsachtsiris, C. F. Soras, and V. T. Makios, "Integrating compact printed antennas onto small diversity/MIMO terminals," *IEEE Trans. Antennas Propag*., vol. 52, no. 7, pp. 2067-2078, July 2008.

[10] M. Ojaroudi, S. A. Ghorashi, and N. Ojaroudi, "Design of triple-band S-shaped monopole antenna with a pair of L-shaped slots for MIMO applications," *GeMic*, 2012.

[11] Ansoft High Frequency Structure Simulation (HFSS), ver. 13, Ansoft Corporation, 2010.

[12] M. Ojaroudi, Sh. Yzdanifard, N. Ojaroudi, and M. Nasser-Moghaddasi, "Small square monopole antenna with enhanced by using inverted T-shaped slot and conductor-backed plane," *IEEE Transactions on Antenna and Propagation*, vol. 59, no. 2, pp. 670-674, Feb. 2011.

[13] A. Ghazi, M. N. Azarmanesh, and M. Ojaroudi, "Muti-resonance square monopole antenna for ultra-wideband applications," *Progress In Electromagnetics Research C*, vol. 14, pp. 103-113, 2010.

[14] T. Y. Wu, S. T. Fang, and K. L. Wong, "A printed diversity dual-band monopole antenna for WLAN operation in the 2.4 and 5.2 GHz bands," *Microwave Opt. Technol. Lett*., vol. 36, no. 25, pp. 436-439, Apr. 2003.