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A Compact UWB Antenna Design for Tumor Detection in Microwave Imaging Systems

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Abstract

In this paper, a new design of multi-resonance ultra-wideband (UWB) monopole antenna for microwave imaging systems is presented. The proposed antenna consist of a square radiating patch and a ground plane with pairs of rotated T-shaped strips protruded inside a pair of rectangular slots and an H-ring slot which provides a wide usable fractional bandwidth of more than 145% (2.3-15.2 GHz). The antenna has an ordinary square radiating patch, therefore displays a good omni-directional radiation pattern even at higher frequencies and also its radiation efficiency is greater than 85% across the entire radiating band. In the presented antenna structure, by cutting a pair of rectangular in the ground plane and also by embedding pairs of T-shaped strips inside the slots additional resonances at 2.5 GHz and 10.8 GHz can be achieved. In addition by employing an H-ring slot in the ground plane the fifth resonance at 14.7 GHz in generated. By using these modified structures at the proposed design, the usable upper frequency of the antenna is extended from 10.3 GHz to 15.2 GHz and the usable lower frequency of the antenna is decreased from 3.1 GHz to 2.3 GHz. Good return loss, fidelity factor, and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

Keywords : microstrip-fed monopole antenna, microwave imaging systems.

1. INTRODUCTION

In general, the microwave imaging system is formed by a circular cylindrical array antenna in order to detect cancerous tissue. In this approach, circular cylindrical microwave imaging systems require small antennas with omnidirectional radiation patterns and large bandwidth [1-3]. The majority of the compact ultra-wideband (UWB) antennas presented in the literature exhibit omnidirectional radiation patterns with relatively low gain and an impulse response with observable distortion. These types of UWB antennas are suitable for the short-range indoor and outdoor communication. However, for radar systems, such as a UWB microwave imaging system for detection of tumor in woman's breast, a moderate gain directional antenna is advantageous. In addition to an UWB impedance bandwidth, as defined by the minimum return loss of the 10 dB, antenna is required to support a very short pulse transmission with negligible distortion. This is necessary to achieve precision imaging without ghost targets.

The unipolar and antipodal Vivaldi antennas presented in the literature [4-5] satisfy the requirements for imaging systems in terms of bandwidth, gain, and impulse response. However, the achieved performance is at the expense of a significant size, which has a length of several wavelengths. Therefore, the challenge is to reduce their physical dimensions such that it can be incorporated in a compact microwave imaging detection system while maintaining its broadband, high-gain, and distortion-less performance. Several UWB antenna designs with compact size and low distortion have been proposed for the use in the medical imaging systems [6-8]. Each has its own merits and drawbacks. Some of the proposed antennas have a no planar structure, whereas others have low-gain and/or low radiation efficiency.

In microwave imaging systems, breast phantom is placed on a rotary stage with antennas scanning at the side to simulate the human breast in prone position. Breast phantom is rotated for 360 degrees relative to the stationary antennas to simulate a circular antenna array around the breast circumference. The overall experimental setup is shown in Fig. 1. The UWB antennas are used as the transmitter and receiver of the UWB signals.

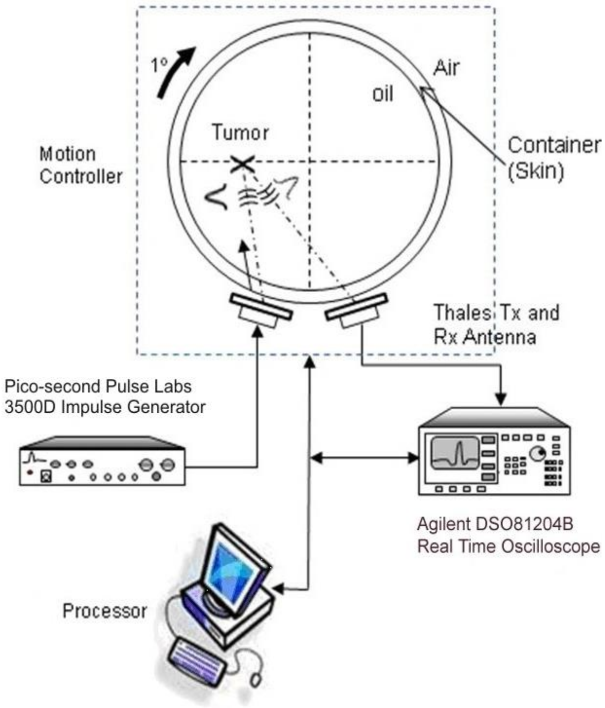

Fig. 1. Overall experimental setup.

A simple method for designing a novel and compact microstrip-fed monopole antenna with multi resonances characteristic for microwave imaging system applications has been presented. In this paper, based on defected ground structure (DGS), for bandwidth enhancement we cut an H-shaped and a pair of rectangular slots in the ground plane. Also based on electromagnetic coupling theory (ECT), by adding pair of rotated T-shaped strips and an H-shaped parasitic structure in the ground plane, the usable frequency of the proposed monopole antenna is extended from 3.1-10.3 GHz to 2.3-15.2 GHz. This antenna provides a wide usable fractional bandwidth of mord than 145%.

2. ANTENNA DESIGN

The structure of proposed monopole antenna fed by a microstrip line is shown in Fig. 1. The dielectric substance (FR4) with thickness of 1.6 mm with relative permittivity of 4.4 and loss tangent 0.018 is chosen as substrate to facilitate printed circuit board integration. The basic monopole antenna structure consists of a square radiating patch, a feed line, and a ground plane. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission. The radiating patch is connected to a feed line with width of W_f and length of L_f .The width of the microstrip feed line is fixed at 2 mm, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane ofwith width of W_{sub} and L_{gnd} length is placed. Final values of the presented antenna design parameters are specified in Table. 1.

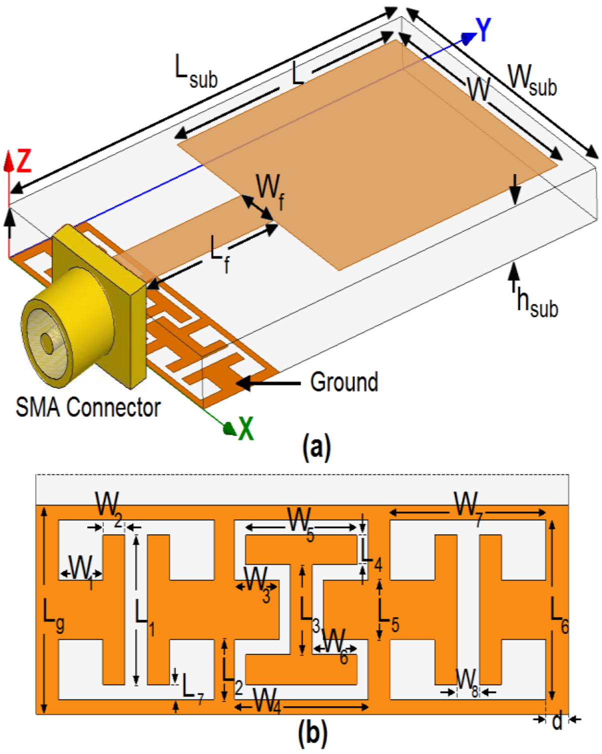

Fig. 1. Geometry of the proposed antenna (a) side view, (b) modified ground plane.

In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, is $W_{Sub} \times L_{Sub} = 12mm \times 18mm$ or about $0.15\lambda \times 0.25\lambda$ 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_{Patch} decreases, so does the antenna bandwidth, and vice versa. Next step, we have to determine the length of the radiating patch L_{Patch}. This parameter is approximately $\frac{\lambda_{lower}}{4}$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the radiating patch width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated. The important step in the design is to choose $L_{resonance}$ (the length of the resonators) which is set to resonate at $0.25\lambda_g$.

Table. 1. Dimensions of the designed antenna

Param.	(mm)	Param.	(mm)	Param.	(mm)
W_{sub}	12	L	10	W_2	0.5
L_{sub}	18	W_f	2	W_3	1
h_{sub}	1.6	L_f	7	W_4	3
W	10	W_1	1	W_5	2.5
W_6	1	L_2	1.25	L_6	3
W_7	3.5	L_3	1.5	L_7	0.25
W_8	0.5	L_4	0.5	L_g	3.5
L_1	2.5	L_5	1	d	0.5

Regarding Defected Ground Structures (DGS) theory, the creating slits in the ground plane provide additional current paths. Moreover, these structures change the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth. Therefore, by using these modified structures in the ground plane, the antenna impedance bandwidth is improved without any cost of size or expense [9-14].

3. RESULTS AND DISCUSSIONS

In this section, the microstrip 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. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement is obtained [15].

The configuration of the various structures used for simulation studies are shown in Fig. 2. Return loss characteristics for ordinary square monopole antenna (Fig. 2 (a)), antenna with a pair of rectangular slots with protruded T-shaped strips in the ground plane (Fig. 2 (b)), and the proposed antenna structures are compared in Fig. 3.

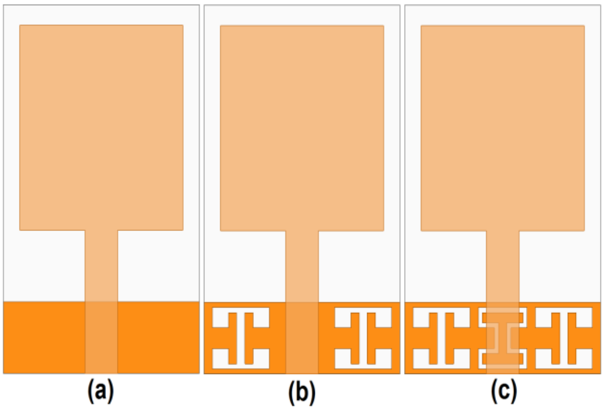

Fig. 2. (a) Ordinary monopole antenna, (b) antenna with a pair of rectangular slots with protruded T-shaped strips in the ground plane, and (c) the proposed antenna.

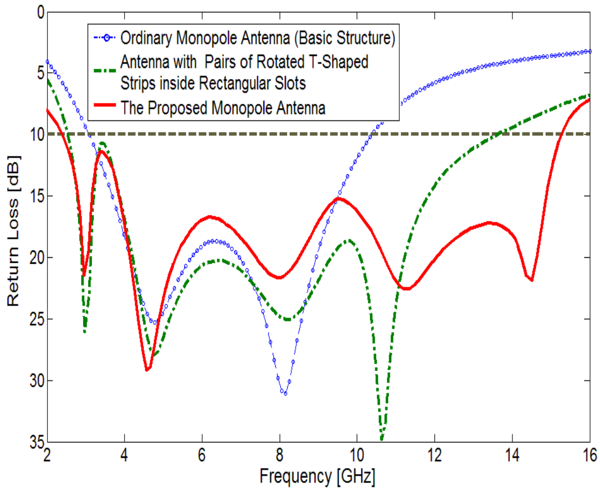

Fig. 3. Simulated return loss characteristics for the various antenna structures shown in Fig. 2.

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 proposed modifed structures but in the proposed antenna design, the upper and lower frequencies bandwidth are significantly affected by using them. It is observed that by using the modified elements including the pair of rectangular slot with pairs of rotated T-shaped strips inside the slots, additional first (3 GHz), and fourth (10.8 GHz) resonances are excited respectively, and hence the bandwidth is increased. Moreover, by adding an H-ring slot inside the ground plane, another new frequency resonance (fifth) at 14.7 GHz can be achieved.

In order to known the phenomenon behind these additional resonances performance, the simulated current distributions on the ground plane for the proposed antenna at 2.3 GHz, 10.8 GHz, and 14.7 GHz are presented in Fig. 4. It can be observed in Fig. 4 (a), 4(b) at the first and fourth resonances, the current concentrated on the edges of the interior and exterior of the rectangular slots and T-shaped strips, respectively. As shown in Fig. 4(c) at the fifth resonance frequency the current flows are more dominant around of the H-ring structure [16-23].

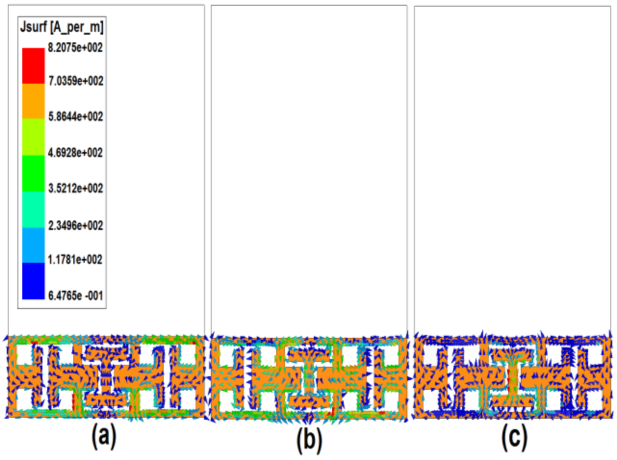

Fig. 4. Simulated surface current distributions on ground plane for the proposed antenna (a) at 3 GHz (first extra resonance frequency), (b) at 10.8 GHz (second extra resonance frequency), and (c) 14.7 GHz (third extra resonance frequency).

The proposed antenna has a slightly higher efficiency rather than ordinary square antenna throughout the entire radiating band, which is mainly owing to the extra resonant properties. Results of the calculations using the software HFSS indicated that the proposed antenna features a good efficiency, being greater than 85% across the entire radiating band.

Fig. 5 depicts the simulated and measured radiation patterns including the co-polarization and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that nearly omnidirectional radiation pattern with low cross-polarization level can be observed on x-z plane. The radiation patterns on the y-z plane are like a small electric dipole leading to bidirectional patterns in a very wide frequency band. With the increase of frequency, the radiation patterns become worse because of the increasing effects of the cross polarization [24-28].

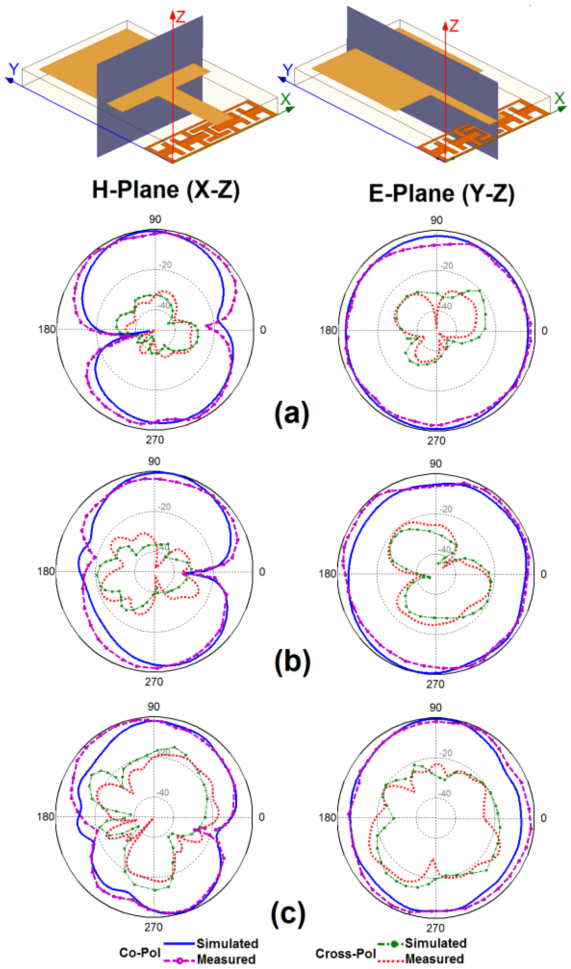

Fig.5. Measured radiation patterns of the proposed antenna (a) 4 GHz, (b) 9 GHz, and (c) 14 GHz.

In UWB microstrip antennas analysis, the transfer function is transformed to time domain by performing the inverse Fourier transform. Fourth derivative of a Gaussian function is selected as the transmitted pulse. Therefore the output waveform at the receiving antenna terminal can be expressed by convoluting the input signal and the transfer function. The input and received wave forms for the face-to-face and side-by-side orientations of the antenna are shown in Fig. 6. It can be seen that the shape of the pulse is preserved in all the cases. Only due to being three notches, there is a bit distortion on received pulses which it was predictable. Using the reference and received signals, it becomes possible to quantify the level of similarity between signals.

In telecommunication systems, the correlation between the transmitted (TX) and received (RX) signals is evaluated using the fidelity factor (1).

$$F = Max_{\tau}\left|\frac{\int_{-\infty}^{+\infty} s(t)r(t-\tau)}{\sqrt{\int_{-\infty}^{+\infty} s(t)^2\,dt.\int_{-\infty}^{+\infty} r(t)^2\,dt}}\right| \qquad (1)$$

Where s(t) and r(t) are the TX and RX signals, respectively. For impulse radio in UWB communications, it is necessary to have a high degree of correlation between the TX and RX signals to avoid losing the modulated information. However for most other telecommunication systems, the fidelity parameter is not that relevant.

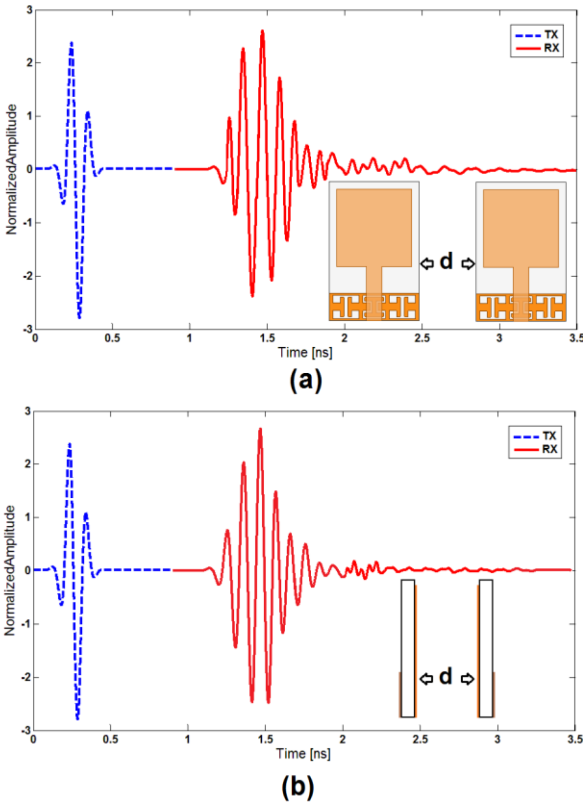

Fig.6. Transmitted and received pulses (a) side bye side and (b) face to face.

In order to evaluate the pulse transmission characteristics of the proposed UWB antenna with dual band-notches, two configurations (side-by-side and face-to-face orientations) were chosen. The transmitting and receiving antennas were placed in a d=250 mm distance from each other.

As shown in Fig. 6, although the received pulses in each of two orientations are broadened, a relatively good similarity exists between the RX and TX pulses. Using (1), the fidelity factor for the face-to-face and side-by-side configurations were obtained equal to 0.85 and 0.87, respectively. Values the fidelity factor show that the antenna imposes negligible effects on the transmitted pulses. The pulse transmission results are obtained using CST [29].

The proposed antenna with final design was built and tested. The measured and simulated VSWR characteristics of the proposed antenna were shown in Fig .7. The fabricated antenna has the frequency band of 2.3 to over 15.2 GHz.

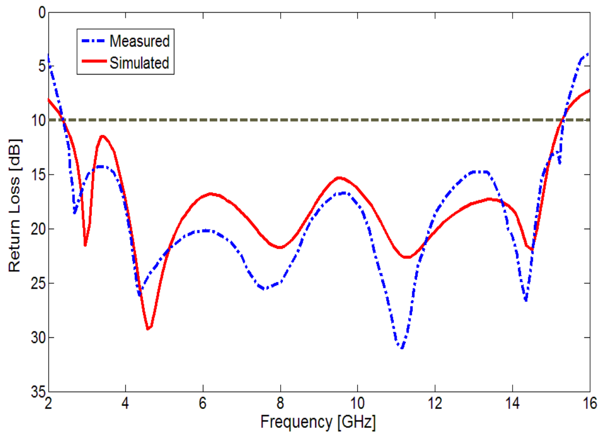

Fig.7. Measured and simulated return loss characteristics for the proposed antenna.

4. CONCLUSION

In this letter, a novel and compact printed monopole antenna (PMA) with multi-resonance characteristics for use in microwave imaging system applications has been proposed. The fabricated antenna satisfies the VSWR<2 requirement from 2.3 to 15.2 GHz. In order to enhance bandwidth we use pairs of T-shaped strips inside two rectangular slot and an H-ring slot in the ground plane, which much wider impedance bandwidth can be produced. The designed antenna has a simple configuration with ordinary square radiating patch and small size of 12×18 mm^2. Simulated and experimental results show that the proposed antenna could be a good candidate for circular cylindrical microwave imaging system applications.

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REFERENCES

[1] E. C. Fear, S. C. Hagness, P.M.Meaney, M. Okonieweski, andM. A. Stuchluy, “Enhancing breast tumor detection with near-field imaging,” *IEEE Microw. Mag.*, vol. 3, no. 1, pp. 48–56, Mar. 2002.

[2] K.D. Paulsen and P.M.Meaney, “Nonactive antenna compensation for fixed-array microwave imaging—Part I: Model development,” *IEEE Trans. Med. Imag.*, vol. 18, no. 6, pp. 496–507, Jun. 1999.

[3] E. J. Bond, X. Li, S. C. Hagness, and B. D. Van Veen, “Microwave imaging via space-time beamforming for early detection of breast cancer,” *IEEE Trans. Antennas Propag.*, vol. 51, no. 8, pp. 1690–1705, Aug. 2003.

[4] E. Guillanton, J. Y. Dauvignac, Ch. Pichot, and J. Cashman, “A new design tapered slot antenna for ultra-wideband applications,” *Microw. Opt. Technol. Lett.*, vol. 19, no. 4, pp. 286–289, 1998.

[5] M. Chiappe and G. L. Gragnani, “Vivaldi antennas for microwave imaging: Theoretical analysis and design considerations,” *IEEE Trans. Instrum. Meas.*, vol. 55, no. 6, pp. 1885–1891, Dec. 2006.

[6] X.Yun, E. C. Fear, and R. Johnston, “Broadband cross polarized bowtie antenna for breast cancer detection,” in *Proc. IEEE Antennas Propag. Soc. Int. Symp.,* Columbus, OH, Jun. 2003, vol. 3, pp. 1091–1094.

[7] C. J. Shannon, E. C. Fear, and M. Okoniewski, “Dielectric filled slot line bowtie antenna for breast cancer detection,” *Electron. Lett.*, vol. 41, no. 7, pp. 388–390, 2005.

[8] H. Kanj and M. Popovic, “Miniaturized microstrip-fed ‘dark eyes’ antenna for near-field microwave sensing,” *IEEE Antennas Wireless Propag. Lett.*, vol. 4, pp. 397–401, 2005.

[9] N. Ojaroudi, “Design of small reconfigurable microstrip antenna for UWB-CR applications,” *19th International Symposium on Antenna and propagation,* ISAP2014, 2-5 December, 2012, Kaohsiung, Taiwan.

[10] N. Ojaroudi, “Design of ultra-wideband monopole antenna with enhanced bandwidth,” *21th Telecommunications Forum,* TELFOR 2013, 27 – 28 November, 2013, Belgrade, Serbia, pp. 1043-1046, 2013.

[11] N. Ojaroudi, “A new design of Koch fractal slot antenna for ultra-wideband applications,” *21th Telecommunications Forum,* TELFOR 2013, 27 – 28 November, 2013, Belgrade, Serbia, pp. 1051-1054, 2013.

[12] N. Ojaroudi, "Compact UWB monopole antenna with enhanced bandwidth using rotated L-shaped slots and parasitic structures,"*Microw. Opt. Technol. Lett.,* vol. 56, pp.175–178, 2014.

[13] N. Ojaroudi, M. Ojaroudi, and Sh. Amiri, "Enhanced bandwidth of small square monopole antenna by using Inverted U-shaped slot and conductor-backed plane," *Applied Computational Electromagnetics Society(ACES) Journal*, vol. 27, no. 8, pp. 685-690, August 2012.

[14] Kh. Halili, M. Ojaroudi, and N. Ojaroudi, "Ultrawideband monopole antenna for use in a circular cylindrical microwave imaging system," *Microw. Opt. Technol. Lett.*, vol. 54, no. 9, pp. 2202–2205, Sep. 2012.

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

[16] N. Ojaroudi, "New design of multi-band PIFA for wireless communication systems," *19th International Symposium on Antenna and propagation,* ISAP2014, 2-5 December, 2012, Kaohsiung, Taiwan.

[17] N. Ojaroudi, "Application of protruded strip resonators to design an UWB slot antenna with WLAN band-notched characteristic," *Progress in Electromagnetics Research C,* vol. 47, pp. 111-117, 2014.

[18] N. Ojaroudi, "Circular microstrip antenna with dual band-stop performance for ultra-wideband systems," *Microw. Opt. Technol. Lett*., vol. 56, pp. 2095–2098, 2014.

[19] N. Ojaroudi, "Microstrip monopole antenna with dual band-stop function for ultra-wideband applications," *Microw. Opt. Technol. Lett*., vol. 56, pp. 818–822, 2014.

[20] N. Ojaroudi, "Microstrip monopole antenna with dual band-stop function for UWB applications," *Microw. Opt. Technol. Lett*., vol. 56, pp. 562-564, 2014.

[21] N. Ojaroudi, "Small microstrip-fed slot antenna with frequency band-stop function," *21th Telecommunications Forum*," TELFOR 2013, 27 – 28 November, 2013, Belgrade, Serbia., pp. 1047-1050, 2013.

[22] N. Ojaroudi, "A new design of very compact UWB band-stop filter using coupled W-shaped strips," *Asia-Pacific Microwave Conference (APMC 2014), 4-7 November***,** Sendai, Japan**.**

[23] N. Ojaroudi, "Investigation and FDTD analysis of UWB microstrip antenna with dual narrow band-notched characteristic," *Asia-Pacific Microwave Conference (APMC 2014), 4-7 November,* Sendai, Japan**.**

[24] N. Ojaroudi, S. Amiri, and F. Geran, "A novel design of reconfigurable monopole antenna for UWB applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 28, no. 6, pp. 633-639, July 2013.

[25] N. Ojaroudi, "Design of UWB monopole antenna with dual band-stop characteristic," *in Proceedings of the Loughborough Antennas and Propagation Conference (LAPC '14),* 10-11 November, 2014, Loughborough, UK**.**

[26] N. Ojaroudi, "Application of protruded Γ-shaped strips at the feed-line of UWB microstrip antenna to create dual notched bands," *International Journal of Wireless Communications, Networking and Mobile Computing*, vol. 1, no. 1, pp. 8-13, 2014.

[27] N. Ojaroudi, "A modified compact microstrip-fed slot antenna with desired WLAN band-notched characteristic," *American Journal of Computation, Communication and Control*, vol. 1, no. 3, pp. 56-60, 2014.

[28] N. Ojaroudi, "Bandwidth improvement of monopole antenna using π-shaped slot and conductor-backed plane," *International Journal of Wireless Communications, Networking and Mobile Computing*, vol. 1, no. 2, pp. 14-19, 2014.

[29] CST Microwave studio, ver. 2008. Computer Simulation Technology, Framingham, MA, 2008.