Bandwidth Improvement of Omni-Directional Monopole Antenna with a Modified Ground Plane

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Abstract **─** This study introduces a new design of low profile, multi-resonance and omni-directional monopole antenna for Ultra-Wideband (UWB) applications. The proposed antenna configuration consists of an ordinary square radiating patch and a ground plane with pairs of inverted fork-shaped slits and inverted Γ-shaped parasitic structures, which provides a wide usable fractional bandwidth of more than 135%. By cutting a pair of inverted fork-shaped slits in the ground plane and also by inserting a pair of inverted Γ-shaped conductor-backed plane in the feed gap distance, additional resonances are excited and hence much wider impedance bandwidth can be produced; especially at the higher band. By obtaining the third and fourth resonances, the usable lower frequency is decreased from 3.12 GHz to 2.83 GHz and also the usable upper frequency of the presented monopole antenna is extended from 10.3 GHz to 14.87 GHz. The proposed antenna has symmetrical structure with an ordinary square radiating patch; therefore, displays a good omni-directional radiation patterns, even at the higher frequencies. The antenna radiation efficiency is greater than 87% across the entire radiating band. The measured results show that the proposed antenna can achieve the Voltage Standing Wave Ratio (VSWR) requirement of less than 2.0 GHz in frequency range from 2.83 GHz to 14.87 GHz, which is suitable for UWB systems.

Index Terms **─** Omni-directional radiating patterns and printed monopole antenna.

I. INTRODUCTION

After allocation of the frequency band from 3.1 GHz to 10.6 GHz for the commercial use of Ultra-Wideband (UWB) systems by the Federal Communication Commission (FCC) [1], ultra-wideband systems have received phenomenal gravitation in wireless communication. Designing an antenna to operate in the UWB frequency range is quite a challenge, because it has to satisfy the requirements such as ultra-wide impedance bandwidth, omni-directional radiation pattern, constant gain, high radiation efficiency, constant group delay, low profile, easy manufacturing, etc. [2]. 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, a number of microstrip antennas with different geometries have been experimentally characterized [3-4]. Some methods are used to obtain the multi-resonance function in the literature [5-8].

In this paper, a different method is proposed to obtain the very wideband bandwidth for the compact monopole antenna. In the proposed antenna, we use pairs of inverted fork-shaped slits and Γ-shaped conductor-backed plane in the ground plane, which provides a wide usable fractional bandwidth of more than 135%. 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 [9-11]. Therefore, by cutting a pair of inverted fork-shaped slits in the ground plane, much enhanced impedance bandwidth may be achieved. In addition, based on Electromagnetic Coupling Theory (ECT), by adding a pair of inverted Γ-shaped conductor-

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backed plane in the air gap distance, additional coupling is introduced between the bottom edge of the square patch and the ground plane and its impedance bandwidth is improved without any cost of size or expense. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. The designed antenna has a small size of 12×18 mm^2.

II. MICROSTRIP 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 of 1.6 mm, permittivity of 4.4 and loss tangent 0.018.

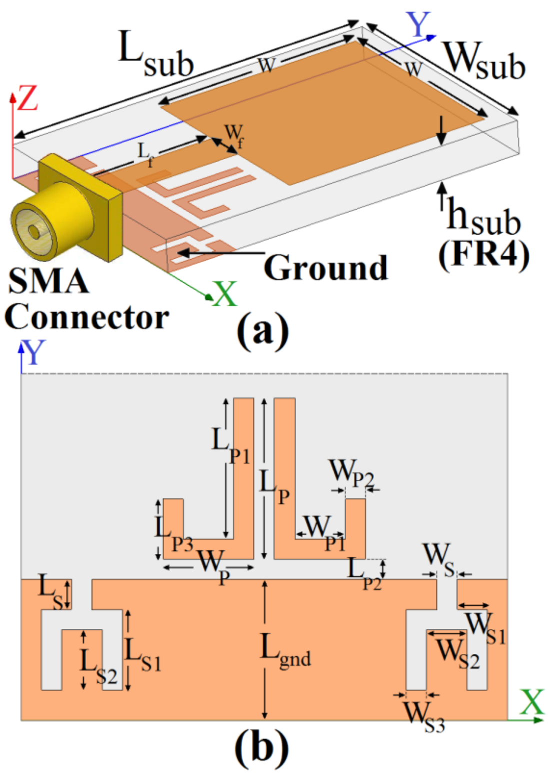

Fig. 1. Geometry of proposed omni-directional monopole antenna: (a) side view and (b) modified ground plane.

The basic monopole antenna structure consists of a square radiating patch, a feed line and a ground plane. The square radiating patch has a width W. The patch is connected to a feed line of width W_f and length 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 with two inverted fork-shaped slits and a pair of Γ-shaped parasitic structures is placed. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission.

The DGS applied to a ground plane causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slits [3]. In addition, based on ECT, by using a parasitic structure in air gap distance, an additional coupling is introduced between the bottom edge of the square patch and the ground plane and its impedance bandwidth is improved without any cost of size or expense. Therefore, by cutting two inverted fork-shaped slits and also by embedding a pair of inverted Γ-shaped parasitic structures and carefully adjusting these parameters, much enhanced impedance bandwidth may be achieved. The final values of proposed design parameters are displayed in Table 1.

Table 1: The final values of proposed design parameters

$W_{sub}=12mm$	$L_{sub}=18mm$	$h_{sub}=1.6mm$
$W_f=2mm$	$L_f=7mm$	$W=10mm$
$W_S=0.5mm$	$L_S=0.5mm$	$W_{S1}=0.75mm$
$L_{S1}=2.5mm$	$W_{S2}=1mm$	$L_{S2}=2mm$
$W_{S3}=0.5mm$	$W_P=2.25mm$	$L_P=3.5mm$
$W_{P1}=125mm$	$L_{P1}=3mm$	$W_{P2}=0.5mm$
$L_{P2}=0.5mm$	$L_{P3}=0.75mm$	$L_{gnd}=3.5mm$

III. RESULTS AND DISCUSSIONS

The proposed microstrip monopole antenna with various design parameters was constructed and the numerical and experimental results of 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 [11].

Figure 2 shows the structure of the various antennas used for simulation studies. VSWR characteristics for ordinary square patch antenna (Fig. 2 (a)), square antenna with a pair of inverted fork-shaped slits (Fig. 2 (b)) and the proposed antenna (Fig. 2 (c)) are compared in Fig. 3. 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 4.8 GHz and 8.2 GHz, respectively; in the absence of the inverted fork-shaped slits and a pair of inverted Γ-shaped conductor-backed plane. It is observed that by using these modified elements including pairs of inverted fork-shaped slits and Γ-shaped conductor-backed plane, additional third (10.9 GHz) and fourth (14.2 GHz) resonances are excited, respectively, and hence the bandwidth is increased. As illustrated in Fig. 3, the embedded structures in the ground plane and also the generation of extra resonances have an effect of disappear for the second resonance of the antenna. This is because the coupling between the ground plane and radiating patch for the second resonance becomes weaker.

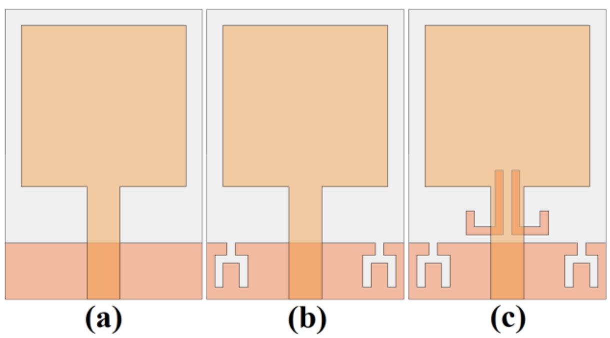

Fig. 2. (a) Ordinary square monopole antenna, (b) the antenna with a pair of inverted fork-shaped slits in the ground plane and (c) the proposed monopole antenna.

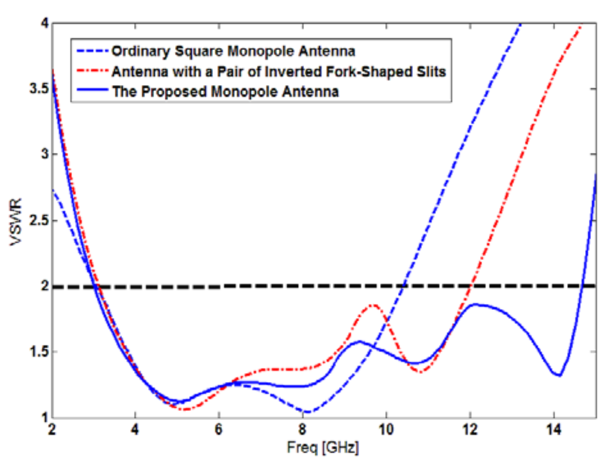

Fig. 3. Simulated VSWR characteristics for the various monopole antennas shown in Fig. 2.

In order to understand the phenomenon behind these additional resonances performance, the simulated current distributions on the ground plane for the proposed antenna at 10.9 GHz and 14.5 GHz (third and fourth resonances) are presented in Figs. 4 (a) and (b), respectively. As shown in Fig. 4 (a), the currents concentrated on the edges of the interior and exterior of the inverted fork-shaped slits at third resonance frequency (10.9 GHz). Also, as illustrated in Fig. 4 (b), the current concentrated on the edges of the interior and exterior of the inverted Γ-shaped parasitic structures at fourth resonance frequency (14.2 GHz).

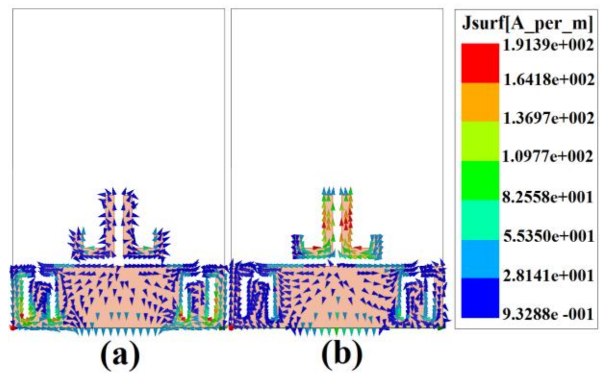

Fig. 4. Simulated surface current distributions on the ground plane for the proposed antenna: (a) at 10.9 GHz and (b) at 14.2 GHz.

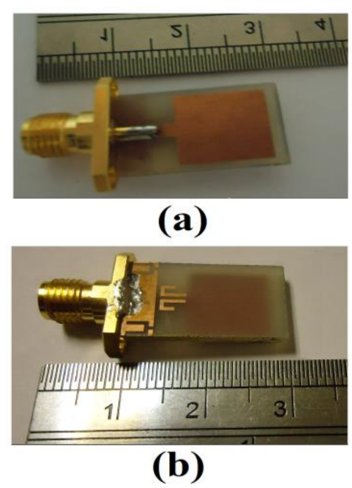

Fig. 5. Photograph of the realized printed monopole antenna: (a) top view and (b) bottom view.

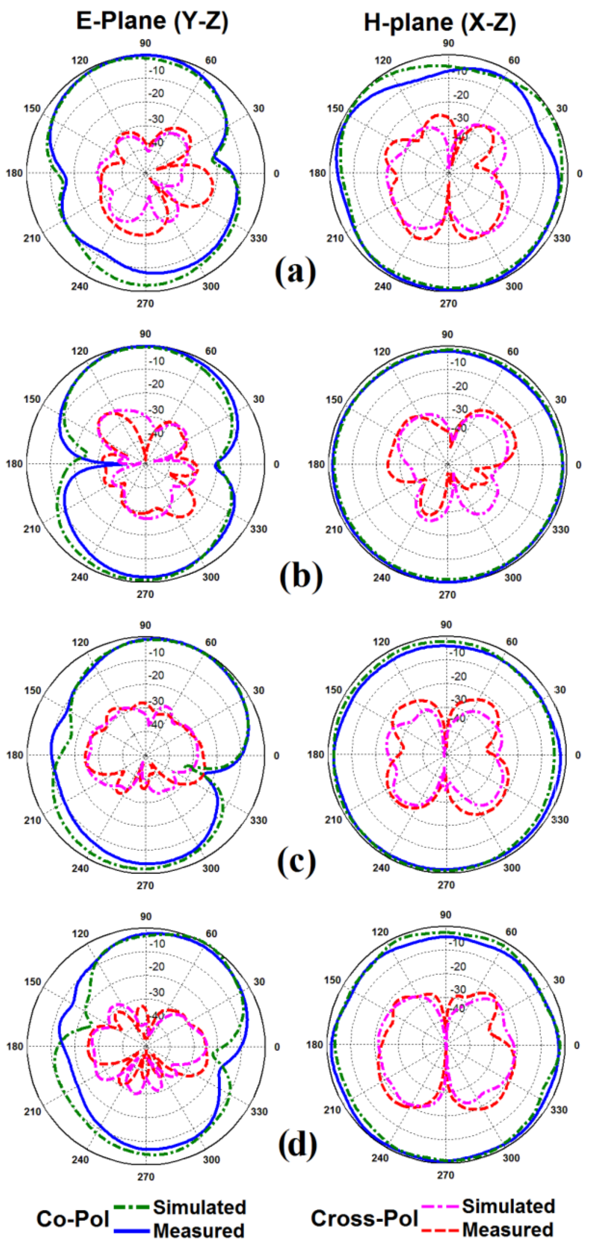

Fig. 6. Measured and simulated radiation patterns of the proposed antenna: (a) 5 GHz, (b) 8 GHz, (c) 11 GHz and (d) 14 GHz.

As shown in Fig. 5, the proposed antenna was fabricated and tested. The VSWR characteristic of the antenna was measured using a network analyzer in an anechoic chamber. The radiation patterns have been measured inside an anechoic chamber using a double-ridged horn antenna as a reference antenna placed at a distance of 2 m. Also, a two-antenna technique using a spectrum analyzer and a double-ridged horn antenna as a reference antenna placed at a distance of 2 m is used to measure the radiation gain in the z axis direction (x-z plane).

Figure 6 depicts the measured and simulated radiation patterns of the proposed antenna, 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 quasi-omni-directional radiation pattern can be observed on x-z plane over the whole UWB frequency range, especially at the low frequencies. The radiation pattern on the y-z plane displays a typical figure-of-eight, similar to that of a conventional dipole antenna. It should be noticed that the radiation patterns in E-plane become imbalanced as frequency increases because of the increasing effects of the cross-polarization. The patterns indicate at higher frequencies and more ripples can be observed in both E and H-planes, owing to the generation of higher-order modes [14-16].

Figure 7 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna has the frequency band of 2.83 GHz to 14.87 GHz.

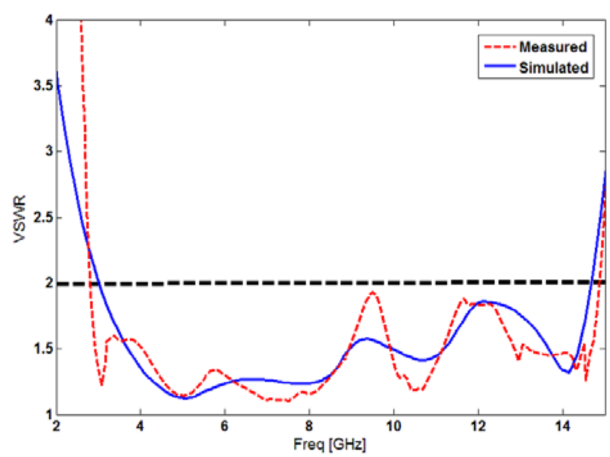

Fig. 7. Measured and simulated VSWR characteristics of the proposed monopole antenna.

The simulated radiation efficiency characteristic of the proposed antenna is shown in Fig. 8. Results of the calculations using the software HFSS indicated that the proposed antenna features a good efficiency, being greater than 87% across the entire radiating band. In addition, the simulated and measured maximum gains of the antenna against frequency are illustrated in Fig. 8.

The antenna gain has a flat property, which increases by the frequency. As seen, the proposed antenna has sufficient and acceptable gain levels in the operation bands [17-18].

In the UWB communication systems, antennas should be able to transmit the electrical pulse with minimal distortion. If group delay variation exceeds more than 1 *ns*, phases are no more linear in far field and phase distortion occurs, which can cause a serious problem for UWB applications. Figure 9 shows the simulated group delay property of the proposed monopole antenna. As illustrated, the variation is less than 0.25±0.4 over the frequency band from 3 GHz to 14.5 GHz. It shows that the antenna has low-impulse distortion and is suitable for UWB applications [18-21].

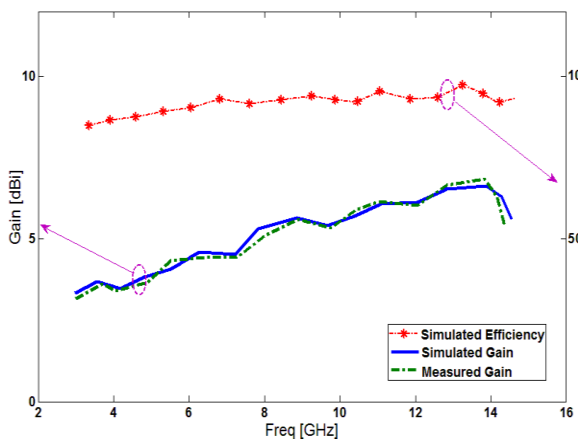

Fig. 8. Measured and simulated radiation efficiency and gain of the proposed antenna.

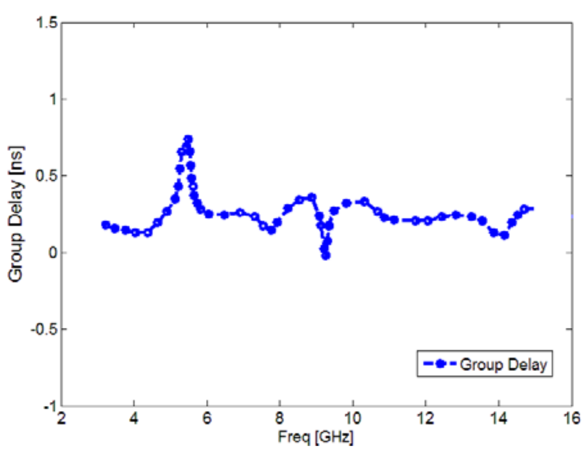

Fig. 9. Simulated group delay characteristic of the proposed antenna.

The radiating mechanism of the proposed antenna is more novel than was explained in previous works. The proposed structure is the combination of the monopole antenna with the dipole and slot antenna. In this study, the modified ground-plane structure is the combination of the monopole antenna and the slot antenna. By using the modified conductor-backed plane, the interaction of the two parts of the overall antenna has occurred. The embedding parasitic structure in the ground plane of the monopole antenna acts as a dipole antenna that can provide an additional current path. Also, the entire back conducting plane could be part of the radiator, especially when operating at lower frequencies [22-24].

Table 2: Comparison of previous designs with the proposed antenna

Ref.	FBW (%)	Dimension (mm)	Gain (dBi)
[13]	47%	33×33	3.5~6
[14]	87%	22×24	1~5.5
[15]	87%	32×25	2~5.5
[16]	91%	26×26	3-7
[17]	112%	20×20	2~4.7
[18]	118%	40×10	2.3~6.3
[19]	130%	12×18	2.7-5.5
[20]	132%	25×26	not reported
This Work	*136%*	*12×18*	*3.3~6.5*

Table 2 summarizes the previous designs and the proposed antenna. As seen, the proposed antenna has a compact size with very wide bandwidth in comparison with the pervious works. In addition, the proposed antenna has good omni-directional radiation patterns with low cross-polarization level, even at the higher and upper frequencies. As the proposed antenna has symmetrical structure and an ordinary square radiating patch without any slot and parasitic structures at top layer, in comparison with previous multi-resonance UWB antennas, the proposed antenna displays a good omni-directional radiation pattern, even at lower and higher frequencies [20]. Also, the proposed microstrip-fed monopole antenna has sufficient and acceptable radiation efficiency, group delay and antenna gain levels in the operation bands [25-27].

IV. CONCLUSION

In this manuscript, a novel compact Printed Monopole Antenna (PMA) with multi-resonance characteristics has been proposed for UWB applications. The fabricated antenna can operate from 2.83 GHz to 14.87 GHz. In order to enhance the bandwidth, we insert a pair of inverted fork-shaped slits in the ground plane and also by adding two inverted Γ-shaped conductor-backed plane with variable dimensions, additional resonances are excited and hence much wider impedance bandwidth can be produced. The designed antenna has a simple configuration with small size of 12×18 mm^2 and an ordinary square radiating patch, which its radiation efficiency is greater than 87%. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB systems application.

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REFERENCES

[1] *FCC News release, FCC NEWS (FCC 02-48)*, February 14, 2002.

[2] D. Cheng, "Compact ultra-wideband microstrip resonating antenna," *US patent7872606*, January 2011.

[3] M. Mighani, M. Akbari and N. Felegari, "A novel SWB small rhombic microstrip antenna with parasitic rectangle into slot of the feed line," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 1, pp. 74-79, January 2012.

[4] M. N. Jahromi and N. K. Barchloui, "Analysis of the behavior of Sierpinski carpet monopole antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 24, no. 1, pp. 32-36, February 2009.

[5] W. C. Weng, "Optimal design of an ultra-wideband antenna with the irregular shape on radiator using particle swarm optimization," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 5, pp. 427-434, May 2012.

[6] G. Zhang, J. S. Hong, B. Z. Wang and G. Song, "Switched band-notched UWB/WLAN monopole antenna," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 3, pp. 256-260, March 2012.

[7] R. Azim, M. T. Islam and N. Misran, "Design of a planar UWB antenna with new band enhancement technique," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 26, no. 10, pp. 856-862, October 2011.

[8] C. Y. D. Sim, W. T. Chung and C. H. Lee, "Planar UWB antenna with 5 GHz band rejection switching function at ground plane," *Progress In Electromagnetics Research*, vol. 106, pp. 321-333, 2010.

[9] N. Behdad and K. Sarabandi, "A compact antenna for ultra-wideband applications," *IEEE Transactions on Antennas and Propagation*, vol. 53, pp. 2185-2192, 2005.

[10] A. J. Kerkhoff, R. L. Rogers and H. Ling, "Design and analysis of planar monopole antennas using a genetic algorithm approach," *IEEE Trans Antennas Propag*., vol. 2, pp. 1768-1771, 2004.

[11] Ansoft high frequency structure simulation (HFSS), ver. 13, *Ansoft Corporation*, 2010.

[12] K. Chung, T. Yun and J. Choi, "Wideband CPW-fed monopole antenna with parasitic elements and slots," *ElectronicsLetters*, vol. 40, no. 17, pp. 1038-1040, 2004.

[13] W. L. Chen, G. M. Wang and C. X. Zhang, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna with a fractal-shaped slot," *IEEE Transactions on Antennas and Propagation*, vol. 57, pp. 1276-2179, 2009.

[14] R. Azim, M. T. Islam and N. Misran, "Compact tapered-shape slot antenna for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1190-1193, 2011.

[15] Y. Li, W. Li and Y. Lu, "A switchable UWB slot antenna using SIS-HSIR and SIS-SIR for multi-mode wireless communications applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, pp. 340-351, 2012.

[16] L. Liu, S. W. Cheung and T. I. Yuk, "Compact MIMO antenna for portable devices in UWB applications," *IEEE Transactions on Antennas and Propagation*, vol. 61, pp. 4257-4264, 2013.

[17] M. Ojaroudi and N. Ojaroudi, "Ultra-wideband small rectangular slot antenna with variable band-stop function," *IEEE Trans. Antennas Propag*., vol. 62, pp. 490-494, 2014.

[18] X. N. Low, Z. N. Chen and T. S. P. See, "A UWB dipole antenna with enhanced impedance and gain performance," *IEEE Transactions on Antennas and Propagation*, vol. 57, pp. 2966-2959, 2009.

[19] N. Ojaroudi and M. Ojaroudi, "Small monopole antenna with multi-resonance characteristic by using rotated t-shaped slit and parasitic structure for UWB systems," *Microw. Opt. Technol. Lett*., vol. 55, pp. 482-485, 2013.

[20] A. K. Gautam, S. Yadav and B. K. Kanaujia, "A CPW-fed compact UWB microstrip antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 151-154, 2013.

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

[22] N. Ojaroudi, "A new eesign of koch fractal slot antenna for ultra-wideband applications," *21st Telecommunications Forum,* TELFOR 2013, Belgrade, Serbia, pp. 1051-1054, November 27-28, 2013.

[23] 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.

[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, "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.

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

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