Small Reconfigurable Monopole Antenna Integrated with PIN Diodes for Multimode Wireless Communications

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Abstract **─** A new printed reconfigurable monopole antenna with multi-resonance and switchable dual band-notched performances is presented, whose frequency characteristics can be reconfigured electronically to have both a single or dual-band notch function to block interfering signals from Wireless Local Area Network (WLAN) for 5-6 GHz and/or X-band communications around 9-10 GHz. The presented antenna consists of a square radiating patch with H-shaped slot and a ground plane with a pair of L-shaped parasitic structures. We use two PIN diodes across the antenna configuration that by changing the on/off conditions of the PIN diodes, the antenna can be used for multimode applications. In the proposed structure, when D_1=ON & D_2=OFF, an UWB antenna with a multi-resonance characteristic can be achieved and we can give additional resonances at higher frequency bands that provides a wide usable fractional bandwidth of more than 125% (3.02-12.43). By changing the condition of integrated diodes to D_1=OFF & D_2=ON, the pair of rotated T-shaped slots at radiating patch have converted to H-shaped slot and the L-shaped parasitic structures have converted to inverted Ω-shaped structure. The proposed antenna can be used to generate either single or dual notch band to isolate and block any interference in the UWB frequency range.

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Index Terms **─** PIN diode, reconfigurable antenna and UWB wireless communications.

I. INTRODUCTION

In UWB communication systems, one of key issues is the design of a compact antenna while providing a wideband characteristic over the whole operating band. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized. Moreover, other strategies to improve the impedance bandwidth, which do not involve a modification of the geometry of the planar antenna have been investigated [1-3].

The frequency range for UWB systems between 3.1-10.6 GHz will cause interference to the existing wireless communication systems; for example, the WLAN for IEEE 802.11a operating in 5.15-5.35 GHz and 5.725-5.825 GHz bands and X-band communication systems, so the UWB antenna with a band-notched function is required. Lately, to generate the frequency band-notched function, several modified planar monopole antennas with band-notched characteristic have been reported [4-5].

In this paper, a reconfigurable square monopole antenna with single or dual-band notched and multi-resonance performances is presented. In the proposed structure, multimode operation is provided by changing the on/off conditions of the PIN diodes, that the antenna can be used to generate either a single or dual notch band to isolate and block any interference in the WLAN and/or X-band frequency bands. The size of the designed antenna is smaller than the UWB antennas with band-notched function reported recently [6-9].

II. ANTENNA DESIGN

The presented small square monopole antenna fed by a microstrip line is shown in Fig. 1, which is printed on FR4 substrate of thickness of 1.6 mm, permittivity of 4.4 and loss tangent of 0.018.

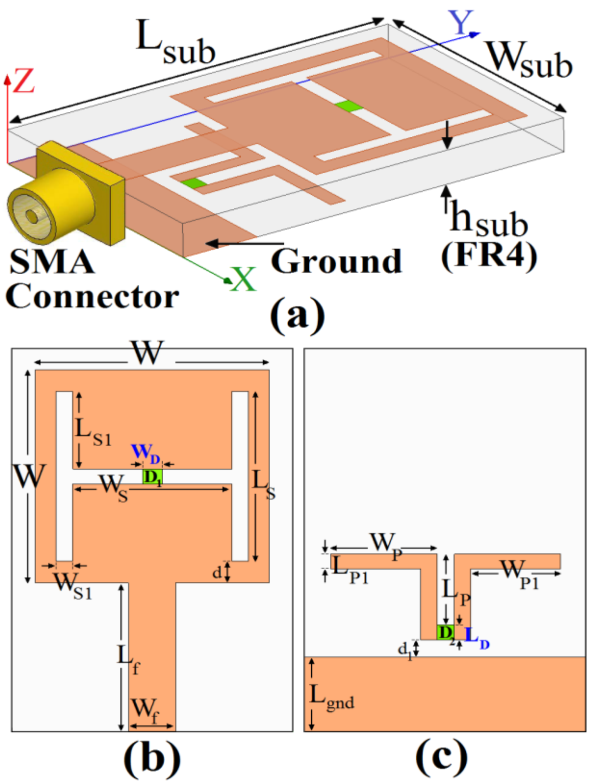

Fig. 1. Geometry of the proposed antenna: (a) side view, (b) top layer and (c) bottom layer.

The basic monopole 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. 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 is placed. The proposed antenna is connected to a 50- SMA connector for signal transmission. The final values of proposed design parameters are as follows: W_{sub}=12 mm, L_{sub}=18 mm, h_{sub}=1.6 mm, W_f=2 mm, L_f=7 mm, W=10 mm, W_S=6 mm, L_S=8 mm, W_{S1}=1 mm, L_{S1}=3.75 mm, L_{S2}=2 mm, W_P=4.75 mm, L_P=3.5 mm, W_P=4.25 mm, L_{P1}=0.5 mm, W_D=0.5 mm, L_D=0.5 mm, d=1 mm, d_1=0.75 mm and L_{gnd}=3.5 mm.

III. RESULTS AND DISCUSSIONS

The proposed 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 [10].

A. UWB antenna (D_1=ON and D_2=OFF)

The configuration of the presented reconfigurable monopole antenna was shown in Fig. 1. Geometry for the monopole antenna with a ground etch (Fig. 2 (a)), with a pair of rotated T-shaped slots (Fig. 2 (b)) and with a pair of rotated T-shaped slots and L-shaped parasitic structures (Fig. 2 (c)) are compared in Fig. 2.

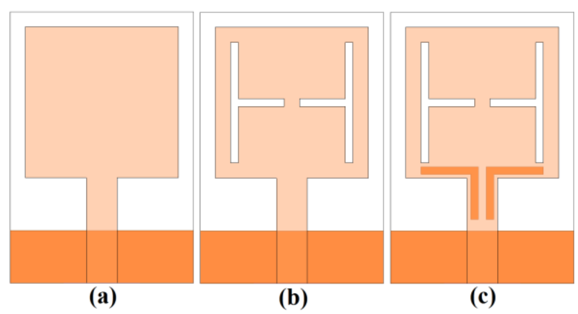

Fig. 2. (a) Basic structure (a square monopole antenna with a ground etch), (b) the antenna with a pair of rotated T-shaped slots and (c) antenna with a pair of rotated T-shaped slots and a pair of L-shaped conductor-backed plane.

Simulated VSWR characteristics for the structures that were shown in Fig. 2 are compared in Fig. 3. As shown in Fig. 3, it is observed that the upper frequency bandwidth is affected by using these structures and we can give additional resonances at higher bands that provide a wide usable fractional bandwidth.

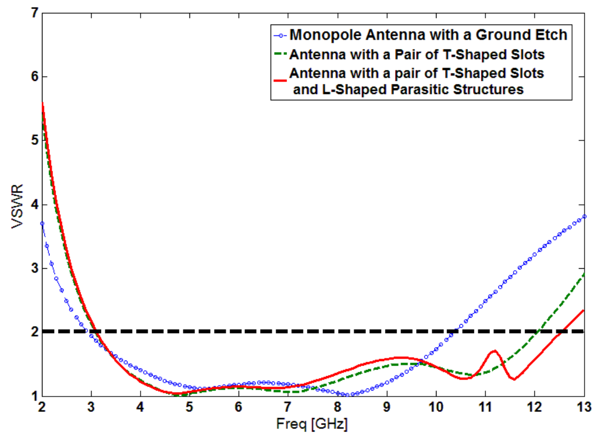

Fig. 3. Simulated VSWR characteristics for the various structures shown in Fig. 2.

In order to understand the phenomenon behind this multi-resonance performance, the simulated current distributions for the proposed antenna on the radiating patch at the third resonance frequency (10.7 GHz) is presented in Fig. 4 (a). It is found that by inserting a pair of rotated T-shaped slots, a new resonance at 10.7 GHz can be achieved. Another important design parameter of this multi-resonance performance is a pair of inverted L-shaped parasitic structure, that by adding this structure in the ground plane fourth resonance at 11.5 GHz has been obtained. The simulated current distributions for the proposed UWB antenna in the ground plane at 11.5 GHz (fourth resonance) are presented in Fig. 4 (b). As shown in Fig. 4 (b), the current flows are more dominant around of the L-shaped parasitic structures [11-13].

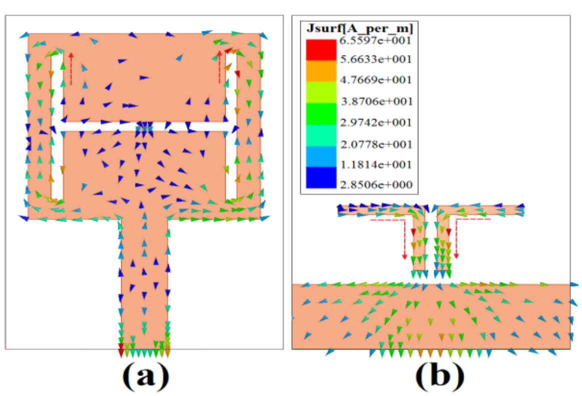

Fig. 4. Simulated surface current distributions for the UWB antenna: (a) on the radiating patch at 10.7 GHz and (b) in the ground plane at 11.5 GHz.

B. Single and/or dual band-notched antenna (D_1=OFF and/or D_2=ON)

In the proposed antenna configuration, by changing the conditions of the PIN diodes, the desired band notching characteristics can be achieved. Geometry for the UWB monopole antenna (D_1=ON and D_2=OFF) (Fig. 5 (a)), with a single band-notched function (D_1=OFF and D_2=OFF) (Fig. 5 (b)) and with dual band-notched function (D_1=OFF and D_2=ON) (Fig. 5 (c)) are compared in Fig. 5.

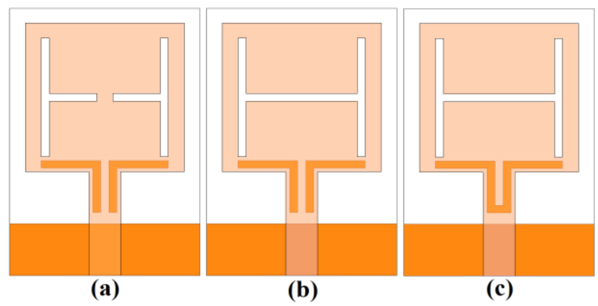

Fig. 5. Various structures for the proposed reconfigurable antenna: (a) D_1=ON & D_2=OFF, (b) D_1=OFF & D_2=OFF and (c) D_1=OFF & D_2=ON.

Simulated VSWR characteristics for the structures that were shown in Fig. 5 are compared in Fig. 6. As shown in Fig. 6, it is observed that the lower frequency band-notched function is affected by using an H-shaped slot on the radiating patch and by using an Ω-shaped conductor-backed plane, a dual band-notched performance has been obtained.

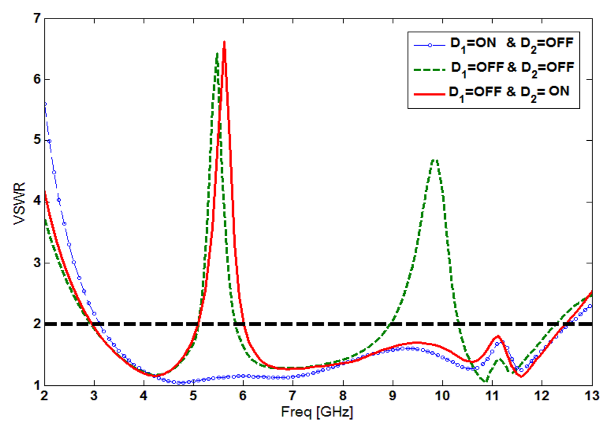

Fig. 6. Simulated VSWR characteristics for the various structures shown in Fig. 5.

To know the phenomenon behind this single or/and dual band-notched performance, the simulated current distributions for the proposed dual band-notched antenna on the radiating patch at 5.5 GHz (first band-notched) is presented in Fig. 7 (a). It is found that by inserting an H-shaped slot at radiating patch, a single band-notched function around 5-6 GHz can be achieved. Another important design parameter of this multi band-notched performance is an inverted Ω–shaped conductor-backed plane. By adding this structure in the ground plane, dual band-notched function has been obtained. The simulated current distributions for the proposed antenna in the ground plane at 9.5 GHz (second frequency band-notched) is presented in Fig. 7 (b). As shown in Fig. 7 (b), the current flows are more dominant around of the inverted Ω-shaped parasitic structure [14].

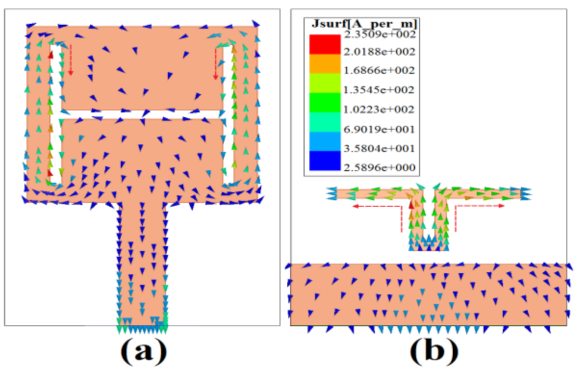

Fig. 7. Simulated surface current distributions for the antenna at the notched frequencies: (a) on the radiating patch at 5.5 GHz and (b) in the ground plane at 9.5 GHz.

For applying the DC voltage to PIN diodes, metal strips with dimensions of 1.2 mm ×0.6 mm were used inside the main slots. In the introduced design, HPND-4005 beam lead PIN diodes [15] with extremely low capacitance were used. For biasing PIN diodes, a 0.7 volt 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 embedded H-shaped slot was converted to the pair of T-shaped slot and the metal L-shaped strips are connected to each other and become a Ω-shaped strip. The desired notched frequency bands can be selected by varying the states of the PIN diodes, which changes the total equivalent length of the strip and slot structures.

The proposed microstrip monopole antenna with final design as shown in Fig. 8, was built and tested and the VSWR and characteristic was measured using a network analyzer.

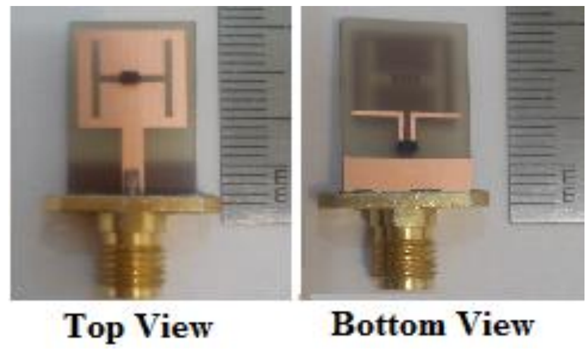

Fig. 8. Photograph of the realized antenna.

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) [16].

The measured and simulated VSWR characteristics of the proposed antenna in multimode operations were shown in Fig. 9. The presented antenna has the frequency band of 3.02 to over 12.43 GHz, with a variable single and/or dual band-stop performance.

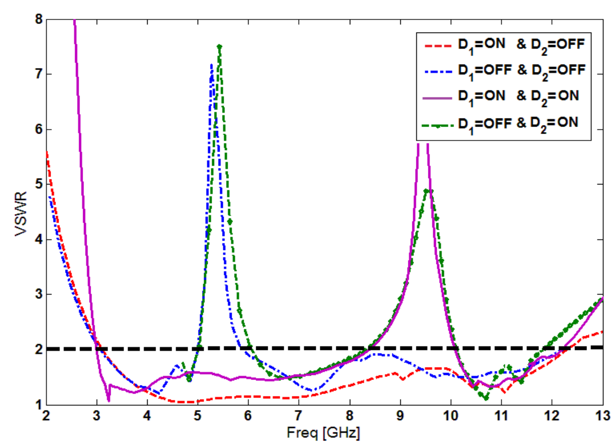

Fig. 9. Measured VSWR characteristics for the proposed antenna.

However, as seen, 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 and the wide range of simulation frequencies. In a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of a SMA connector and a microstrip line (the microstrip feed-line is excited by a SMA connector); whereas, the simulated results are obtained using the HFSS, that in HFSS by default, the antenna is excited by a wave port that it is renormalized to a 50-Ohm full port impedance at all frequencies. 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.

Figure 10 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-omnidirectional 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. [17-18].

Measured maximum gain levels of the proposed antenna with different conditions of active elements were shown in Fig. 11. The antenna gain has a flat property, which increases by the frequency. As illustrated, two sharp decreases of maximum gain in the notched frequency bands at 5.5 and 9 GHz are shown in Fig. 11. As seen, the proposed antenna has sufficient and acceptable gain levels in the operation bands [19].

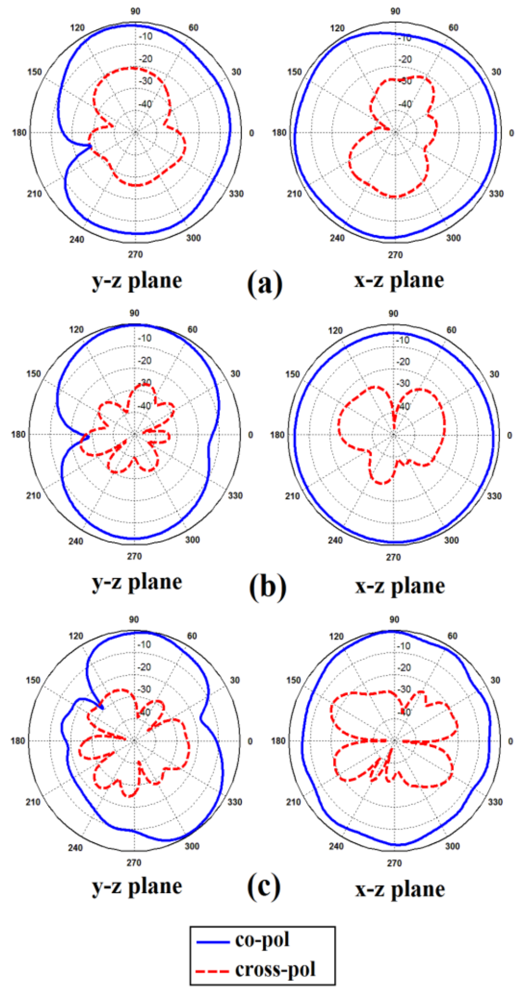

Fig. 10. Measured radiation patterns of the antenna for D_1=OFF & D_2=ON: (a) 4 GHz, (b) 7.5 GHz and (c) 11 GHz.

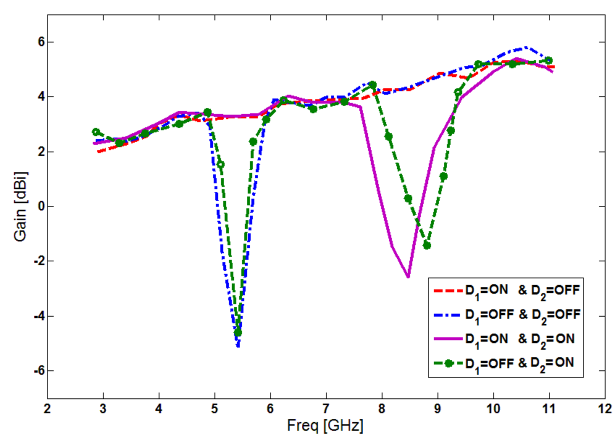

Fig. 11. Measured maximum gain characteristics for the proposed antenna.

IV. CONCLUSION

A new reconfigurable monopole antenna with electrically switchable notch band and multi-resonance functions for UWB applications is presented. The antenna is reconfigurable to suppress unwanted interfering signals by using PIN diodes integrated within the antenna configuration. By changing the on/off conditions of the PIN diodes, the antenna can be used to generate either a single or dual notch band to isolate and block any interference in the X-band and/or WLAN frequency bands. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB applications.

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REFERENCES

[1] H. Schantz, "The art and science of ultra wideband antennas," *Artech House*, 2005.
[2] 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.
[3] N. Ojaroudi, "A new design of koch fractal slot antenna for ultra-wideband applications," *21st Telecommunications Forum, TELFOR 2013*, Belgrade, Serbia, pp. 1051-1054, November 27-28, 2013.
[4] 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.
[5] 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.
[6] D. Piazza, P. Mookiah, M. D'Amico, and K. R. Dandekar, "Experimental analysis of pattern and polarization reconfigurable circular patch antennas for MIMO systems," *IEEE Trans. Veh. Technol*, vol. 59, pp. 2352-2362, 2010.
[7] S. L. S. Yang, A. A. Kishk, and K. F. Lee, "Frequency reconfigurable u-slot microstrip patch antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 7, pp. 127-129, 2008.
[8] S. Nikolaou, N. D. Kingsley, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, "UWB elliptical monopoles with a reconfigurable band notch using MEMS switches actuated without bias lines," *IEEE Trans. Antennas Propag.*, vol. 57, pp. 2242-2251, 2009.
[9] Y. Li, W. Li, and W. Yu, "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, no. 4, pp. 340-351, April 2012.
[10] "Ansoft high frequency structure simulation (HFSS)," ver. 13, *Ansoft Corporation*, 2010.
[11] N. Ojaroudi, "Design of microstrip antenna for 2.4/5.8 GHz RFID applications," *German Microwave Conference, GeMic 2014*, RWTH, Aachen University, Germany, March 10-12, 2014.
[12] N. Ojaroudi, "Microstrip monopole antenna with dual band-stop function for UWB applications," *Microw. Opt. Technol. Lett.*, vol. 56, pp. 818-822, 2014.
[13] N. Ojaroudi, "Circular microstrip antenna with dual band-stop performance for ultra-wideband systems," *Microw. Opt. Technol. Lett.*, vol. 56, pp. 2095-2098, 2014.
[14] M. R. Hamid, P. S. Hall, P. Gardner, and F. Ghanem, "Switched WLAN wideband tapered slot antenna," *Electronics Letters*, vol. 46, pp. 23-24, 2010.
[15] HPND-4005, "Beam lead PIN diode," *Avago Technologies*.
[16] K. C. Chen and R. Prasad, "Cognitive radio networks," *John Wiley & Sons*, West Sussex, United Kingdom, 2009.
[17] N. Ojaroudi, N. Ghadimi, and Y. Ojaroudi, "UWB microstrip-fed slot antenna with band-rejection performance using an SRR conductor-backed plane," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 3, pp. 203-207, 2014.
[18] N. Ojaroudi, M. Mehranpour, S. Ojaroudi, and Y. Ojaroudi, "Application of the protruded structures to design an UWB slot antenna with band-notched characteristic," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 2, pp. 184-189, 2014.
[19] 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.