Frequency Reconfigurable Monopole Antenna for Multimode Wireless Communications

Nasser Ojaroudi [1], Noradin Ghadimi [1], Yasser Ojaroudi [2], and Sajjad Ojaroudi [2]

[1] Young Researchers and Elite Club
Islamic Azad University, Ardabil Barnch, Ardabil, Iran
n.ojaroudi@yahoo.com, noradin.ghadimi@gmail.com

[2] Young Researchers and Elite Club
Islamic Azad University, Germi Barnch, Germi, Iran
y.ojaroudi@iaugermi.ac.ir, s.ojaroudi.p@yahoo.com

Abstract **─** This paper describes a compact reconfigurable microstrip antenna for multimode wireless communications, whose frequency characteristic can be reconfigured electronically to operate at 2.4 GHz (Bluetooth), 3.5 GHz (WiMAX) or 5.2/5.8 GHz (WLAN). The presented microstrip monopole antenna consists of an open-stub microstrip line with two inverted coupled U-shaped parasitic structures and ground plane. Reconfigurability is obtained by implementing two PIN diodes across the antenna structure and biasing these active elements. The proposed antenna can obtain good return loss property with -38 dB at 2.4 GHz, -42 dB at 3.5 GHz and -47 dB at 5.5 GHz. The proposed microstrip antenna fabricated on an FR4 substrate with thickness of 1.6 mm, relative permittivity of 4.4 and has a small size of 12×18 mm^2. The measured return loss characteristics are in good agreement with simulated results, which verified the reliability of the designed antenna. So this new design should have many applications in the circuit where reconfigurable antenna is used.

Index Terms **─** Bluetooth, reconfigurable microstrip antenna, WiAMX, wireless communication and WLAN.

I. INTRODUCTION

It is a well-known fact that printed microstrip antennas present really appealing physical features, such as simple structure, small size and low cost [1]. In recent years, reconfigurable devices have received growing attention in microwave components design. Reconfigurable antennas are becoming more and more important in defense and commercial wireless applications, since with such antennas, a single aperture can be used to support multiple functions at multiple frequency bands. This will result in a significant reduction in antenna size and cost. An antenna can be reconfigured using PIN diode or transistor switches [2]. In [3], a microstrip antenna was reconfigured using MEMS switches. The patch geometry was subdivided and the MEMS switches were positioned at different locations of the antenna to increase or decrease its size, thereby changing the antenna resonant frequency. A MEMS reconfigurable antenna was proposed in [4], where the beam was steered or shaped using micro actuators. A reconfigurable patch antenna with switchable slots using the p-i-n diodes was introduced in [5]. Switching to use p-i-n diodes helped achieve polarization diversity.

To satisfy the frequency needs of the systems of Bluetooth (2.4-2.484 GHz), Wireless Local Area Network (WLAN, 2.4-2.484 GHz, 5.15-5.35 GHz and 5.725-5.875 GHz) and the Worldwide Interoperability for Microwave Access (WiMAX 3.3-3.6 GHz), the antennas with multiple reconfigurable bands and excellent radiation characteristics are required. Various schemes about antennas with frequency reconfigurable characteristics, which are suitable for the multi-mode applications have been reported [6-8]. This work proposes a novel compact antenna with

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reconfigurable performance for Bluetooth, WiMAX and WLAN applications.

In the proposed antenna, to generate a variable single-band function, we use a pair of PIN diodes within the antenna configuration, which by changing the on/off conditions of the PIN diodes the antenna can be used to operate in variable modes. The measured impedance bandwidth of the antenna for 10 dB return loss is from 2 to 2.8 GHz (33%), 2.9 to 4.7 GHz (47%) and 4.5 to 6.5 GHz (36%); covering the major wireless communication bands like Bluetooth, WiMAX, WLAN, etc. The achieved results for the investigated structures and design curves can be applied to other frequencies of interest. The proposed microstrip antenna has a small dimension of 12×18×1.6 mm^3.

II. ANTENNA DESIGN

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

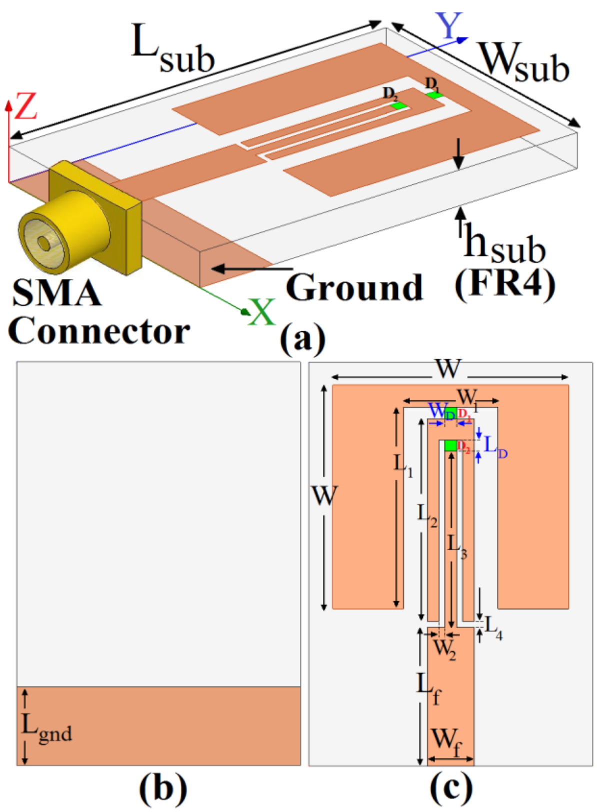

Fig. 1. Geometry of proposed antenna: (a) side view, (b) bottom layer and (c) top layer.

The basic monopole antenna structure consists of an open-stub microstrip line, a feed line and a ground plane. The antenna is connected to a feed line with width of W_f and length of L_f. 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. The Ansoft simulation software High-Frequency Structure Simulator (HFSS) [9] is used to optimize the design. The final dimensions of the designed antenna are specified in Table 1.

Table 1: Final dimensions of the antenna

Param.	mm	Param.	mm	Param.	mm
W_{sub}	12	L_{sub}	18	h_{sub}	16
W	10	L_{gnd}	3.5	W_f	2
L_f	6	W_1	4	L_1	9
W_2	0.25	L_2	9.25	L_3	7.5
L_4	0.25	W_D	0.5	L_D	0.5

III. RESULTS AND DISCUSSIONS

The proposed reconfigurable antenna with various design parameters was constructed and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The configuration of the various structures with different conditions of diodes for the proposed antenna used for simulation studies are shown in Fig. 2. Simulated return loss characteristics of the antenna for D_1 & D_2 = ON [Fig. 2 (a)], D_1 = OFF & D_2 = ON [Fig. 2 (b)] and D_1 & D_2 = OFF [Fig. 2 (c)], was shown in Fig. 3.

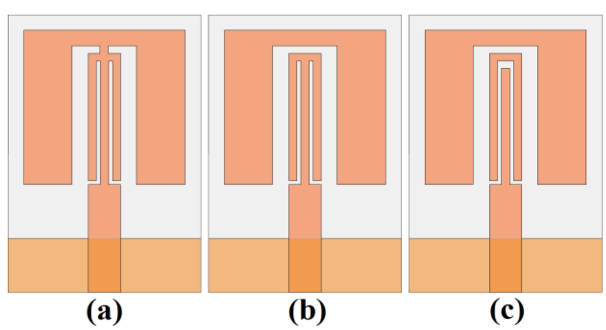

Fig. 2. The various structures of the proposed antenna for: (a) D1 & D2 = ON, (b) D1 = OFF & D2 = ON and (c) D1 & D2 = OFF.

As shown in Fig. 3, by changing the on/off conditions of the diodes, the antenna can be used to operate in variable modes, which for D_1 = ON & D_2 = ON, D_1 = OFF & D_2 = ON and D_1 & D_2 = OFF antenna can operate at 2.4 GHz (Bluetooth), 3.5 GHz (WiMAX) and 5.5 GHz(WLAN), respectively.

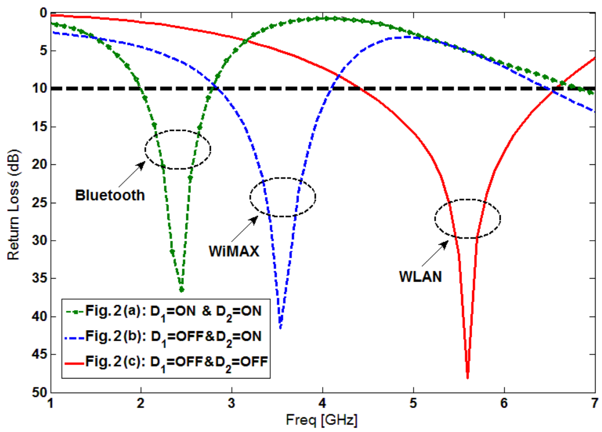

Fig. 3. Simulated return loss characteristics for the proposed antenna.

The simulated current distributions for various structures of the presented reconfigurable antenna were shown in Fig. 4. It can be observed by controlling the states of diodes, the distributions of surface current are altered and then three resonant frequency bands can be reconfigurable at 2.4, 3.5 and 5.5 GHz, due to the resonant properties of PIN diodes conditions [10]. Also, the input impedance of the various monopole antenna structures that studied in Fig. 2 on Smith charts is shown in Fig. 5.

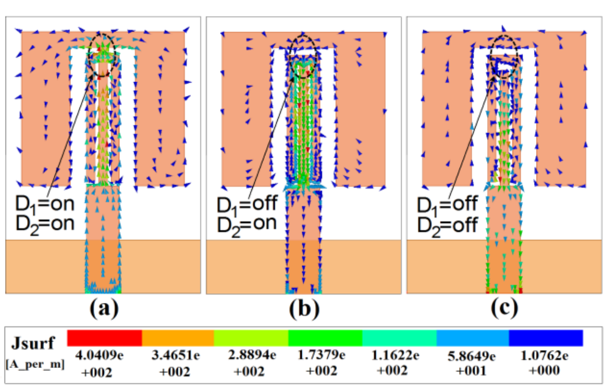

Fig. 4. Simulated surface current distributions for the proposed antenna at different resonance frequencies: (a) 2.4 GHz, (b) 3.5 GHz and (c) 5.5 GHz.

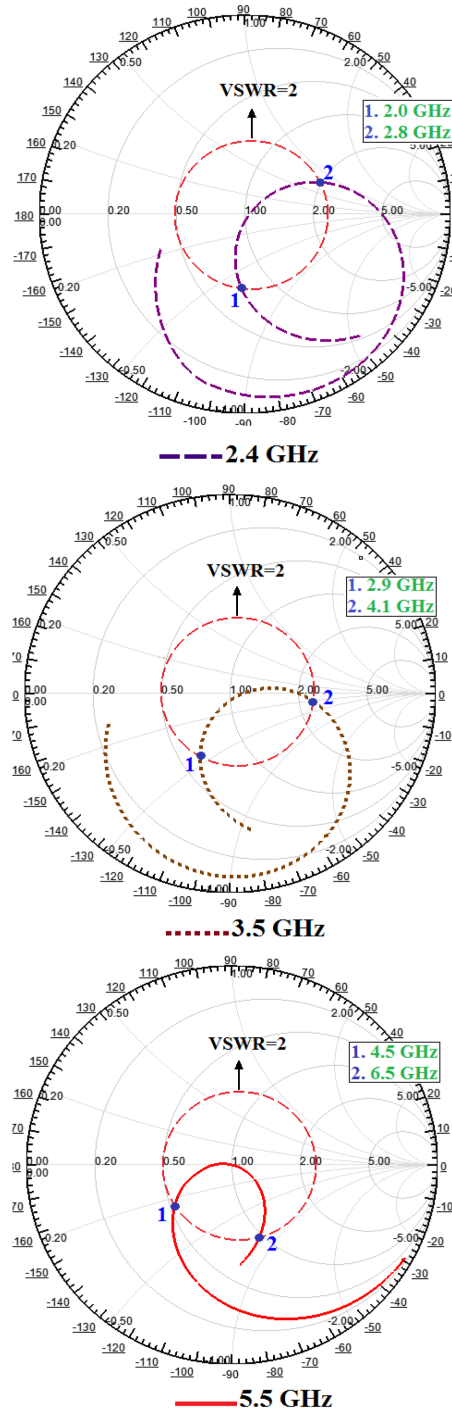

Fig. 5. Simulated input impedances on a Smith-chart for the various structures shown in Fig. 3.

As shown in Fig. 6, the proposed antenna is successfully implemented and tested. Figure 7 shows the measured and simulated return loss characteristics of the proposed reconfigurable antenna. As illustrated, the simulation results show reasonable agreement with the measurement results [11-16].

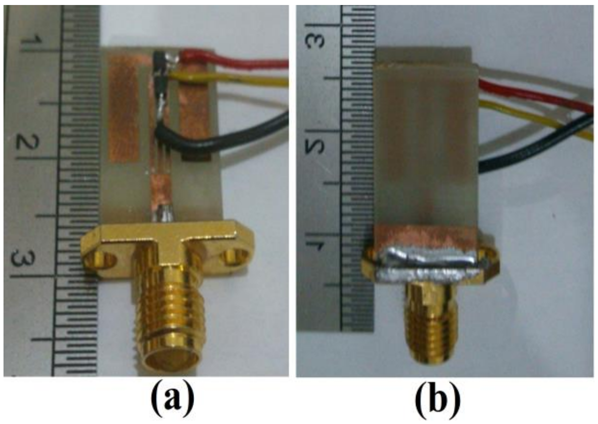

Fig. 6. Photograph of the realized antenna: (a) top view and (b) bottom view.

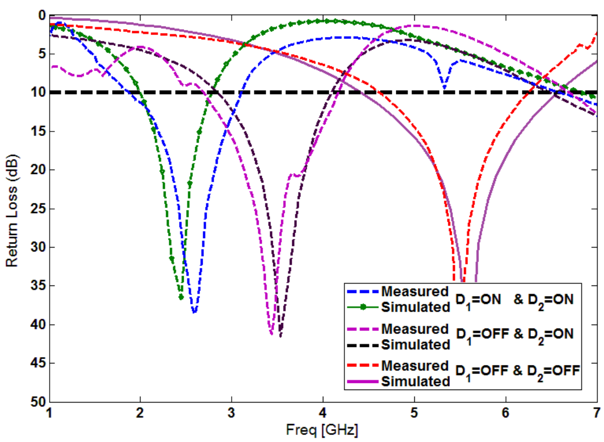

Fig. 7. Measured and simulated return loss characteristics for the proposed antenna.

As seen, the antenna can obtain good return loss characteristics with -35 dB at 2.4 GHz, -42 dB at 3.5 GHz and -40 dB at 5.5 GHz.

Figure 8 depicts the measured radiation patterns, including the co-polarization in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that quasi-omnidirectional radiation patterns can be observed on the H-plane. 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 the 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 [17-20]. Figure 9 shows the measured maximum gain of the proposed antenna for the various conditions of switches. As illustrated, the proposed reconfigurable antenna has good antenna gain properties in 2.4, 3.5 and 5.5 GHz for different conditions of the PIN diodes [21-26].

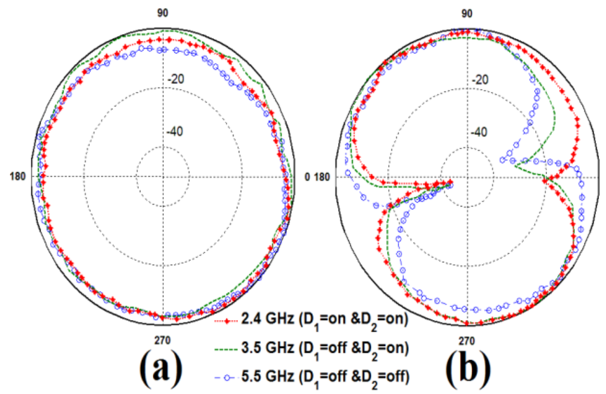

Fig. 8. Measured radiation patterns of the proposed antenna: (a) H-plane and (b) E-plane.

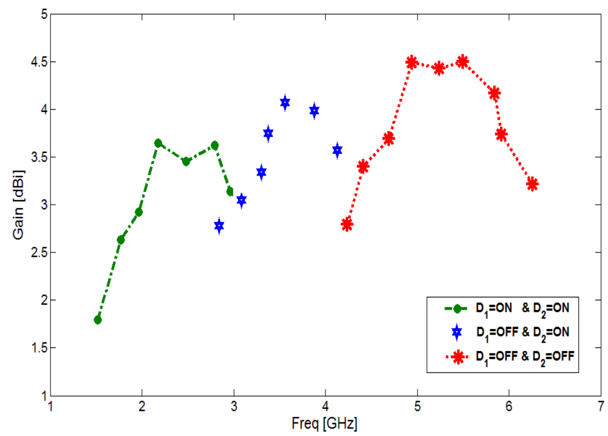

Fig. 9. Measured maximum gains of the proposed reconfigurable antenna.

The simulated radiation efficiencies of the proposed antenna are shown in Fig. 10. Results of the calculations using the software HFSS indicated that the proposed antenna features a good efficiency, being greater than 75% across the entire radiating band. Also, the simulated directivity characteristics for the proposed antenna are illustrated in Fig. 10. As seen, the directivity characteristics of the proposed monopole antenna have a variation similar to other monopole antennas directivity at Bluetooth, WiMAX and WLAN frequencies bands [27-30].

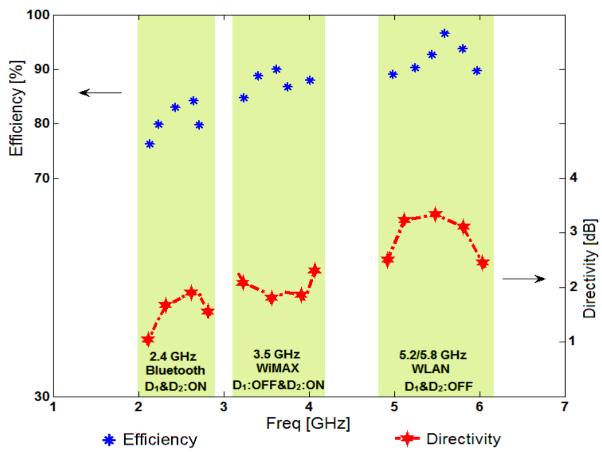

Fig. 10. Simulated directivity and radiation efficiency characteristics of the proposed monopole antenna.

IV. CONCLUSION

In this paper, a novel printed frequency reconfigurable antenna for Bluetooth, WLAN and WiMAX applications is proposed. The proposed antenna has low profile, symmetrical structure and excellent radiation patterns properties. In order to generate a variable single frequency-band function, we use a pair of PIN diodes within the antenna configuration, which by changing the on/off conditions of the PIN diodes, the antenna can be used to operate at variable modes. An excellent agreement between measured and simulated was obtained. The presented antenna is a good choice for multi-frequency wireless communication systems.

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