A Novel Multiband Frequency Reconfigurable PIFA Antenna

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Abstract— **In this paper, we design and implement a novel six-band frequency reconfigurable Planar Inverted-F Antenna (PIFA) for GSM1800, WCDMA, m-WiMAX and WLAN applications. The antenna consists of three radiator patches whose optimal parameters are iteratively selected on different configurations using Genetic Algorithm (GA). PIN-diodes are used in appropriate locations to accurately control the operating frequency bands. Simulation results show that depending on ON/OFF states of the PIN-diodes, the antenna can operate in six applicable frequency bands i.e., 1.8 GHz, 2.1 GHz, 2.4 GHz, 3.5 GHz, 3.7 GHz and 5.8 GHz with corresponding peak gains of 3.34 dBi, 2.8 dBi, 5.16 dBi, 3.95 dBi, 5.05 dBi and 6.98 dBi, respectively. The efficiency of the six frequency bands is spread from 64% to 96%. The overall size of the radiated parts is 42.5×20 mm^2 which makes it easy and possible to be integrated into small wireless handsets. Measurements have also been carried out on a fabricated prototype in order to validate the correctness our design.**

Keywords— PIFA, frequency reconfigurable antenna, PIN diode, optimization algorithm.

I. INTRODUCTION

Nowadays, due to the development of the wireless communication systems, mobile terminals are expected to perform different functions. Thus, terminals' antennas are required to be smart, compatible and multi-band satisfactory. Different approaches have been proposed to cope with the issue, among which, reconfigurable antenna is one of the most promising solutions [1]. In a reconfigurable antenna, different characteristics such as frequency, polarization, and radiation pattern are automatically changed to adapt with systems or channel conditions [2]. Several techniques have been proposed to design reconfigurable antennas such as RF-MEM [3][4], PIN-diode [5][6], varactor diode [7][8].

In wireless system applications, the need to use multiband reconfigurable antenna is huge. Several studies on multiband reconfigurable PIFA antennas have been published. In [9], a reconfigurable frequency PIFA antenna is designed for four applications (USPCS, WLAN, WCDMA, m-WiMAX). The antenna advantages are simple structure, good average efficiency (84%). However, the antenna has a high profile (70×30×9mm^3) and a low average gain (2.12 dBi). In [10], the published antenna occupies a size of 53×48×8 mm^3 with six frequencies. By switching states of five PIN diodes, the proposed PIFA antenna is able to cover LTE/GSM850/Wi-Max/WLAN bands with average gain is 3.5dBi but the medium-low efficiency is 67.8%. The reconfigurable PIFA antenna with a parasitic strip line is reported in [11], which occupies an overall size of 50×90 mm^2. This antenna operates at five frequencies with the efficiency of over 46 % but the lowest gain is 0.89 dBi. However, those above works show that a design expectation of low profile, high average gain, and high average efficiency has not been yet achieved simultaneously.

In a design process of a reconfigurable antenna, the parameters optimization is necessary and important. Many articles with different optimization techniques were reported, such as Genetic Algorithms (GA) [12][13], Particle Swarm[14], Clonal Selection Algorithm [15], Neural Network [16]. However, these articles are only interested in optimizing a specific configuration of the antenna, while the reconfigurable antenna operates in several different configurations. Therefore, there should be necessary and interesting to optimize the parameters for all configurations of the antenna.

Based on the above discussions, we design a novel frequency reconfigurable PIFA antenna using three radiator patches and three PIN-diodes. An optimize algorithm is used to optimize antenna's parameters in different configurations. The proposed reconfigurable PIFA antenna operates in four configurations and resonates at six frequencies to serve GSM1800, WCDMA, m-WiMAX and WLAN applications. The antenna has low profile 42.5×80×3 mm^3. The major advantage of this reconfigurable antenna is high average gain and high efficiency, over 4.5dBi and 84 %, respectively.

In this paper, the design process of the proposed reconfigurable PIFA antennas is detailed. Section II describes the frequency reconfigurable antenna geometric and parametric optimize. In Section III, the measurement and simulation results are presented and discussed. Finally, Section IV concludes our paper.

II. DESIGN OF RECONFIGURABLE PIFA ANTENNA

A. Geometric of reconfigurable antenna

The initial antenna is illustrated in **Figure 1**, the proposed reconfigurable PIFA antenna has three radiator patches: the main radiator plate (P1) and two additional radiating elements (P2, P3). All patches are printed on an FR4 substrate with a relative permittivity ε_r of 4.4. Two shorting pins are used to connect two additional radiators to ground plane. The size of the ground plane is 42.5×80 mm^2 with thickness of 0.8 mm.

The distance between radiator patches and the ground plane is 3 mm to reduce the PIFA antenna's size.

The proposed reconfigurable PIFA antenna is designed base on T-shape structure. Antenna's physical parameters were investigative and simulated with Microwave Studio of the CST. The shape and structure of the radiator plates is the result of the study process shown in **Figure 2** and **Figure 3**. First, we start the design with a T-Shaped P1 main radiation plate as show in **Figure 2(a)**. The antenna tends to operates and resonance at near 3.5 GHz, but impedance matching is not good. In order to move the resonance frequency downward lower frequencies, the inverted L-shape P2 is added to the right side of P1 (**Figure 2(b)**), and the antenna operates at near 1.8 GHz frequency. Finally, as shown in **Figure 2(c)**, the radiation plate P3 is added to the left side of P1, PIN-diodes (OFF state) are used to connect the radiator plates. The antenna can now operate at near 1.8 GHz and 2.4 GHz frequencies. We decided to use this result to continue design the proposed antenna.

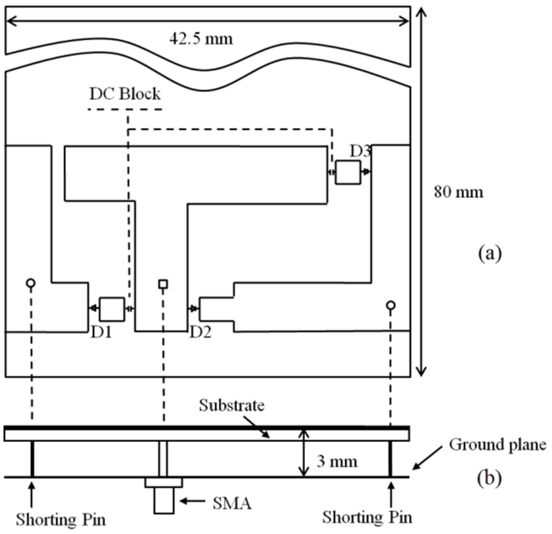


Figure 1. Structure of the proposed reconfigurable PIFA antenna (a) Top view, (b) Front view.

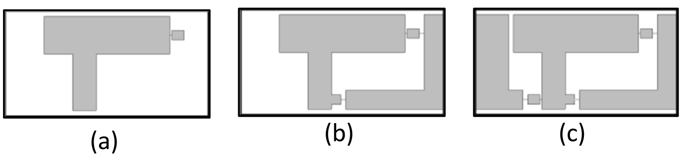


Figure 2. Different antenna's radiator structures

TABLE I. SURVEY CONFIGURATIONS BASED ON SWITCHING STATE OF THE PIN DIODES

No	State of Diodes	Frequency(GHz)	S|11| (dB)
1	All diodes are OFF.	1.93	-18.8
		2.46	-13.5
2	D1 and D3 are ON. D2 is OFF.	3.58	-19.8
3	D1 and D2 are ON. D3 is OFF.	2.18	-13.7
		3.64	-14.3
4	All diodes ON	5.74	-18.4

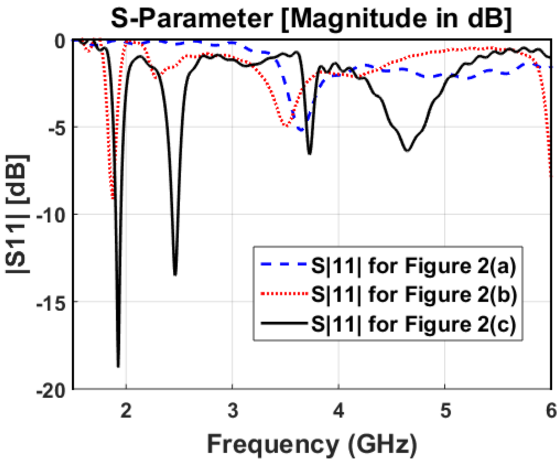


Figure 3. The frequency responses of various antenna structures shown in Figure 2.

Three PIN-diodes (D1, D2 and D3) are used to connect main radiator with two additional radiators. Depending on the switching states of the PIN-diodes, the proposed antenna will operates in several different configurations as shown in **TABLE I**. When three PIN-diodes are on state OFF, the antenna has only the main radiator, which operates at near 1.8 and 2.4 GHz, as an IFA antenna. When one of three PIN diodes is ON, the main radiator is connected to an additional radiator and turn into a PIFA antenna. When D1 and D3 are on state ON with D2 is OFF, the proposed antenna operates at near 3.5 GHz. In another case, D1 and D2 turn ON, D3 is OFF, and the antenna operates at near 2.1 GHz and 3.7 GHz. When three PIN-diodes are all on state ON, the antenna operates at near 5.8 GHz.

Three PIN diodes are Skyworks SMP1345-079LF, the simple equivalent circuits of a PIN-diode is shown in Figure **4**. The circuit parameters are provided from the manufacturer's datasheet where L_S=0.7nH, R_S=1.5Ω and C_R= 1.8pF. Two capacitors (C=33pF) are used as DC block, capacitor's placement ensures that the power supply for each diode does not affect the remaining PIN-diodes.

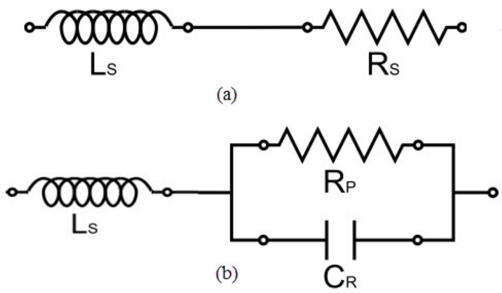


Figure 4. Equivalent circuit of a PIN-diode (a) Forward biased, (b) Reverse biased.

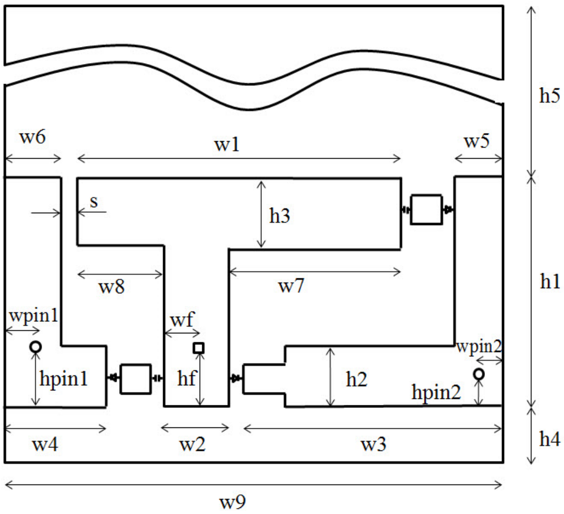


Figure 5. Dimension of the proposed PIFA antenna

B. Optiminze parameters

In the base configuration, all PIN-diodes are OFF, the proposed antenna has only the main radiator plate, without connection between P1, P2 and P3. As a result, quarter-wave lengths are chosen at approximately 43.5mm and 30 mm, at near 1.8 GHz and 2.4 GHz, respectively. Hence, the 1st configuration of antenna is composed as the following: *w2*, *w7*, *w8*, *h1* and *h3* parameters (**Figure 5**). The proposed antenna is fed through a discrete port (i.e., coaxial probe), the position of fed is located at *wf* and *hf*. In order to verify the theoretical computation of the PIFA antenna's parameters [17], the initial antenna is simulated using CST software to obtain the following values: *w9*=40mm, *h1*=20mm, *w1*=32mm, *h3*=5mm, *w2*=5mm, *wf*=2.5mm, *hf*=3mm.

The proposed reconfigurable PIFA antenna has four operating configurations; each configuration has a particular purpose, such as resonant frequency range, bandwidth and performance. In a configuration, values of a group of parameters can influence greatly to the operation of the proposed antenna. In reality, the optimal result of a configuration doesn't mean that this will produce the same results for the remaining configuration. For example, after a group of parameters is optimized for 1st configuration, we will optimize the next group for 2nd configuration. But when we set the operation configuration of the antenna back to 1st configuration, the result can be varied and exceeded the permitted range compared with the early optimal result. In this case, we have to optimize the values of the group of parameters for 1st configuration, then checking for the operation of the antenna in 2nd configuration, and re-optimizing 2nd configuration if it is necessary. This process is continued until we find a set of parameters' values which is optimized for both 1st and 2nd configuration. We can conclude that the optimize process for all configurations is vital.

In the proposed reconfigurable PIFA antenna designing process, the parameters are optimized according to the following algorithm:

Step 1: The initial parameters are set: the operational objectives of configurations; the values of antenna initial parameters.

Step 2: Create the antenna and solve in CST with 1st configuration. The frequency, gain and the S-parameter will be called by the fitness function.

Step 3: The GA [18] is used to assign a fitness value to each of the individuals in the population, in which the fitness value is calculated using the operating frequency, gain, and the S11 parameter of antenna exported from CST. In particular, CST executes Crossover and Mutation processes until parameters of the 1st configuration approaches designated ones.

Step 4: Set the antenna operates in 2nd configuration. Use GA optimizes according to the operation objective of the 2nd configuration.

Step 5: Set the antenna operates in the 1st configuration and solve again. The operation results can be changed, and if so, then run again from step 3.

Step 6: Carried out with the remaining configuration until reaching the final result.

In our algorithm, the important point is that GA can only be used optimize some parameters effect on each configuration. This process is repeatedly until the simulation results of all configurations meet the target goal.

The Visual Basic for Application language is used to program the optimization algorithm into CST. After the implementation of our algorithms, parameter's values are determined and shown in **TABLE II**.

TABLE II. ANTENNA DIMENSIONS (UNIT: mm)

w1	*29.5*	w8	*6*	wpin1	*2*
w2	*5*	w9	*42.5*	wpin2	*3.5*
w3	*23.5*	h1	*20*	hpin1	*4*
w4	*10*	h2	*4*	hpin2	*2*
w5	*4*	h3	*8*	wf	*2.5*
w6	*7*	h4	*10*	hf	*6*
w7	*18.5*	h5	*50*	s	*1*

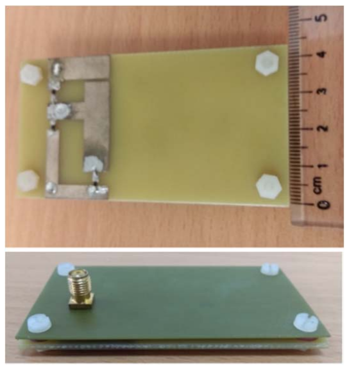
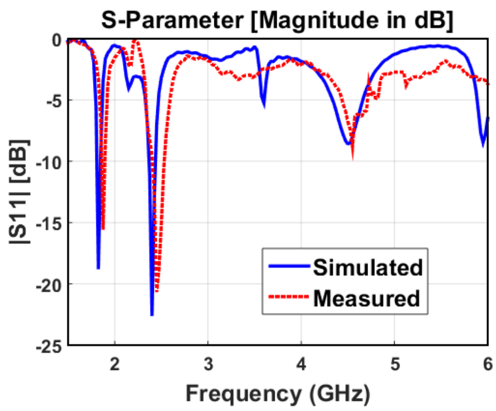
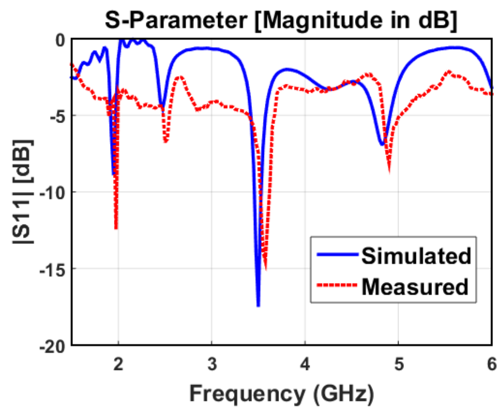


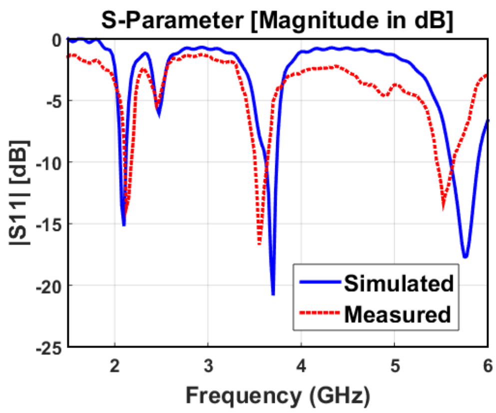
Figure 6. Prototype of the proposed antenna.



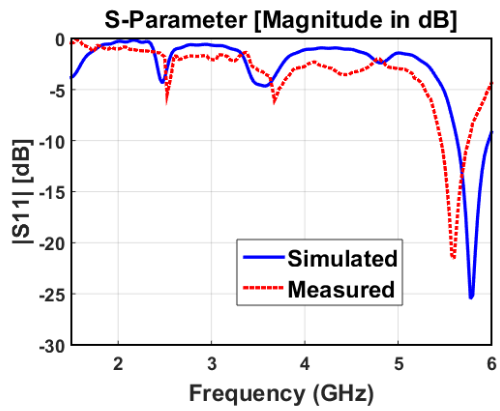
(a) State 1 at 1.8 and 2.4 GHz



(b) State 2 at 3.5 GHz



(c) State 3 at 2.1 and 3.7 GHz



(d) State 4 at 5.8 GHz

Figure 7. Measured and simulated S|11| response of the proposed antenna.

III. SIMULATED AND MEASURED RESULTS

The proposed reconfigurable PIFA is fabricated on FR4 dielectric substrate with a permittivity of 4.4 and a dimension of 42.5×80×1.6mm^3. The radiator patches have dimension of 42.5×20×0.035mm^3. Figure **6** shows the photograph of a manufactured antenna prototype.

The proposed antenna operates in four configurations and at six different frequencies as following: State 1 (1.8 GHz and 2.4 GHz), State 2 (3.5 GHz), State 3 (2.1 GHz and 3.7 GHz) and State 4 (5.8 GHz). The simulation results show that all configuration of the antenna has VSWR<2 at desired frequency bands. Figure **7** shows the measured and simulated results of S|11| in four states with six resonant frequencies. **TABLE III** shows the different states ON/OFF of the PIN-diodes and corresponding frequency bands of the antenna. As in Figure **7**, there are small differences between simulated and measured results in each state. This difference is attributed due to the realization accuracy of fabrication, the effect of material and the quality of PIN-diodes. However, these results can be acceptable.

The radiation pattern (3D and polar graph) for the six frequencies of the antenna are shown in Figure **8**. These results show high-gain, the radiation curves is smooth at all frequencies. Details about gain, total efficiency at each frequency are shown in **TABLE IV**.

TABLE III. THE DIFFERENT STATES OF THE PROPOSED RECONFIGURABLE PIFA ANTENNA.

State	Diode	Frequency	VSWR
State 1	All diodes are OFF.	1.8 GHz	1.12
		2.4 GHz	1.2
State 2	D1 and D3 are ON. D2 is OFF.	3.5 GHz	1.23
State 3	D1 and D2 are ON. D3 is OFF.	2.1 GHz	1.3
		3.7 GHz	1.16
State 4	All diodes ON	5.77 GHz	1.09

TABLE IV. GAIN AND RADIATION EFFICIENCY OF THE PROPOSED PIFA ANTENNA.

State	Frequency	Gain (dBi)	Total efficiency (%)
State 1	1.8 GHz	3.34	87
	2.4 GHz	5.16	96
State 2	3.5 GHz	3.95	90
State 3	2.1 GHz	2.8	78
	3.7 GHz	5.05	64
State 4	5.8 GHz	6.98	93

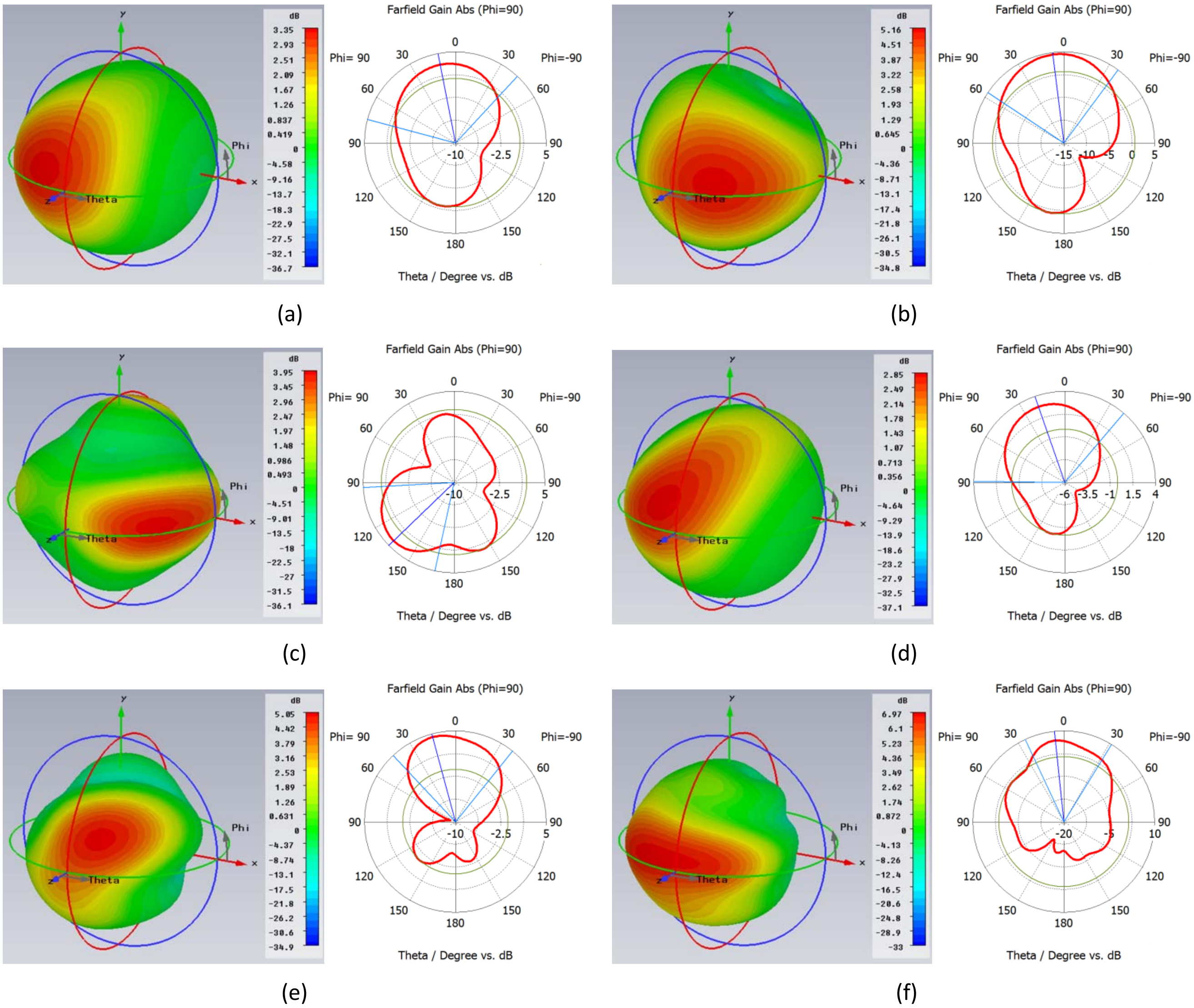


Figure 8. The simulated 3D and 2D radiation pattern of the proposed PIFA antenna in four states at (a) 1.8 GHz (b) 2.4 GHz (c) 3.5 GHz (d) 2.1 GHz (e) 3.7 GHz (f) 5.8 GHz.

IV. CONCLUSIONS

In this paper, the design of the frequency reconfigurable PIFA antenna is presented. Three PIN diodes were used to achieve frequency reconfigurability. The GA optimization algorithm is used to determine the values of antenna's parameters. Depending on the switching of PIN diodes, the proposed antenna is able to generate four states which operate at six different frequency bands: 1.8 GHz, 2.4 GHz, 2.1 GHz, 3.5 GHz, 3.7 GHz and 5.8 GHz. The average gain of the proposed antenna is 4.55 dBi and average radiation efficiency is 84.67%. With this result, the proposed antenna can be equipped for wireless communication mobile devices that operate at GSM1800, WCDMA, WLAN/Bluetooth and m-WiMAX frequency bands.

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REFERENCES

[1] Y. Tawk, S. E. Barbin, and C. G. Christodoulou, "Reconfigurable Antennas: Design and Applications," *Proc. IEEE*, vol. 103, no. 3, pp. 424–437, Mar. 2015.

[2] C. G. Christodoulou, Y. Tawk, S. A. Lane, and S. R. Erwin, "Reconfigurable Antennas for Wireless and Space Applications," *Proc. IEEE*, vol. 100, no. 7, pp. 2250–2261, Jul. 2012.

[3] K. R. Boyle and P. G. Steeneken, "A five-band reconfigurable PIFA for mobile phones," *IEEE Trans. Antennas Propag.*, vol. 55, no. 11, pp. 3300–3309, 2007.

[4] M. Unlu, H. Mopidevi, A. Zohur, and B. A. Cetiner, "Frequency reconfigurable, 220–5000 MHz, five-band RF MEMS PIFA," in *2012 IEEE 55th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2012, pp. 65–68.

[5] T. D. Nguyen, Y. Duroc, V. Y. Vu, and T. P. Vuong, "Novel

reconfigurable 8 - Shape PIFA antenna using PIN diode," in *International Conference on Advanced Technologies for Communications*, 2011, pp. 272–275.

[6] Y. K. Park and Y. Sung, "A reconfigurable antenna for quad-band mobile handset applications," *IEEE Trans. Antennas Propag.*, vol. 60, no. 6, pp. 3003–3006, 2012.

[7] M. Kehn, T. Quevedo, and E. Rajo-Iglesias, "Reconfigurable Loaded Planar Inverted-F Antenna Using Varactor Diodes," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 466–468, 2011.

[8] B. Avser and G. M. Rebeiz, "Tunable Dual-Band Antennas for 0.7-1.1-GHz and 1.7-2.3-GHz Carrier Aggregation Systems," *IEEE Trans. Antennas Propag.*, vol. 63, no. 4, pp. 1498–1504, Apr. 2015.

[9] J. H. Lim, G. T. Back, Y. Il Ko, C. W. Song, and T. Y. Yun, "A reconfigurable PIFA using a switchable PIN-diode and a fine-tuning varactor for USPCS/WCDMA/m-WiMAX/WLAN," *IEEE Trans. Antennas Propag.*, vol. 58, no. 7, pp. 2404–2411, Jul. 2010.

[10] M. Abou Al-Alaa, H. A. Elsadek, E. A. Abdallah, and E. A. Hashish, "PIFA frequency reconfigurable antenna," in *IEEE Antennas and Propagation Society, AP-S International Symposium (Digest)*, 2014, pp. 1256–1257.

[11] S. W. Lee and Y. J. Sung, "Reconfigurable PIFA with a parasitic strip line for a hepta-band WWAN / LTE mobile handset," *Microwaves, Antennas Propagation, IET*, vol. 9, no. May 2014, pp. 108–117, 2015.

[12] T. D. Nguyen, Y. Duroc, V. Y. Vu, and T. P. Vuong, "Genetic algorithm for optimization of L-shaped PIFA antennas," *Int. J. Microw. Wirel. Technol.*, vol. 3, no. 06, pp. 691–699, 2011.

[13] S. Song and R. D. Murch, "An efficient approach for optimizing frequency reconfigurable pixel antennas using genetic algorithms," *IEEE Trans. Antennas Propag.*, vol. 62, no. 2, pp. 609–620, 2014.

[14] H. Rajagopalan, J. M. Kovitz, and Y. Rahmat-Samii, "MEMS reconfigurable optimized e-shaped patch antenna design for cognitive radio," *IEEE Trans. Antennas Propag.*, vol. 62, no. 3, pp. 1056–1064, 2014.

[15] A. Akdagli, K. Guney, and B. Babayigit, "Clonal selection algorithm for design of reconfigurable antenna array with discrete phase shifters," *J. Electromagn. Waves Appl.*, vol. 21, no. 2, pp. 215–227, 2007.

[16] A. Patnaik, D. Anagnostou, C. G. Christodoulou, and J. C. Lyke, "Modeling frequency reconfigurable antenna array using neural networks," *Microw. Opt. Technol. Lett.*, vol. 44, no. 4, pp. 351–354, 2005.

[17] H. T. Chattha, "A Comprehensive Parametric Study of Planar Inverted-F Antenna," *Wirel. Eng. Technol.*, vol. 03, no. 01, pp. 1–11, 2012.

[18] R. L. Haupt, "An introduction to genetic algorithms for electromagnetics," *IEEE Antennas Propag. Mag.*, vol. 37, no. 2, pp. 7–15, 1995.