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Compact reconfigurable PIFA antenna for wireless applications

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ABSTRACT

This paper presents, new compact and multiband frequency reconfigurable planar inverted-F antenna (PIFA). The antenna is designed and optimized to cover mobile application devices like GPS, WLAN/Wi-Fi, WiMAX, 4G LTE, UWB, and satellite applications. The frequency reconfigurability is obtained by using only a single RF switch (PIN diode) for changing the operating frequency. The antenna dimensions are 45.6 x 39.6 x 1.6 mm^3 printed on an FR-4 epoxy substrate with relative dielectric constant $\varepsilon r = 4.3$, loss tangent tan (δ) =0.002 and 50 Ω coaxial feed line. The proposed antenna has two patches connected by a single PIN diode. The antenna introduces nine resonant frequencies under ($S11 \leq -10$ dB) which are: 0.980 GHz, 3.392 GHz, 3.924 GHz, 4.554 GHz, 5.82 GHz, 6.81 GHz, 7.305 GHz, 8 GHz and 8.105 GHz in the ON and OFF states of the PIN diode which are applicable to cover GSM900, WLAN/Wi-Fi, WiMAX, 4G LTE, UWB, and satellite systems. The obtained maximum simulated gain is 8.45 dB at 6.81 GHz. The lowest return loss is obtained to be -42 dB at 5.854 GHz. Detailed simulation and measurement results are explored and studied in this research. The CST software is used to simulate and optimize the proposed PIFA antenna. The proposed antenna has been fabricated and produced a good agreement with the simulation results.

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1. INTRODUCTION

The continuous development in communications especially in the wireless communications needed more compact and multifunctional devices to be designed and applicated. The communication standards like (PCS, GPS, DCS1800, UMTS, LTE2100 GSM1800/1900, Wi-Fi, and WiMAX, etc.) require to be developed by using small radio receivers with small and low profile antennas. To cover such different standards, small structures and multiband antennas are requested for such applications. The decreasing in the antenna dimensions can still while the specifications allow switching between different standards [1-10]. Microstrip patch is commonly used in the design of the PIFA antenna due to the compact size, low cost, low profile and multifunctional, more details in [11, 12]. Slot-type antennas, monopole antennas, and planar inverted-F antenna (PIFAs) are the most current multi-band antenna designs being used in mobile applications. A multiband PIFA is well-known and most likely used for mobile application devices [5]. Because of suitable Specific Absorption Rate (SAR), low profile, low cost, omnidirectional pattern, and easy fabrication the PIFA antennas are generally used for internal antenna, but it has some drawbacks such as narrow bandwidth, low gain, and low efficiency [2, 6, 13, 14]. There are four classes of reconfiguration techniques, frequency reconfigurability [3, 5, 15, 16], radiation pattern reconfigurability [17], polarization reconfigurability [18], and the combination of them [17, 19]. Frequency reconfigurability can be achieved by using electronic switches like PIN [2, 7, 13, 20] and varactor diodes [21, 22] to adjust the frequency of operation, and by an electromechanical switch (MEMS) [1, 23]. In this paper, a new multiband and compact size frequency reconfigurable PIFA is designed to cover the operation bands of mobile application devices. The contributions behind this research are:

- A New compact frequency reconfigurable PIFA antenna with wide frequency reconfigurability range from 0.6 to 9 GHz, which is applicable to cover nine different systems such as GSM900, WLAN/Wi-Fi, WiMAX, 4G LTE, UWB, and satellite systems using only single PIN diode.
- A new compact frequency reconfigurable PIFA antenna design having a single patch and partial GND plane with areas of 33 x 30 mm^2 and 45.6 x 39.6 mm^2 respectively, which it can operate with a maximum gain of 8.43 dB.

2. PIFA ANTENNA THEORY

A rectangular element with a short metallic plate to the ground plane made up a PIFA. The first resonant frequency of the non-slotted PIFA is given by (1):

$$fr = \frac{C}{4(Lp+Hres)} \qquad (1)$$

where C is the speed of light, Lp is the length and Hres is the height of the radiating element [1].

The antenna takes the inverted-F shape as shown in Figure 1 (a), and it resonates at a quarter-wavelength because of the short-pin at the end. The feeding of the antenna found between the shorted and open end, and the distance from the feeding to the short-pin controls the input impedance, whenever it closed to the short-pin the impedance decreased as shown in Figure 1 (b) [24]. From Figure 1 (b) the PIFA antenna has a length (L1), width (L2), short-pin width (W), and distance (D) from the short-pin. The short-pin at high frequencies (≥1 GHz) introduces parallel inductance (jXL) with the antenna impedance (ZA) and it shifts the resonant frequency as shown in Figure 2.

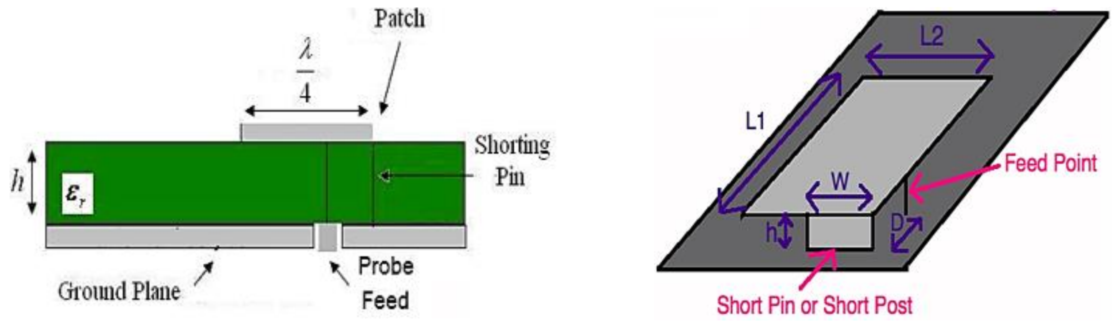


Figure 1. Planar inverted-F antenna (PIFA)

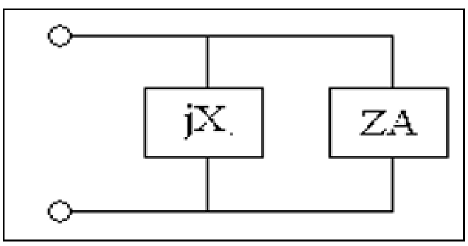


Figure 2. Equivalent circuit of PIFA antenna

The resonant frequency can be found by (2), which represents the general form of a PIFA antenna according to the far-field criteria from the farthest point on the antenna clockwise and counterclockwise the resonant frequency is given by:

$$L1 + L2 - W = \frac{\lambda}{4} \quad (2)$$

if (W<<L2), W is just a pin, so (1) can be approximated to:

$$L1 + L2 = \frac{\lambda}{4} \quad (3)$$

if (W = L2) the antenna operates in maximum efficiency and (1) becomes:

$$L1 = \lambda/4 \quad (4)$$

after that to find the resonant frequency substitute (5):

$$Fr = \frac{C0}{\lambda\sqrt{\varepsilon r}} \quad (5)$$

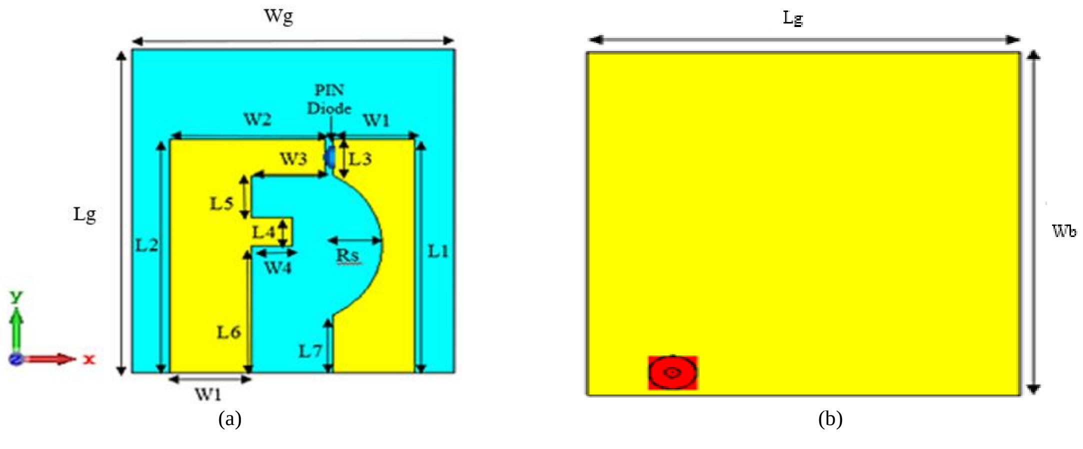
3. PROPOSED PIFA ANTENNA DESIGN AND PIN DIODE MODELING

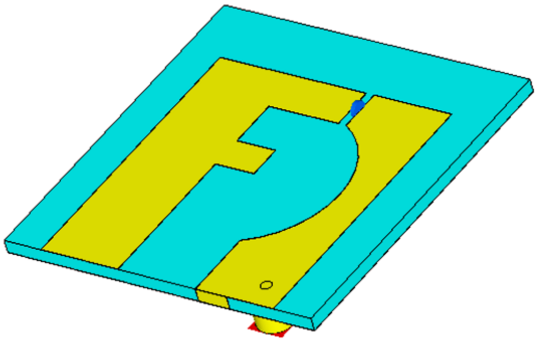
3.1. Proposed PIFA antenna design

The proposed design of multiband reconfigurable PIFA can be shown in Figure 3. After the study of the latest researches and determine which applications to cover by the antenna the proposed antenna shape is chosen after some parametric study of the patch dimensions to be completely different from the literature. The antenna is consists of a patch printed on an FR-4 substrate with εr = 4.3, tan (δ) =0.002 relative dielectric constant and loss tangent respectively, the thickness of (1.6 mm) and 50Ω coaxial feed line. The patch height above the ground by a distance of (1.67 mm). a short plate from the patch to the ground with (4 mm) width is produced. The overall antenna size is 45.6 x 39.6 x1.6 mm^3, which is applicable in the mobile application devices and meet the compact antenna properties and classifications. All optimum parameters of the antenna are summarized in Table 1. (4 mm) the width of the short-pin, and only single (DSM8100-000 Mesa Beam-Lead) from Skyworks PIN diode used to modify the length of the PIFA to reconfigure the resonant frequency to meet other bands of frequencies. The PIN diode is placed in an optimized position to achieve the desired operation.

Table 1. The Optimum parameters of reconfigurable PIFA antenna

Parameters	Values in mm	Parameters	Values in mm
Wg	39.6	L4	5
Lg	45.6	W4	4
L1	33	L5	5.9
W1	10	Rs	11
L2	33	t	0.035
W2	19	h	1.6
L3	5.2	L6	17.9
W3	9	L7	8.2
Ld	1	W7	10
Ws	4	Ls	1.67



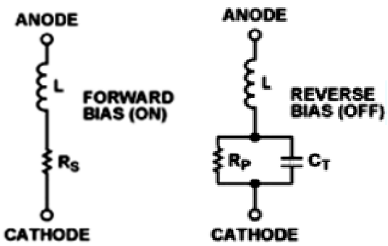


(c)

Figure 3. The proposed multiband reconfigurable PIFA antenna

3.2. Pin diode modelling

The states of the electronic switch are ON and OFF. They can be realized by biasing the PIN diode in the forward or reverse bias. At the ON state, the switch is forward bias and it has low impedance acts as a short circuit and the current can pass through the diode, while in the OFF state the switch is reversed bias and it presents a high impedance and acts as an open circuit which indicates no current flown through the diode. An electrical circuit is shown in Figure 4, which explain the forward and reverse biased, where the only resistor of (3.5 ohms) in series with an inductor of (0.15 nH) in the ON state and a combination of (1Kohm) resistor in parallel with the capacitance of (0.025 pF) all in series with an inductor of (0.15 nH) [25].



(a) (b)

Figure 4. PIN diode modeling under (a) forward (b) reversed biased condition

4. RESULTS AND ANALYSIS

The CST software is used to simulate the proposed reconfigurable PIFA. The fabricated antenna is shown in Figure 5. The obtained simulated and measured multi-bands with the (S11) through the two states of the PIN diode is pragmatically shown in Figure 6, where obtained lowest S11 of (-39.054) in the (5.75 GHz). There are five frequency bands under the (S11 ≤ -10 dB) condition have resulted in the ON state of the PIN diode, they are 0.980 GHz, 3.392 GHz, 3.924 GHz, 4.554 GHz, 5.82 GHz, 6.81 GHz, 7.305 GHz, 8 GHz, and 8.105 GHz, which are applicable to cover (GSM900, WLAN/Wi-Fi, WiMAX, 4G LTE, UWB, and satellite systems) systems, where these bands are obtained from the F-shaped sidearm of the patch, after some important parametric study on the antenna dimensions. The maximum simulated gain is (8.181) dBi at 6.81 GHz. As shown in Figure 7. The simulated VSWR of the proposed PIFA meets the practical requirements of (VSWR ≤ 2) at all the multiband frequencies resulted, where the VSWR is a measure for how the line is matching with the load.

The radiation pattern and surface current distribution of the proposed PIFA are shown in Figure 8 and 9 respectively, they represent the 2D/3D results. The surface current distribution presented in the left side of Figure 9 shows the OFF state of the PIN diode where no current flown to the second arm of the patch, while the other state present the ON state. The proposed antenna can be compared with the literature to produce the strength of the system and is listed in Table 2.

Figure 5. The fabricated PIFA antenna

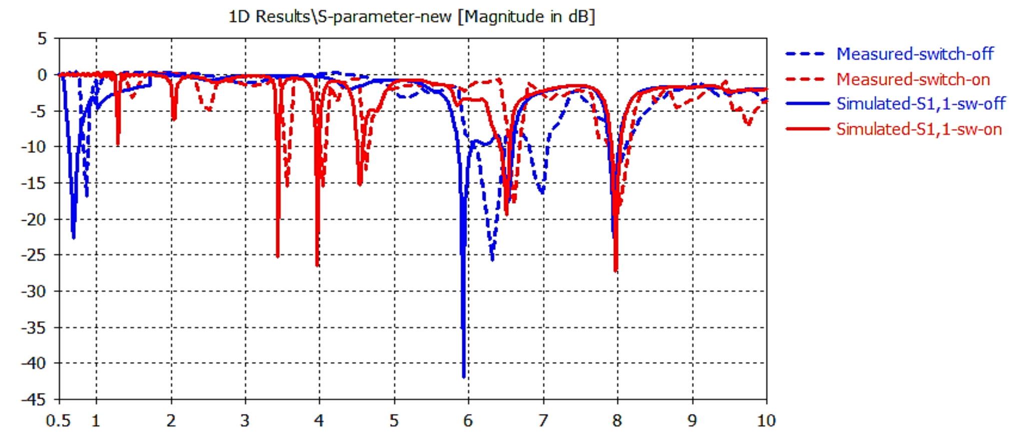


Figure 6. The simulated (S11) parameter versus frequency

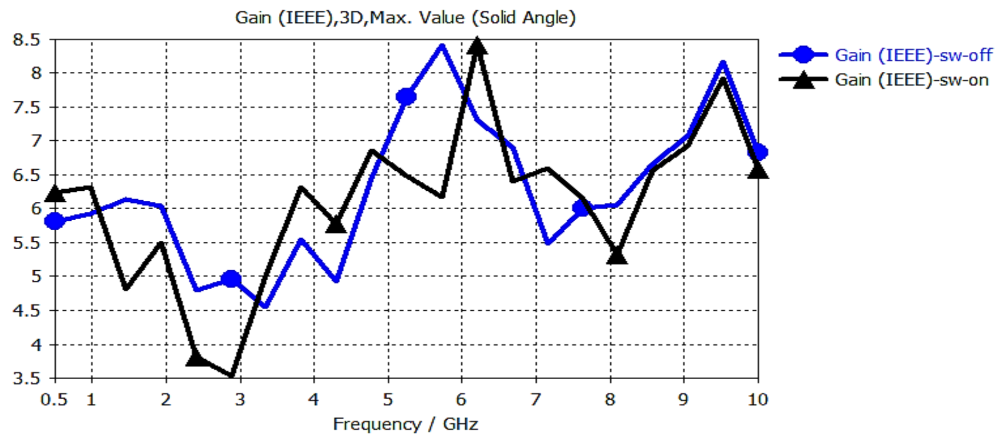
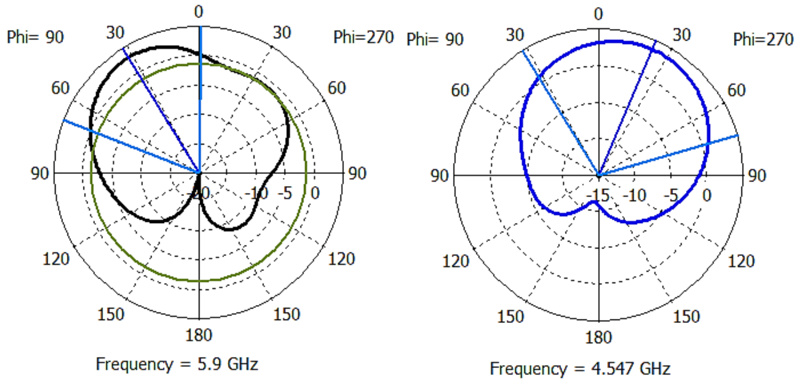
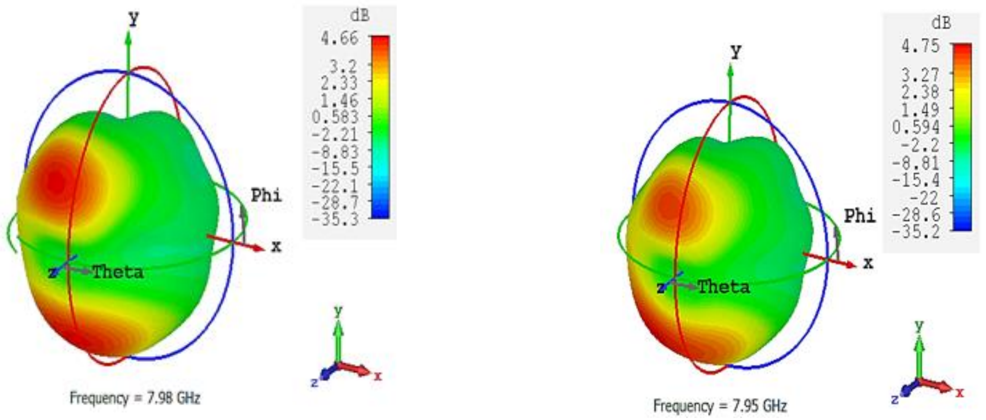


Figure 7. The gain variation with the frequency of the proposed reconfigurable PIFA antenna



(a)



(b)

Figure 8. The (2D/3D) radiation pattern of the proposed reconfigurable PIFA antenna, (a) 2D radiation pattern, (b) 3D radiation pattern

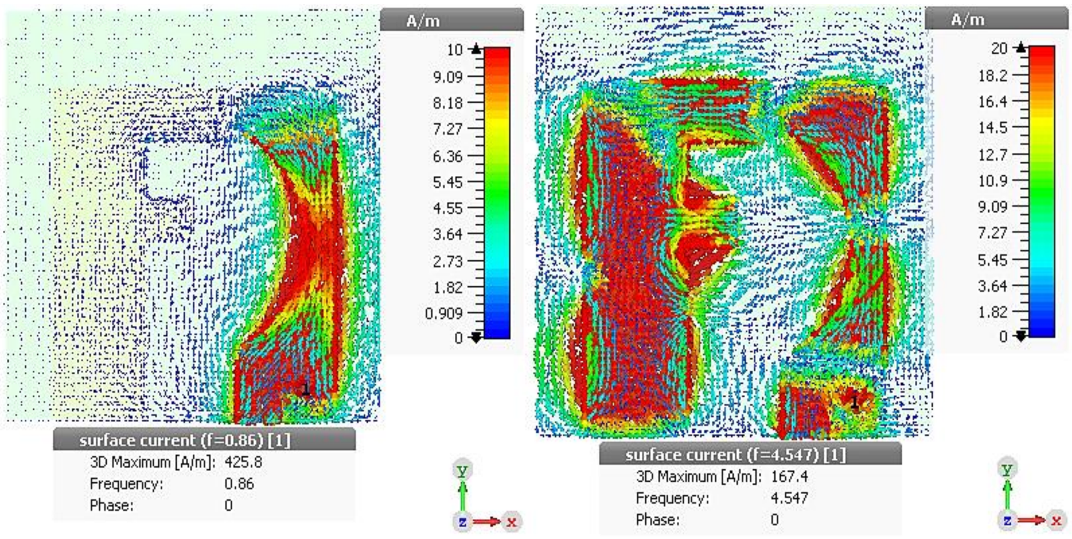


Figure 9. The (3D) surface current distribution of the proposed PIFA

Table 2. A Comparison between the proposed PIFA antenna and the literature

References	Antenna dimensions (mm^2) GND	Patch	No. and type of switches	Bands (GHz)	Peak gain (dB)	Applications
2	100x60	40x16	1-PIN	0.74, 1.85, 2.17	4.62	GSM850, GSM900, DCS, PCS,UMTS, LTE
3	95x60	15x25	2-PIN	1.54-5.75	4	GPS, 3G, WiFi, GSM 4G UMTS and LTE
4	42.5x80	42.5x20	3-PIN	1.93, 2.18, 2.46, 3.58, 3.64, 5.47	6.98	GSM1800, WCDMA, m-WiMAX, WLAN
5	50x50	28x38	3-PIN	1.9, 2.1, 2.2, 2.4		Bluetooth, Wifi, WLAN, 3G, UMTS, WCDMA, GSM, CDMA
6	105x70	15x25	2-PIN	0.77, 0.9 1.54, 1.8, 2.1, 3.55	9	LTE, GSM, GPS,3G,WiMAX, Wi-Fi
Proposed PIFA	45.6x39.6	33x30	1-PIN	0.980, 2.392, 3.924, 4.554, 5.2, 6.81, 7.305, 9 and 9.105	8.45	GSM900, WLAN/Wi-Fi, WiMAX, 4G LTE, UWB, and satellite

5. CONCLUSION

A new compact multiband reconfigurable PIFA antenna for wireless communications application is presented in this paper with a compact to meet the requirements for mobile integration. The proposed structure operates with only a single PIN diode to obtains six resonant frequency bands appropriate for various wireless devices applications. The proposed structure is universal in the ultra-wideband frequency range (UWB) due to a compact size and planar structure, good characteristics such as gain, efficiency, radiation pattern return loss, and VSWR. The system has been fabricated and produced good agreement between the results from the simulation with the measurement one.

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