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I-Shaped Frequency and Pattern Reconfigurable Antenna for WiMAX and WLAN Applications

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Abstract—This paper shows a dual-band frequency and pattern reconfigurable antenna. The proposed antenna is designed on an FR4 substrate of thickness 1.6 mm and size $25 \times 15\,\mathrm{mm}^2$. Depending on the ON/OFF states of the PIN diode, the proposed antenna resonates at two distinct frequencies, i.e., 3.5 GHz and 5.2 GHz, and has a pattern tilt from -170° to $+160^\circ$ in yz plane. In HFSS simulation, lumped RLC elements are used to reconfigure the antenna frequency and pattern. For switching, the PIN diode is used for frequency and pattern reconfiguration in the fabricated antenna to verify the simulated performance. In the simulated and measured performance, the proposed antenna shows reasonable matching. The proposed antenna is suitable for WiMAX and WLAN applications.

1. INTRODUCTION

The desire for handheld devices, which run at various frequencies, has been intensified because of the increasing development of wireless communication systems. The key prerequisite for this system is to have a single antenna, which can work for separate applications at different frequency bands. Owing to their ability to work on multiple frequency bands, reconfigurable and multiband antennas are of concern today. On the basis of the parameter to be reconfigured, reconfigurable antennas can be divided into three groups, i.e., frequency reconfiguration [1], radiation pattern [2], and polarization [3, 4]. By modifying the existing distributions electrically, the parameters may be reconfigured. The reconfigurability of the antenna can be accomplished by the use of multiple switching techniques.

A wideband frequency reconfigurable Koch snowflake fractal antenna is investigated in [5]. For the UHF band, the frequency reconfigurable result is obtained using RF PIN diodes, lumped capacitors, and inductors. In [6], for GSM/Wi-Fi (1.8/2.48 GHz) wireless applications, a dual-band reconfigurable Koch fractal antenna is developed. In [7], a dual-band low-profile monopolar frequency reconfigurable antenna is proposed which uses varactor diodes for frequency reconfiguration. In [8], a pattern reconfigurable planar circular monopole antenna is discussed in which four PIN diodes are placed on two parasitic elements. In [9], an S-shaped frequency reconfigurable antenna using PIN diodes is discussed. In [10], a planar antenna array is discussed in which radiation pattern is reconfigured using RF switches. In [11], the design of a switched beam antenna array based on an optimized Butler matrix feeding network is presented with a compact microstrip structure and a microchip antennas working at 2.45 GHz. In [12], the design of forward-looking monopulse arrays is presented which is able to reconfigure radiation pattern by electronically switching a set of parasitic dipoles. In [13], the design and optimization of a pre-fractal WiMAX band antenna printed on dielectric substratum has been described.

There are a number of ways to achieve frequency and pattern reconfiguration simultaneously. A novel patch antenna with frequency and pattern reconfiguration is presented in [14] with polarization

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switching using PIN diodes. In [15], a slot antenna with a reflector is introduced in which PIN diodes are used for pattern and frequency reconfiguration. In [16], PIN diodes are used in a patch antenna for pattern reconfiguration. In [17], the novel structure of a microstrip antenna integrated with an aperture-coupling technique is introduced in which PIN diodes are used to reconfigure frequency and pattern. A planar parasitic array antenna is presented in [18] with reconfigurability in operating frequency and pattern using PIN diodes. In [19], a fork-shaped frequency and pattern reconfigurable antenna is presented. The frequency and pattern reconfiguration are achieved using PIN diodes. In [20–23], various frequency and pattern reconfigurable antennas are given.

In this paper, an I-shaped antenna is presented which reconfigures operating frequency and pattern using a PIN diode. The proposed antenna resonates at two different frequency bands, including WiMAX and WLAN. To attain frequency and pattern reconfiguration, the lumped RLC elements are used, which act as switches within the radiating monopole in simulation. In the measurement of the fabricated antenna, frequency and pattern reconfigurations are achieved by the PIN diode.

2. ANTENNA DESIGN

The geometry, design technique, and the switching state of the proposed antenna are seen in this section. The frequency and pattern of the proposed antenna are reconfigured in the simulation using lumped RLC components. To obtain frequency and pattern reconfigurability, the PIN diode is incorporated in fabrication.

2.1. Design Procedure

The I-shaped proposed antenna has a size of 25 mm × 15 mm. The substrate used is FR-4 of 1.6 mm thickness, loss tangent of 0.02, and dielectric constant of 4.4. Figures 1(a) and (b) show the top view and bottom view of proposed antenna, respectively. Feeding line width ($W1$) is kept 3 mm in order to match impedance. The length of metallic ground plane is Lg (10 mm). The truncated metallic ground plane provides optimal gain, directivity, and radiation efficiency. A PIN diode is used in the proposed antenna to achieve reconfiguration in terms of frequency and pattern. The proposed antenna has parameter values obtained from parametric analysis as shown in Table 1.

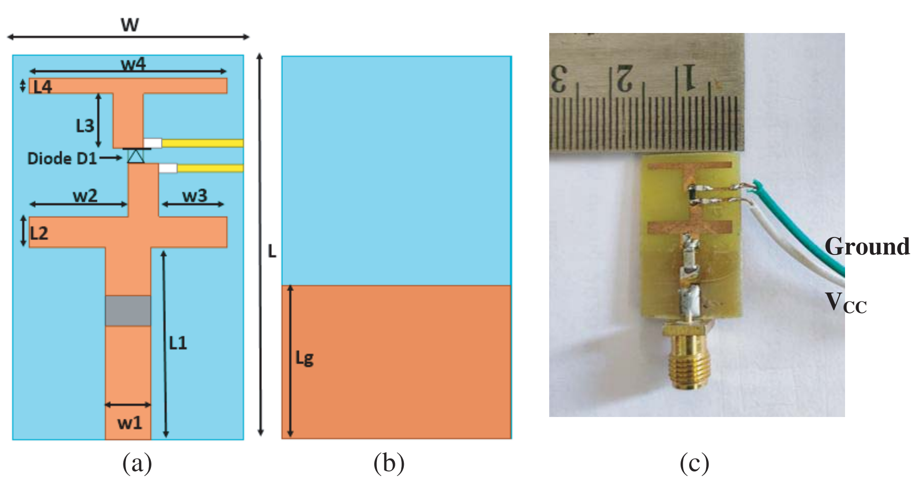


Figure 1. Proposed antenna. (a) Top view (Grey-capacitor, White-inductor, Yellow-biasing strips). (b) Bottom view. (c) Fabricated antenna.

2.2. Parametric Result Analysis

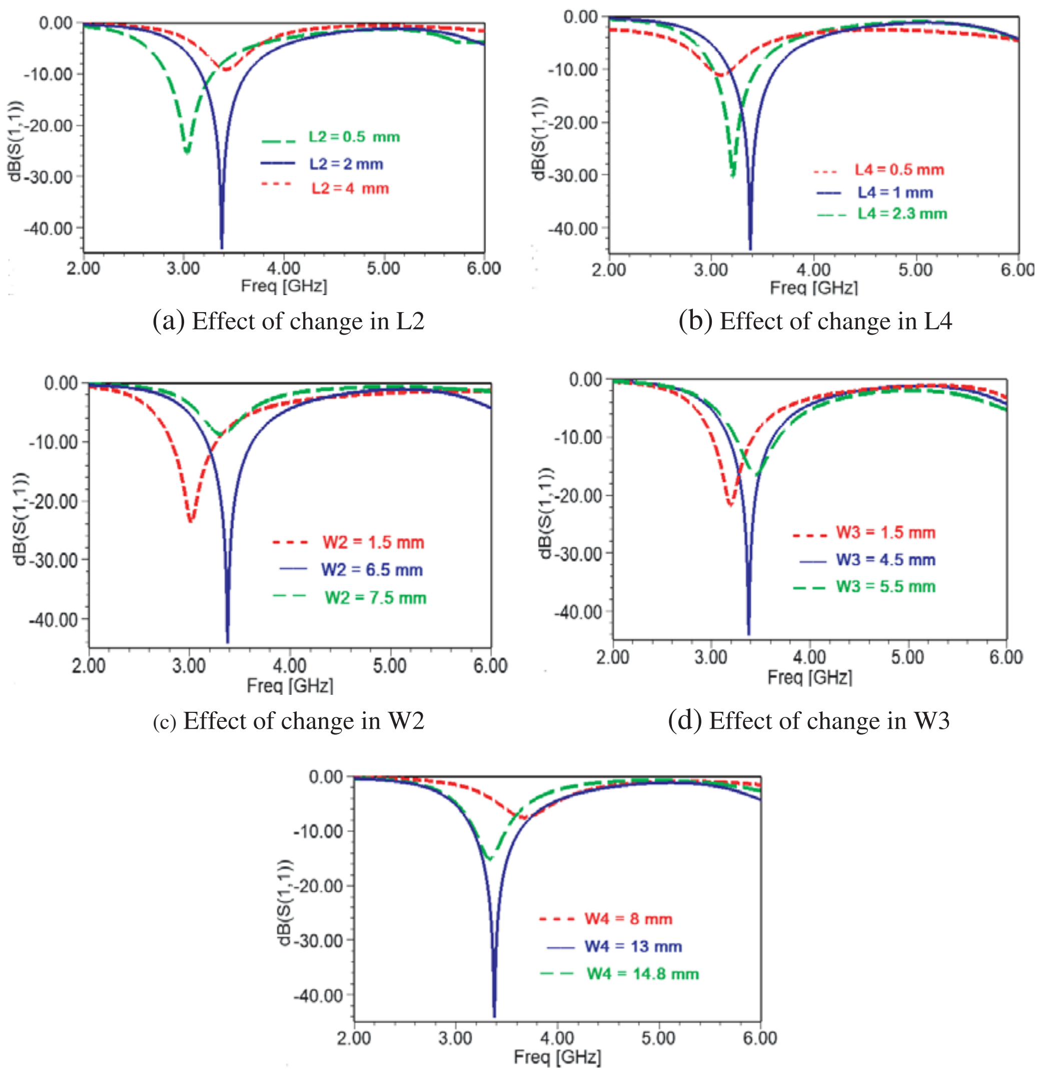
The parametric analysis of the proposed antenna is seen in Figure 2 to evaluate the shift in resonant frequency at various values of given parameters. It can be seen from Figure 2(a) that the change in $L2$

Table 1. Optimized Parameters of proposed antenna.

Parameters	Value (mm)	Parameters	Value (mm)	Parameters	Value (mm)
L	25	$L3$	3.5	$W3$	4.5
W	15	$L4$	1	$W4$	13
$L1$	12.5	$W1$	3	Lg	10
$L2$	2	$W2$	6.5		

shifts the resonant frequency value. The value of $L2$ is selected as 2 mm in order to obtain a resonant frequency closer to 3.5 GHz. Similarly, Figure 2(b) shows that resonant frequency changes with the change in value of $L4$. Hence, the value of $L4$ is chosen as 1 mm to achieve desired frequency.

Figures 2(c), (d), and (e) show that change in the values of parameters $W2$, $W3$, and $W4$, respectively, changes the value of resonant frequency. Hence, the value of $W2$ is chosen as 6.5 mm, $W3$ chosen as 4.5 mm, and $W4$ chosen as 13 mm to obtain desired resonant frequency.



(a) Effect of change in L2

(b) Effect of change in L4

(c) Effect of change in W2

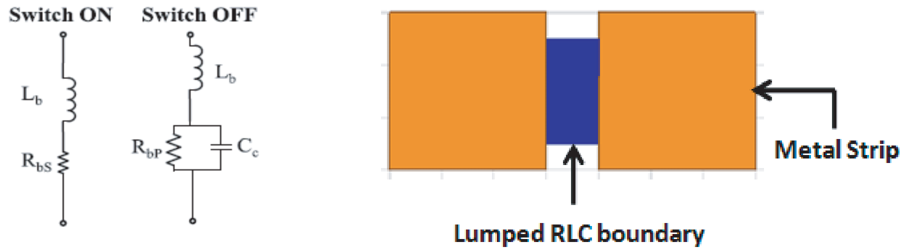
(d) Effect of change in W3

(e) Effect of change in W4

Figure 2. Parametric analysis.

2.3. PIN Diode and Its Biasing Circuit

The equivalent circuit of a PIN diode is shown in Figure 3(a). During ON state, PIN diode acts as a short circuit which provides path for current to flow in radiating structure. In simulation environment, PIN diode is designed as lumped RLC boundary as shown in Figure 3(b). During simulation, open circuit and short circuit behaviours of PIN diode are considered.

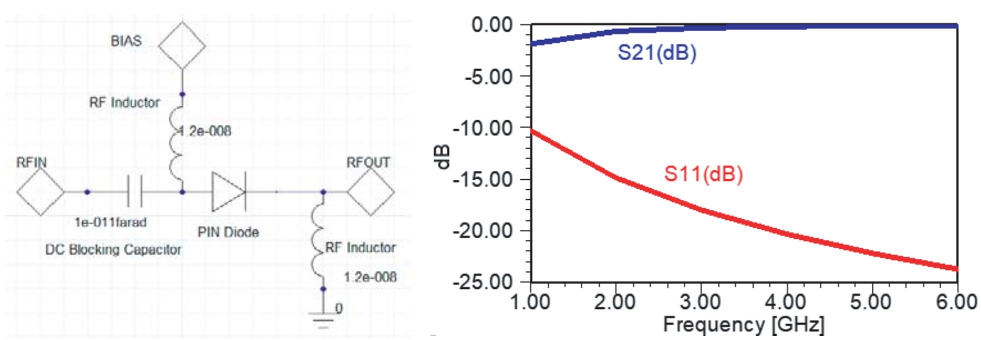


(a) (b)

Figure 3. (a) Equivalent circuit of PIN diode. (b) PIN diode model in HFSS.

In the proposed antenna simulation, PIN diode is modelled by a resistance of 1.5 Ω in an open state and a capacitance of 0.19 pF in an off state as given in the datasheet of PIN diode of Skyworks product (SMP 1345-079LF). In the design, 1 mm slot is retained to connect PIN diode at that position in radiating structure of proposed antenna. The PIN diode of the Skyworks product (SMP 1345-079LF) is used in the measurement setup to verify the frequency and pattern reconfiguration of the antenna.

Figure 4(a) shows the biasing circuit of a PIN diode. This circuit is modelled in ANSYS circuit designer to check the effect of biasing circuit on the proposed antenna. To prevent the DC signal passing into the RF source of the antenna, a 10 pF capacitor is mounted on the feedline, and biasing strips are etched to connect 12 nH value inductors to separate the DC and RF signals. The values of RF inductor and DC block capacitors are chosen in such a way that they will not alter the operation of proposed antenna. Figure 4(b) shows the values of S_{11} (dB) and S_{21} (dB) for the biasing circuit of PIN diode. During measurement, PIN diode (Skyworks SMP 1345-079LF) is used. The biased voltage of 3 V is applied to PIN diode, which is supplied by two Alkaline AA batteries.



(a) (b)

Figure 4. (a) PIN diode biasing circuit. (b) S_{11} and S_{21} Graph of PIN diode.

3. RESULT ANALYSIS

To analyze the performance, an I-shaped proposed antenna is simulated in High Frequency Structure Simulator (HFSS) and fabricated. The proposed antenna is experimentally tested. The values of return loss in different ON/OFF states of PIN diode are measured using Agilent, model-N9912A Vector

Network Analyzer (VNA). The experimental assessment has been carried out in an anechoic chamber where the radiation patterns are measured.

3.1. Frequency Reconfigurability

In the proposed antenna, frequency reconfiguration can be realized by turning the PIN diode ON or OFF. The switching states are illustrated in Table 2. By changing the switching mode of the PIN diode, frequency reconfiguration is obtained.

Table 2. Switching states.

Switching state	Resonant Frequency
Mode 1 (ON state)	3.5 GHz
Mode 2 (OFF state)	5.2 GHz

It can be seen clearly from Figure 5 that a good matching exists between the simulated results and measured results. The minor change between the simulated and measured results is due to PIN diode (Skyworks SMP 1345-079LF) insertion loss. As defined in the datasheet, the maximum PIN diode insertion loss value is -0.4 dB. Due to this, there is a small discrepancy between the measured and simulated results. Table 3 shows the comparison of simulated and measured results of the proposed antenna.

Table 3. Comparison of Simulated and Measured results of the proposed antenna.

Switching State	**Frequency Band**		**Bandwidth (MHz)**		**Peak Gain (dB)**
	Simulated	**Measured**	**Simulated**	**Measured**	**Simulated**
Diode ON	3.25 GHz–3.69 GHz	3.25 GHz–3.68 GHz	440	430	1.0732
Diode OFF	4.27 GHz–5.52 GHz	4.20 GHz–5.35 GHz	1250	1150	2.9684

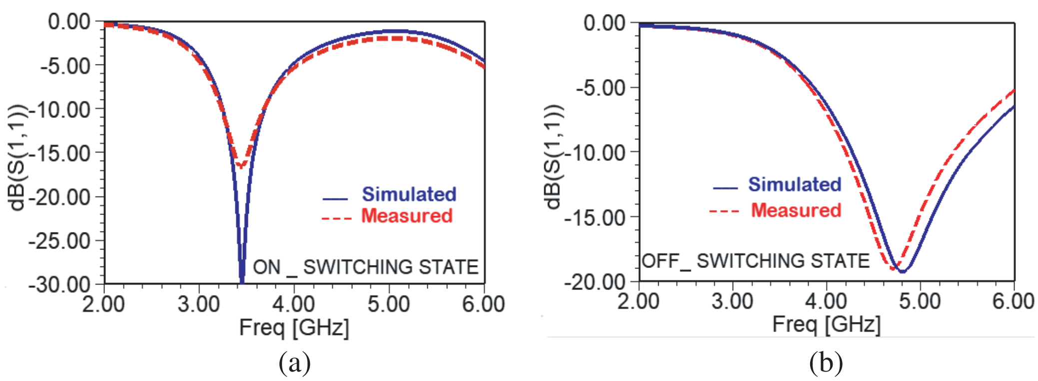
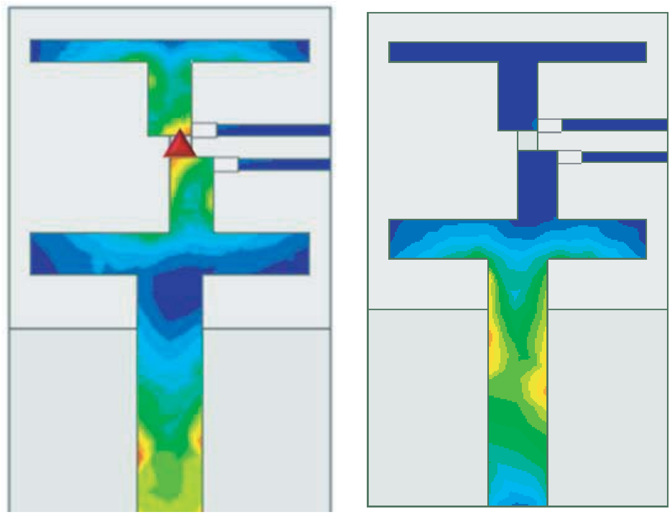


Figure 5. Simulated and measured value of S_{11} in dB. (a) ON state. (b) OFF state.

Surface current distribution is depicted for switching states in Figure 6 which clearly shows effective resonance lengths responsible for different frequencies in radiating structure. The resonant lengths of the proposed antenna are analysed using the transmission line model concept [24]. In an ON condition, the corresponding current path length is nearly $\lambda 1$ ($\lambda 1$ is the guided wavelength at 3.5 GHz), as shown in Figure 6(a). Similarly, the corresponding current path length for Figure 6(b) in an OFF state is nearly $\lambda 1$ ($\lambda 1$ is the guided wavelength at 5.2 GHz).

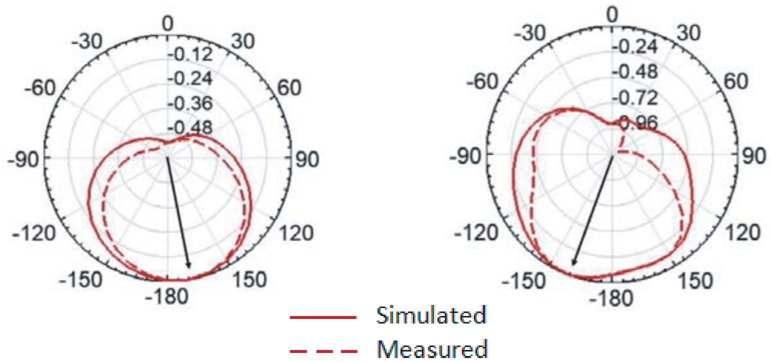


(a) ON state (3.5 GHz) (b) OFF state (5.2 GHz)

Figure 6. Simulated electric field distributions for ON/OFF switching modes.

3.2. Pattern Reconfigurability

The reconfiguration of the pattern is obtained by adjusting the current path of the radiating element. The difference in the phase of the current excitation results in pattern reconfiguration in the traditional antenna system. But in the proposed antenna, path through which current travels has been changed keeping excitation source constant. As a result, current travels additional distance resulting in a phase difference which reconfigures the pattern in different switching states. For the sake of clarity, pattern reconfiguration mechanism at different frequencies is illustrated in Figure 7. From Figure 7, it can be seen that main lobe is directed at $-170°$ when the diode is in ON state, and main lobe is directed at $+160°$ when the diode is in OFF state.



(a) Mode 1 at 3.5 GHz (b) Mode 2 at 5.2 GHz

Figure 7. Simulated and Measured 2D H plane Normalized radiation pattern in dB to illustrate pattern reconfiguration in various switching modes.

Figure 7 shows the pattern configuration in various switching states. The arrow indicates the direction of main lobe at Phi $= 90°$. Radiation pattern in H plane is tilted in different modes of the PIN diode. The pattern of E plane radiation is not affected by varying switching states. So the simulated and measured H plane radiation patterns are presented to illustrate pattern reconfiguration. The main beam directions are suitable for top mounted or wall antenna for intended applications.

Table 4. Comparison of proposed antenna with aforesaid work.

Ref No.	Size (mm^2)	Reconfigurable Frequency (GHz)	Pattern Reconfigurable	Actuators	Relative Dimensions	Simulated Peak Gain (dB)
[7]	280×280	0.9, 1.7	No	2 Varactor diodes	$1.16\lambda_1 \times 1.16\lambda_1$	-0.70 to 5.50
[5]	80×40	2.8, 3, 3.9	No	4 PIN diodes	$0.63\lambda_1 \times 0.32\lambda_1$	1.87 to 3.30
[14]	50×60	5.2, 5.8	Yes	6 PIN diodes	$1.38\lambda_1 \times 1.66\lambda_1$	2.30 to 3.00
[6]	48×48	1.8, 2.48	No	4 PIN diodes	$0.35\lambda_1 \times 0.35\lambda_1$	Not Given
[This work]	15×25	3.5, 5.2	Yes	1 PIN diode	$0.26\lambda_1 \times 0.44\lambda_1$	1.07 to 2.96

Table 4 shows the comparison of proposed work with previously published work in terms of size, type of reconfiguration, and number of actuators used to reconfigure frequency and pattern. The relative dimensions are calculated in terms of λ_1, which is the minimum resonating frequency of a particular antenna. It is clear that the proposed antenna is compact and has fewer actuators than other antenna designs discussed.

4. CONCLUSION

The proposed I-shaped antenna which is frequency and pattern reconfigurable is simulated and fabricated. A good agreement exists between the measured and simulated results. In the proposed antenna, One PIN diode is used to reconfigure frequency and pattern. In different switching modes of the PIN diode, the antenna resonates at 3.5 GHz (WiMAX), and 5.2 GHz (WLAN). The values of gain of proposed antenna are reasonable for intended applications. With these values of gain, the proposed antenna can be used for small or medium coverage.

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