A DESIGN OF FREQUENCY RECONFIGURABLE CPW-FED ANTENNA USING PIN DIODE FOR WIRELESS APPLICATIONS

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Abstract - A frequency reconfigurable CPW-fed antenna using PIN diodes is proposed in this paper. The antenna uses two PIN diodes located on the radiating patches to achieve frequency configurability. By switching states of the two PIN diodes, the proposed antenna can operate at three configurations. The antenna can cover three bands with the center resonant frequencies of 2.1 GHz, 2.6 GHz, and 3.3 GHz. The antenna dimensions are calculated based on theoretical formula of CPW fed antenna, then simulated and optimized using CST Microwave and CST Design software. The proposed antenna is designed on FR4 substrate with the permittivity of 4.4. The overall size of the antenna is $24x34x1.6\ mm^3$which is suitable for small wireless handsets. The antenna can be used for UMTS, LTE, and WiMax applications

Key words - reconfigurable antenna;frequency reconfigurable antenna;CPW fed antenna; PIN diode; antenna for wireless handsets

1. Introduction

With the development of wireless communications, there have been more requirements in designing transceivers with multi-functionality, flexibility, minimized dimensions, and low cost. Furthermore, the system may be required to operate at different standards for various applications. Therefore, the antennas should be able to operate at various modes such as wideband [1]- [2] or multiband [3]- [4]. However, these antennas work at fixed frequency bands, which make them difficult to accommodate new services as well as decrease flexibility. A frequency reconfigurable (FR) antenna can alter automatically different frequency bands by switching among its configurations including single-band, wideband or multiband modes to adapt to the requirements of the system or to the changes of channel environment. Moreover, due to its being capable of switching between different configurations, a reconfigurable antenna can replace a number of single-band antennas used in transceivers, helping to reduce cost and size of systems. There are various techniques used to achieve configurability such as using electronic components, optical photoconductive elements, structural alterations, and material changes. However, electronic switching components asPIN diodes have been widely used for reconfigurable antennas because of their low energy-loss and high isolation [5]. Recently, there has been a lot of research on frequency reconfigurable antennas based on some conventional structure such as bow-tie[6], monopole [7], helical [8], stacked microstrip patch [9], PIFA [10 –12], and Co-planar waveguide (CPW) fed antennas [13-15].However, the CPW fed antenna has attracted researchers due to its advantages: easy fabrication, no need of via holes, low radiation loss [16].

In [13], the authors proposed a CPW-fed reconfigurable antenna with a minimum operating frequency of 2.47 GHz but its dimensions are still quite large, at $36 \times 45\ mm^2$. The same kind of antenna was presented in [14], using two PIN diodes can operate at two frequency states, at 4.27 GHz and 3.36 GHz. Although its size is relatively compact, the antenna peak gain at 3.36 GHz is low, only at a minor 0.2 dBi. In [15],a CPW-fed reconfigurable antenna using PIN diode obtains two configurations of wideband and narrow band at 5.8 GHz. However, the overall antenna dimensions is $60 \times 69\ mm^2$, which is still large in comparison with its operating frequency.

In this paper, we propose a frequency reconfigurable CPW fed antenna using PIN diodes. By switching the states of four PIN diodes, the antenna achieves three states with operating resonant frequencies of 2.1 GHz, 2.6 GHz, and 3.3 GHz, and antenna gain of 1.3dBi, 2 dBi, and 2.1 dBi. The obtained frequency bands cover for UMTS, LTE, andWiMax applications.

In comparison with the previous antennas [13-15], the proposed antenna is more compact with the overall dimension of $24 \times 34\ mm^2$. The antenna is designed and simulated using CST Microwave in combination with CST Designed Software. An antenna prototype has been fabricated and its return loss has been measured with the results presented below.

The rest of this paper is organized as follows.Section2 presents the Design of reconfigurable antenna. Section 3 presents the results of the simulation and measurements with some discussion. The conclusion of the paper is in Section 4.

2. Design of Reconfigurable Antenna

2.1. Antenna Design

The geometry of the proposed frequency reconfigurable CPW fed antenna is displayed in Fig. 1. The antenna has a symmetric structure fed by a CPW line with a slot to increase impedance matching. The antenna is designed on FR4 substrate with the permittivity of the 4.4 and the loss tangentof 0.02. To design the proposed reconfigurable antenna, radiating element dimensions were firstly calculated. At each antenna configuration, the total electric length of radiating elements are chosen as approximately a quarter-wavelength of desired resonant frequencies. These radiating elements are then folded to reduce overall antenna size. The antenna dimensions are then simulated and optimized by the combination of CST microwave and CST design software [17]. As a result, the overall antenna size is $24 \times 34 \times 1.6\ mm^3$ and the optimized values for the proposed antenna are described in Table I. Four PIN diodes are used in order to connect or disconnect between the radiating patches to obtain three operating states. Frequency range of these PIN diodesisfrom 10 MHz to 6 GHz, which meets the requirements of designed frequency bands. The equivalent circuit of PIN diode is shown in Fig. 2. The states of PIN diodes in three configurations are described in Table II.Two capacitors $0.1\mu F$ are used to isolate DC voltagesupplying to PIN diodes. An antenna prototype is fabricated as shown in fig.3.

In order to achieve frequency reconfigurability, the length of the radiating elements is changed by switching the diodes. When a DC forward bias voltage is applied to diode, it is ON and vice versa, diode is OFF. In this way, the antenna can achieve three configurations, namely S1, S2, and S3.

Table 1. *Operation of PIN diode at the states*

State	D1	D2	D3	D4
S1	ON	ON	ON	ON
S2	OFF	OFF	OFF	OFF
S3	ON	OFF	ON	OFF

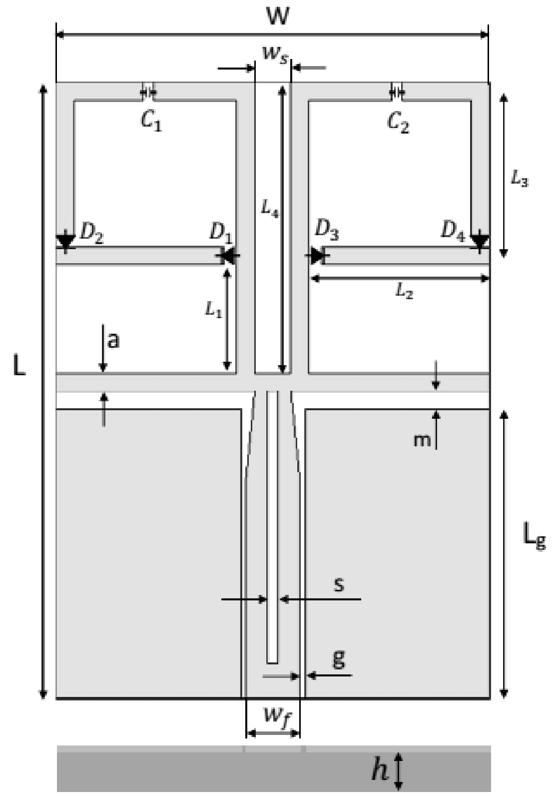


Figure 1. *Antenna structure*

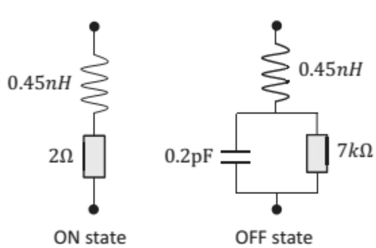


Figure 2. *Equivalent circuit of PIN diode SMP1345*

In state S1 when all the PIN-diodes are ON, the antenna operates at the UMTS bands. In contrast, in state S2, when all the PIN-diodes are OFF, the antenna operates at LTE band. In state S3, the diodes D1 and D3 are ON, whereas the diode D2 and D4 are OFF, the antenna achieves two frequency operating bands of UMTS and WiMax.

Table 2. *Detail dimensions of the antenna*

Parameter	W	L	w_f	w_s	a	m
Value (mm)	24	34	3	3	1	1
Parameter	g	L_1	L_2	L_3	L_4	L_g
Value (mm)	0.3	5	9	7.5	16	16

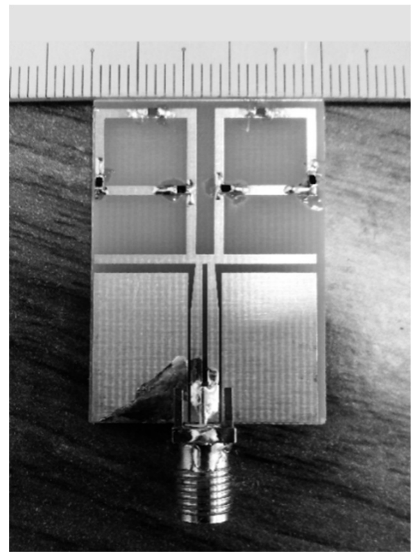
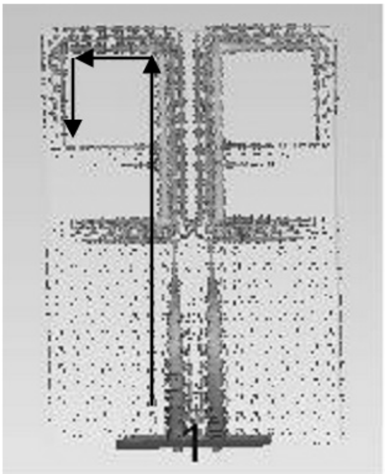


Figure 3. *Prototype of the proposed antenna*

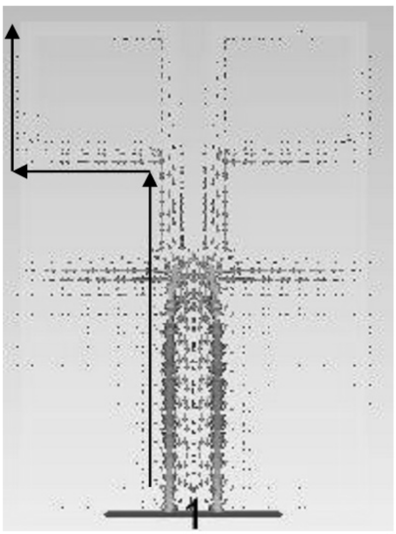
2.2. Surface Current Distributions

To explain operations of the frequency reconfigurable antenna in each state, the surface current distributions on the radiating elements are displayed in Figure 4.

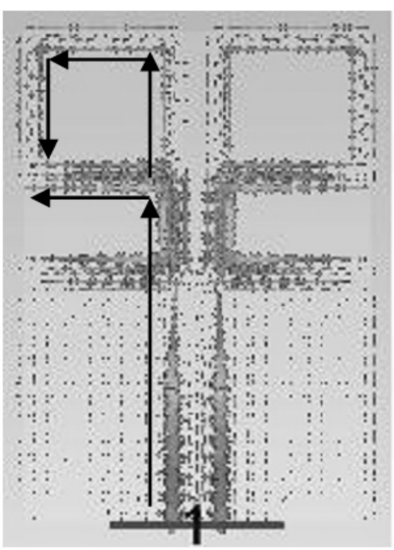
Figure 4(a) shows the simulation surface current distributions of antenna at the state S1 with the resonant frequency of 2.1GHz. The surface current flows from the CPW feed line to the radiating elements as the direction of arrows. The total electric length of radiating elements (3*a+L1+L2+2*L3), in this configuration, is approximately at the quarter-wavelength of 2.1 GHz for UMTS application.The simulation surface current distributions at the state S2 are shown in Fig.4 (b). This figure shows that the surface current flows through all the PIN diodes ON as the direction of arrows. In state (S2), the total electric path of the radiating elements (3*a+L1+L2+L3) is approximately at the quarter-wavelength of 2.6 GHz for LTE application. Fig. 4 (c) shows the surface current distribution in the state S3. The surface current in this configuration is divided into two directions, so the antenna operates at two frequency bands. It can be observed that the surface current lengths (a+L1+L2) and (3*a+L1+L2+2*L3) are close to the quarter-wavelength of 2.1 GHz and 3.3 GHz for UMTS and WiMax applications, respectively.



(a) State S1



(b) State S2

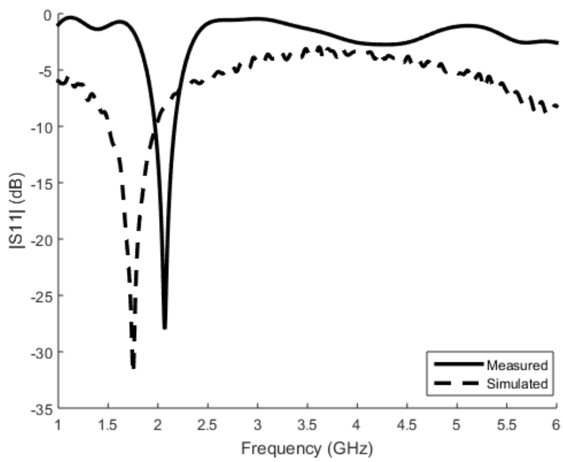


(c) State S3

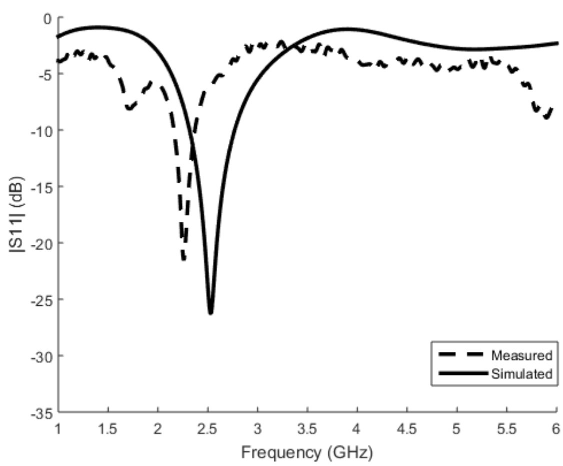
***Figure 4.** Simulated surface current distributions at three states*

3. Results and Discussion

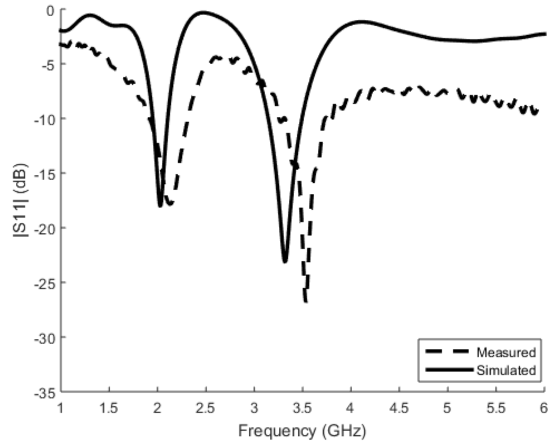
This section presents the simulated and measured results of reflection coefficients as well as simulated radiation patterns. Fig 5 a-c shows the simulated and measured reflection coefficients of the proposed reconfigurable antenna at each configuration. These three configurations have resonant frequencies of 2.1 GHz, 2.6 GHz, 2.1/3.3 GHz with bandwidths of 200 MHz (from 1970 MHz to 2170 MHz), 468 MHz (from 2313 MHz to 2781 MHz), 154 MHz (from 1953 MHz to 2107 MHz)/ 358 MHz (from 3140 MHz to 3498 MHz), respectively. They are suitable for UMTS, LTE, and WiMax applications. It can be seen that the states S1 and S2 produce a single band whereas the state S2 produce two bands. These simulated results of reflectioncoefficients are validated by the measured results. There is an insignificant discrepancy in resonant frequency between simulated and measured results. This frequency shift may be due to the fabrication accuracy, soldering and PIN diode effect and the accuracy of substrate dielectric constant.



(a) State S1

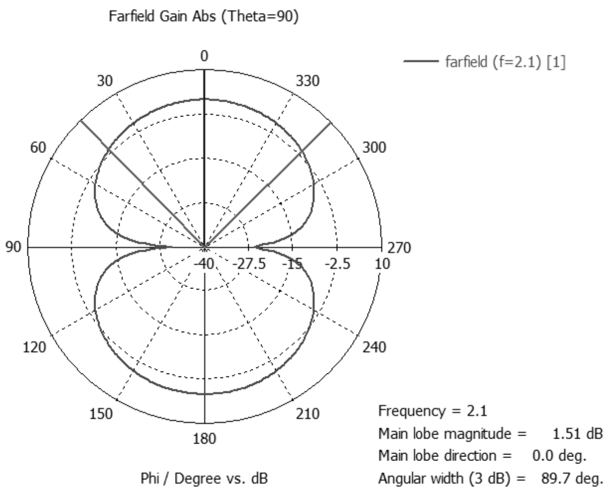


(b) State S2

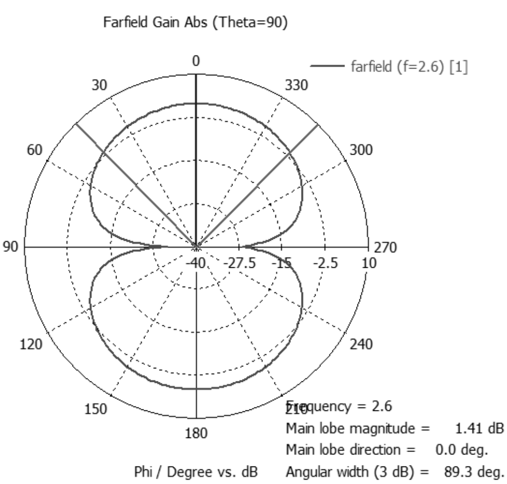


(c) State S3

***Figure 5.** Simulated and measured results of |S11| at three states*

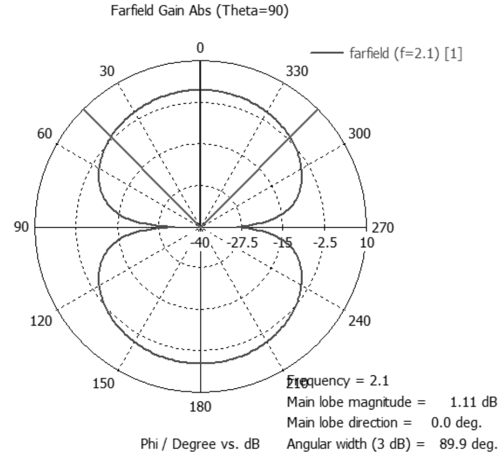


(a) State S1: 2.1 GHz

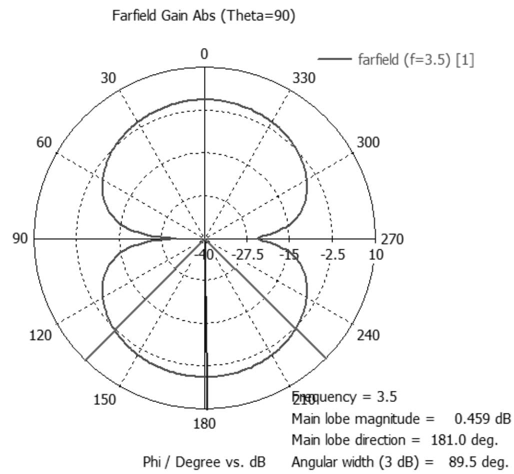


(b) State S2: 2.6 GHz

(d)



(c) State S3: 2.1 GHz



(d) State S3: 3.3 GHz

***Figure 6.** 2D radiation patterns at X-Y plane*

The simulated radiation patterns of the antenna at the three states are plotted in Fig. 6(a-c). We can see that the simulated radiation patterns of the antenna at three different states are quite similar. The antenna peak gains are about1.3 dBi for state S1, 1.9 dBi for states S2, 1.1dBi/2.0 dBi for state S3. Table 3 summarizes all the simulated results of the resonant frequencies, bandwidths, peak gains, and radiation efficiencies at the three states of the proposed antenna.

***Table 3.** Summary of antenna performance*

State	Observed Frequency (GHz)	Bandwidth (MHz)	Peak gain (dBi)	Tot.Efficient (%)
S1	2.1	200	1.2	84%
S2	2.6	468	1.9	93%
S3	2.1 3.3	154 358	1.1 2.0	75% 76%

4. Conclusion

This paper presents the design of frequency reconfigurable CPW-fed antenna using PIN diode for UMTS/LTE/WiMax applications. By using the diodes, the antenna obtains three different configurations with the center resonant frequencies of 2.1 GHz, 2.4 GHz, 3.3 GHz while the radiation patterns are quite similar. The proposed antenna is simple and easy to fabricate with small size of$24\times34mm^2$. The prototype of the proposed antenna is fabricated on FR4 and the antenna performance is verified through simulation as well as measurement.

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(The Board of Editors received the paper on 10/10/2016, its review was completed on 29/11/2016)