

Frequency Reconfiguration Mechanism of a PIN Diode on a Reconfigurable Antenna for LTE and WLAN Applications

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ABSTRACT

Microstrip patch antennas are increasingly gaining popularity for usage in portable wireless system applications due to their light weight, low profile structure, low cost of production and robust nature. The patch is generally made of a conducting material such as copper or gold and can take any possible shapes, but rectangular shapes are generally used to simplify analysis and performance prediction. Microstrip patch antenna radiates due to the fringing fields between the patch edge and ground plane. In this work, a frequency reconfigurable antenna with a BAR63-02V Positive-Intrinsic-Negative (PIN) diode is designed, simulated and fabricated. The antenna operates at 2.686GHz for Long-Term Evolution (LTE2500) and 5.164GHz for Wireless Local Area Network (WLAN) applications. In the OFF state, the antenna operates at 5.302GHz, which is also suitable for WLAN application. The proposed antenna is fabricated on a FR-4 substrate with a relative dielectric constant, ϵ_r of 4.5, thickness, h of 1.6mm and loss tangent, $\tan \delta$ of 0.019. The fabrication process is carried out at the Advanced Printed Circuit Board (PCB) Design Laboratory in UTHM.

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1. INTRODUCTION

There are numerous wireless communication systems in our daily lives such as cellular radio systems, mobile satellite systems and wireless local area networks. Although it is hard to predict precisely how the systems will appear in the future, it is clear that there will be a need for new solutions in the field of antennas. The new solutions are commonly to cater for the need to include the growing number of communication services in a single mobile device such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) and satellite communication, only to name a few [1]. In this context, there is an evident interest in developing new reconfigurable antennas, which allow dynamic reconfiguration of parameters such as operating frequency, radiation pattern and polarization [2].

Reconfigurable antennas have the ability to simultaneously operate in different frequency bands for different communication services [3]. Therefore, to operate in multiple frequency bands with improved radiation efficiency, the RF engineers are focusing on designing reconfigurable antenna. There are many ways of reconfiguring the antennas such as by using active switches and tunable devices. The development of active components such as PIN diodes, varactor diodes and RF MEMS, has accelerated the rapid evolution of the reconfigurable antennas [4]. Recently, PIN diodes have been used as the switching elements in the

reconfigurable antennas for the purpose of multiple frequency bands operation [5]. In addition, reconfigurable antenna can be a cheaper alternative to traditional adaptive arrays [6].

Microstrip patch antennas are increasingly gaining popularity for use in portable wireless system applications due to their light weight, low profile structure, low cost of production and robust nature [7]. In its most basic form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. The patch is generally made of a conducting material such as copper or gold and can take any possible shape, but regular shapes are generally used to simplify analysis and performance prediction [8]. The radiating patch and the feed lines are usually photo-etched on the dielectric substrate. Microstrip patch radiate due to the fringing fields between the patch edge and ground plane.

In this work, a frequency reconfigurable antenna with a PIN diode will be designed, simulated and fabricated. PIN diodes have been used for RF switching of reconfigurable antennas in many applications such as mobile and satellite communications, cellular radio system and radar application. PIN diodes is a current controlled device that operates as a variable resistor in the RF switching operation. PIN diodes have many advantages such as small in size, high switching speed, low distortion, low insertion loss, good isolation with low power handling and low in cost [9]. The operation of PIN diode is based on the ON or OFF states of the PIN diodes. The antenna will operate at WLAN frequency (5.15GHz–5.825GHz) and LTE2500 frequency (2.5GHz – 2.69GHz). The Computer Simulation Technology Microwave Studio (CST MWS) software is used to design and simulate the reconfigurable antenna. The proposed antenna is fabricated on a FR-4 substrate with a relative dielectric constant, ϵ_r of 4.5, thickness, h of 1.6 mm and loss tangent, $\tan \delta$ of 0.019. The fabrication process is carried out at the Advanced Printed Circuit Board (PCB) Design Laboratory.

2. RESEARCH METHODOLOGY

2.1. Antenna design and configuration

The design and simulation processes are done by using CST MWS® software. The simulation result is optimized to achieve the best performance of antenna. Then, In order to achieve the required reconfiguration, the antenna is designed in an orderly manner which involved two stages. Firstly, the proposed antenna comprises of only the main radiating plane which is fed by a microstrip line with a stub for impedance matching. Secondly, an additional radiating plane is added on top of the main radiating plane that is connected by the BAR63-02V PIN diode. The main reason to introduce the additional radiating plane is to alter the length of current travelled across the antenna which will in return also reconfigure the resonant frequencies. Figure 1 shows the structure of the reconfigurable antenna. The dimensions of the antenna are listed in Table 1.

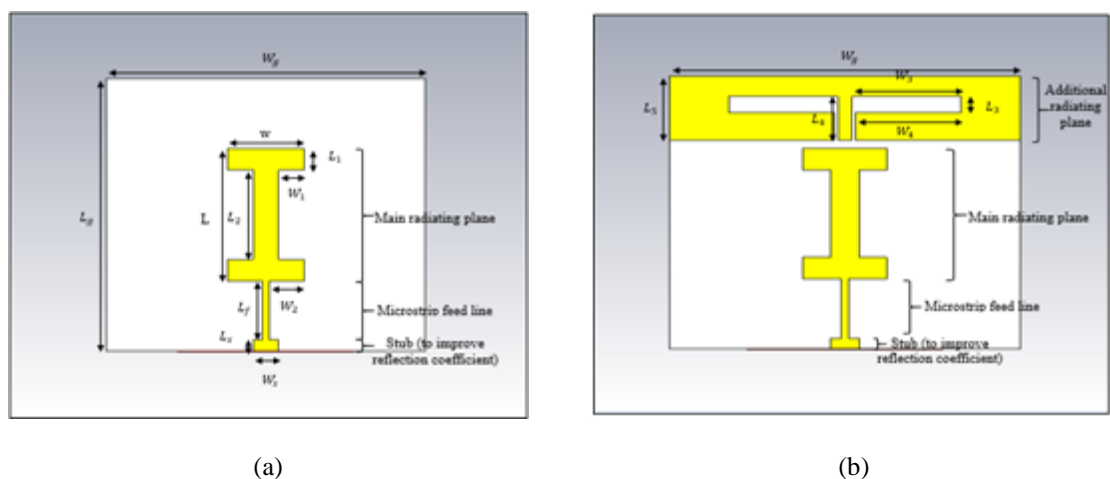


Figure 1. Reconfigurable antenna with a BAR63-02V PIN diode: (a) With only the main radiation plane
(b) With the main and an additional radiating planes

Table 1. Dimensions of the Reconfigurable Antenna with a BAR63-02V PIN diode

Parameter	Value (mm)	Parameter	Value (mm)
W_g	50	W_s	4
L_g	50	L_s	2
W	12	L_f	10.8
L	23.9	W_3	15.5
W_1	4	L_3	3
L_1	4	W_4	15
W_2	5.5	L_4	8
L_2	15.9	L_5	11.9

2.2. Antenna Simulation

In the reconfigurable antenna design, a BAR63-02V PIN diode from Infineon Technologies is used as a switch since it has a very low capacitance which provides high isolation. The PIN diode is modeled by using the equivalent circuit model in CST MWS® software. Figure 2(a) shows the discrete port in CST MWS software which can be modelled by the equivalent circuit model of the PIN diode in the ON and OFF states. Figure 2(b) and Figure 2(c) show the equivalent circuit model in the ON and OFF states of the BAR63-02V PIN diode.

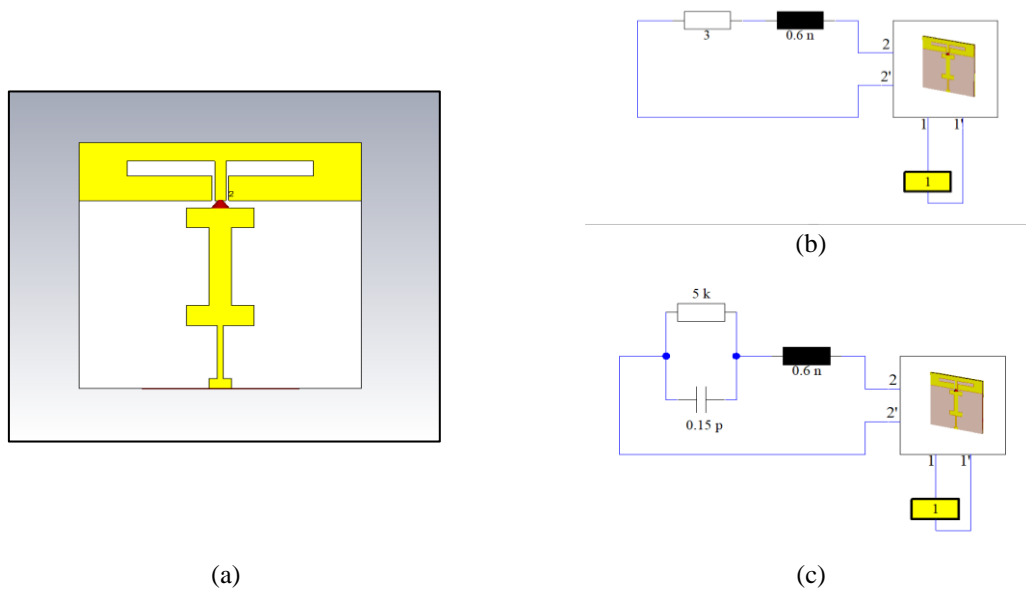


Figure 2. The reconfigurable antenna with a BAR63-02V PIN diode: (a) The discrete port to connect the main radiation plane to the additional plane (b) Equivalent circuit model of the BAR63-02V PIN diode in the ON state (c) Equivalent circuit model of the BAR63-02V PIN diode in the OFF state

2.3 Antenna fabrication

The fabrication process is performed at the Advanced Printed Circuit Board (PCB) Design Laboratory. The outcomes of the fabrication process can be viewed in Figure 3. The antennas are fabricated on a FR-4 substrate with a relative dielectric constant, ϵ_r of 4.5, thickness, h of 1.6mm and loss tangent, $\tan \delta$ of 0.019. Figure 4 shows the final prototype of the reconfigurable antenna with a BAR63-02V PIN diode and the biasing circuit.

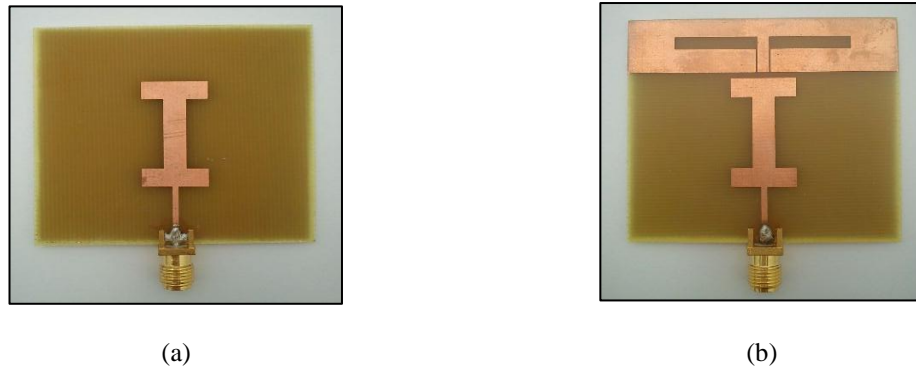


Figure 3. The fabricated reconfigurable antenna with a BAR63-02V PIN diode: (a) With only the main radiating plane (b) With the main and an additional radiating planes

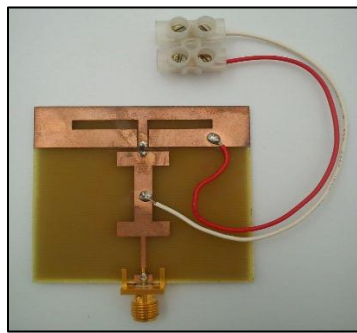


Figure 4. The reconfigurable antenna with a BAR63-02V PIN diode and the biasing circuit

3. RESULTS AND ANALYSIS

3.1. Reconfigurable antenna with the main radiating plane

The simulation results of reflection coefficient and bandwidth of the antenna and the comparison with the measurement results are shown in Figure 5. From the simulation results, the proposed antenna operates at 5.206GHz with a reflection coefficient, S_{11} of -25.51dB and bandwidth, BW of 99.1MHz. The measurement results, on the other hand, show that the S_{11} is the greatest at 5.26GHz at -21.48dB. There is a slight shift in the measurement result with the simulation result of 5.206 GHz, which can be attributed to the fabrication losses.

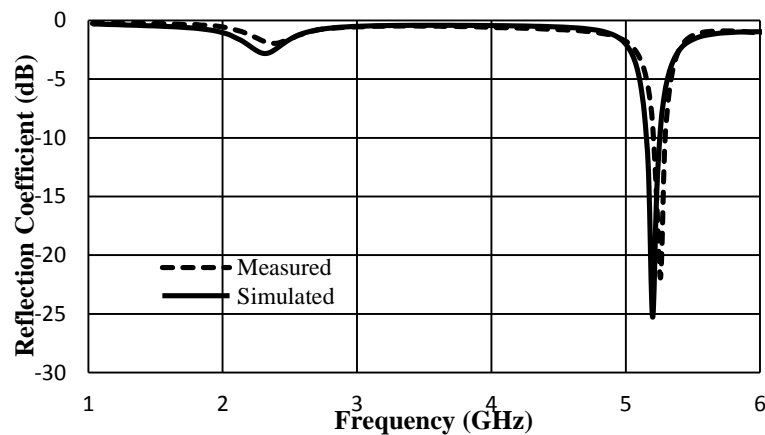


Figure 5. Reflection coefficients of the reconfigurable antenna with only the main radiating plane

Figure 6 shows the surface current distribution on the main radiating plane. From the figure, the maximum surface current is seen to be concentrated in the middle and around the edges of the radiating plane.

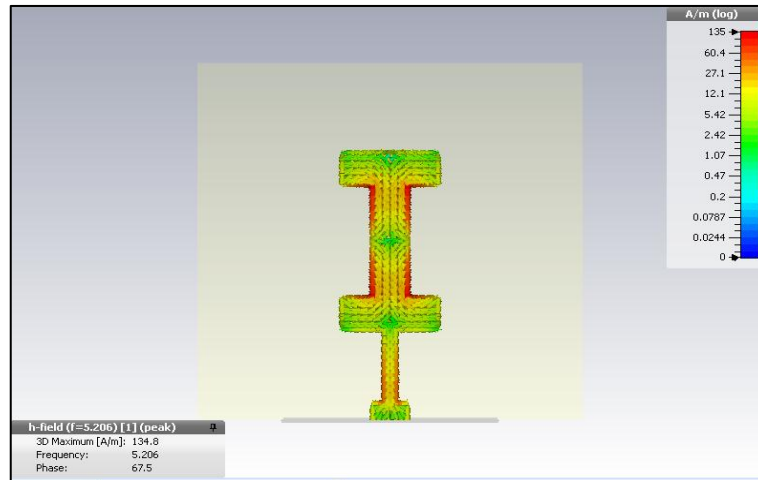


Figure 6. Simulated surface current of the reconfigurable antenna with only the main radiating plane

3.2. Reconfigurable antenna with the main and additional radiating planes

The simulation and measurement results of the reflection coefficient and bandwidth of the antenna can be viewed in Figure 7. From the simulation results, it is observed that the antenna is operating at the resonant frequency of 5.302GHz with the S_{11} of -25.385dB and BW of 99.4MHz. The measured S_{11} of the antenna is the greatest at 5.35GHz at -21.52dB. There is a slight difference between the simulation result of 5.302GHz, which can be attributed to the fabrication losses. In addition, it is also shown that the existence of the additional radiating plane has further increased the resonant frequency to 5.302GHz from 5.206GHz.

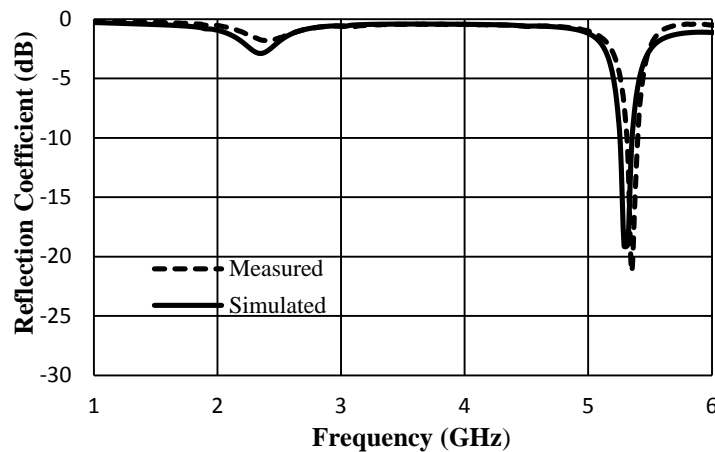


Figure 7. Reflection coefficients of the reconfigurable antenna with two radiating planes

The surface current distribution of the reconfigurable antenna with the main and additional radiating planes can be viewed in Figure 8. Even though there is an additional radiating plane, but there is no current flow between the main and the additional radiating plane since there is no physical connection between the two planes. Therefore, that explains the occurrence of only a single frequency band from the antenna.

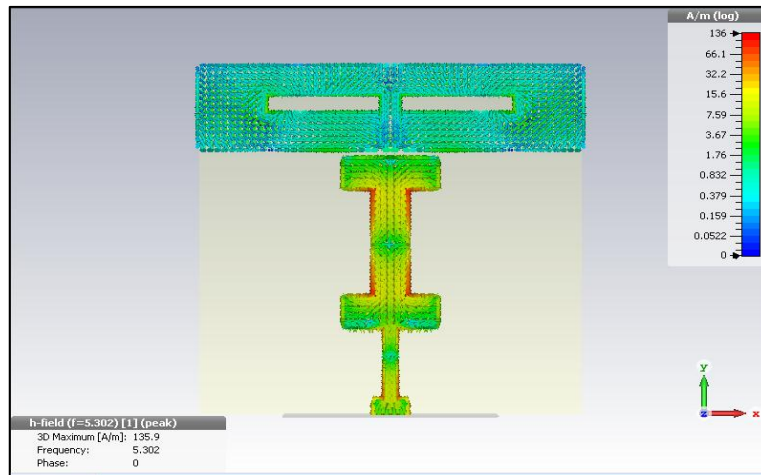


Figure 8. Simulated surface current of the reconfigurable antenna with two radiating planes

3.3. Reconfigurable antenna with a BAR63-02V PIN diode

In this work, the PIN diode acts as an active switch and thus, the operations are based on the ON and OFF states of the PIN diode. Figure 9 shows the simulated S_{11} and BW of the reconfigurable antenna in the ON and OFF states. From the figure, the antenna operates at a dual-band frequency of 2.686GHz and 5.164GHz in the ON state. For the frequency of 2.686GHz, the S_{11} and BW are -12.1dB and 50.6MHz while for the frequency of 5.164GHz, the S_{11} and BW are -10.822dB and 32.2MHz, respectively. In the OFF state, the antenna operates as a single band antenna at a resonant frequency of 5.302GHz with a S_{11} and BW of -24.835dB and 99.8MHz. Therefore, it is shown that in the ON state of the PIN diode, the upper resonant frequency is further reduced to 5.164GHz as compared to 5.302GHz when the PIN diode is not present. This can be attributed to the fact that the current travels a longer path from the main radiating plane to the additional plane through the PIN diode that in return, reduces the resonant frequency [10]. It is also shown that the resonant frequency of the reconfigurable antenna in the OFF state of the PIN diode at 5.302GHz is almost similar (vary slightly) to the resonant frequency of the antenna without the presence of the PIN diode (refer Figure 8).

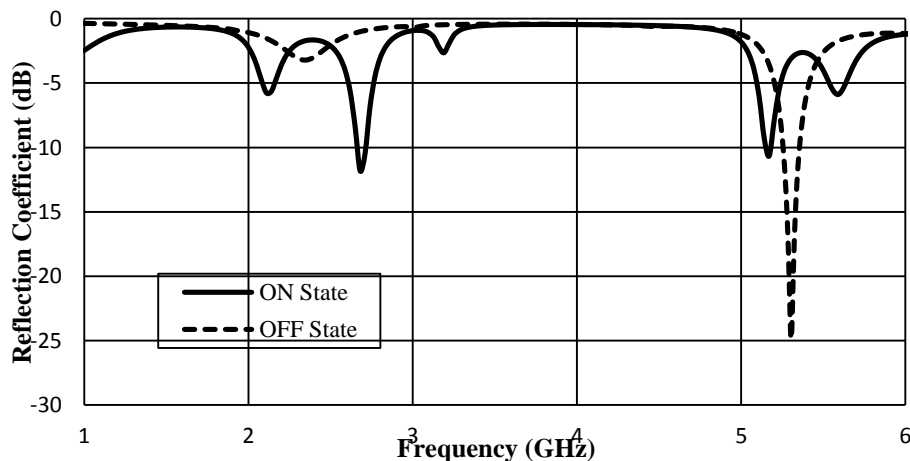


Figure 9. Reflection coefficients of the reconfigurable antenna with a BAR63-02V PIN diode in the ON and OFF states

The reconfigurable antennas are measured by using the ZVB14 Rohde & Schwarz Vector Network Analyzer (VNA). Due to the lack of facilities, only the reflection coefficients are measured. The

measurement data retrieved from the VNA also do not reflect the reflection coefficients on display. Therefore, only the screen display of the reflection coefficients are shown in this paper. The reflection coefficients of the reconfigurable antenna in the ON and OFF states can be viewed in Figure 10. In the ON state, a 12V DC voltage is supplied to the antenna to produce a 10mA of current across the PIN diode. The power supply is switched off in the OFF state. From Figure 10(a), the measured S_{11} are -11.471dB at 2.504GHz and -20.131dB at 5.210GHz. (The marker at 5.210GHz is not available on the display). Figure 10(b) shows the measured reflection coefficient of the reconfigurable antenna in the OFF state. From the figure, it can be seen that the antenna operates at 5.26GHz with a S_{11} at -22.36dB.

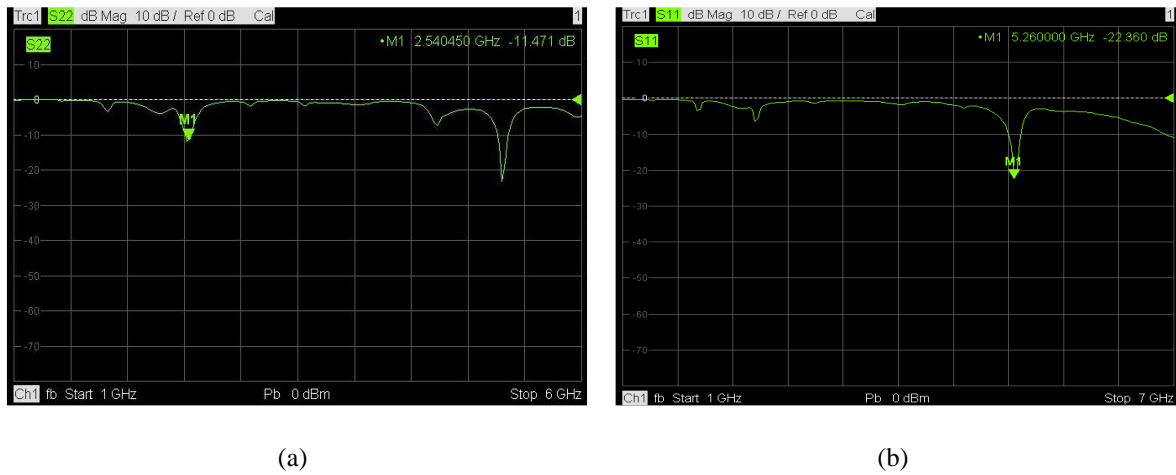


Figure 10. Measured reflection coefficients of the reconfigurable antenna with a PIN diode in the: (a) ON state (b) OFF state

Figure 11 shows the surface current distribution of the simulated reconfigurable antenna with the PIN diode in the ON state. The current is seen to flow across the main radiating plane to the additional plane that explains the dual-band frequency operation of the antenna at 2.686GHz and 5.164GHz. It is shown from the figure that the current travels a longer path from the main radiating plane to the additional plane through the PIN diode in both resonant frequencies. From the previous simulation results, it can be concluded that the main radiating plane produces the upper resonant frequency at 5.164GHz while the additional radiating plane, on the other hand, produces the lower resonant frequency at 2.686GHz. The surface current distribution of the simulated reconfigurable antenna in the OFF state of the PIN diode at 5.302GHz can be viewed in Figure 12. Since the PIN diode is in the OFF state, there is no current flows through the PIN diode to the additional radiating plane. Thus, the current travels a shorter path which increases the resonant frequency.

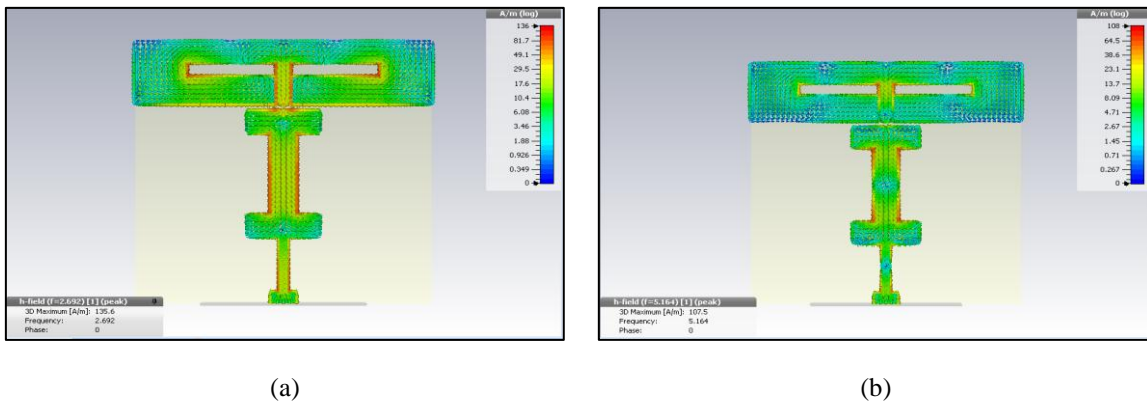


Figure 11. Simulated surface current of the reconfigurable antenna with a PIN diode in the ON state at: (a) 2.686GHz (b) 5.164GHz

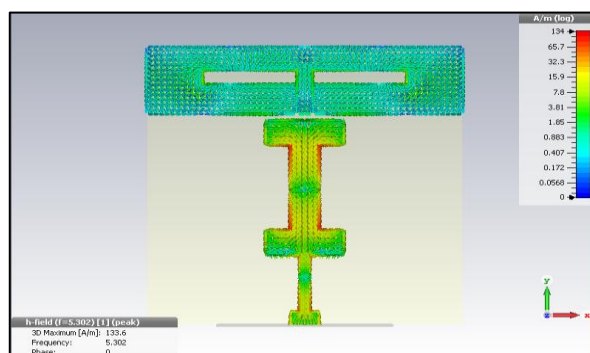


Figure 12. Simulated surface current of the reconfigurable antenna with a PIN diode in the OFF state at 5.302GHz

4. CONCLUSION

A reconfigurable antenna with a BAR63-02V PIN diode has been designed, simulated, fabricated and measured in this work. The antenna is fabricated on a FR-4 substrate with a relative dielectric constant, ϵ_r of 4.5, thickness, h of 1.6mm and loss tangent, $\tan \delta$ of 0.019. The equivalent circuit model of the PIN diode has been modelled in the ON and OFF states. In order to switch ON the PIN diode, a 12V DC voltage is supplied to the antenna in order to produce a 10mA of current to pass through the PIN diode while in the OFF state, the power supply is switched off. Based on the obtained results, the antenna operates at 2.686GHz and 5.164GHz in the ON state which are suitable for LTE2500 and WLAN applications. On the other hand, the antenna operates at 5.302GHz in the OFF state for WLAN application. The antenna is measured on the ZVB14 Rohde & Schwarz Vector Network Analyzer.

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