Design A Reconfigurable U-Slot Rectangular Microstrip Patch Antenna For Multiband Applications

M.A. Shafie, M. T. Ali, Syafiq Amari, Khairul Anuar CM, Amirah Adam
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam,Selangor, Malaysia
fetgizmo@yahoo.com, mizi732002@yahoo.com, laven7@gmail.com, cmkhairu88@gmail.com, amirah.adam272@gmail.com,

Abstract - **In this paper, a reconfigurable U-slot rectangular microstrip patch antenna for multiband applications is proposed. This prototype antenna is designed for mobile and wireless applications. Two pin diodes were placed and used as a switch at two specific positions of the slot. The proposed designed was simulated using the Computer Simulation Technology (CST) Software. Both simulation and measurement results were compared and analyzed to identify the actual characteristics of this prototype antenna.**

Keywords- Reconfigurable, U-Slot, Microstrip Patch Antenna, Computer Simulation Technology (CST) Software and Substrate.

I. INTRODUCTION

Microstrip antenna has many advantages such as small in size, lightweight, low cost, conformability to planar and non-planar surfaces, rigid and easy installation compared to other type of materials These features have made the microstrip antenna very popular in nowadays technology.

By definition, a single band antenna refers to antenna which is designed to operate at a single resonant frequency while a multiband antenna is an antenna designed to operate in more than one band of frequency. Multiband antenna uses a concept of one part of the antenna is active in one frequency band, while another part of it is active in a different frequency band. This type of antenna may have lower than average gains or might be physically large in comparison to single-band antennas in order to accommodate the multiple bands of frequencies.

In the early days, each antenna was only designed to operate at a single operating frequency. This is might be caused by the limitation of the technologies at that particular time. However, due to the increasing in demand towards the technology advancement, the multiband concept of an antenna was introduced. Frequency reconfigurable for multiband applications is one of the latest inventions which are getting very popular nowadays. The reconfigurable characteristic of these antenna types is very valuable for the modern mobile and wireless applications in the market [1].

The first concept of reconfigurable antenna was firstly introduced in D.Schaubert's patent "Frequency Agile, polarization diverse microstrip antenna and frequency scanned arrays" in 1983 [2]. This type of antenna has several advantages such as the capability to vary in the operating frequency, radiation pattern and the polarization [3].

In this paper, a reconfigurable U-slot rectangular microstrip patch antenna for multiband applications is presented. The main focus of this paper is to analyze the function of switch between the slotted areas in achieving the frequency reconfigurable antenna. Different sizes of slot in the patch element are used and all dimensions have been varied in order to observe the relationship between maximum attainable linear phase range and the loss performances [4]. Lots of work had been carried out especially through the parametric studies of the patch, ground and the substrate material including the sizes of the entire related element.

II. ANTENNA DESIGN AND GEOMETRY

The shape and dimension of the antenna was designed using the formulae given in [5]. The formulae used are as follows:

$$W = \frac{c}{2f_r\sqrt{\frac{2}{\varepsilon_r+1}}} \qquad (1)$$

Effective dielectric constant (ε_{reff}) is given in Equation below:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

$$\Delta L = 0.412h\frac{(\varepsilon_r+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_r-0.258)\left(\frac{W}{h}-0.8\right)} \qquad (3)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (4)$$

$$W_g = 6h + W \qquad (5)$$

$$L_g = 6h + L \qquad (6)$$

$$L_f = \frac{6h}{2} \qquad (7)$$

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r+1.41}}\ln\left[\frac{5.98h}{0.8wf}\right] \qquad (8)$$

The proposed reconfigurable U-slot rectangular microstrip patch antenna for multiband applications is designed using the Rogers RT Duroid 5880 substrate (ε_r = 2.2) with the height (thickness) of 1.57 mm. The dimensions of width and length of the microstrip rectangular patch element was calculated based on the centre frequency of 3.5 GHz by using a conventional design procedure of rectangular patch [6].

In the early stage of the design process, few positions of the switches were tested on the main slotted design and patterns of plotted frequency were recorded accordingly.

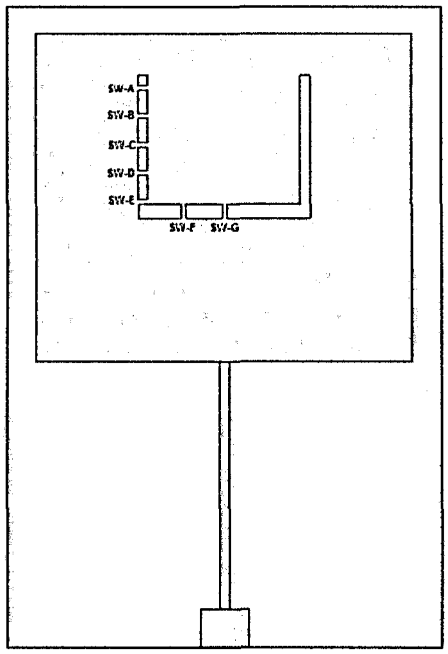


Fig. 1. Antenna Shape And Tested Switches Position

Series of resonant frequencies caused by the changes of the switches position are as shown in figure 2.

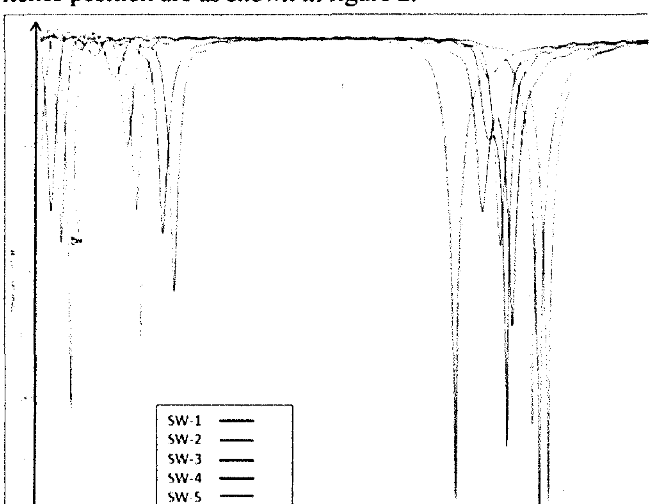


Fig. 2. Patterns Of Return Loss For All 7 Switches Position

TABLE I. PLOTTED FREQUENCY PATTERNS

Switch position	f_1 (GHz) / S_{11} (dB)	f_2 (GHz) / S_{11} (dB)	f_3 (GHz) / S_{11} (dB)
SW-A	3.578 / -31.18	-	-
SW-B	2.043 / -11.78	3.685 / -11.73	3.797 / -19.64
SW-C	2.086 / -11.93	3.896 / -34.66	-
SW-D	2.117 / -24.56	2.367 / -11.613	3.932 / -31.36
SW-E	2.148 / -13.269	2.383 / -20.018	3.869 / -26.553
SW-F	2.469 / -13.19	3.773 / -27.74	-
SW-G	2.51 / -17.31	3.75 / -14.10	-

After taking all the considerations from the parametric studies, two positions of the switch were selected in the design and fabrication process. The geometry of the proposed antenna structure is shown in Fig. 3 and the fabricated antenna are as in figure 4. The proposed U-slotted patch antenna structure are composed of rectangular patch, substrate and U-slotted part with two pins diode act as a switch connecting the slotted area at a specific position. However, the ideal case was chosen in the fabricating process (due to the simplicity and equipment limitation) where the copper strip represents the switch. The measurement were then made from the three differents fabricated ideal condition.

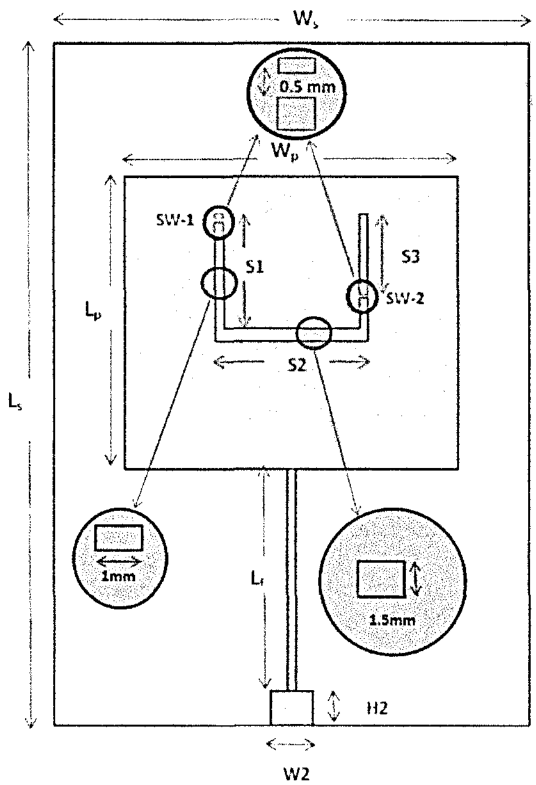


Fig. 3. Antenna Structure

All the sizes and dimensions of this design are shown in the Table II below.

TABLE II. PARAMETERS AND DIMENSIONS

Parameters	Dimensions (mm)
Patch Width, W_p	39.4
Patch Length, L_p	34.4
Substrate Width, W_s	56
Substrate Length, L_s	80
Feeder Length L_f	26
Feeder Width, W_f	1
SW 1 = SW 2	0.5
S1	13.5
S2	18
S3	9.5
H2	4
W2	5

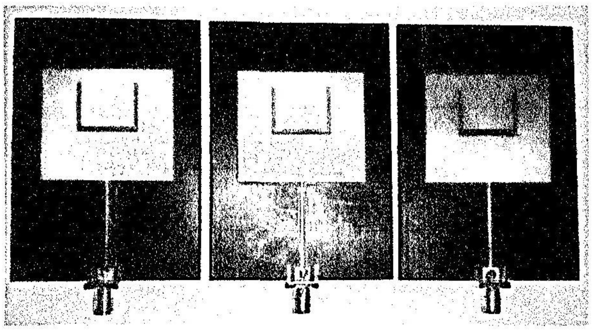


Fig. 4. Photo Of The Fabricated Antenna

The basic principle of this reconfigurable antenna design is the capability to switch from one operating frequency to multiple operating frequencies without changing the whole dimension of the antenna configuration. Two PIN diodes were placed at specific positions to create short circuits across the slot. The changes in current and magnetic field distributions (due to the short/open circuit conditions around the slot) resulted in different resonant frequency of the antenna.

TABLE III. DETAILS OF SWITCH CONFIGURATION

State	S1	S2
Case 1	*Off*	*Off*
Case 2	*Off*	*On*
Case 3	*On*	*On*

III. RESULTS AND DISCUSSIONS

A. Case-1: Both SW1 and SW2 are not activated.

The initial design for this project is a U-Slot Rectangular Microstrip Patch Antenna. Through the parametric study, it was then altered to meet the specification of single resonant frequency at 3.5 GHz.

With both switches at off position, the antenna resonates at frequency of 3.5 GHz. The return loss (S_{11}) and Gain of the antenna for both simulation and measurement are shown in figure 5 and 6 below:

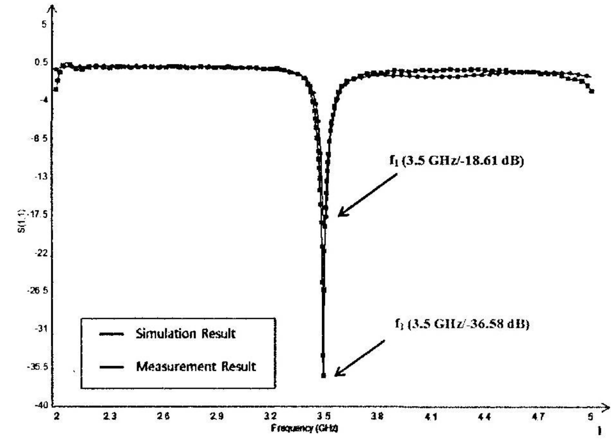
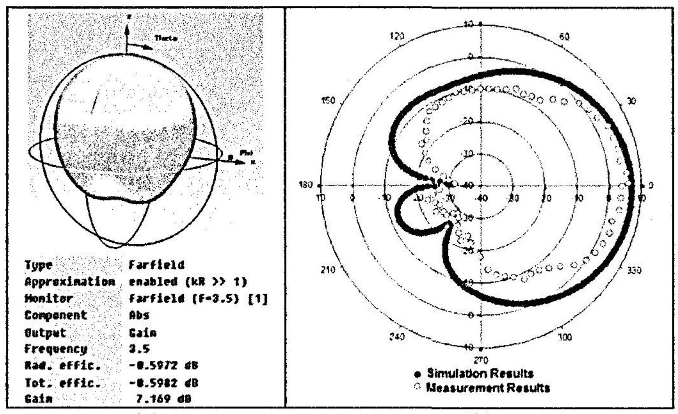


Fig. 5. S_{11} For Case-1



(a) (b)

Fig. 6. Radiation Pattern & Gain For Case-1

B. Case-2: Only SW-2 activated.

In Case-2, SW-2 is activated while SW-1 is remained at "Off" position. The changes of SW-2 has resulted the antenna to change its initial characteristic and operate in two resonant frequencies. Both simulation and measurement results are shown in figure 7, 8 and 9.

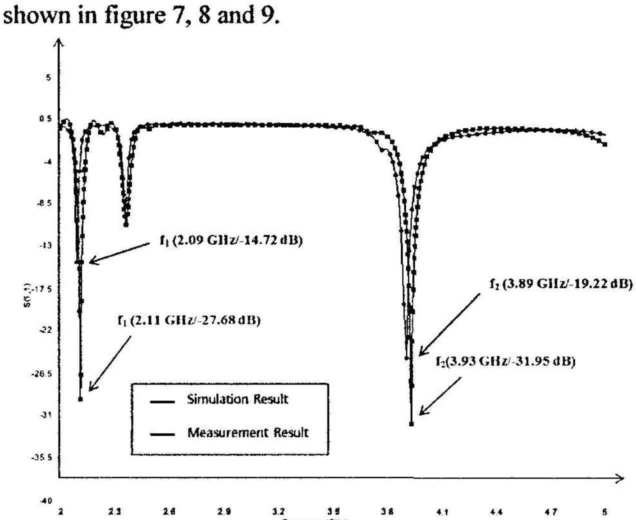


Fig. 7. S_{11} For Case-2

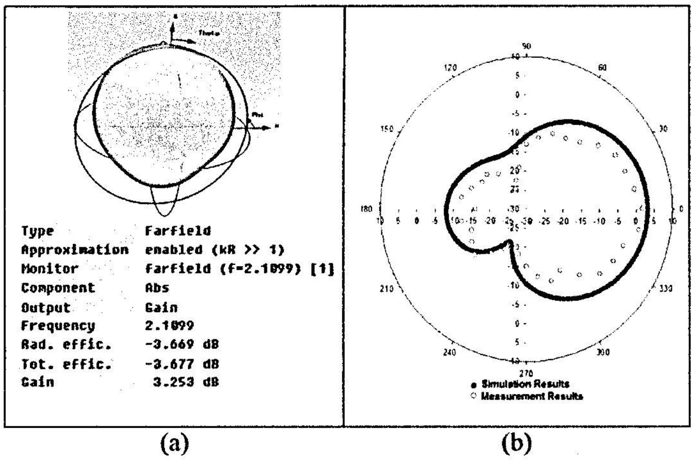


Fig. 8. Radiation Pattern & Gain For Case-2 (f_1)

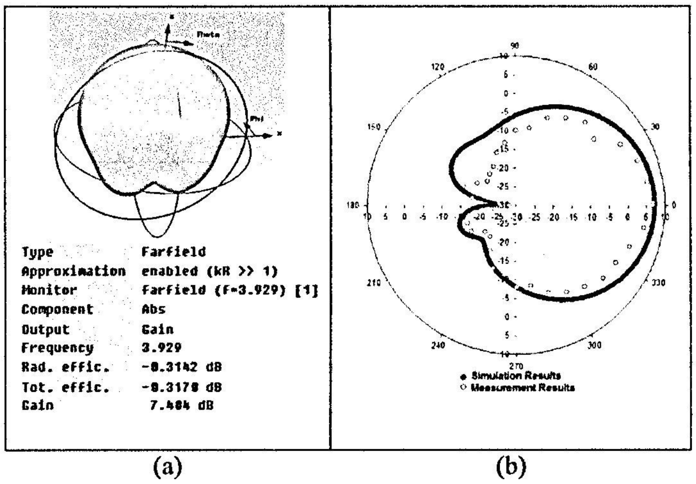


Fig. 9. Radiation Pattern & Gain For Case-2 (f_2)

C. *Case-3: Both SW1 and SW2 are activated.*

In Case 3, both switches (SW-1 & SW-2) were put to 'On' position. Throughout the observation, the return loss still yields at two different frequencies. However, there are some changes in resonant frequency, antenna gain and the radiation pattern. All results are shown in figure 10, 11 and 12.

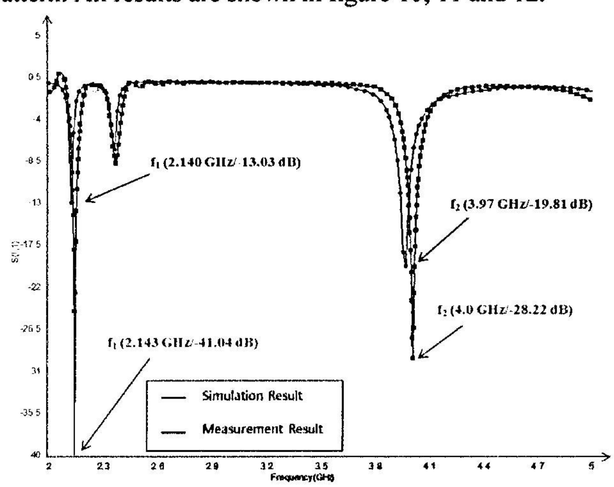


Fig. 10. S_{11} For Case-3

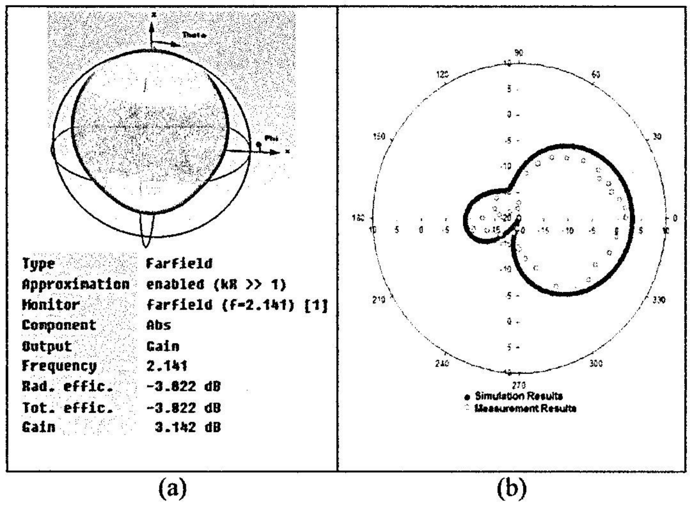


Fig. 11. Radiation Pattern & Gain For Case-3 (f_1)

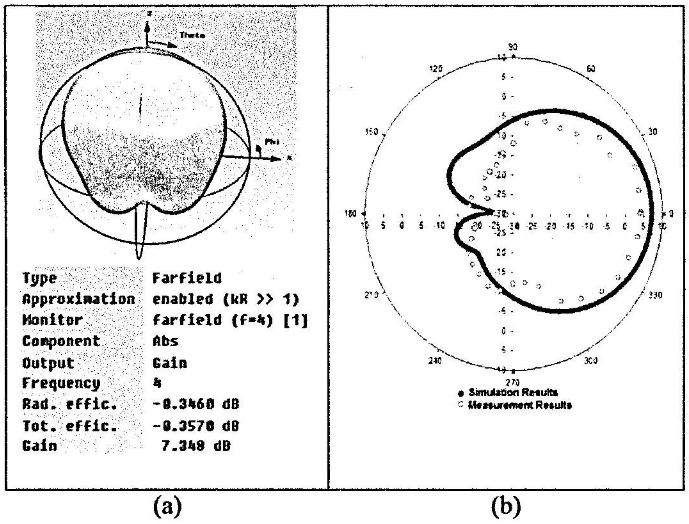


Fig. 12. Radiation Pattern & Gain For Case-3 (f_2)

TABLE IV. RESULTS FROM SIMULATION & MEASUREMENT

		SIMULATION RESULTS (MEASUREMENT RESULTS)					
SW-1	SW-2	f_1 (GHz)	S_{11} (dB)	Gain (dB)	f_2 (GHz)	S_{11} (dB)	Gain (dB)
Off	Off	3.5 (3.5)	-36.58 (18.61)	7.17	-	-	-
Off	On	2.11 (2.09)	-27.68 (14.72)	3.25	3.93 (3.89)	-31.95 (19.22)	7.40
On	On	2.14 (2.14)	-41.04 (13.03)	3.14	4.00 (3.97)	-28.22 (19.81)	7.35

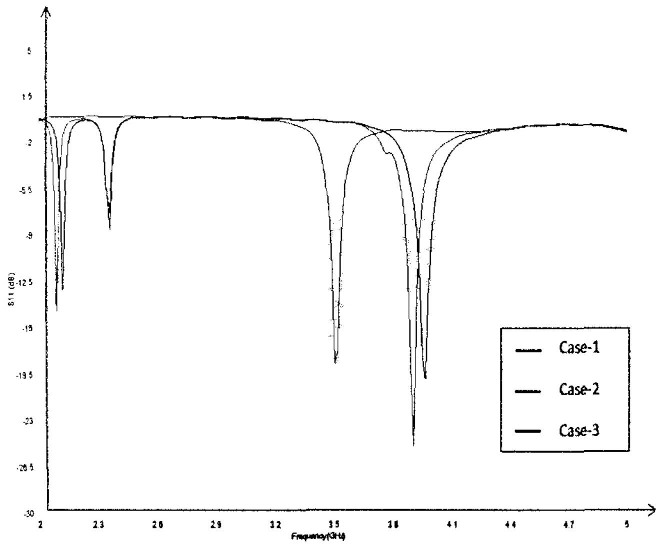


Fig. 13. Overall Simulation Results For Return Loss

Table 4 displays all results from the simulation and measurement process. The main purpose of this project is to design and demonstrate the frequency tuning ability by using the switches. Overall, result shows that the resonant frequency of this prototype antenna can be changed from a single band frequency to a multiple band frequencies by activating the switches/pin diode.

From the observation and analysis of the results, it was observed that each parameter variation causes some changes in all aspects of resonant frequencies. However, some of these changes are larger and more pronounced than others, which lead to hypotheses about the relationships between geometry and behavior.

In the parametric studies, only one parameter was altered at a time and all parameters not specified remain at values given in Table 1. Initially, in the earlier stage, the dimensions and position of the U-Slot were varied accordingly to achieve the desired and optimum results.

The distribution of the magnetic and electric field along the slotted area plays important role to determine the resonant frequencies as well as the return loss of the antenna. By adding additional switches, it will automatically introduce a new slotted pattern which will then contribute to major changes of E and H field around the area [7]. These drastic changes will then cause the antenna to change its characteristic and radiate in a different specification where the concept of reconfigurable antenna can be achieved [8].

The simulation results and the radiation pattern of this prototype antenna show the consistency of a directional antenna which is suitable for any related applications within this band of frequencies.

The simulated and measured results achieved on gain from this prototype antenna strongly agree that this prototype antenna is capable to operate within the desired goal which is above 3 dB Gain.

IV. FUTURE WORKS

In future design, Infineon bar 63-02V PIN diodes are suggested to be used for the frequency shifting operation. This is because of its good nominal isolation. The equivalent circuit of a PIN diode corresponds to an inductance L, for both states of the switch, in series with a resistance R_S for the on state, and with the parallel connection n of a capacitor C_T and a resistance R_P for the off state [9]. The RF equivalent circuit of the diode is shown in Figure14 for both on and off states.

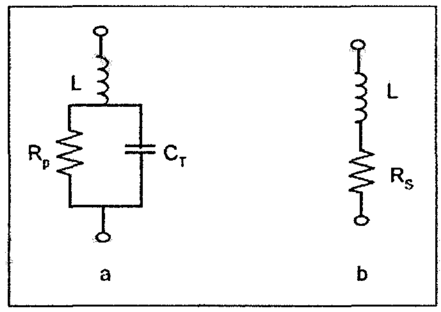


Fig. 14. Pin Diode Equivalent Circuits (a) Off States (b) On State

V. CONCLUSION

There are three different configurations tested during the simulation and measurement processes involving this prototype antenna. By comparing all the results, we can notice two main consistencies in specifications about this prototype antenna.

The simulated and measured results show that the radiation pattern has a minor effect by the frequency tuning. This prototype antenna produces a stable radiation pattern

Both simulated and measured results also proved that the antenna radiate with a sufficiently high gain which is suitable for application in wireless communication system.

A reconfigurable U-slot rectangular microstrip patch antenna for multiband applications was successfully designed in this paper. Simulation results have prove that this antenna is capable to operate according to the designed specification.

During the design process, a comprehensive parametric study has been carried out by optimizing the various dimensional parameters (slots and position of switches). Slots are added to a rectangular patch antenna in order to obtain desired resonance frequency with the return loss less than -10 dB.

This reconfigurable antenna can further be modified by using different type of substrate and a proper study can enhance towards a better results.

VI. REFERENCES

[1] M. T. Ali, et al., "A novel of reconfigurable planar antenna array (RPAA) with beam steering control," Progress In Electromagnetics Research B, pp. 125-146, 2010

[2] D. Schaubet. "Frequency-Agile Polarization Diverse Microstrip Antennas and Frequency Scanned Arrays [P] ", US Patent #4, 367,474, Jan. 4, 1983

[3] K. Chung, Y. Nam, T. Yun, and J. Choi, "Reconfigurable Microstrip Patch Antenna with Switchable Polarization", *ETRI Journal*, Volume 28,Number 3, June 2006.

[4] Based on Phase Agility Technique", Conference on Antennas, Propagation and Systems (INAS 2009), Dec.2009.

[5] C.A.Balanis, "Antenna Theory, Analysis and Design" John Wiley and Sons, New York 1977.

[6] M.Y. Ismail, M. Inam and J.Abdullah, "Design Optimization of Reconfigurable Reflectarray Antenna.

[7] K. Hirasawa, Analysis, Design, and Measurement of Small and Low- Profile Antennas. Norwood, MA: Artech House, 1991.

[8] M.-I. Lai, T.-Y. Wu, J.-C. Hsieh, C- H. Wang, and S.-K. Jeng "Design of reconfigurable antennas based on an L-shaped slot and PIN diodes for compact Wireless devices ", IET Microwave. Antennas Propag. 2009, Vol. 3, Iss. 1, pp. 47–54.

[9] Ggg A. Mansoul, H. Kimouche, "A simple frequency reconfigurable microstrip patch antenna for wireless communication" Ecole militaire, polytechnique Microwaves/Radar Laboratory.