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Comparative Analysis of PIN Diode Switch for Microwave Applications

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Abstract—*As we know that pin diode make enable the performance of reconfigurable slot-ring antenna. We can say that an equivalent circuit is used to the ON and OFF states of the switches in the antenna structure. Two different antennas with ideal switches and real switches are fabricated and measured. After proper analysis we observed that pin diode switches having some loading effects on the respective antenna.Parametric & conceptual analysis of each circuit element is also simulated and described in this paper.*

Keywords: *PIN diodes; PIN diode equivalent circuit model; reconfigurable antennas; slot-ring antennas.;*

I. INTRODUCTION

In previous years, demand of advanced wireless communication system, smart devices related to communication system are on the top most level as well as increasing. While we are discussing about wireless communication devices, antennas play a major vital role and antenna should be smart and multifunctional. We know that, reconfigurable antennas having ability as multifunctional devices. This type of antennas are able to regulate and make change in their operating frequency, radiation pattern and polarization in real time without changing their structure.

The advanced approaches for designing reconfigurable antennas are using the electromechanical or electrical switches, such as RF microelectromechanical systems (MEMS) [1], pi-n (PIN) diodes [2], varactors [3], and the field-effect transistor (FET) [4]. The MEMS switches have advantages of low loss and high Q compared to the PIN diodes and varactor diodes. Afterall, the RF PIN diodes have low cost and relatively high power-handling capability. However, reconfigurable antennas using PIN diode switches are easier to fabricate. However, PIN diodes needs to be connected with forward bias DC current when in the ON state which will degrade the power efficiency and antenna performance.

In the assumption, it is seen that switches are modeled as short or open circuits in reconfigurable antennas. Some facts studied the effects of switches by using an equivalent circuit representation for the switch in the antenna structure. Although it reflect a better representation over open or short circuit representation of the switches, the switch model can still be further improved by using analysed S parameters and extracting the equivalent circuit elements of the switches. In [5], the effect of using PIN diode switch model on impedance matching and the radiation patterns of a reconfigurable leaky-wave antenna (LWA) has been assumed but they considered a very simple model for PIN diodes and did not study the effect of each circuit element on the performance of the antenna.

In this paper, the effect of PIN diode switches on the performance of reconfigurable antenna is reflected. The antenna geometry and equivalent circuit model for the switch will be presented in section II. In section III, the measured return losses of the fabricated antennas as well as the effect of each circuit element on the antenna performance such as resonance frequency, radiation pattern and gain is studied. Finally, the conclusions will be given in section IV.

II.ANTENNA DESIGN

A. Antenna geometry

When we are discussing about reconfigurable slot-ring antenna.It can beswitch its operating frequencies between 2.18 GHz and 7 GHz is used in this study. The antenna is designed and fabricated on a Rogers RT/Duroid 5880 substrate (ε_r=2.2 and tanδ=0.0009) with the thickness of h=0.79 mm. Four PIN diode switches (DSM8100-000 from Skyworks) are placed between the big and small slot-rings. Fig. 1 shows the geometry of the antenna. The inset in this figure shows the close view of the small slot-ring that contains all four switches. Due to the small dimensions of the switches, they cannot be soldered by hand. Instead, stencil printing is used to mount the switches on the PCB and then reflowing process is done using a reflow oven.

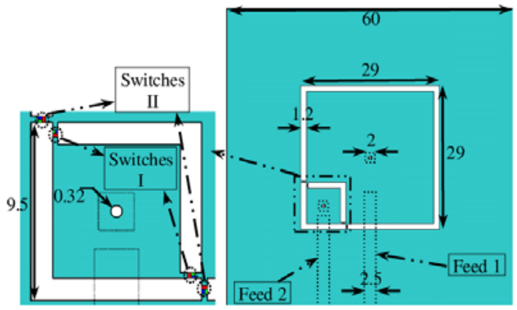


Fig. 1 Antenna geometry. The inset is the close view of the small slot and dotted.

The holes are placed near the center of each slot where the magnitude of electric field is minimum level. Because of that, the electric field is not manipulated and the switches do not affect the performance of the antenna.

B. Equivalent circuit for the PIN diodes

While comparing the diodes are modeled in two ways: An ideal model and a circuit model consists of RLC components. Fig. 2 (a) and (b) depict the circuit model that is used for the switch in the ON and OFF states, respectively. The inductance in the model is due to the packaging and it is the same for both states. The circuit element values are extracted from the measured S parameters of the switch provided by the manufacturers.

III.RESULTS AND DISCUSSION

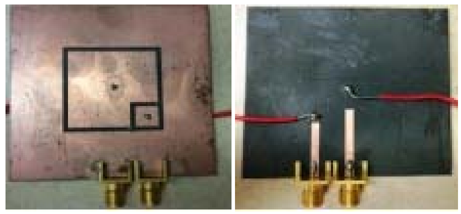
A. Measured results

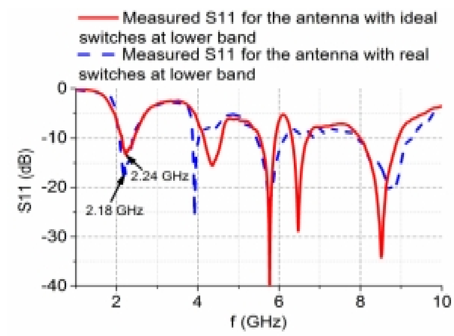
Given Fig. 2 relate the fabricated antenna with four PIN diode switches. Two other antennas have also been fabricated with ideal switches (short circuit for the switch in the ON state and open circuit for the switch in the OFF state) to operate at 2.16Ghz and

7 GHz, respectively. The measured return losses of the antenna with real switches and the antenna with ideal switches at lower band and higher band are compared in Fig. 4 (a) and (b), respectively. It is seen that the switches have some loading effects on the antenna that shift the resonance frequency. f_0 for the antenna with real switches is approximately 3.5% lower than f_0 for the antenna with ideal switches. In another part will be discuss about shifting of frequency due to capacitances of switches.

TABLE : I.ELEMENT REQUIRED FOR PIN DIODE SWITCH IN ON AND OFF MODES.

State of the sw	Resistance	Capacitance (fF)	Inductance (nH)
ON	R_S = 3 ohm	-	0.15
OFF	R_O = 15 Kohm	32	0.15





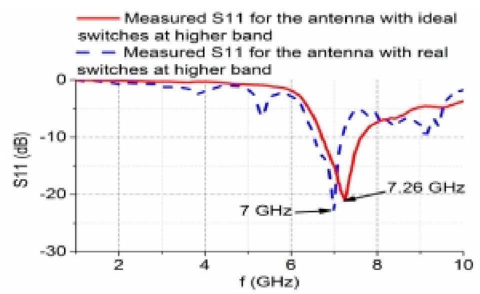


Fig. 3: Measured S11 for the antenna with ideal switches (red solid line) and the

antenna with real switches (DSM 8100-000) (blue dashed line) (a) at lower

frequency band (b) at higher frequency band

The gain and efficiency of the antenna with ideal switches and real switches at 2.18 GHz and 7 GHz is compared in Table .

II. It is seen that the gain of the antenna with real switches is decreased and accordingly the efficiency of the antenna with real switches is less than the antenna with ideal switches.

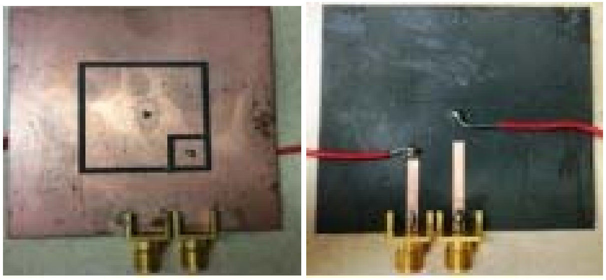


Fig. 2 Fabricated antenna. Top view (ground plane side) on the left and Bottom view (feed line and bias side) on the right.

B. Parametric analysis

In this part, a parametric study on each circuit element of the switch is done. According to Fig. 2, there are four circuit elements for the PIN diode switch in the ON and OFF states.

The effect of each element on the gain and resonance frequency of the antenna is studied. Fig. 5 illustrates the effect of capacitance (C_O) on the resonance frequency of the antenna at lower and higher bands. It is seen that C_O has more effect on f_0 at higher frequencies. f_0 vs. inductance of the switch (L) is also depicted in Fig. 6. The effect of Lonf_0 is almost the same at lower and higher frequency bands. Afterall, according to Figs. 4 and 5, C_O has much more effect on the resonance frequency of the antenna than L.

TABLE-II.GAIN AND EFFICIENCY OF THE ANTENNA WITH IDEAL SWITCHES AND CIRCUIT MODELED SWITCHES (REAL SWITCHES) AT BOTH FREQUENCY BANDS.

Ideal/non-ideal (real)	Freaquncy (measured)	Gain (db) (simulated)	Efficiency (%)	BW(%)
Ideal Switch	2.24ghz	0.01	97.3	13.5
Real switch*	2.18ghz	-0.29	93.1	15.1
Ideal switch	7.26ghz	5.72	98.8	12.6
Real switch*	7ghz	5.23	91.4	9.4

The equivalent circuit shown in Fig. 3 is used to model the real switches in the antenna structure

On one hand, the gain of the antenna vs. resistance of the switch in the ON state (short switch, R_S) is depicted in Fig. 7. On the other hand, Fig. 8 shows the gain of the antenna vs.

resistance of the switch in the OFF state (open switch, R_O). Comparing Figs. 7 and 8 illustrates that the effects of R_O on the gain is more than R_S.

It is known that the resistance doesn't have any effect on

It is known that the resistance doesn't have any effect on the resonance frequency of the antenna. Furthermore, the capacitance and inductance of the switches do not affect the

gain of the antenna. So there are no figures in this paper to show f_0 vs. R, or G vs. C_O, or G vs. L.

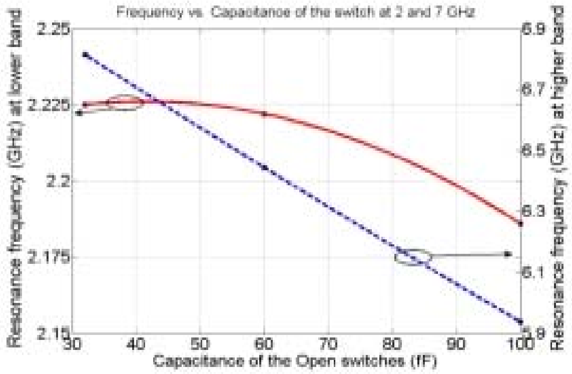


Fig. 4: Resonance frequency of the antenna vs. capacitance of the switch at lower (red solid line) and higher (blue dashed line) frequency bands.

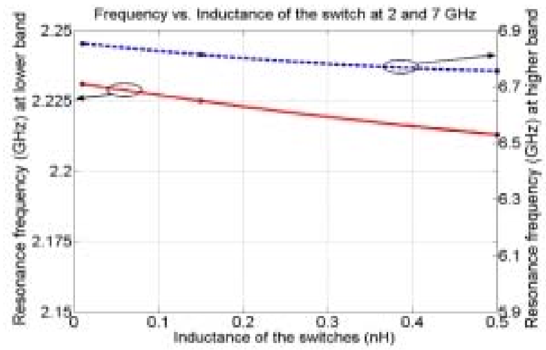


Fig. 5 Resonance frequency of the antenna vs. inductance of the switch at lower (red solid line) and higher (blue dashed line) frequency bands.

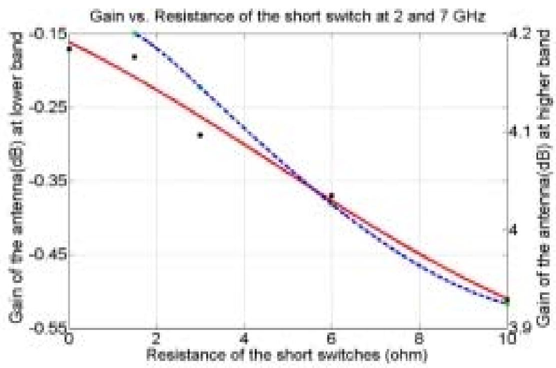


Fig. 6 Gain of the antenna vs. resistance of the short switch (R_S) at lower (red solid line) and higher (blue dashed line) frequency bands.

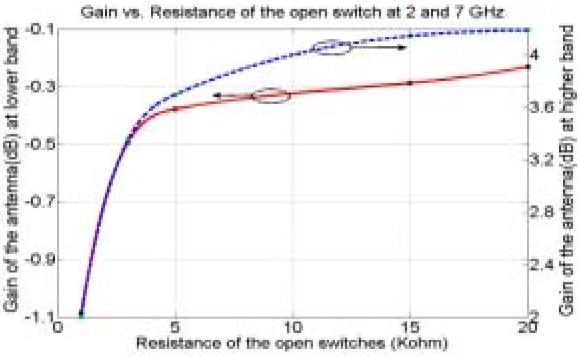


Fig. 7 Gain of the antenna vs. resistance of the open switch (R_O) at lower (red solid line) and higher (blue dashed line) frequency bands

CONCLUSION

After above discussion and conceptual analysis, we assumed that effect of PIN diode switches on a reconfigurable slot-ring antenna has been presented. The antenna operates at 2.16 GHz and 7 GHz based on the state of the switches. The measured results of an antenna with real switches has been compared to the measured results of an antenna with ideal switches. However, parametric analysis for each circuit element in the equivalent circuit of the switch has been done. Itis found that the capacitance of the switch is responsible for the shift in resonance frequency and the resistance of the switch in the OFF state is responsible for the gain reduction.

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