Planar Reconfigurable Antenna with Integrated Switching Control Circuitry

Damiano Patron and Kapil R. Dandekar
Electrical and Computer Engineering Department
Drexel University, Philadelphia, PA, 19104, USA

***Abstract*—In this paper we propose a pattern reconfigurable planar antenna with integrated control circuitry, for flexible applications with Software Defined Radio (SDR) platforms. The antenna's layout is made by four folded microstrip elements placed symmetrically on a low cost FR-4 substrate. By using PIN diodes, the metallic elements can be switched to generate a single omnidirectional beam or six directional beams around the azimuth plane. The design includes MOSFET based control circuitry for switching the PIN diodes. The RF performance has been experimentally evaluated under different levels of control voltage. The radiation of omnidirectional and directional beams along with an integrated control board, allows for convenient utilization of the antenna in numerous SDR MIMO platforms.**

***Index Terms*—Adaptive and reconfigurable antennas, MIMO, Multiband and wideband antennas.**

I. INTRODUCTION

Pattern reconfigurable antennas were demonstrated to be an important solution to improve channel capacity and security in wireless communications [1] [2]. The antenna's radiation characteristic can be changed according to the wireless channel response, improving the Signal to Noise Ratio (SNR) and consequently, the data throughput [3].

Pattern reconfigurability can be achieved through different techniques. A central radiating element can be surrounded by switchable parasitics creating the so-called ESPAR antenna [4]. More complex structures based on metamaterial technology use varactor diodes to dynamically change the propagation constant β along the structure achieving uniform beam steering [5]. Recently, the novel design of a Reconfigurable Alford Loop Antenna has shown the ability to generate omnidirectional and directional patterns by switching dual active/passive elements through PIN diodes [6]. However, the presence of such lumped elements often requires an additional control board to boost the current from the General Purpose Input/Output (GPIO) pins coming from the main board of the wireless radio platform.

In this work, we propose an improved design of a Reconfigurable Alford Loop Antenna with an integrated control board for flexible employment with SDR wireless platforms. The antenna radiates a single directional beam or six directional beams, covering WiFi and WiMAX channels from 2.4 GHz to 3 GHz. The following sections describe the antenna design and modes of operation, discussing control circuitry performance and concluding with comprehensive characterization of antenna's input impedance and radiation patterns.

II. ANTENNA DESIGN

The antenna design consists of four 90° microstrip elements arranged symmetrically between top and bottom layer of a 1.6 mm thick FR-4 substrate. Design and dimension are depitced in Figure 1. The antenna is fed by a coaxial SMA connector having ground soldered to the larger bottom layer circle and inner conductor soldered on the top smaller circle.

When all the microstrip elements are connected to the central port a uniform surface current generates an omnidirectional radiation pattern around the azimuth plane. Alternatively, when two adjacent elements are connected to the central port, the beam is reflected toward the disconnected pairs, generating a directional pattern. Considering the four 90° spaced microstrip elements, the antenna can generate a total of four directional beams with 90° of spacing between each other. Lastly, a bi-directional beam can also be generated by activating a couple of opposite elements, keeping the other two disconnected. Thus, an additional two bi-directional beams can also be generated.

Each element has been designed with square shape to mantain uniform current distribution when omnidirectional mode is activated, but also to enhance the front-to-back ratio when the element act as reflector for directional operations.

Detailed descriptions of the achievable radiation patterns are described in Section V-B.

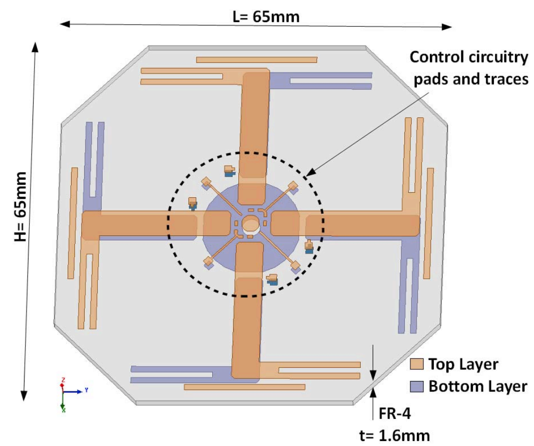

Fig. 1. 3D view and dimensions of the proposed antenna

978-88-907018-4-9/14/$31.00 ©2014 IEEE

A. Switching Control Circuitry

The proposed reconfigurable antenna requires switching components to connect/disconnect the microstrip elements to the central RF port. This can be accomplished by using PIN diodes, single-pole-single-throw (SPST) switches that operate in the RF domain. For our purpose we have used a Skyworks™ SMP-1345, a PIN diode specifically designed to operate up to 6 GHz.

In order to avoid external control boards for driving the PIN diodes, we wanted to equip the proposed antenna with appropriate switching control circuitry. The aim of the circuitry design was to add to the antenna the flexibility for use with common GPIO voltages found in SDR platforms, typically 3.3V or 5V.

In Figure 2, we show the schematic of the circuit for the PIN diode control along with a picture of the transmission line built for scattering parameters measurements. In order to reduce complexity and power consumption, we have used an N-Channel MOSFET BSS-138 and a resistive network to provide the appropriate voltage and current to the PIN diode (V=1V, I=10mA). In essence, when the control voltage V_G is at logic level 0, V_{PIN} is equal to zero, turning the PIN diode to the OFF state (high RF isolation). On the other hand, when V_G rises to higher voltage levels (greater than the MOSFET threshold voltage) it enables the current flowing through the circuit, thus turning ON the PIN diode (low RF insertion loss). The inductor L= 220nH act as a RF-choke preventing the RF leakage along the DC circuit.

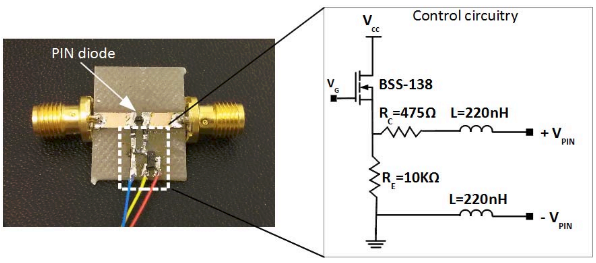

Fig. 2. Transmission line used for PIN diode measurements and control circuitry schematic.

Scattering parameters of the circuitry described in Figure 2 were measured within the bandwidth of interest, from 2 GHz to 3 GHz. By considering the two cases V_{CC}= 3.3V and V_{CC}= 5V, we have measured the scattering parameter S_{12} under different levels of the control voltage V_G. The network analyzer has been calibrated with the port extension function accounting for the $\lambda/4$ microstrip line used to solder the PIN diode.

In Figure 3, we depict the S_{12} curves for five levels of control voltage V_G, the bias voltage V_{CC} was set to 3.3V. When the circuit is turned off, V_G= 0, the PIN exhibits a relatively high isolation of about 10 dB. On the other hand, when V_G is increased to values greater than the threshold voltage (V_{th}= 1.5 V) the MOSFET's operation point moves to the saturation region, allowing the current to flow through

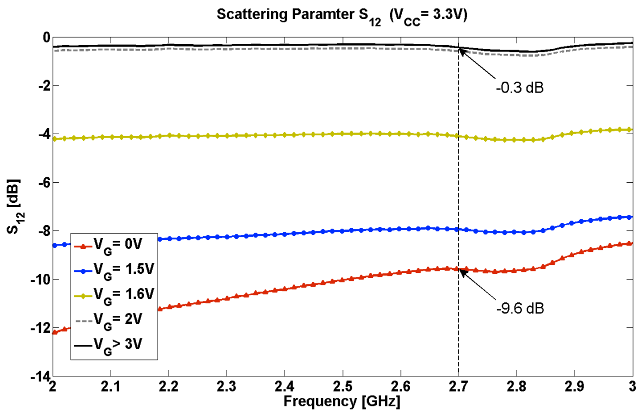

Fig. 3. S_{12} measurements under different control voltage levels, at V_{CC}= 3.3V

the resistive network. For V_G greater than 3 V, the MOSFET is in the saturation region and the PIN diode is in fully forward bias, achieving an insertion loss of about 0.3 dB. The same experiment run at V_{CC}= 5V yields very similar isolation and insertion loss under the same control voltages V_G.

Once the PIN diode along with the switching circuitry were validated, we integrated the circuit design on the proposed reconfigurable antenna. Figure 4 shows the circuit and the component arrangement to switch one pair of microstrip elements (the same circuitry is replicated next to each couple of elements). In order to reduce the number of wires, the DC voltage V_{CC} is provided through the RF cable by means of a bias-tee. Such voltage is then extracted from the input port by using 220 nH RF chokes (RFC) and a 15 pF decoupling capacitor (DC-block). The MOSFET as well as the resistive network were placed on the bottom layer and the resulting voltage V_{PIN} is shared between the two layers through via hole. Resistor R_1=10 KΩ and R_2= 230 Ω are set in order to provide a current of 20 mA for the two PIN diodes.

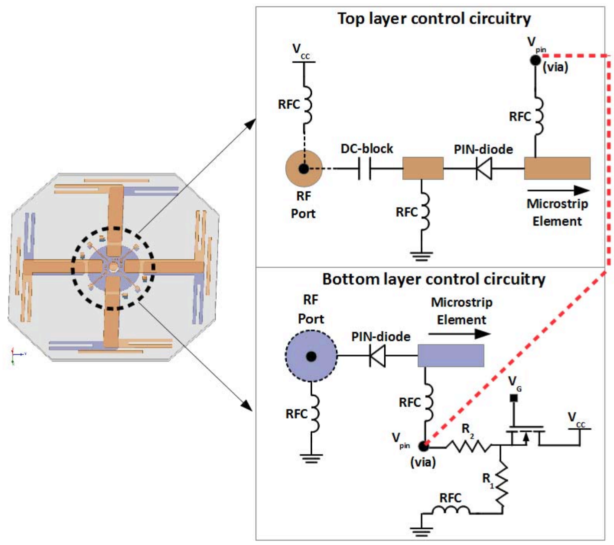

Fig. 4. Schematic and arrangement of the switching circuitry components.

III. Antenna Characterization

The proposed antenna has been designed and simulated using the High Frequency Structural Simulator HFSS™. A lumped element equivalent model of the PIN diode has been extracted for the best fit with the S-Parameters measurements described in Section II-A. The equivalent model and relative lumped elements values under forward (ON state) and reverse bias (OFF state) conditions are depicted in Figure 5. The elements L_S and R_S account for packaging and wire-bonding parasitics effects, while C_J and R_J are respectively, junction capacitance and junction resistance under 0V DC bias.

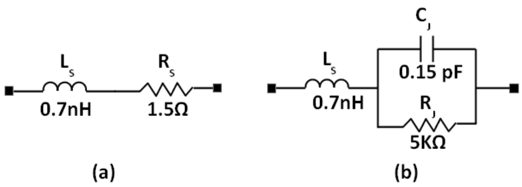

Fig. 5. PIN diode equivalent model: (a) Forward bias, ON state. (b) Reverse bias, OFF state.

The PIN diode equivalent models were loaded into the HFSS antenna model by means of lumped RLC ports, connected between gaps having the same length of the actual SMD component. Accounting for such losses allows for more realistic simulations in terms of isolation and insertion loss of the PIN diode in ON and OFF states.

A. Input Impedance

The input impedance characteristics of the proposed antenna were simulated from 1 GHz to 4 GHz assuming a matched 50 Ω feed port. The return loss, or S_{11}, is shown in Figure 5 for each mode of operation: omnidirectional, directional and bi-directional beams. By looking at the 10 dB return loss bandwidth, the antenna covers a minimum bandwidth of 400 MHz in omnidirectional mode, covering WiFi and WiMAX channels from 2.4 to 2.8 GHz. When directional modes are activated, a larger bandwidth is achieved, extending the coverage up to 3 GHz.

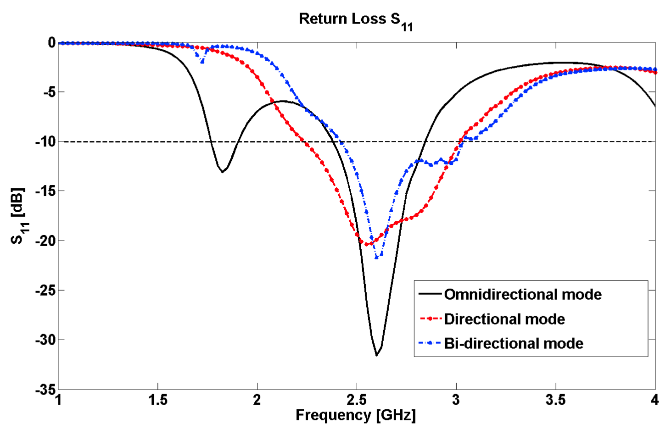

Fig. 6. Return loss of the proposed antenna for the three possible radiation modes.

B. Radiation Patterns

Simulation analysis of radiation patterns were carried out for each antenna state. When all the microstrip elements are connected to the central RF port the current distribution is uniform through the metallic elements, radiating an omnidirectional beam having 1.8 dBi of gain. The simulated radiation pattern is depicted in Figure 7, showing azimuth plane θ= 0 (solid line) and elevation plane ϕ= 0 (dashed line).

Four distinct directional modes can be generated when two adjacent couples of elements are connected to the central port while the other three are disconnected, acting as reflectors. In Figure 8 we show one such directional mode, having gain of 3.6 dBi and Half-Power Beamwidth (HPBW) of 60°.

Two bi-directional beams can be radiated when two opposite elements are connected to the central port. The beam is reflected toward the disconnected pairs, radiating two main lobes in the direction of the excited pairs. Figure 9 shows one of the two bi-directional modes with a gain of 4 dBi and HPBW= 50°.

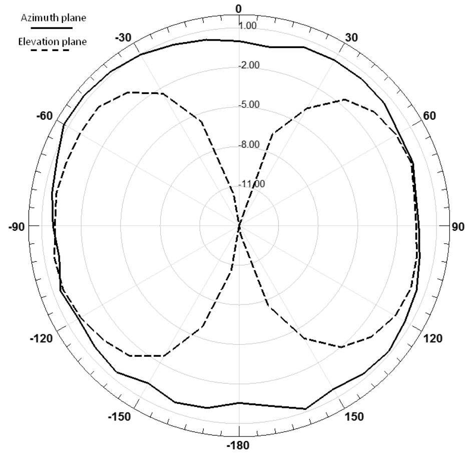

Fig. 7. Omnidirectional beam

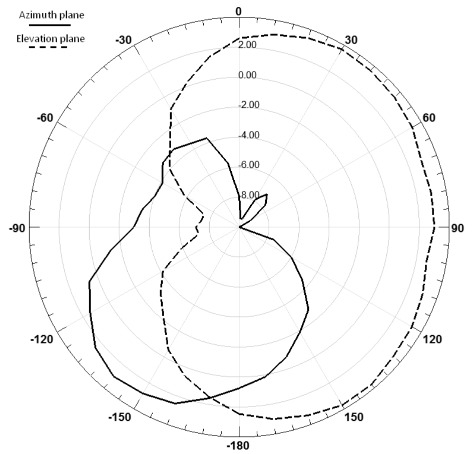

Fig. 8. Example of one of the four directional beams

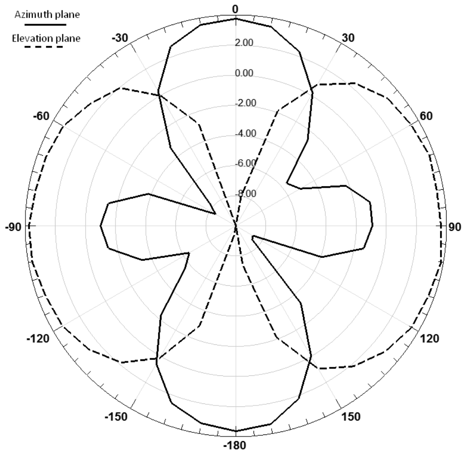

Fig. 9. Example of one of the two bi-directional beams

IV. Conclusion

We have shown the design of a planar reconfigurable antenna equipped with switching control circuitry to turn the PIN diodes. The switching circuitry is made by an N-channel MOSFET and a resistive network that provides appropriate forward and zero bias conditions to the PIN diode. The circuit has been validated through scattering parameter measurements, and by estimating the proper control voltages necessary to turn the PIN diode from OFF to ON state. Finally the circuitry has been added to a reconfigurable planar antenna and input impedance as well as radiation patterns were simulated accounting for the realistic PIN diode losses. The proposed antenna along with the integrated control circuitry, can be a viable antenna solution for modern WiFi and WiMAX SDR platforms.

Acknowledgment

The paper is based upon work supported by the National Science Foundation under Grants CNS-0916480 and CNS-1147838.

References

[1] J. Kountouriotis, D. Piazza, P. Mookiah, M. D'Amico and K. R. Dandekar, "Reconfigurable antennas for MIMO ad-hoc networks", *IEEE Radio and Wireless Symposium*, 2008.

[2] P. Mookiah and K. R. Dandekar, "Enhancing wireless security through reconfigurable antennas", *IEEE Radio and Wireless Symposium*, 2010.

[3] Y. Zhou, R. Adve and S. Hum "Design and Evaluation of Pattern Reconfigurable Antennas for MIMO Applications", *IEEE Journal on Selected Areas in Communications*, vol. PP, no. 99, pp. 1-1, 2013.

[4] K. Gyoda and T. Ohira "Design of electronically steerable passive array radiator (ESPAR) antennas", *IEEE International Symposium Antennas and Propagation Society*, vol. 2, pp. 922-925, 2000.

[5] S. Lim, C. Caloz and T. Itoh "Metamaterial-based electronically controlled transmission-line structure as a novel leaky-wave antenna with tunable radiation angle and beamwidth", *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 1, pp. 161-173, 2005.

[6] D. Patron, D. Piazza and K. R. Dandekar "Wideband planar antenna with reconfigurable omnidirectional and directional radiation patterns", *IET Electronics Letters*, vol. 49, no. 8, pp. 516-518, 2013.