Investigation of Switching Techniques for Reconfigurable Multiband Planar Antennas

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***Abstract*—This paper discusses the design of a dual band planar antenna, able to generate omnidirectional and directional radiation patterns. The antenna employs RF switching devices to select microstrip elements. Qualitative analysis of isolation and insertion loss is performed for three possible switching solutions. Specifically, using commercially available devices, an analysis is conducted for the insertion loss and isolation characteristics on both the 2.4 and 5 GHz Wi-Fi bands. The best resulting strategy is applied to the proposed multiband reconfigurable antenna, which is designed to operate at the Wi-Fi center frequencies of 2.4 GHz and 5.5 GHz, as defined by the IEEE 802.11 ac standard.**

I. Introduction

Increasing the capacity of MIMO systems has spurred the investigation of reconfigurable antennas as a possible answer to this multi-faceted problem. Planar reconfigurable antennas are a promising solution due to their compactness and low-cost. As summarized in [1], frequency and pattern reconfigurable antennas are able to modify their structure to allow for a change in their operating frequency or radiated pattern. Some applications of pattern-reconfigurable antennas stem from their ability to direct signal energy to the intended receiver, increasing the link quality while reducing interference towards unintended devices. In this paper, we describe the design of a multiband pattern-reconfigurable antenna, designed to operate within the 2.45 and 5.5 GHz Wi-Fi bands. An investigation of the most efficient switching technique is performed using two commercially available devices, commonly used as switching mechanisms for reconfigurable antennas: PIN diodes and Single-Pole Double-Throw (SPDT) switches. These devices are compared in terms of insertion loss and isolation characteristics on both bands, and the best switching solution is applied to the proposed reconfigurable antenna.

II. Reconfigurable Alford Loop Antenna

The proposed antenna, the Reconfigurable Alford Loop Antenna, is a planar design motivated by the need to generate omnidirectional and directional patterns in a compact design. The first single band design was presented in [2]. The layout is made of four folded microstrip elements spaced 90° apart in each quadrant and arranged symmetrically on a top and bottom layer of an FR-4 substrate. As a feed port, a coaxial line is connected to ground on the bottom layer larger circle, while the inner conductor is connected on top through a via hole. The modes of operation are such that, when all the elements are connected to the central port, the uniform current distribution generates an omnidirectional beam in the horizontal plane (x-y). When just one pair of elements are connected to the central port, the three disconnected pairs act as reflectors pointing the beam towards the excited pairs. A total of four directional beams are generated, as pairs of elements are activated in each quadrant.

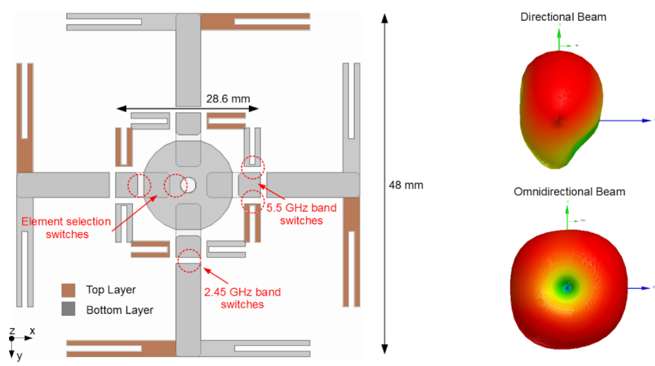

Fig. 1 Top and bottom layer view of the proposed antenna with example of omnidirectional and one of the four directional beams.

In this paper, we propose the re-design of metallic elements in the above antenna structure for Wi-Fi operations at 2.45 and 5.5 GHz, as defined by the standard 802.11 ac. As shown in Figure 1, the gaps between the center circles and the microstrip elements are designed to include switching elements responsible for selecting the elements for pattern reconfigurability. Each pair of microstrip elements is comprised of two sections, each of them resonating at the lower and upper band. The gaps on the shorter and longer section of the elements are designed to switch between the two resonating bands. This strategy allows for high decoupling between the bands, reducing the grating lobes under different pattern configurations.

III. Switching Techniques

To ensure low insertion loss and high isolation on both the 2.45 and 5.5 GHz bands, three topologies are considered using PIN diodes and an SPDT switch.

A. Simulation Analysis

The two devices were modeled using their equivalent circuits in Agilent Design System. Simulations showed a single PIN diode doesn't give a desired isolation above 10dB at the 5GHz frequency, so two PIN diodes in series were examined. This topology, as compared to a single PIN diode, offered reasonable isolation above 10dB at both design frequencies while the single PIN diode at the 5GHz frequency offered 6.6dB of isolation.

Insertion loss and isolation are estimated by simulating the S_{21} of the devices in the ON and OFF state, respectively. Based on the simulations, summarized in Table I, the series PIN diodes were chosen since they have a desirable isolation above 10 dB while at the same time maintaining a low insertion loss. Despite the SPDT's good simulation switching results, the PIN diode's activation resulted in easier integration, compared to the SPDT. The low insertion loss performance of PIN diodes has also been shared in other works [1,3].

TABLE I. SUMMARY OF DEVICE SIMULATION

Frequency band	S_{21}	*Single PIN Diode*	*Series of PIN Diodes*	*SPDT switc*
2.45 GHz	**Insertion Loss**	0.13	0.30	0.53
	Isolation	12.00	17.42	24.17
5.5 GHz	**Insertion Loss**	0.20	0.54	0.61
	Isolation	6.60	11.44	31.12

B. Measurement Results

To validate the simulations, series PIN diodes mounted on a transmission line had scattering parameters measured through a network analyzer. The driving voltages were set to 0V for the OFF state (isolation) and 1.55V for ON state (insertion loss). As depicted in Figure 2, the insertion loss of the series PIN diode at the design frequencies of 2.4 GHz and 5 GHz was measured to be 0.46 dB and 0.12 dB respectively. The isolation, for 2.4 GHz and 5 GHz, was measured to be 17.78 dB and 13.32 dB, respectively. The series PIN diodes were chosen over the SPDT due to good switching performance and ease of integration on the proposed antenna.

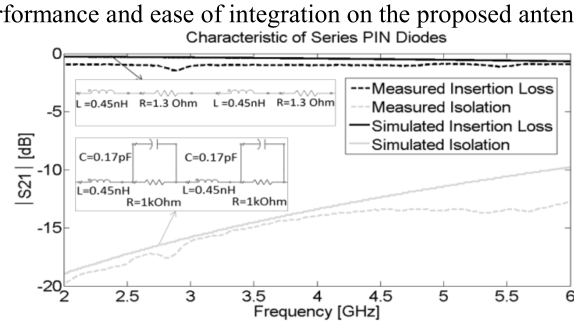

Fig. 2 Comparison of measured and simulated isolation and insertion loss for the series PIN diodes.

IV. ANTENNA SIMULATION

The equivalent model of the series PIN diodes were loaded into the HFSS antenna model. Numerical analysis was performed for each state. Input impedance simulations, depicted in Figure 3, showed good matching on both configurations over the two desired frequency bands. At the 2.45 GHz the antenna covered the entire band from 2.41 to 2.45GHz, with return loss (RL) below the 10 dB threshold. At 5.5GHz, the 10 dB RL bandwidth is about 350 MHz, however, the entire bandwidth (5.1 to 5.8 GHz) can be covered by increasing the RL threshold to 6dB.

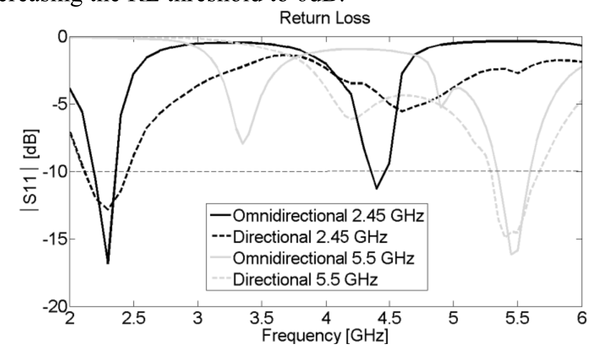

Fig. 3 Return loss of the proposed antenna. For each band are shown omnidirectional and directional modes of operations.

The radiation characteristics of each band were simulated for omnidirectional and directional beam configurations. At 2.45GHz, the omnidirectional beam has a gain of about 2dBi, while the single directional beam approaches 4dBi with a half-power beam-width (HPBW) of 60°. When the 5.5GHz elements are selected, gain in the omnidirectional and directional beams are close to 1.8 and 3.5dBi, respectively. Despite the HPBW being comparable to the 2.45GHz case, the 3dB extension of the beam results are slightly influenced by the surrounding 2.45 GHz elements. As a result, this compact planar design can generate omnidirectional and directional beams covering 2.45 and 5.5 GHz bands.

CONCLUSION

A planar dual-band pattern-reconfigurable antenna design with analysis for the best switching solution is presented. Use of series PIN diodes resulted in good RF performance and antenna impedance matching for all configurations.

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