

RECONFIGURABLE SINGLE AND MULTIBAND INSET FEED MICROSTRIP PATCH ANTENNA FOR WIRELESS COMMUNICATION DEVICES

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Abstract—Two novel designs for compact reconfigurable antennas are introduced for wireless communication devices. These designs solve the steering frequency problem by tracking the desired resonance frequency or by generating various operating frequency bands to be selected electronically. In the first design, the length of the rectangular defected ground structure (RDGS) is electrically adjusted to change the resonant frequency of the MPA. While in the second design different turns of spiral AMC ground plane generate frequency bands, or modes, that are selected/optimized to serve different communication systems simultaneously. These systems may include various combinations of bluetooth, S-band and wireless local-area network (WLAN). These designs have several advantages as the total antenna volume can be reused, and therefore the overall antenna will be compact, although, the radiation of the MPA is kept fixed without any degradation. The designs are verified through both numerical simulations and measurement of a fabricated prototype. The results confirm good performance of the single and multiband reconfigurable antenna designs.

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1. INTRODUCTION

The rapid development of electronics and wireless communications led to great demand for wireless devices that can operate at different standards such as the universal mobile telecommunications system ((UMTS) 1920–2170 MHz), bluetooth (2400–2484 MHz) and wireless local-area network (WLAN) (5200–5284 MHz). However, frequency steering capability shows that it is difficult to keep the frequency fixed without any changes [1]. In addition, compact small size is a demand factor for several applications as mobile devices. These two requirements have triggered research on the design of compact and single or multiband antennas operation [2].

Microstrip patch antennas (MPA) are widely used in wireless devices and offer compact sizes with multiband antenna operation. MPA can be integrated easily with diode switches or optoelectronic devices to form reconfigurable patch antennas [3–6]. The techniques for reducing the size of MPA are reported extensively and include capacitive loading [1], LC resonator [2], meander configuration [3], and reactive loading [4, 5]. However, these techniques usually trade off the antenna bandwidth or antenna efficiency to achieve the reduction in antenna size. Different techniques [7] for creating multiband MPA antennas have been published, such as adding parasitic elements [5, 8] to create an additional resonant frequency or adding more radiating elements shared with the same feed and ground [6, 9]. These techniques inevitably increase the physical size in order to create the multiband characteristics. There is a tradeoff between number of operating bands and antenna size. Reconfigurable antennas represent a recent innovation in antenna design that changes from classical fixed-form, fixed-function antennas to modifiable structures that can be adapted to fit the requirements of a time varying system. Advances in microwave semiconductor technologies enabled the use of compact, ultra-high quality RF and microwave switches in novel aspects of antenna design.

This paper introduces a concept of reconfigurable antenna for controlling the resonant frequency in order to avoid the problems raised in frequency steering by using rectangular defected ground structure (RDGS) [10]. Multi-band resonance frequency is generated and controlled by adjusting the number of turns of the spiral AMC ground plane [11].

2. RECONFIGURABLE ANTENNA DESIGN

2.1. Antenna Structure and Switch

The basic structure of our proposed reconfigurable antenna is the microstrip patch antenna built on a Rogers duroid substrate with size of $25 \times 25 \times 0.813 \text{ mm}^3$, ϵ_r dielectric constant = 3.38 and substrate height $h = 0.813 \text{ mm}$ as shown in Figure 1. The antenna is fed by a 50Ω inset feed with $W_f = 1.8 \text{ mm}$ at resonant frequency 5.2 GHz. The ground plane size $L_g \times W_g$ while the radiator dimensions are $W_p \times L_p = 16 \times 13.5 \text{ mm}^2$. All antenna parameters are kept the same in the next two design antennas.

In this study, ideal switch models are used to imitate PIN diode switches for proof of the concept, i.e., the opened (Off) and closed states (ON) of the switches are simulated in the absence or presence of a metal pad with the area $W_{sw} \times L_{sw} = 0.3 \times 0.9 \text{ mm}^2$, respectively. This is approximately the same area of a real PIN diode switch. The PIN diode HPND-4005 is forward biased with 0.7 V and 10 mA. It exhibits an ohmic resistance of 3Ω and intrinsic capacitance of 0.1 pF for forward bias. While exhibits $2.7 \text{ K}\Omega$ and 9 pF at 0 V. The 10 pF capacitors are used to isolate the RF signal from the DC. An accurate equivalent circuit model is established for simulating the opened and closed states of the beam lead PIN diode switch (HPND-4005). In order to simulate the influence of real PIN diode switches on the antenna performance, the equivalent circuit models of the PIN diode switch introduced in [9] are considered in HFSS (High Frequency Structure Simulator) simulations.

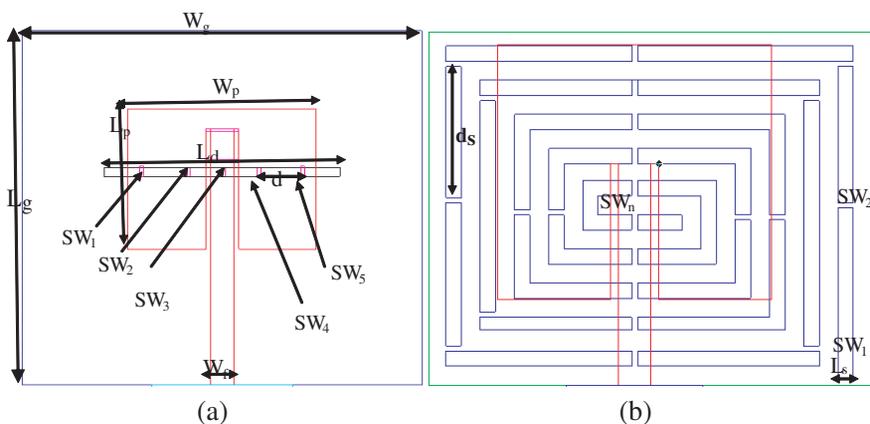


Figure 1. Geometry of the reconfigurable antenna with switches. (a) Single frequency tracking, (b) multi resonant.

HFSS version 11, is used for simulating the characteristics of MPA with both RDGS and SAMC ground plane. PIN diodes have the advantages of low-cost, low-loss and are easily modeled by lumped elements. However, the PIN diode requires extra biasing circuits and also it has high power consumption.

2.2. Single Frequency Design

The proposed simple reconfigurable antenna to generate single frequency that enables frequency steering using switched diodes with rectangular defected ground structure (RDGS) is shown in Figure 1(a). The antenna consists of a rectangular element, a ground plane with etched RDGS at appropriated location [10–12] and an active switching network, which can break or make a ground connection. The mode is defined by breaking or making the ground connection and this corresponds to mode (Off) and mode (ON), respectively. When the active switching network breaks the connection with the ground plane, it is mode 0 and the resonant frequency band is the fundamental frequency 2.8 GHz of the patch antenna. When the active switching network makes the connection with the ground, it is mode 1 and the fundamental resonant frequency band increases than 5.25 GHz. First, the location of the RDGS is chosen to provide maximum coupling between the radiator element and ground plane [13]. In mode 0, the resonant path that is approximately half-wavelength creates the resonating frequency. The lower resonating frequency is created by less than half-wavelength resonant path depending on the dimensions of the RDGS. In this mode, the length contributes to the lower resonant frequency.

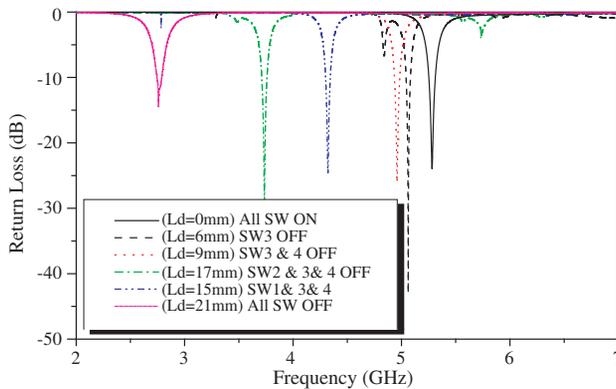


Figure 2. Simulated results of antenna resonant frequency with different switching mode.

Table 1. Simulated antenna gain for switched feed and switched group design.

Length of RDGS L_d (mm)	Number of Switches in ON state	Average gain (dBi)	Average Efficiency	Frequency (GHz)
Conventional ground	No RDGS exist	4	0.97	5.25
0	5 (all switch on) (state 1)	3.8	0.9	5.3
6	4 (state 2)	3.75	0.83	5.1
9	3 (state 3)	3.6	0.86	4.9
15	2 (state 4)	3.5	0.85	4.3
17	1 (state 5)	3.44	0.82	3.8
21	0 (all switches off) (state 0)	3.4	0.8	2.8

The operation of all modes are shown in Figure 2, whereas the active switching network makes a ground connection, the RDGS is removed and by optimizing the locations of the switches and the separations between them, we can cancel the RDGS effect. The dimensions of the RDGS are $22 \times 0.9 \text{ mm}^2$. The higher resonant frequency in mode 1 is the half wavelength path. Five pin diodes are inserted into the RDGS etched in the ground plane. By the activation of each switch the antenna resonant frequency increases. Table 1 summarizes the results of the antenna characteristics for all switches shown in Figure 1(a). Figure 2 shows the simulated antenna resonant frequency at different switches modes with corresponding RDGS dimensions.

2.3. Multi-band Frequency Design

The basic structure of our proposed reconfigurable antenna is the microstrip patch antenna with spiral AMC [14–16] as shown in Figure 1(b). The mechanism of multi-band resonant frequency is provided by each spiral turn. Hence each turn provides at least one resonant frequency. In addition the fundamental patch resonant frequency is reduced due to adding reactive loads of the spiral

configuration. The multi-band operation is explained qualitatively. The spiral AMC with one arm and five turns is used with widths of arms and air gap equal to 2 mm and 0.9 mm, respectively. 21 switches are installed and the distance between each two switches is d_s , all parameters of the antenna design are kept the same as the previous design in Section 2.1. The switch size is $W_{sw} \times L_{sw}$.

The antenna can operate with various states: 1) All the switches in the spiral AMC ground plane are turned off, named state 0, 2) all the switches in the spiral AMC ground plane are turned on, named state 1, 3) all the switches in the outer turn of spiral AMC ground plane are turned on, named state 2, 4) all the switches in the outer two turns of spiral AMC ground plane are turned on, named state 3 and so on. For the state 0, the antenna resonates at several bands and the fundamental resonate frequency of the patch is 2.3 GHz shown as black dotted line in Figure 3 with acceptable bandwidth. In state 1, the antenna operates at higher resonant frequencies and number of multi-band resonant frequencies are reduced as shown in Figure 3. Table 2 summarizes these results. Alternatively, when all the switches in SAMC ground plane are turned on, named state 1, the antenna operates in this case as conventional MPA and the resonate fundamental frequency at 5.55 GHz as shown in the black solid line in Figure 3, i.e., the conventional MSA fundamental frequency of 5.2 GHz, while state 1 operational frequency is 5.55 GHz. This could be attributed due to the spiral inductive load added on the substrate surface which affect on impedance matching. The difference in resonant frequency between them is about 4%, however the designed antenna

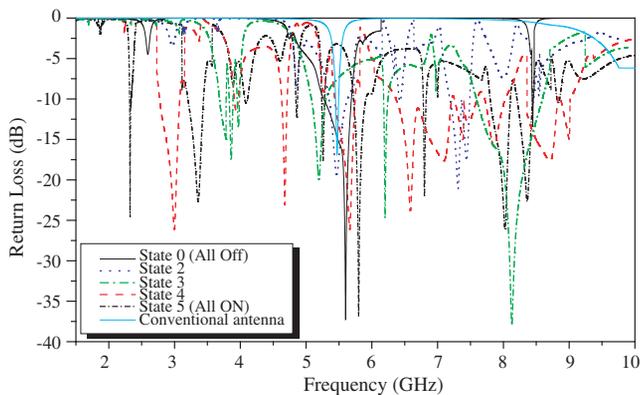


Figure 3. The reflection coefficient of MPA with SAMC ground plane at different switches states.

gives better bandwidth due to slots in the ground plane which add an inductive load that improves the impedance matching. According to the results of the MPA with SAMC ground plane with switches, the antenna parameters are changed as a frequency reconfigurable antenna. Table 2 summarizes the results of the antenna characteristics at different modes.

Table 2. Simulated antenna gain for switched feed and switched group design.

Switches turns	Number of Switch ON	Average gain (dBi)	Average Efficiency (%)	Frequency (GHz)
All State 0 (all switches Off)	0	3.5	75	2.3/3.4/4.6 /5.1/5.7/6.7 /8.3/8.5
State 1 (all switches ON)	21	5	90	5.55
State 2 (one outer turns)	7	3.7	80	4.2/5.1/6.2/7
State 3 (two outer turns)	13	4	79	3.4/5.2/6.1/8.1
State 4 (three outer turns)	17	4.5	85	5.3/7.1/8.5

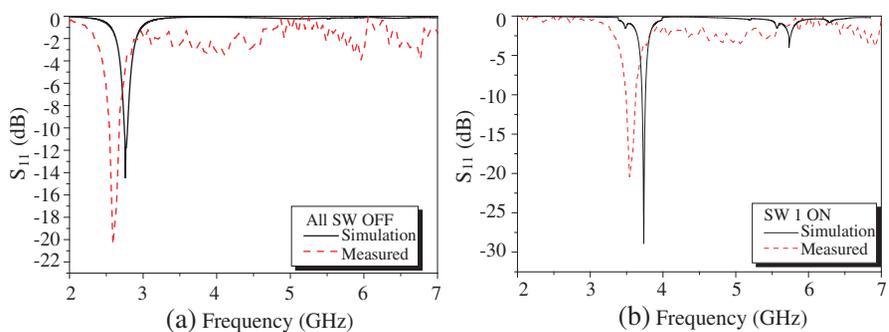


Figure 4. Comparison between measured and simulated reflection coefficient for MPA with RDGS.

3. RECONFIGURABLE ANTENNA RESULTS

The performances of the two antennas designed in Sections 2.2 and 2.3 were investigated by both simulations and measurements. The simulation was done by using the commercially available, HFSS version 11. The fabrication of the antenna was done by using photolithographic techniques and measurement by using vector network analyzer E8364A. In the first step, to confirm the frequency reconfigurable characteristics, the proposed antenna was measured with two different modes of diodes. The on/off state diodes was considered as the ideal connection. For single frequency design the results are as shown in Figure 4 while for multi band design the results are shown in Figure 5. From the figures, there are discrepancies between the simulated and measured results. This may be attributed due to some error in fabrication as soldering problem with inconsiderable associated discontinuity effect. In addition, the switches parasitic lead as capacitive and inductive that added and decreases the resonant

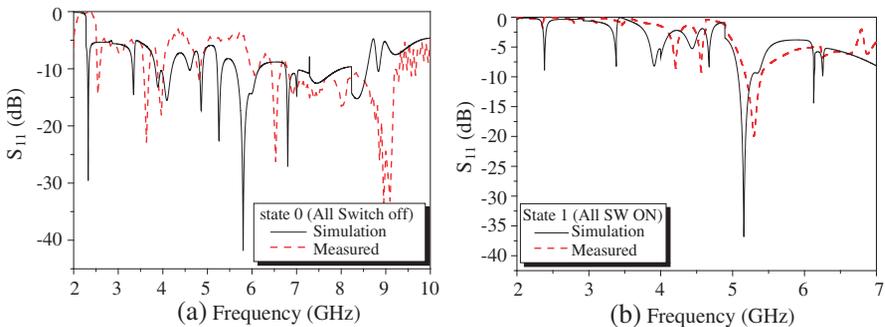


Figure 5. Comparison between measured and simulated reflection coefficient for MPA with spiral ground plane.

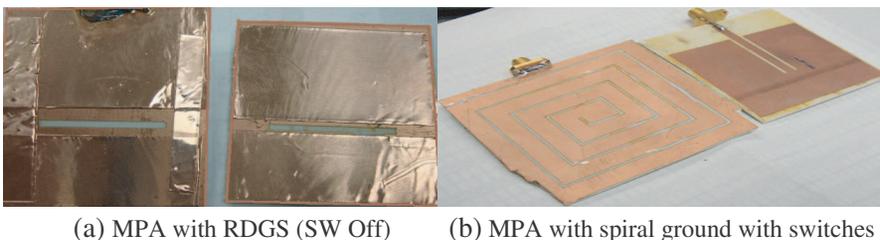


Figure 6. Photo of the fabricated antenna. (a) MPA with RDGS, (b) MPA with spiral ground.

frequency. The photos of the fabricated 2D-EBG antennas are shown in Figure 6. The simulated E -plane and H -plane radiation patterns for the MPA with RDGS are studied as shown in Figure 7, while E -plane and H -plane radiation patterns for the MPA with spiral AMC ground plane are shown in Figure 8.

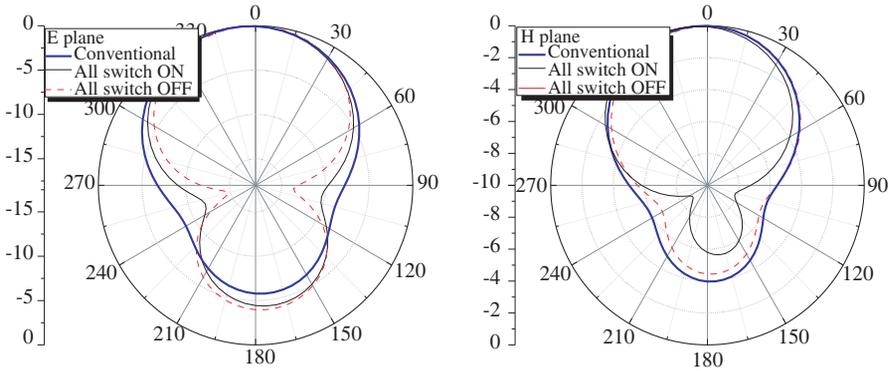


Figure 7. The simulated E -plane and H -plane radiation patterns for MPA RDGS.

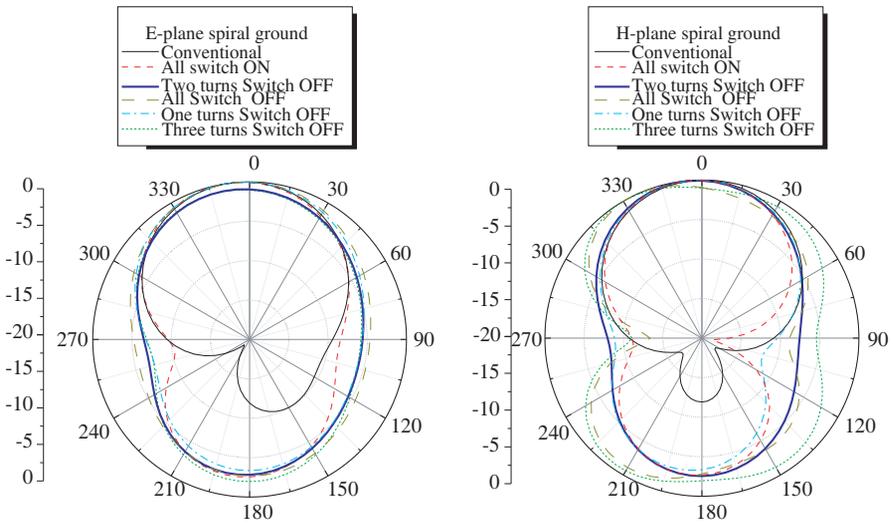


Figure 8. The simulated E -plane and H -plane radiation patterns for MPA with spiral ground plane.

4. CONCLUSION

In this paper, the combination of microstrip patch antenna with rectangular defected ground structure (RDGS) and PIN diodes for reconfigurable designs is presented. Two reconfigurable antennas for single and multiband characteristics are constructed, analyzed and measured. The first design allows frequency steering and adjusts the single resonant frequency by adjusting the rectangular defect (RDGS) length by a set of PIN diode switches. The second design uses a switched-ground approach by connecting or disconnecting the antenna's ground at specific locations, different operating frequency bands can be created and optimized. The switched ground reconfigurable antenna was also prototyped, and the antenna can operate within multiband as GSM, DCS, PCS, UMTS, Bluetooth, WLAN frequency, and S bands. Electromagnetic simulations confirmed the results for both reconfigurable antenna designs using ideal switches model. Both the simulation and measurement results verify the design principal with acceptable discrepancy in between.

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