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Design and Analysis of Frequency-Reconfigurable Microstrip Antenna using Multiple Parasitic Patches

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Abstract. This letter presents frequency-reconfigurable microstrip patch antenna with three switchable modes. Two RF p-i-n diodes are positioned between inner and outer patches to achieve frequency reconfigurability. Six parasitic patches are added to the antenna; therefore, gain and bandwidth are noticeably increased. The results indicate that the highest achieved bandwidth and gain are 90 MHz and 3.4 dBi, respectively. The return loss, together with the radiation patterns, are presented.

1. Introduction

Due to the exponential growth in the wireless communication systems, the reconfigurable antennas have received a considerable attention. Significant features such as reconfigurable capability, multipurpose functions, size miniaturization, and low cost have made reconfigurable antennas the best choice for providing multifunctionality [1]. Cognitive radio (CR), which is the promising future of the communication systems, relies upon two types of antennas. The first is called a sensing antenna which is able to monitor the spectrum while the second is named a communicating antenna that is capable of reconfiguration to communicate over a chosen frequency band. Therefore, to utilize the spectrum efficiently, a great attention in the development of frequency reconfigurable antennas is taking place [2].

Although microstrip patch antenna (MPA) has several advantages, it has inherent well-known limitations of low gain and narrow bandwidth. To overcome the aforementioned limitations, many techniques have been studied and applied [3]. Some of these techniques are broad folded flat dipoles [4], log periodic structures [5], [6], resonator antennas with capacitive coupled parasitic patch element [7], impedance matched resonator antennas [8], curved line and spiral antennas [9], modified shaped patch antenna [10], and multilayer structures [11].

In this letter, double microstrip patches are designed and investigated. Next, six parasitic patches around the inner patch are added and compared with the first design [12]. Due to the introduction of those parasitic patches, two more resonance frequencies can be obtained. In addition, the effect of the mentioned parasitic patches has been examined [13]. Seen from the simulated results, the impedance bandwidth (<-10 dB) of the optimized antenna for mode1, mode2, and mode3 are (3.48 and 4.18) GHz, (2.56, 3.04 and 4.15) GHz, and (3.37 and 4.17) GHz, respectively.

2. Antenna Design

The structure of the first design of the reconfigurable microstrip patch antenna is described in this section. The geometry is presented in figure 1. The material chosen to be the substrate of the antenna is FR4 with the thickness of 1.6 mm and relative permittivity of 4.4. The dimensions (L × W × h) of the antenna are 40 mm × 40 mm × 1.6 mm and the rest of parameters are listed as follows:

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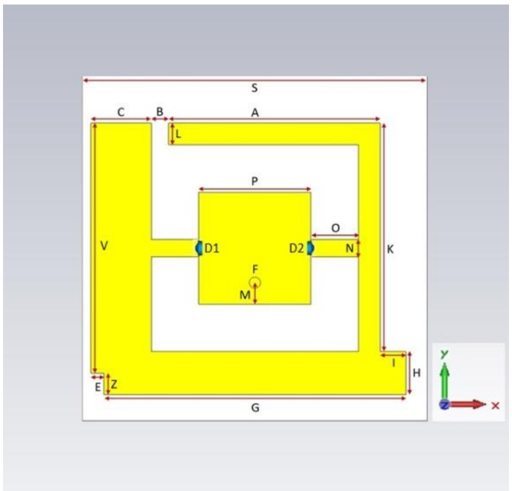
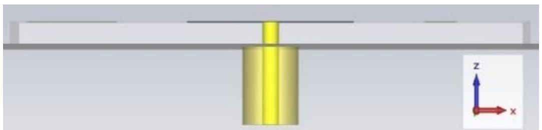
A= 24.5mm, B= 2mm, C= 7mm, D= 29mm, E= 1.5mm, Z= 2.5mm, G= 35mm, H= 5mm, I= 3mm, K= 26.5mm, L= 2.5mm, M= 2.5mm, N= 2mm, O= 5.4mm, P= 13mm, S= 40mm, R= 5.3mm, T= 10.4mm, and Y= 4.9mm.

To excite the antenna, the direct coaxial cable with 50 Ω characteristic impedance is used. The outer and inner conductors are made of pure cupper with radius of 2.17mm and 0.65mm, respectively. The optimized feed point (F) is located at a distance (M) of 2.5mm from bottom edge of the inner rectangular patch to achieve an excellent impedance matching of approximately 50 Ω.

Two lumped elements are used to model the two RF p-i-n diodes. Both patches (inner and outer patches) are electronically connected by two RF p-i-n diodes (D1 & D2) to obtain reconfiguration between different frequency bands. These two RF p-i-n diodes used as switching elements, which can be reconfigured into two operating states (ON and OFF). They are modeled as a combination of a series-parallel (RLC) circuit for the OFF state, and a series (RL) circuit for ON state as shown in figure 2 [14]. The type of diodes used is SMP1322-040LF. According to the RF p-i-n diode datasheet [15], it represents resistance of 0.5 Ω for ON state, and capacitance of 1 pF for OFF state.



(a)



(b)

Figure 1 (a). Geometry of the first design top view.

Figure 1 (b). Geometry of the first design side view.

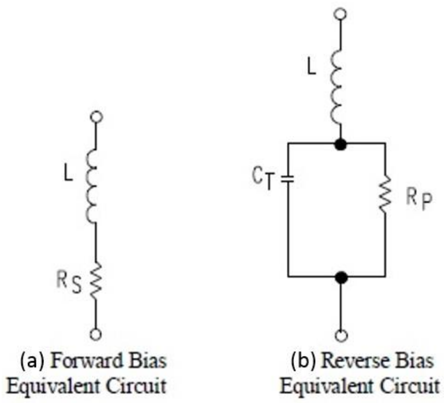


Figure 2. The equivalent circuits of the RF p-i-n diode (a) ON state, (b) OFF state [14].

3. Results and discussion

Simulation studies of the reconfigurable antenna are executed using Computer Simulation Technology (CST) Microwave Studio software. Figure 3 presents the return loss results against frequency of the first design. It shows that there are five different frequency bands and the return loss results are less than (-10 dB) for all frequency bands. The resonant frequency (f_o), bandwidth, and realized gain of each band with different RF p-i-n diode states are tabulated in table 1.

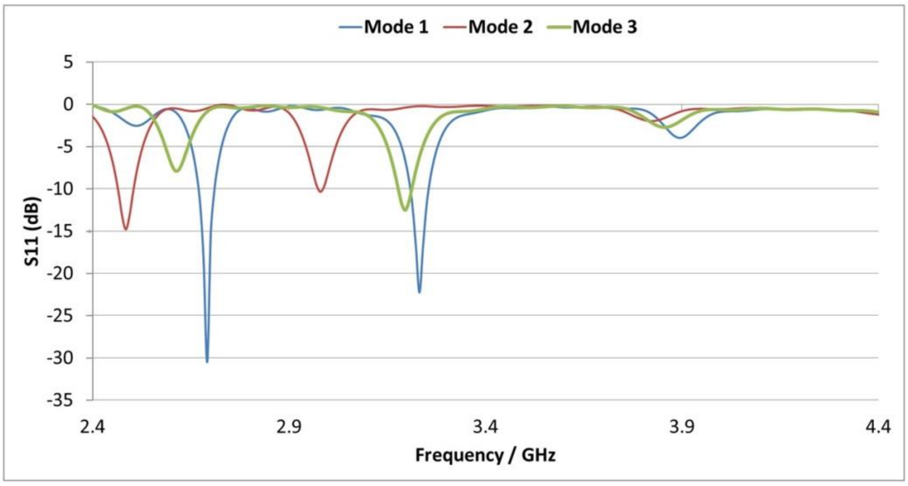


Figure 3. Return loss results of the first design.

Table 1. Compilation of simulated results of the first design.

Modes	Diode 1	Diode 2	Resonant Frequency (GHz)	Bandwidth (MHz)	Realized Gain (dBi)
Mode 1	Off	off	2.69 and 3.23	50 and 50	-2.63 and 1.27
Mode 2	On	on	2.48 and 2.98	40 and 10	0.33 and -2.55
Mode 3	Off	on	3.19	40	1.73

In order to broaden the bandwidth and increase the gain, six parasitic patches are positioned around the inner patch to construct the optimized design, as displayed in figure 4. The simulated results of the optimized design are shown in table 2. It is obvious that all resonances are moved to the higher frequencies.

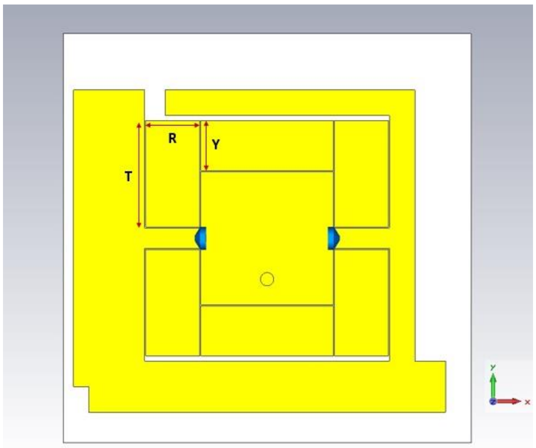


Figure 4. Geometry of the optimized design.

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Table 2. Compilation of simulated results of the optimized design.

Modes	Diode 1	Diode 2	Resonant Frequency (GHz)	Bandwidth (MHz)	Realized Gain (dBi)
Mode 1	off	Off	3.48 and 4.18	50 and 40	1.9 and 2.51
Mode 2	on	On	2.56, 3.04 and 4.15	50, 30, and 90	0.14, -2.04, and 3.4
Mode 3	off	On	3.37 and 4.17	20 and 80	2.87 and 3.09

Compared with the first design, the optimized one has more two resonant frequencies as presented in Figure 5. It is clear that the optimized design has better realized gain results than those of the first design. Although the optimized design has a low realized gain (-2.04 dBi) at the frequency of 3.04 GHz, it has more resonance frequencies with higher realized gain values.

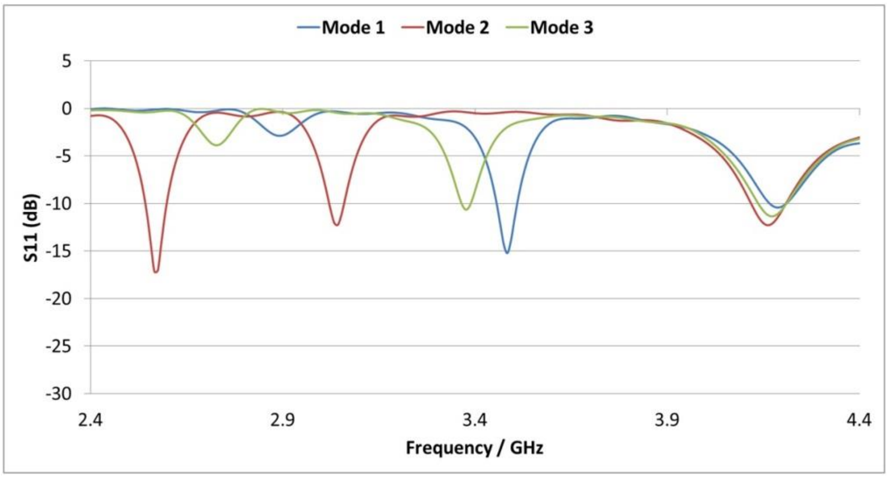
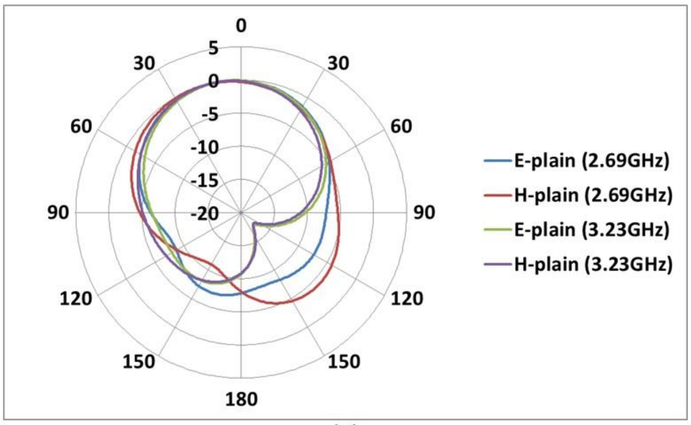


Figure 5. Return loss results of the optimized design.

The simulated radiation characteristics in E-plane (xz-plane) and H-plane (yz-plane) for three modes of both designs are depicted in figures 6 and 7, respectively.



(a)

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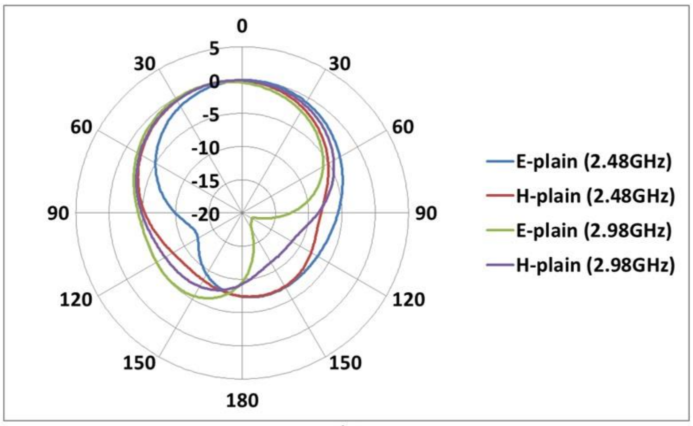
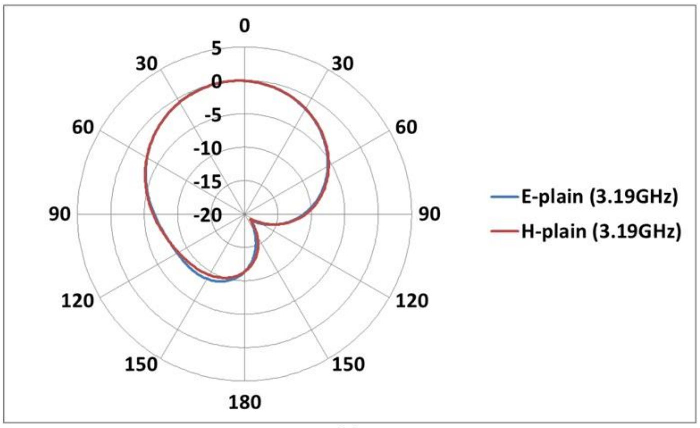


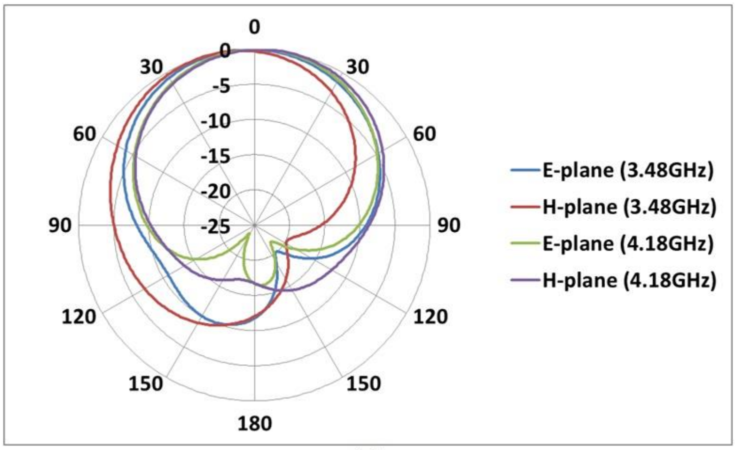
(b)



(c)

Figure 6. Radiation pattern of the first design (a) Mode 1 at (2.69 and 3.23) GHz, (b) Mode 2 at (2.48 and 2.98) GHz, and (c) Mode 3 at (3.19) GHz.

It is clearly perceived that the far-field characteristics for both the E-plane and H-plane of the optimized antenna are better than those of the first one as shown in Figure 7. In addition, the radiation patterns of Mode 1 and 3 of the optimized design are almost similar at booth bands as desired by the antenna reconfigureability scheme. For Mode 2, the patterns are not identical due to the significant difference of the antenna structure.



(a)

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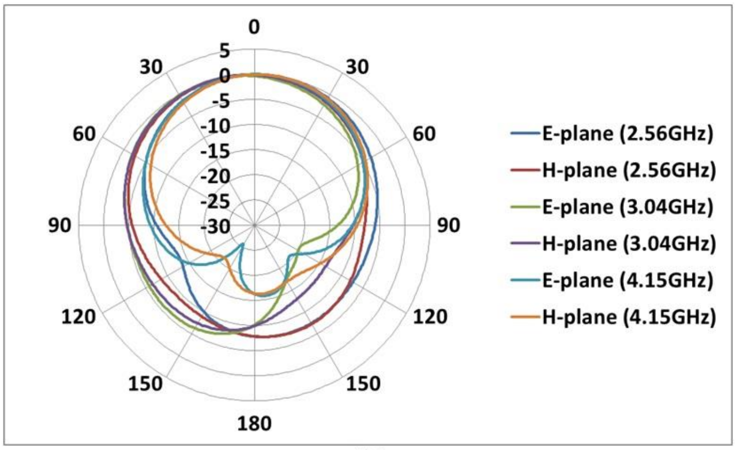

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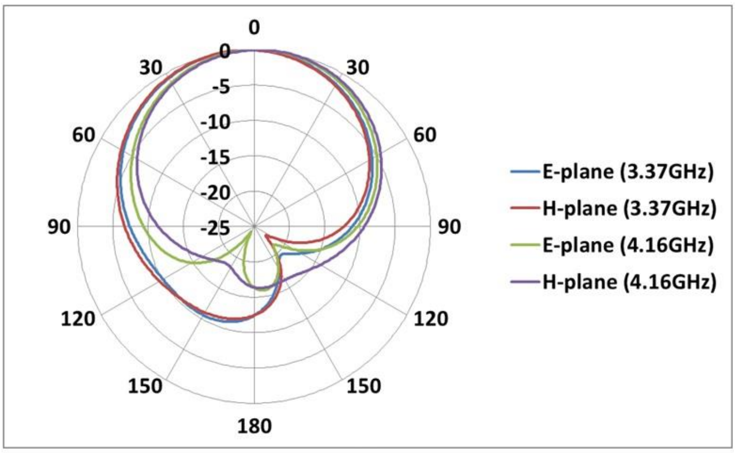

(c)

Figure 7. Radiation pattern of the optimized design (a) Mode 1 at (3.48 and 4.18) GHz, (b) Mode 2 at (2.56, 3.04, and 4.15) GHz, and (c) Mode 3 at (3.37 and 4.16) GHz

4. Conclusion

In this work, a frequency-reconfigurable microstrip patch antenna with multiple parasitic patches for seven resonance frequencies has been designed and analyzed. When six parasitic patches are introduced in the structure of the first design, two more resonance frequencies were obtained, thus the bandwidth and the gain were increased effectively. The frequency reconfigurability is achieved by utilizing two RF p-i-n diodes, consequently, the antenna can reconfigure at three modes. The size of the optimized design is relatively compact, and good return loss results (<-10 dB) have been attained. Worthy far-field radiation patterns within the operating frequency bands for different operating modes were obtained.

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