



Low-Profile Frequency Reconfigurable Patch Antennas for Cognitive Radio Applications

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Abstract. In this paper, low-profile frequency reconfigurable patch antennas for cognitive radio applications are proposed on the ultra-wideband (UWB) frequency range. The methodology of the proposed antennas is described in this paper, and is achievable by controlling the electrical length of the antenna. additionally, miniaturized patch antennas are achieved by using shorting post technique and partial ground plane. The substrate used in the proposed antennas is the Rogers duroid 6010 with a dielectric constant of 10.2 and thickness of 0.635 mm. The presented antennas are designed and simulated using High-Frequency Structure Simulator (HFSS). The advantage of the proposed antenna designs is the compact size 8 mm × 8 mm (and smaller). The proposed antennas are designed, analyzed, and compared to a conventional microstrip patch antenna, and the total area size reduction is about 89% to meet the size requirements of wireless miniaturized systems and cognitive radio applications.

Keywords: Frequency reconfigurable · Cognitive radio applications · Miniaturized patch antenna · Shorting post technique

1 Introduction

Cognitive radio is an intelligent radio system that can sense and learn from the surrounding environment to adjust its mode of operation to provide a high quality of service [1]. There are a lot of parameters that cognitive radio depends on such as: modulation, transmit power, carrier frequency, polarisation, and radiation pattern as it learns and understands more about its surroundings. The operating frequency is the most critical parameter to change for a cognitive radio system [1]. Thus, a reconfigurable antenna is crucial to meet this need. The compact size of antenna is also needed in modern portable wireless communication systems, a miniaturized antenna size is also required for many applications, like the internet of things (IoT) sensors and actuators, and fifth-generation evolution (5G) portable systems [2–9]. Microstrip patch antennas are a popular choice for that type of integrated technology due to their characteristics. There are many methods for miniaturizing patch antenna size namely,

making slots, using a defected ground structure, loading material, and folded and shorting post [10–14]. The resonance frequency of the patch antenna loading with shorting post (connecting the patch with a ground plane) depends on the size and position of the post. In this paper, a low-profile frequency reconfigurable patch antenna for cognitive radio applications is presented. The proposed approach depends on varying the operating frequency of patch antenna configurations into a tunable frequency by changing the partial ground length in addition to the miniaturized patch dimensions using shorting post technique. The proposed antennas are much smaller in size compared to the corresponding antennas proposed in the literature, which gives them the advantage of being more suitable for modern applications.

This paper is organized as follows. Section 2 presents the proposed antenna design. Then, Sect. 3 introduces the results and discussion. Finally, the conclusion is provided in Sect. 4.

2 Proposed Patch Antenna Design

The proposed loaded square patch antenna design is introduced and analyzed at operating frequencies around 3 GHz, 4 GHz, and 5 GHz. The proposed loaded frequency reconfigurable patch antenna is printed on a 0.635 mm thicker, using dielectric

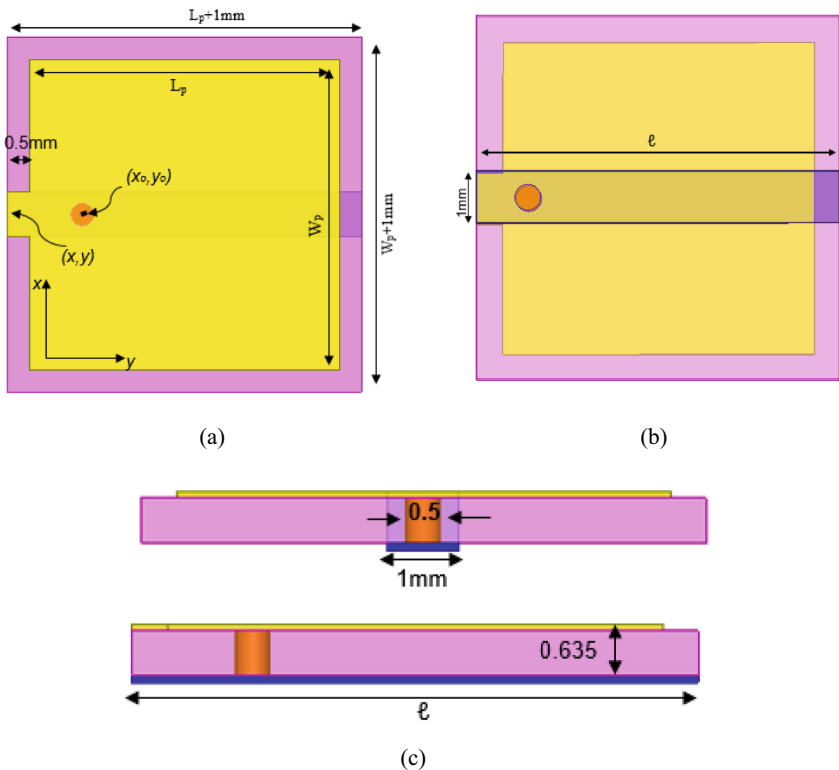


Fig. 1. The geometry of the proposed antennas: (a) top view, (b) bottom view, and (c) side view.

substrate Rogers duroid 6010 ($\epsilon_r = 10.2$, and $\tan(\delta) = 0.0023$). The suggested patch antenna dimensions in mm were chosen to form part of the $\lambda/4$ ($\lambda/4q$), where q is a rational number proportional to the dielectric constant of the substrate ($q \approx \sqrt{\epsilon_r}$). The bottom layer is a partial ground plane in the form of a microstrip transmission line (TL), where the partial ground width is 1 mm and length is the same as the dielectric length, at the first, and then different length, ℓ , depending on the desired patch antenna configuration. Figures 1(a), (b), and (c) show the proposed frequency reconfigurable patch antenna's configuration top view, bottom view, and side view, respectively.

The main proposed antenna geometry has been shown in Fig. 1, and the entire proposed patch antennas (I to III) have been designed using the new design approach introduced in this paper, and simulation results are tabulated in Table 1.

Table 1. The specification of designed antennas

Antennas #	Wp	Lp	ℓ	Shorting post (x_0, y_0)	f (GHz)	S11 (dB)
I	8 mm	8 mm	9 mm	(0, 1.4)	3.6	-8
II	7 mm	7 mm	8 mm	(0, 1.7)	4.26	-17.7
III	6 mm	6 mm	7 mm	(0, 1.6)	5.13	-17.7

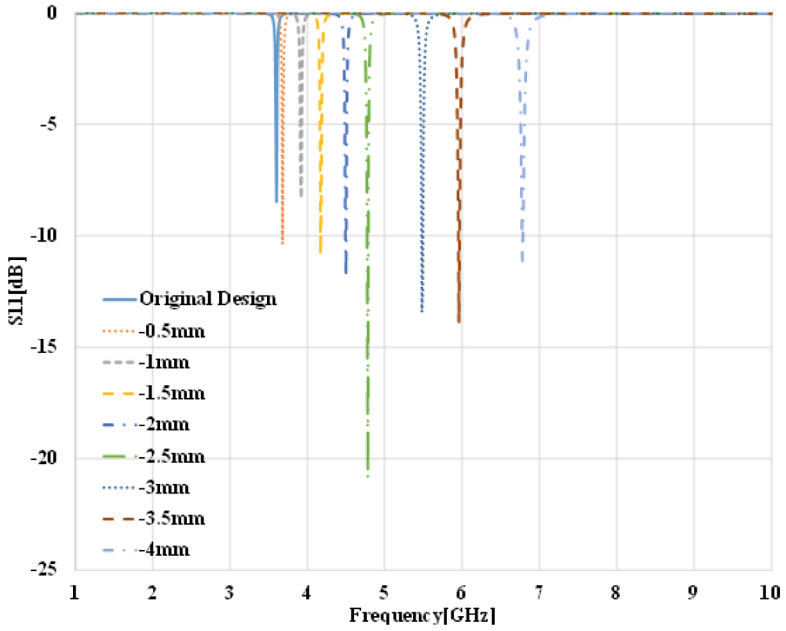
From Table 1, the post's position does not change for the same patch. This post position was chosen after a parametric study. The post position and size also affect the operating frequency. In the following section, we will study the effect of changing partial ground length without changing the antenna patch dimensions at the top layer of the antenna.

3 Results and Discussion

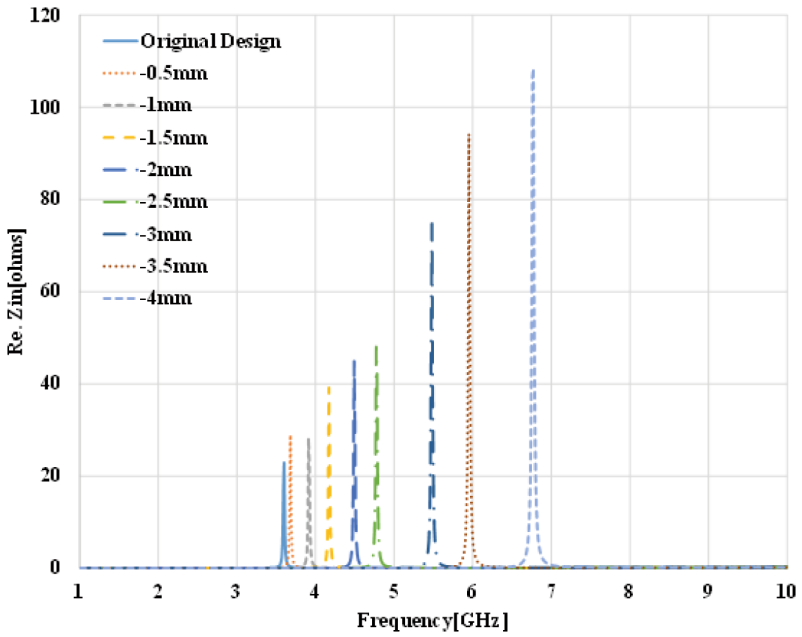
The scattering parameter, S11 in dB, and the real input impedance, Real [Z_{in}] in ohms, analysis simulation results for different partially ground length varieties with constant patch width and length were obtained using a commercial software HFSS [15] for the entire proposed patch antenna design configurations, which are referred to in Table 1. The simulation results are shown in Figs. 2, 3, and 4, respectively. The proposed designs' performance will be compared with traditional microstrip antennas, which operate on the same frequencies. The new approach technique will be verified using a lower mode resonance operation than the dominant mode (f_{10} or f_{01}) of square patch antennas' resonant frequency can be calculated using the formula [13]:

$$f_{mn} = \frac{C_0}{2\sqrt{\epsilon_r}} \sqrt{\left[\frac{m}{L}\right]^2 + \left[\frac{n}{W}\right]^2}$$

Where the C_0 is the speed of light, ϵ_r the relative permittivity of the substrate, L and W the length and width of the patch. The study of the cases starts from the main proposed patch antenna I, II, and III, with partial ground length is equal to the dielectric substrate, as shown in Table 1, and then by reducing l with a step of 0.5 mm sequentially.

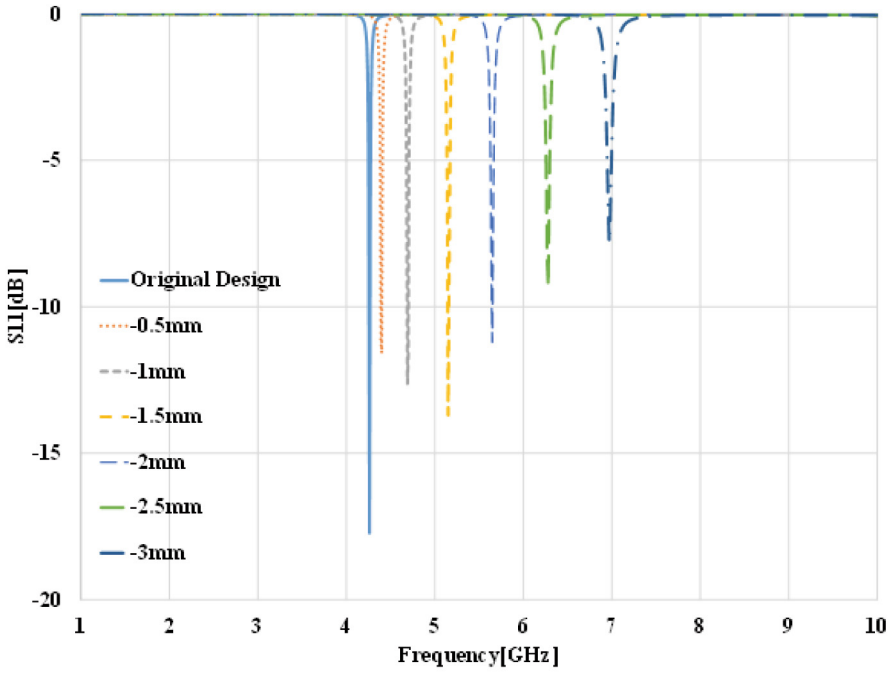


(a)

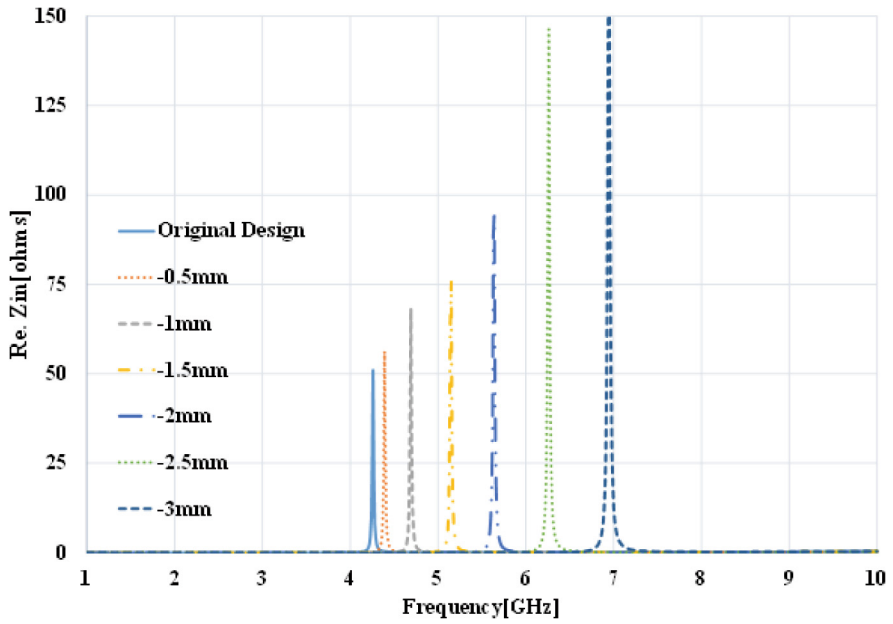


(b)

Fig. 2. The analysis of the suggested antenna design I when partially ground length reduces.

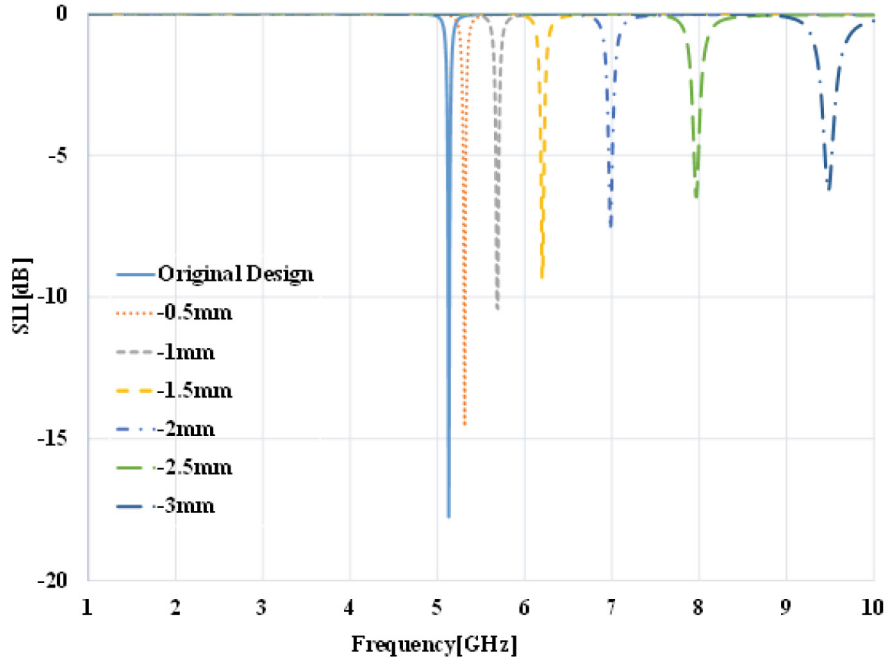


(a)

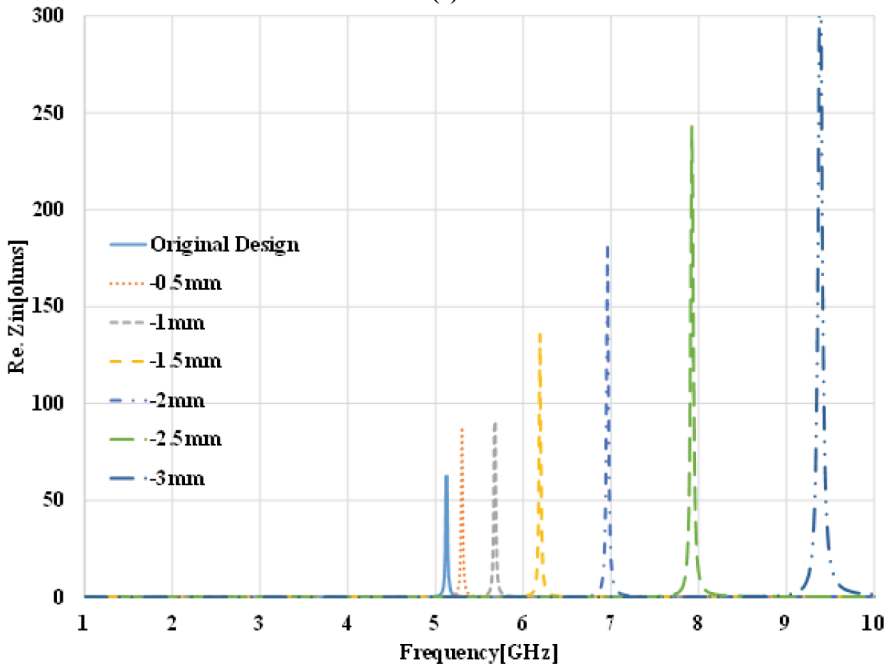


(b)

Fig. 3. The analysis of the suggested antenna design II when partially ground length reduces.



(a)



(b)

Fig. 4. The analysis of the suggested antenna design III when partially ground length reduces.

From the study and analysis of Figs. 2, 3, and 4, it was found that for the same patch, and by varying lengths of partial ground, the resonance frequency can be tuned to get the resonance of other patch antenna designs. Additionally, a reduction in size is achieved by using the new approach with a lower operating mode than the zero-mode to form a reconfigurable patch antenna for cognitive radio applications. The total area of antenna size is compared with conventional microstrip antenna and is found to achieve a reduced size of about 89%. Table 2 illustrates the summary of the proposed patch resonance frequencies according to partial ground lengths, where the patch width and length remain constant.

Table 2. The results of analyses when varying partial ground at the same patch

Antennas #	Patch dimensions	Shorting post (x_o, y_o)	ℓ	f (GHz)	S11 (dB)
I	8 mm \times 8 mm	(0, 1.4)	9	3.6	-8
		(0, 1.4)	8.5	3.68	-10
		(0, 1.4)	8	3.92	-8
		(0, 1.4)	7.5	4.17	-10.8
		(0, 1.4)	7	4.5	-11.89
		(0, 1.4)	6.5	4.79	-20.89
		(0, 1.4)	6	5.48	-13.43
		(0, 1.4)	5.5	5.96	-13.88
		(0, 1.4)	5	6.78	-11.2
II	7 mm \times 7 mm	(0, 1.7)	8	4.26	-17.7
		(0, 1.7)	7.5	4.4	-11.57
		(0, 1.7)	7	4.69	-12.62
		(0, 1.7)	6.5	5.15	-13.69
		(0, 1.7)	6	5.65	-11.2
		(0, 1.7)	5.5	6.28	-9.3
		(0, 1.7)	5	6.97	-7.8
		(0, 1.7)	4.5	7.97	-7
III	6 mm \times 6 mm	(0, 1.6)	7	5.13	-17.7
		(0, 1.6)	6.5	5.31	-14.5
		(0, 1.6)	6	5.69	-10.4
		(0, 1.6)	5.5	6.2	-9.3
		(0, 1.6)	5	6.98	-7.65
		(0, 1.6)	4.5	7.97	-7
		(0, 1.6)	4	9.48	-6.27

4 Conclusion

Low-profile reconfigurable frequency patch antennas for cognitive radio applications were presented in this paper. The loading patch antennas with the shorting post were designed and compared. Results showed that the size of the post and position changed the resonance frequency. The compact size of the proposed antenna was achieved by

using shorting post and a partial ground plane. The total area of the proposed antenna resulted in reduction in the size of 89% compared to conventional microstrip antenna. The length of the partial ground plane affected the operating frequencies, which in turn can be tuned to meet the cognitive radio applications requirements.

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