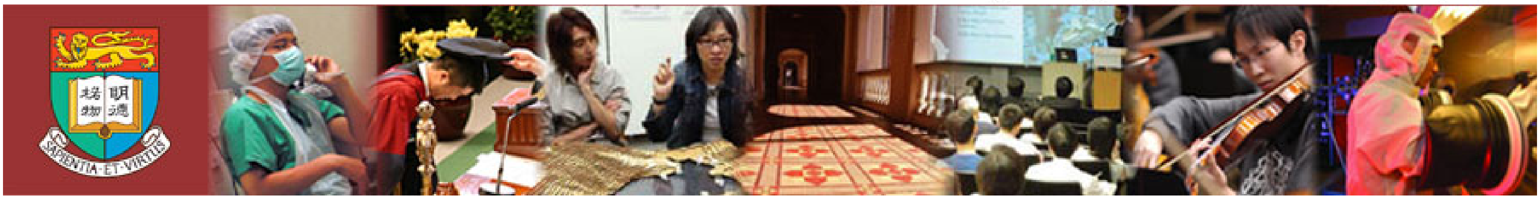

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Compact Frequency Reconfigurable Slot Antenna with Continuous Tuning Range for Cognitive Radios

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***Abstract*—The design of a compact frequency-reconfigurable slot antenna for cognitive radios is proposed in this paper. The antenna consists of a rectangular-ring slot, a *T*-shaped feed line, an inverted *T*-shaped stub and two varactors. The length of the rectangular-ring slot is designed to resonate at about 2.4 GHz. The inverted *T*-shaped stub is used to extend the current path, making the total size of the antenna smaller for low frequency operation. The two varactors are used to achieve continuous tuning. The proposed antenna is studied and designed using computer simulation. The simulated return loss, radiation pattern, realized peak gain and efficiency of the antenna are presented. Results show that the antenna has a wide tuning range from 2.14 to 3.33 GHz (43.51%) and is a potential candidate for use in cognitive radios.**

***Index Terms*—frequency reconfigurable, slot antenna, continuous tuning, biasing circuit, cognitive radio.**

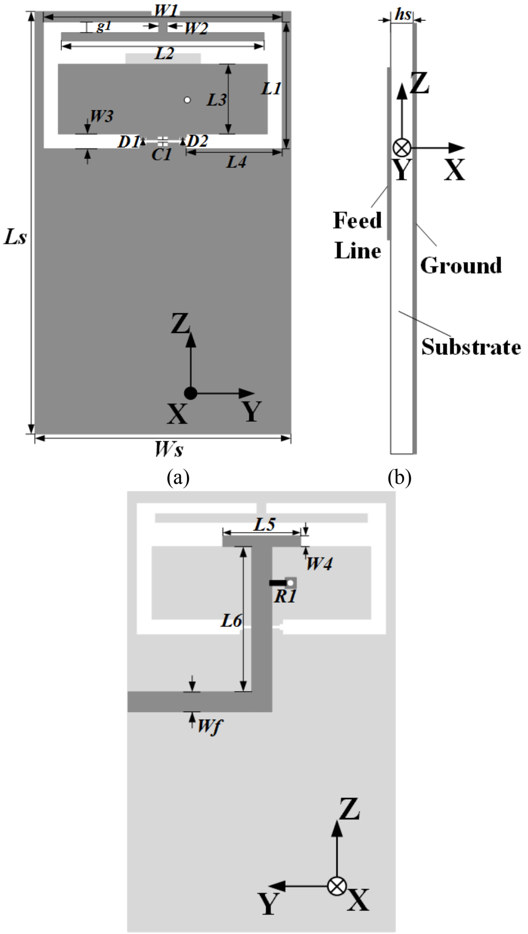
I. INTRODUCTION

Cognitive radio has been proposed to solve the spectrum congestion problem in modern communications systems [1]. In cognitive radios, frequency-reconfigurable antennas can be used to transmit and receive data, monitor the wireless channels, and reduce interferences between the ratios [2]. Reconfigurable antennas have received much attention and been designed using different techniques [3-5]. Frequency-reconfigurable antennas can be classified into two categories: continuous tuning and discrete tuning which can be achieved using varactor diodes and PIN-diode switches, respectively. For the discrete-frequency reconfigurable antennas in [6, 7], different operating bands were generated by turning ON/OFF the PIN-diode switches placed on the feed lines for the patch radiators. In [8], a discrete-frequency reconfigurable loop antenna was designed by switching ON/OFF the PIN-diode switches placed at different shorting points of the loop radiator. For the continuous-frequency reconfigurable monopole antennas in [9], a varactor and a PIN-diode switch together were used to continuously tune the operating frequency band of a monopole. For the uniplanar composite right/left-handed transmission line resonant antenna in [10], a varactor was used as termination of an asymmetric coplanar strip to achieve the continuous tuning. In [11, 12], continuous tuning of the antennas were achieved by integrating a varactor with the interdigital capacitor of the substrate-integrated waveguide structure. Among these frequency-reconfigurable antennas, the one in [10] had the largest tuning range of 26.26%.

In this paper, a compact frequency-reconfigurable slot antenna with continuous tuning for cognitive radios is proposed. Compared with the frequency-reconfigurable antennas in [9-12], the proposed antenna can achieve the widest tuning range from 2.14 to 3.33 GHz (43.51%) through the use of two varactors. The EM simulation tool CST is used to design and study the proposed antenna. The simulated S11, radiation pattern, efficiency and peak gain are presented.

II. ANTENNA DESIGN

The geometry of the proposed frequency-reconfigurable slot antenna is shown in Fig. 1, which consists of a rectangular-ring slot, an inverted *T*-shaped stub, two varactors, and a *T*-shaped feed line on the other side of the substrate. The use of a rectangular-ring structure is to reduce the size of the slot antenna and the length of the rectangular-ring slot is designed to resonate at about 2.4 GHz. The inverted *T*-shaped stub is used to extend the electrical length of the current path (as will be seen later), and hence to further reduce the total size of the antenna. The two varactors, *D1* and *D2*, are placed at both ends of the rectangular-ring slot as shown in Fig. 1(a) for continuous tuning of the operating frequency band. A *T*-shaped feed line, having a width of *Wf* =1.8 mm to achieve a characteristic impedance of 50 Ω, is printed on the other side of the substrate to feed the slot antenna, as shown in Fig. 1(c). The feed line is bent so that it does not block the way for placing other electronic components on the PCB. An RF coupling capacitor *C1* with a value 100 pF is placed across the ends of the rectangular-ring slot and over the feed line on the other side of the substrate. At RF frequency, the capacitor behaves like a short circuit to separate the rectangular-ring slot, but is also used for DC isolation for the design of the biasing circuit. A DC pad is created next to the feed line on the other side of the substrate and is connected with the ground plane through a via, so a DC voltage can be applied to bias the varactors through the use of a bias-Tee at the input of the antenna. A resistor *R1*= 27 kΩ is used to connect the DC pad to the feed line and hence to provide a continuous DC path and choke off the RF signal.



(a) (b)

(c)

Fig. 1. Geometry of proposed antenna: (a) top view, (b) side view and (c) bottom view (▨ metal in front and ░ metal in bottom)

The practical varactor, SMV 1405 (SC-79) [13] from Skyworks is used in our design. The equivalent circuit of the varactor obtained from the data sheet is shown in Fig. 2(a), which consists of a series packaging parasitic inductance *Lf* (= 0.7 nH), a series resistance *Rs* (= 0.8 Ω) and a variable capacitance C_T. The variable capacitance C_T ranges from 2.67 to 0.63 pF with the reverse-biased voltage from 0 to 30 V as shown in Fig. 2(b).

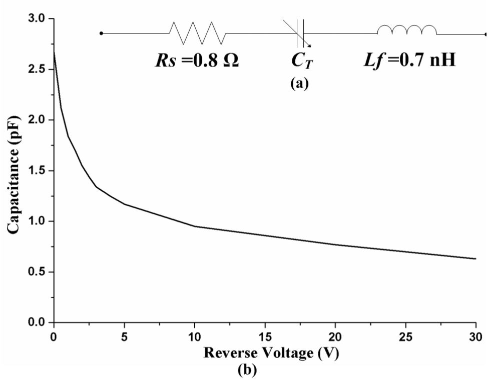


Fig. 2. (a) Simulation model of varactor (b) capacitance vs reverse voltage for varactor SMV 1405(SC-79)

The EM simulation software tool CST is used to study the proposed frequency-reconfigurable slot antenna on a substrate with a total area of 24×40 mm^2 (0.260×0.433 λ_g^2, λ_g is the guided wavelength at the center frequency of the proposed antenna), a relative permittivity of 3.6 and a loss tangent of 0.004 as shown in Fig. 1. The final dimensions are shown in Table I.

TABLE I. OPTIMIZED DIMENSIONS OF THE PROPOSED ANTENNA (MM)

L1	*L2*	*L3*	*L4*	*L5*	*L6*	*W1*	*W2*
12.0	19.0	6.6	9.3	7.0	13.2	22.4	0.8
W3	*W4*	*Wf*	*Ws*	*hs*	*Ls*	*g1*	
1.4	1.0	1.8	24.0	0.8	40	1.0	

III. SIMULATION RESULTS AND DISCUSSIONS

A. S-Parameters

The simulated S11 with different values of C_T used in the proposed frequency-reconfigurable antenna is shown in Fig. 3. It can be seen that, as C_T decreases from 2.67 pF to 1.7, 1.17 and 0.7 pF, the simulated impedance bandwidth (IMBW) for S11 < -10 dB shifts from 2.12-2.17 GHz to 2.33-2.44, 2.64-2.84, and 3.18-3.47 GHz, respectively, and the resonant frequency shifts continuously from 2.14 GHz to 2.38, 2.73 and 3.33 GHz, resulting in a wide tuning range of 1.19 GHz (43.5%).

The antenna is further studied using current distribution. Simulation results have shown that the current on the feed line is not affected much by the diodes and capacitor *C1* underneath, and is just like on other normal feed lines feeding antennas, so to save space, only the currents on the slot are used for analysis. Fig. 4 shows the simulated current distribution of the antenna at 2.14 GHz (which is the resonant frequency of the IMBW using the higher value of C_T = 2.67 pF).. It can be seen in Fig. 4 that the current is concentrated along the rectangular-ring slot and the inverted *T*-shaped stub. Thus the *T*-shaped stub increases the length of the current path and hence reduces the required size of the antenna for low frequency operation.

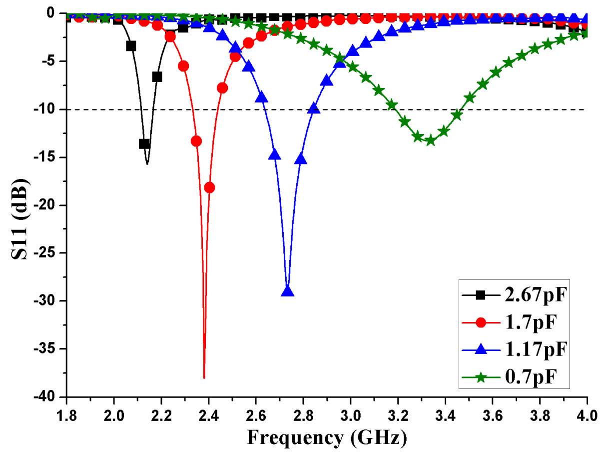


Fig. 3. Simulated S11 with different values of C_T

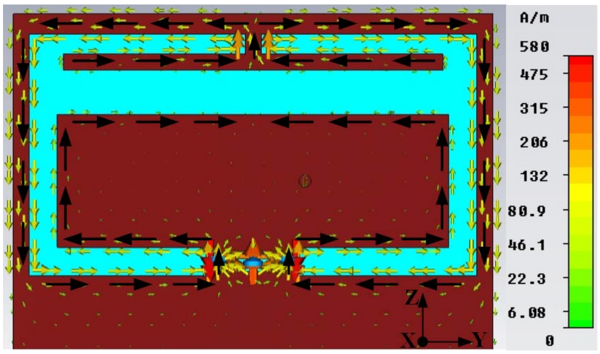
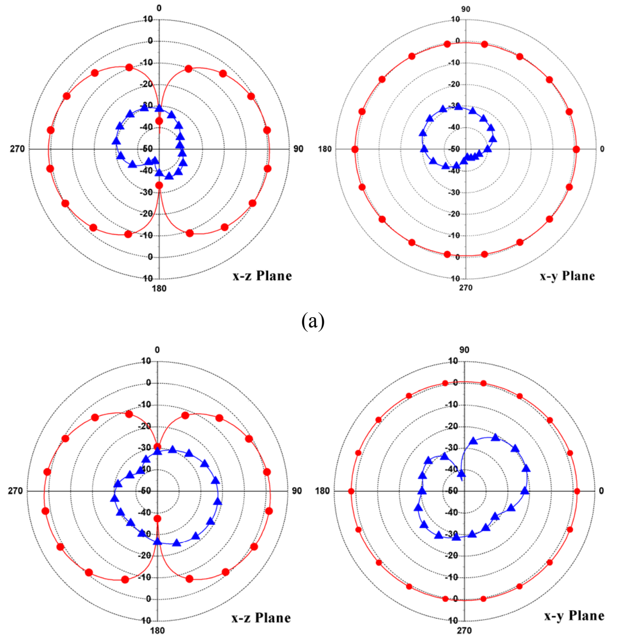


Fig. 4. Simulated current distribution at 2.14 GHz with $C_T = 2.67$ pF

B. Radiation Patterns

The simulated radiation patterns of the frequency-reconfigurable antenna with different values of C_T are shown in Fig. 5. Results have shown that the radiation patterns with different values of C_T are quite similar, so we only show the simulated patterns at 2.14 GHz (which is the resonant frequency of the IMBW using the higher value of $C_T = 2.67$ pF) and 3.33 GHz (which is the resonant frequency of IMBW using the lowest value of $C_T = 0.7$ pF). It can be seen in Fig. 5 that the co-polarization radiation patterns at both frequencies have dump-bell shapes in the x-z plane and are omnidirectional in the x-y plane. The cross-polarization radiation patterns are in the low levels.



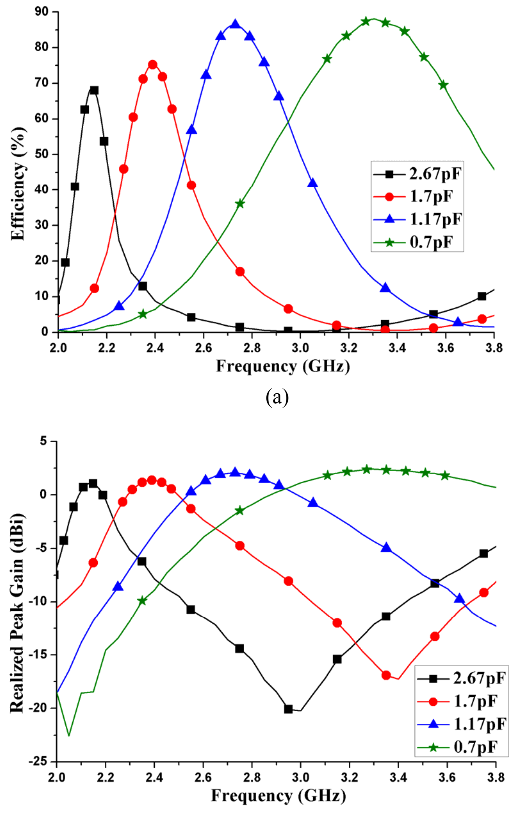
(a)

(b)

Fig. 5. Simulated radiation patterns at (a) 2.14 GHz with $C_T = 2.67$ pF and (b) 3.33 GHz with $C_T = 0.7$ pF. —●—: co-polarization, —▲—: cross-polarization)

C. Efficiency and Gain

The simulated efficiency and realized peak gain of the proposed antenna are shown in Fig. 6. With C_T decreased from 2.67 pF to 1.7, 1.17 and 0.7 pF, Fig. 6(a) shows that the simulated efficiencies at the resonant frequencies of 2.14, 2.38, 2.73 and 3.33 GHz are 68.7% to 75.2%, 86.4%, and 88.1%, respectively, with the corresponding simulated peak gains of 1.10 to 1.38, 2.04, and 2.42 dBi, as shown in Fig. 6(b).



(a)

(b)

Fig. 6. Simulated (a) efficiency (b) realized peak gains with different values of C_T

D. Comparison with other works

Finally, the tuning range and the total size of the proposed frequency reconfigurable antenna are compared with other continuously tunable antennas in [9-12]. It can be seen that the our proposed antenna has the widest tuning range of 43.51% and a very compact size of only $0.260 \times 0.433\ \lambda_g^2$, where λ_g is the guided wavelength at the lowest resonant frequency of 2.14 GHz.

TABLE II. COMPARISON WITH OTHER WORKS

	Lowest Resonant Frequency (GHz)	Tuning Range (%)	Total Size (λ_g^2)
[9]	2.35	22.98	0.333×0.535
[10]	2.15	26.26	0.145×0.063
[11]	2.99	18.24	0.580×0.630
[12]	4.13	8.57	0.731×0.731
Proposed	2.14	43.51	0.260×0.433

IV. CONCLUSIONS

A compact frequency-reconfigurable slot antenna with a wide tuning range for cognitive radios has been presented. The antenna consists of a rectangular slot, an inverted *T*-shaped stub, two varactors, and a *T*-shaped feed line printed on the other side of the substrate. By varying the reverse-bias voltage across the varactors, the resonant frequency of the proposed antenna can be continuously tuned from 2.14 to 3.33 GHz which is a potential candidate for use in cognitive radios.

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