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Tri-Band Concentric Slot-Ring Antenna with Ultra-Wide Frequency Tunability for Cognitive Radio Applications

Monika Tulsyan, Rajarshi Bhattacharya

Abstract: ***This paper presents a compact, triband, rectangular slot-ring frequency reconfigurable antenna designed on FR-4 board having dimension 43 x 48 x 1.56 mm^3. Two concentric slot-rings are placed such that their mutual interaction leads to triband operation of the antenna. Frequency reconfigurability is achieved by reactive loading of each slot-ring with varactor diode. The proposed antenna could be continually tuned over ultra-wide frequency range from 1.91-5.9 GHz. The antenna covers major wireless standard bands such as Bluetooth (2.38-2.49), Wi-Max (3.3-3.6), WLAN (5.15-5.725), LTE 2300/2600 and Wi-Fi (2.4–2.5). Hence, the designed antenna is appropriate for handheld mobile terminals for cognitive radio based applications.***

Index Terms: ***Cognitive radio, frequency reconfigurable, slot-ring antenna, ultra wideband tuning.***

I. INTRODUCTION

The rapid advancement in the modern wireless communication technology elevates the need for systems having efficient spectral utilization and high throughput. Various new services and standards are being rolled out such as LTE, UWB DVB-H etc. to the wireless devices, which are supposed to be accessed simultaneously sometimes. Hence, designing an antenna system which should be capable of supporting multiple wireless standards and services is a challenging task for mobile terminal designers. One solution to this problem is using frequency agile antennas in cognitive radio platform, which promises high spectral resource utilization factor by adjusting its frequency bands on the basis of spectrum availability in the continuously changing environment [1]. However, in order to comply with the physical size constraints, the tuning range of frequency is often kept limited for a conventional antenna [2]. Therefore, it is highly recommendable to use frequency reconfigurable antenna with wideband tuning range in cognitive radio based applications [3]. Frequency reconfigurability can be achieved either by mechanically controlled stepper motors [4]-[5] or by electronically controlled components such as PIN diode [6] and varactor diodes [7].

In literature [7]–[12], many wideband tuning frequency reconfigurable antennas were reported. In [7], a frequency reconfigurable slot antenna was designed on RO-4003 substrate having board dimensions of 150 x 110 x 0.5 mm^3. A pair of varactor diode was used in order to tune both the band individually resulting in dual mode operation. Frequency sweep from 1.3-2.67GHz was achieved by applying two distinct sets of reverse bias voltage. A printed inverted-F antenna (PIFA) with size of 40 x 5 x 7 mm^3 was reported in [8], having ground plane dimension of 100 x 40 mm^2. The frequency bands covered were from 0.778 to 2.896 GHz. In [9], an electrically small PIFA was designed having frequency-reconfigurability over lower bands ranging from 0.457-0.894GHz. The dimension of elevated PIFA was 50 x 50 x 15 mm^3, with ground plane size of 200 x 200 mm^2. In [10], a frequency agile bow tie antenna was designed to cover a continuous tuning wideband frequency from 3.04~5.89GHz with the help of varactor and PIN diodes. The antenna was having a dimension of 45 x 50 x 1 mm^3. In [12], a half annular-slot-based antenna is designed having frequency reconfigurability over ultra wideband and dual band. The radius of annular slot was 10.5 mm and the size of ground plane was 32 x 35 mm^2. In dual band, the reported antenna's first resonance covered 2.5- 3.22 GHz and antenna's second resonance covered 4.36- 6.58 GHz. While in ultra wide band, the antenna covered three wideband frequency ranges from 3.48-5.5 GHz, 5.18- 7.35 GHz, and 6.06- 8.05 GHz. In [13], a dual concentric pentagonal slot-line fed MIMO antenna is reported, which has a discrete tuning range from 1.32~1.49 GHz and 1.76~5.2 GHz. It is observed that a wide tuning range could be obtained with the help of PIN diode as well [6]. However, as the tuning is discrete, more number of diodes is required to switch between different multi-operating bands, which in turn increase the structural complexity. So, in this work, we have used varactor diodes to achieve continuous tuning and smooth transitions between each operating bands.

In this paper, a novel frequency reconfigurable concentric rectangular slot-ring based antenna is presented. The proposed antenna is triband antenna having an ultra-wide band tuning capability. First resonant band sweeps from 1.91 to 2.98 GHz. The second band tunes from 2.68 to 4.17 GHz and the third band tunes from 4.57 to 5.9 GHz. Apart from the aforementioned discrete tuning ranges, the wide -6 dB operating bandwidth of the individual bands enables the proposed antenna to continuously sweep from 1.91~5.9 GHz. Thus, we get an ultra wide band sweep of 3.98 GHz, which is an improvement over [13]. The rest of this paper is organized as given below. The design procedure of the proposed antenna is described in Section II.

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Section III contains the simulation and measurement results for the designed antenna and lastly, the paper is concluded in Section IV.

II. RECONFIGURABLE SLOT ANTENNA DESIGN

The schematic layout of the proposed antenna is shown in Fig. 1. It consists of two concentric rectangular slot-ring antennas etched out from the ground plane. The designed antenna is fabricated on FR-4 board of thickness 1.56 mm, relative permittivity (ε_r) 4.4 and loss tangent (δ) 0.002. For designing the proposed antenna, first we design a single rectangular slot-ring element having slot width of 1 mm. The slot-ring antenna is excited by a 50 Ω microstrip line of width $W_f = 3$ mm. The dimension of single-band outer rectangular slot-ring based antenna is optimized such that it can achieve resonance at 3 GHz in absence of any reactive loading on the slot. Next, the inner rectangular slot-ring, fed by the same feeding line, is etched out. The mutual interaction between the electromagnetic fields of inner and outer slot results in tri-band operation as depicted in Fig. 3. Without capacitive loading, it is found to provide resonances near 3 GHz, 4 GHz, and 6 GHz. In order to make the designed antenna frequency reconfigurable, we place two varactor diodes D1 and D2 across the radiating slots as shown in Fig. 1 (b) and 2 (b). Varactors are used to reactively load the antenna. As the capacitance of the varactor diodes changes, the effective electrical length of the slots changes, altering the resonant frequency of the antenna accordingly. Parametric analysis is carried out to locate the optimum position of varactor diodes in terms of frequency tunability. It is found that placing D1 and D2 right at the center, i.e. at slightly offset with the microstrip line best tunability in the antenna. The return loss (RL) of the designed antenna is shown in Fig. 3. Evidently, the proposed antenna provides frequency tunability over ultra-wide frequency range from 1.91-5.9 GHz. The bias pads are designed for DC power supply and ground. The biasing circuit consists of bias pads and RF choke connected to the varactor diode terminals [13]. In the proposed antenna, the RF choke is realized using the self-inductance of a narrow PCB trace. Two resistors R1 and R2 of 2.1 kΩ are used in the biasing circuit for limiting the dc current. The presence of RF chokes blocks the high frequency current to enter into the biasing circuitry, whereas the varactor diodes take care of the DC leakage current by effectively blocking it from entering the antenna section. The model number of the varactor diode used in this work is MA46580 and is modeled in HFSS using lumped R, L, and C elements. The outer peripheral length of outer rectangular slot ring is 70 mm and that of the inner rectangular slot ring is taken to be 50 mm. The detailed dimensions of the proposed antenna are listed in Table I. The fabricated prototype of the proposed antenna design is shown in Fig. 2. Two plated through holes (PTHs) are used to connect the varactor diode terminals to the biasing circuit as shown in Fig. 2(a). The top view of the fabricated antenna along with the feedline and bias circuit for diodes D1 and D2 is shown in Fig. 2(a). Fig. 2(b) shows bottom view of the design, consisting of a dual concentric rectangular shaped slot ring etched out from the ground plane.

All resonating bands are made continually tunable over 1.91 to 5.9 GHz covering several important wireless bands such as Bluetooth (2.38-2.49 GHz), Wi-Max (3.3-3.6 GHz), WLAN (5.15-5.725 GHz), LTE 2300/2600 and Wi-Fi (2400–2500 MHz), etc. A close observation of Fig 3 (a) reveals that unlike the antenna, recently designed by Hussain et al., the proposed antenna results in triband operation for all values of capacitance corresponding of the varactor diodes [13].

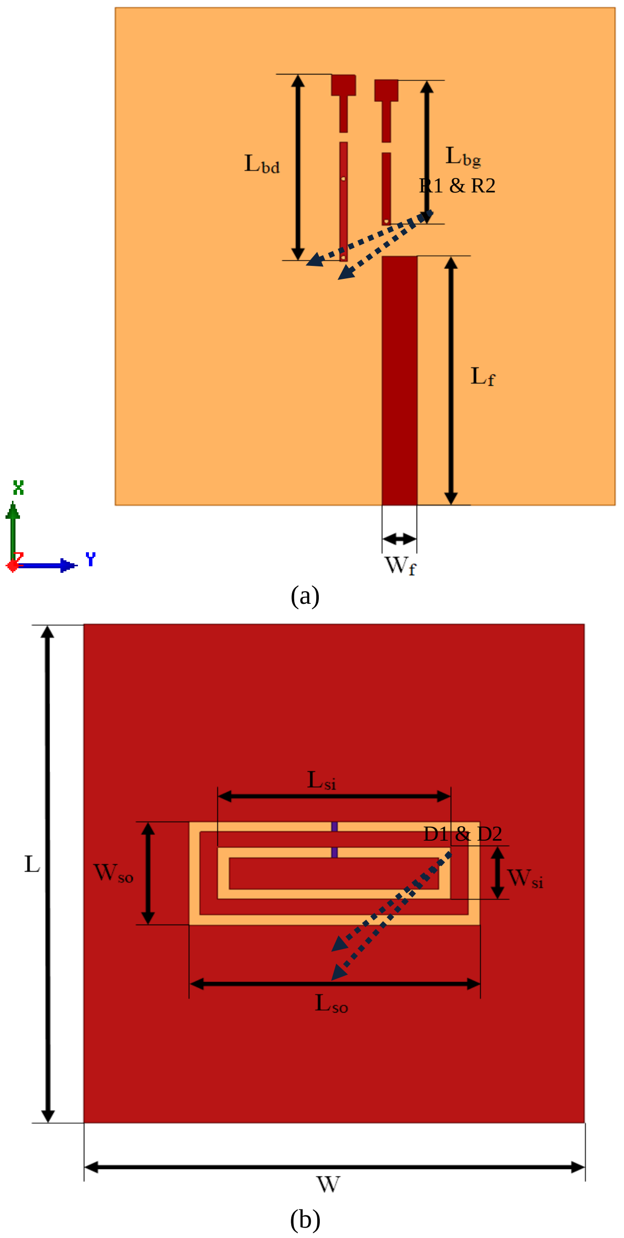

Fig 1. Proposed antenna for CR platform (a) Top view (b) Bottom view

Table I
Dimension of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	48	L_{bd}	19	L_{so}	25
W	43	L_{bg}	15	W_{si}	5
L_f	24	L_{si}	20	W_{so}	10

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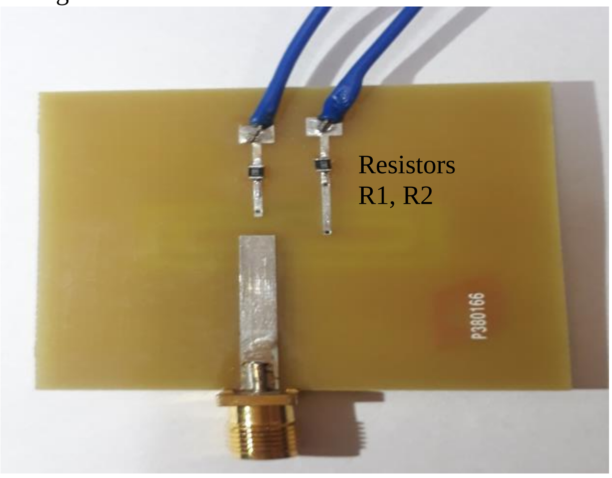
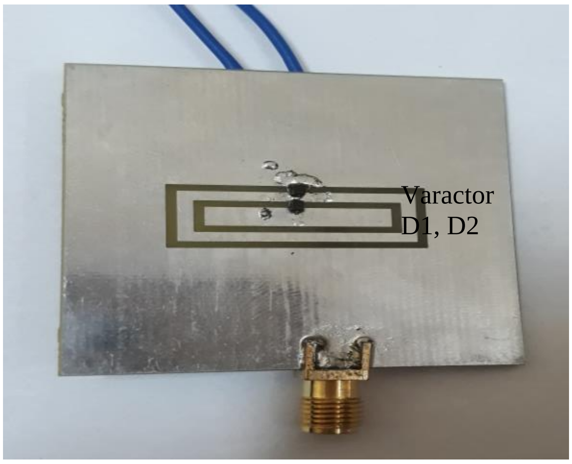
Further, the proposed antenna has planar structure and it is quite compact in size. The foot-print area of the whole antenna is only 0.49 λ_g x 0.44 λ_g, where λ_g is the guided wavelength at 1.9 GHz.



(a)

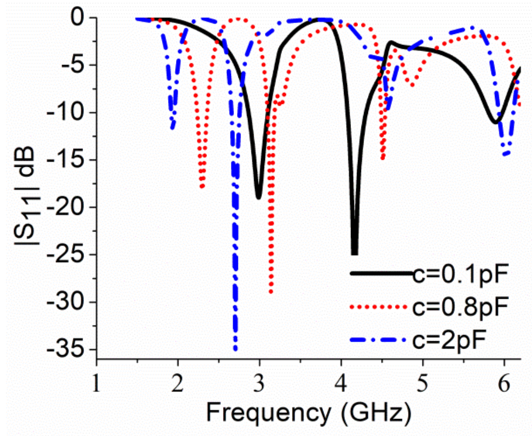


(b)

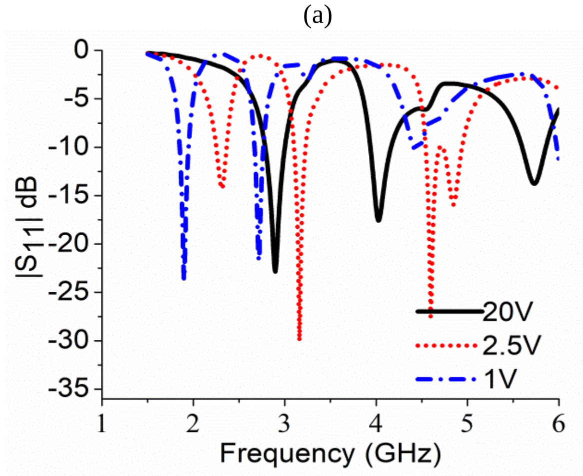
Fig. 2. Fabricated prototype of the proposed antenna (a) Top view (b) Bottom view

III. SIMULATED AND MEASURED RESULTS

The proposed reconfigurable antenna is designed and simulated using High Frequency Structure Simulator (HFSS). The S_{11} is measured using Agilent N5222A PNA Vector Network Analyzer. The simulated RL of the proposed triband antenna is depicted in Fig. 3 (a) for different values of capacitance. A wide sweep of resonant frequencies is attained by tuning the capacitance of varactor diodes over a range of 0.1 pF to 2.0 pF. Evidently, the resonant frequency of the three bands are varying over 1.91~2.98 GHz, 2.68~4.17 GHz, and 4.57~5.9 GHz, respectively. Hence, the designed antenna can sweep almost entire range of frequencies from 1.91 GHz to 5.9 GHz. Fig. 3(b) shows the measured reflection coefficient at the antenna port. It is found to be in good agreement with the simulated results. The measured frequency bands are found to vary from 1.89~2.89 GHz, 2.71~4.03 GHz, and 4.44~5.73 GHz for variation of bias voltage from 20 volt to 1 volt. The slight deviation in the measurement results could be attributed to DC bias lines and fabrication tolerance. The simulation and measurement result of far-field radiation patterns of the proposed antenna at 2.28, 3.15, 4.57 and 5.88 GHz is shown in Fig. 4. The measured normalized gain patterns in both XZ and YZ planes are in good agreement with simulated normalized gain patterns and maintain similar shape throughout the entire frequency band.



(a)



(b)

Fig. 3. |S_{11}| of the proposed antenna with ultra-wide tuning range of 3.99 GHz (a) Simulated results (b) Measured results

IV. CONCLUSION

In this paper, a simple and compact frequency-reconfigurable dual concentric rectangular slot-ring-based antenna having an ultra-wide tuning range of 3.98 GHz (from 1.91 to 5.9 GHz) has been presented. The tri-band operation has been obtained using only two radiating elements, where the third resonance owes to the coupled mode of two slot-ring radiators. Two varactor diodes have been used to incorporate frequency tunability in all the three bands through variable reactive loading. Furthermore, the designed antenna covers most of the sub-six GHz RF band used in modern-days wireless communication and this antenna is quite compact in size. This makes the proposed antenna a suitable candidate for modern cognitive radio enabled handheld devices.

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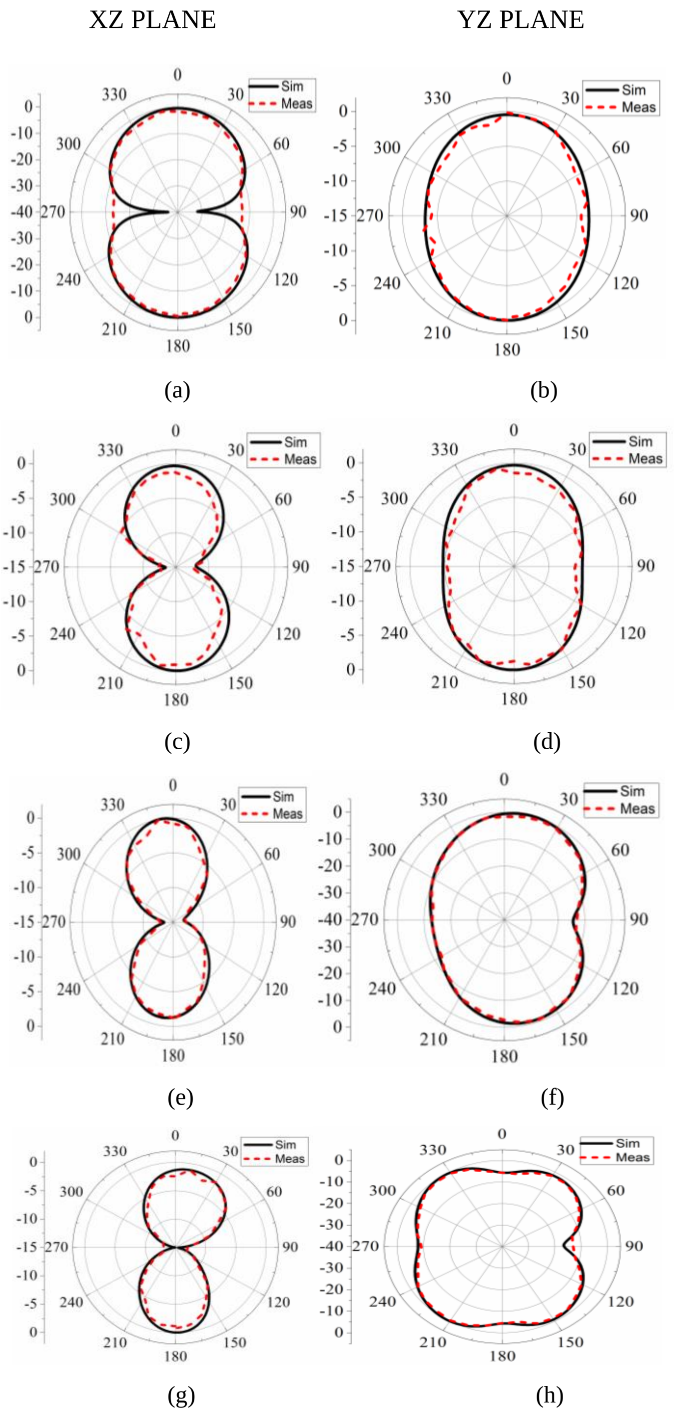

Fig. 4. Simulated and measured radiation patterns of antenna at (a) 2.28GHz (XZ-plane), (b) 2.28GHz YZ-plane), (c) 3.15GHz (XZ-plane), (d) 3.15GHz (YZ-plane), (e) 4.57 GHz (XZ-plane), (f) 4.57GHz (YZ-plane), (g) 5.88GHz (XZ-plane), (h) 5.88GHz (YZ-plane)

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