Experimental Investigation of Reconfigurable Harmonic Suppressed Fractal Dipole Antenna

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1. Introduction

Cognitive radio (CR) is a very promising technology of future wireless communications that has greater demands for antenna designs. One practical antenna is a reconfigurable antenna that has dual mode operations, i.e. scanning a free RF spectrum and transmitting or receiving information data via a CR link. One possible compact antenna configuration is based on the dipole or monopole that has narrow or wideband frequency features for handheld or base station terminal.

A typical technique is to create two antennas with wideband and narrow band features of omni-directional and directional patterns for sensing and frequency agile purposes [1]-[3]. A three L-shaped monopole antennas designed on the same substrate with the inter-band frequency being changed using a PIN diode while a DC supply is used to control the reactance of a varactor diode for frequency tuning purposes that covers UHF band, mobile radio and wireless LAN [4]. A single patch antenna integrated with parasitic elements via RF switches to create a tunable feature from 550 MHz to 1500 MHz has been proposed [5]. In [6], a single band antenna is connected via a harmonic filter. Similar approach has been employed in earlier works on a dipole, aimed as a reconfigurable antenna [7]-[8].

In this paper, an experimental investigation of a tunable fractal dipole antenna is presented. It is aimed for CR handheld unit with wideband features such as hand phone or personal digital assistant (PDA) [9]. In addition, this paper proposed an alternative implementation using low loss material showing better performances. The structure is formed from the integration of Koch fractal dipole antenna, stubs-filter and wide-band taper balun as will be explained in the next section (section 2). The experimental results are explained in section 3 while the concluding remarks are given in section 4.

2. Harmonic Suppressed Koch Dipole Antenna Design

The antenna is designed similar to [7]-[8] to the desired specification. Firstly, the antenna is designed to operate at 0.9 GHz as a linear Koch dipole on a lossy dielectric substrate with relative permittivity, ε_r, of 4.6 and thickness, h, of 1.6 mm. Then, it is iterated to a fractal Koch until N=2nd iteration [10]. The antenna is then fabricated. The dimensions of the substrate are 95 X 136 X 1.6 mm^3. A 76 X 3 mm^2 microstrip feed line and a tapered balun of 64 X 64 mm^2 are designed for 50 Ω input impedance. To suppress the antenna higher order modes, one or two open circuit stubs are used as depicted in Figure 1. The length of the stub depends on $\lambda/4$ of a higher order mode in a free space while the width is approximately 3 mm.

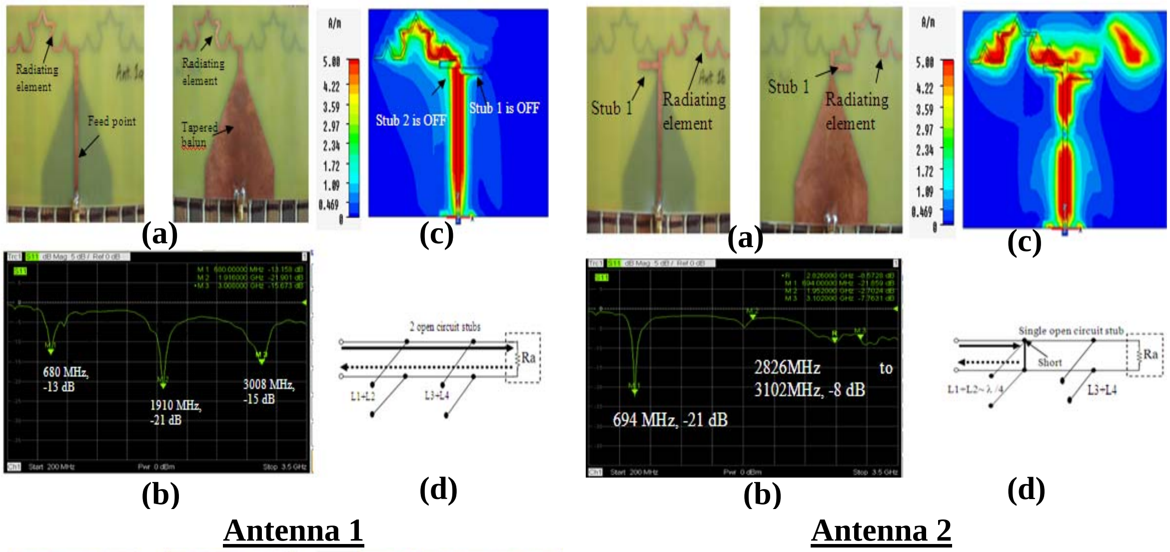
3. Results and Discussion

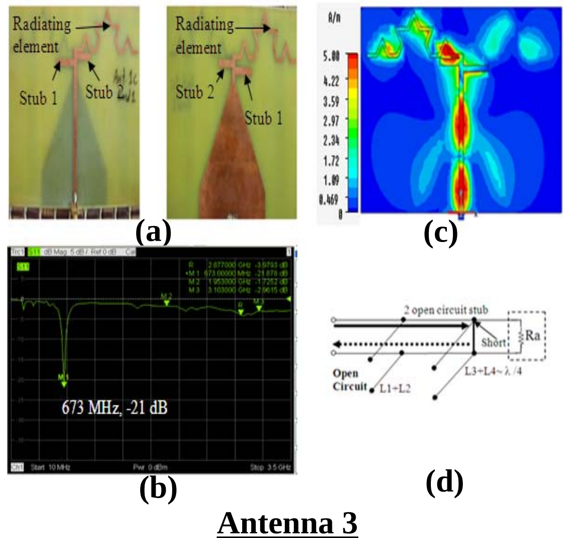
The antenna prototypes was constructed and studied. The measurements are realized by using the Vector Network Analyzer (VNA), ZVB14.

A. Single band Koch dipole antenna

The surface current distributions at three frequencies are presented in Figs. 3, 7 and 11. The radiation element, stubs and parallel strip line are illuminated. The radiation pattern depends on the operating frequency whether it operates at a fundamental mode or higher order modes. In Fig. 3, the current flows along the parallel transmission line and dipole arms, showing that the antenna is in a passband mode at 680 MHz. In Fig. 7, higher current flows along stub 1 that eliminates the first harmonic frequency, 1856 MHz. Stub 1 is shorting the antenna, while stub 2 eliminates the second harmonic frequency, 2800 MHz. The surface current distribution is shown in Fig. 11.

The measured return losses are presented in Figs. 2, 6 and 7. There are three operating frequencies from 0.2 GHz to 3.5 GHz. The antenna operates at 680 MHz, with two harmonics, 1.916 GHz and 3.008 MHz, having low return losses of -13.2 dB, -21.9 dB and -15.7 dB, respectively. The results agree well with the simulations [8]. The fractal curve has successfully reduced the first resonant frequency to 680 MHz and at the same time produced two harmonic frequencies. Stub 1 (length = 42 mm, width = 3 mm) is used to eliminate the 1.916 GHz frequency as shown in Fig. 6. The antenna operates at 694 MHz frequency and successfully eliminated the 1.916 GHz frequency. However the new second harmonic frequency with wideband feature resonates within 2.82 GHz to 3.5 GHz with return loss ~ -8 dB. Stub 2 of 21 mm length is used to produce a smooth single band Koch dipole antenna as shown in Fig. 10. The antenna operates at 673 MHz with l)ow -21.9 dB return loss. Based on the normalized surface current distributions, three conceptual equivalent circuit models are developed as shown in Fig. 4, 8 and 12, respectively.





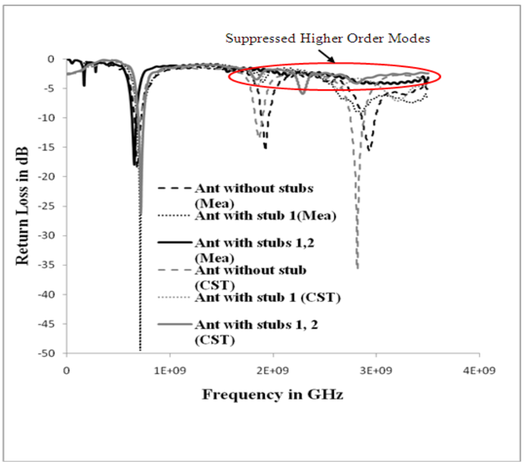


Figure 2: Simulated and measured S_{11}

Figure 1: Antennas 1, 2, and 3: (a) Antenna prototype, (b) measured S_{11}, (c) surface current distribution, and (d) conceptual equivalent circuit model

B. Reconfigurable Koch dipole antenna

A single band 2nd iteration Koch meander dipole is combined with the open circuit stubs to operate as a tunable antenna. The lengths of the resonant elements (single dipole arm) are 64 mm, 60 mm, 56 mm, 52 mm, 48 mm, 44 mm, 42 mm, 38 mm, 34 mm, 30 mm, 26 mm, 22 mm, 18 mm, and 14 mm, and are controlled through hard core wire with 2 mm in diameters as shown in Fig. 5. The parallel stubs were used to eliminate the harmonic frequency. Stub 1 has lengths of 42 mm, 30 mm, 28 mm, 27 mm, 25 mm, 23 mm, 20 mm, and 19 mm, while stub 2 operates at 30 mm, 22 mm, 20 mm, 18 mm, and 16 mm, respectively. The total number of switches is 39 units. The simulated and measured tunable frequencies are given in Table I. The antenna enables the operating frequency to change between 673 MHz (band 1), 712 MHz (band 2), 760 MHz (band 3) to 2.462 GHz (band 15). The equivalent low return loss and VSWR is -21.9 dB&1.21 (band 1), -24.6 dB&1.33 (band 2), -26 dB&1.11 (band 3) until -20 dB&1.26 (band 15), respectively.

Table I
Simulated and Measured Results

Band	**Return Loss**				**VSWR**	
	Simulated Freq.(MHz), dB		Measured Freq.(MHz), dB		Sim.	Meas.
1	732	-26	673	-21	1.10	1.21
2	756	-26	712	-24	1.11	1.33
3	787	-31	712	-26	1.06	1.11
4	837	-38	760	-26	1.03	1.08
5	889	-42	792	-22	1.02	1.13
6	956	-19	798	-22	1.27	1.13
7	1012	-18	858	-19	1.30	1.25
8	1113	-17	858	-17	1.34	1.32
9	1211	-17	930	-20	1.33	1.25
10	1330	-19	1146	-24	1.24	1.13
11	1470	-10	1306	-42	1.88	1.02
12	1656	-14	1446	-9	1.53	2.16
13	1900	-19	1674	-9	1.26	2.16
14	2485	-20	1892	-12	1.24	1.66
15	2971	-19	2462	-20	1.26	1.19

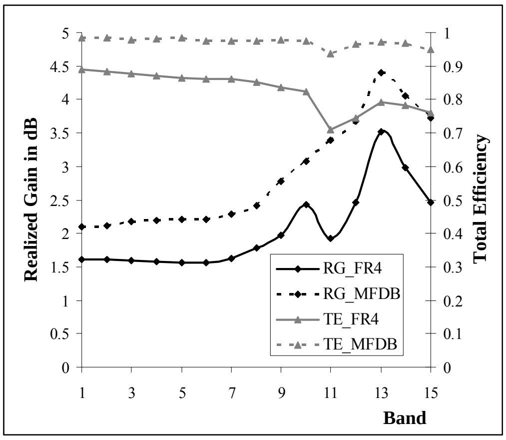


Figure 3: Realized gain and total efficiency as a function of frequency for antenna using FR-4 and Rogers 4350B

Finally, the proposed antenna has the following features: 15 microwave band channels from 673 MHz to 2642 MHz, RL of -9 dB to -42 dB, VSWR of 1.02 to 2.15, % bandwidth of 2% to ~5%, and reflection BW of 1.79 GHz.

C. Proposed implemented the antenna by using low loss material

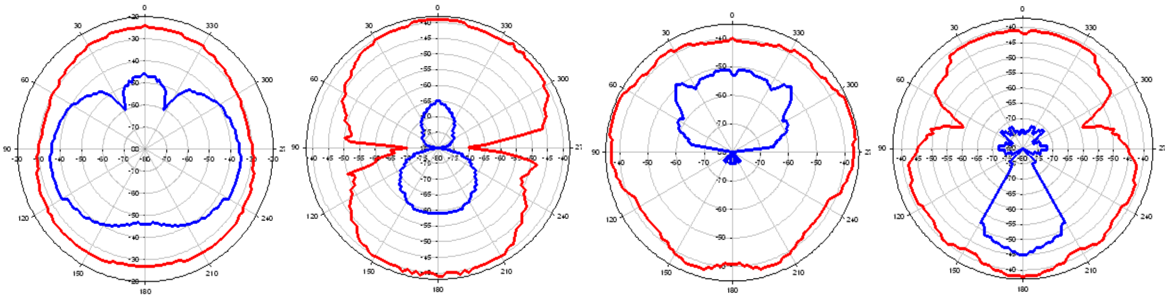
Table II gives the realized gain (RG) and total efficiency (TE) of the antenna, implemented on FR-4 and Rogers 4350B. Rogers antenna is named as MFDB. Its clearly shown that the reconfigurable antenna using low loss Rogers material exhibits better efficiency and gain.

Table II
Simulated E_{HPBW} (°), Realized Gain (dB), and Total Efficiency, η.

Bands	**Realized Gain (dB) -FR4**	**Total η -FR4**	**Realized Gain (dB) -4350B**	**Total η -4350B**
1	1.611	0.8898	2.103	0.9832
2	1.601	0.8842	2.118	0.9847
3	1.587	0.8783	2.182	0.9793
4	1.573	0.8707	2.186	0.9800
5	1.563	0.8651	2.205	0.9837
6	1.567	0.8599	2.203	0.9742
7	1.626	0.8601	2.283	0.9753
8	1.790	0.8513	2.408	0.9761
9	1.964	0.8361	2.773	0.9771
10	2.430	0.8238	3.083	0.9755
11	1.920	0.7096	3.385	0.9354
12	2.467	0.7447	3.675	0.9639
13	3.515	0.7913	4.403	0.9719
14	2.977	0.7809	4.049	0.9687
15	2.463	0.7604	3.724	0.9482

4. Conclusion and Future Work

A microwave switchable dipole antenna concept using Koch curve integrated with open circuit stubs is presented. The structure employed fractal technology that can eliminate higher order modes. With the utilization of Koch curves, the antenna size is reduced, but the number of higher order modes has proportionally increased. The size of the proposed antenna is small with regards to the operating frequency. The simulation and measurement results showed that the stub has improved the antenna performance. The antennas will be implemented on a low loss substrate for better performance.



***f* = 712 MHz** ***f* = 2462 MHz**

Figure 3: Selected measured co-polar (red color) and cross polar (blue color) H-plane (left) and E-plane (right) radiation patterns of band 2, *f* = 712 MHz, and band 15, *f* = 2462 MHz.

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References

[1] Y. Hur, J. Park, W. Woo, K. Lim, C. H. Lee, H. S. Kim and J. Laskar, "A wideband analog multi-resolution spectrum sensing (MRSS) technique for cognitive radio (CR) systems," *in Conf. Rec. 2006, ISCAS 2006*, pp. 4090-4093.

[2] J. T. Aberle, S. H. Oh, D. T. Aukland and S. D. Roegers, "Reconfigurable antenna and RF front-ends for portable wireless devices," *IEEE Ant. and Prop. on Mag*., vol. 45, no. 6, pp. 148-154, ____ 2003.

[3] P. S. Hall, P. Gardner, J. Kelly, E. Ebrahimi, M. R. Hamid and F. Ghanem, "Antenna challenges in cognitive radio," *in Proc. of ISAP2008* (Invited paper).

[4] K. Ligusa, H. Harada, and S. Kato, "Proposal and evolution of relatively loaded inverted-F for cognitive wireless communication," in *Conf. Rec. IEEE 2007*, pp. 837-840.

[5] J. A. Zammit and A. Muscat, "Design and configuration of low-profile reconfigurable antenna for a cognitive radio system", in *Conf. Rec. IEEE 2008*.

[6] A. Mirkamali, P. S. Hall and M. Soleiman, "Reconfigurable printed dipole antenna with harmonic trap for wideband applications," *Micro. and Opt. Tech. Lett*., vol. 48, no. 5, pp. 927-929, March 2006.

[7] S. A. Hamzah and M. Esa, "Reconfigurability Characteristics of a Microwave Fractal Dipole Antenna", *Proc. of IEEE 2008 Regional Student Conference on Research and Development (SCOReD 2008)*, 2008, pp. 68-1 to 68-4.

[8] S. A. Hamzah, M. Esa and N. N. N. A. Malik, "Reduced Size Microwave Fractal Meander Dipole Antenna with Reconfigurable Feature", Proc. of ISAP 2009, pp. 1-4, 2009.

[9] P. Vainikainen, J. Holopainen, C. Icheln, O. Kivekas, M. Kyro, M. Mustonen, S. Ranvier, R. Valkonen, and J. Villanen, "More Than 20 Antenna Elements in Future Mobile Phones, Threat or Opportunity", *in Conf. Rec. IEEE 2008*. pp. 2940-2943.

[10] K. J. Vinoy, "Fractal Shaped Antenna Elements for Wide and Multiband Wireless Applications," *Unpublished PhD Dissertation*. The Pennsylvania State University, 2002.