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Fractal Reconfigurable Multiband Communicating Antenna for Cognitive Radio

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Abstract: *A novel antenna structure is proposed by combining the concept of a reconfigurable and fractal with the parasitic elements technique to obtain the multiband frequency reconfigurable antenna. Fractal antenna with triangular slot is designed for operating at multiple frequencies. The integration of PIN diode switches to the antenna changes the frequency of the antenna dynamically. This is done by changing the switch state to either on or off mode. Proposed antenna is designed and simulated in HFSS and parametric analysis has been carried out and fabricated on FR4 substrate. The electrical lengths are varied by operating switches on and off. The proper activation/deactivation of the switches alters the current flow and changes resonance frequency. This paper presents a fabricated compact fractal shaped frequency reconfigurable antenna for multiband operation along with measured results. The proposed antenna is most suitable for Cognitive Radio.*
Keywords**:** *Reconfigurable antenna, Fractal antenna, HFSS, Cognitive radio*

I. Introduction

Recent times, the explosive growth rate of subscriber base for the modern wireless communication throws an important challenge on the spectrum management which is valuable and limited natural resource. Cognitive Radio (CR) communication is one of the upcoming radio technologies for enhancing the performance of radio communication systems through the efficient utilization of radio spectrum. A CR is a Software Defined Radio (SDR) that additionally senses its environment, tracks changes, and reacts upon its findings [1],[2]. A CR is an independent unit in a communications environment that frequently exchanges information with the networks it is able to access as well as with other CRs. The antenna for CR should be able to sense wide band spectrum and operate at various available frequencies, it is the combination of both wideband and frequency reconfigurable antennas [3], [4].

Many researchers have been concentrating on designing antennas for cognitive radio in recent times. It has been reported that the reconfigurable antennas with multiple switches are able to operate at multiple frequencies and are suitable for cognitive radio secondary user which requires switching over to various available frequencies. Secondary user also requires a wideband antenna for searching a wider band for available primary user unused frequency band [5], [6]. Fractal shaped reconfigurable antennas have been suggested for such applications with suitable slots to achieve such multi frequency operations [7].

Fractal antenna [8] provides miniaturization and has multi-band characteristics. These are composed of multiple iterations of a single elementary shape and are used to describe a family of complex shapes that possess an inherent self-similarity and self-affinity in their geometrical structure. Though these antennas reduce the size and cost, but in case of communication system many applications are used that works at different frequency band hence a single fractal antenna cannot be used to serve the purpose of the whole communication system. We are of the opinion that reconfiguration concept can be applied to fractal and it will be a great advantage for wireless communication system since it provides enhanced miniaturization in size of the overall communication system as well as provides frequency selectivity.

This paper proposes a new fractal reconfigurable microstrip antenna design, based on a triangular shaped fractal antenna with switches mounted at different slits cut on each triangle of patch antenna. The states of the switches change the functionality of the antenna by allowing certain frequencies of operation. The radiation patterns for different switching configurations are very similar.

II. Antenna Configuration And Design

The geometry of the proposed antenna is illustrated in Fig. 1.The antenna is printed on the FR4 substrate with thickness of 1.6mm, relative permittivity of 4.4 and dimension of 65 X 60mm.

It consists of a triangular patch with triangular shaped slot on the patch and full ground plane. The antenna has side length of dimension of 41 mm and height is of 36mm. The width of the 50Ω microstrip feed line with length of 11 mm is fixed at 3 mm. At first, in order to have three different resonance frequencies without considering the switches in the design, slots have been inserted in the suitable position on the antenna patch. It is important to notice that the different orientation for each of the slots is for having lower mutual coupling between the slots.

Exact position for the slots is achieved using a trial-and-error procedure. The width of all the slots is set approximately to 1mm. The values of various parts of the slots are first set as aforementioned and to have good matching and low cross-polarization level for all of the three resonances.

The exact place for the switches along the slots is selected somehow to change the slot length and so as to have a slot matched in its nominal resonance frequency to 50Ω. The exact positions for switches in each slot are found during the design procedure by various simulations with different positions for switches. Optimized distances between slots for the top, right, and left triangles are 6mm, 4.27mm, and 4.36 mm respectively.

To implement the switches, a narrow metal strip is used inside of each slot. The metal strips are placed 1 mm from the edge of each slot, and in this method, no bias line or choke capacitance is needed to switch between the bands. By turning diodes on, the metal strips are connected to the ground plane and become a part of it. Therefore, the slot is shortened, and the related resonance is eliminated without any effects on the other resonances. The antenna can have any combination of the mentioned four resonance frequencies, and this is another novelty of this work.

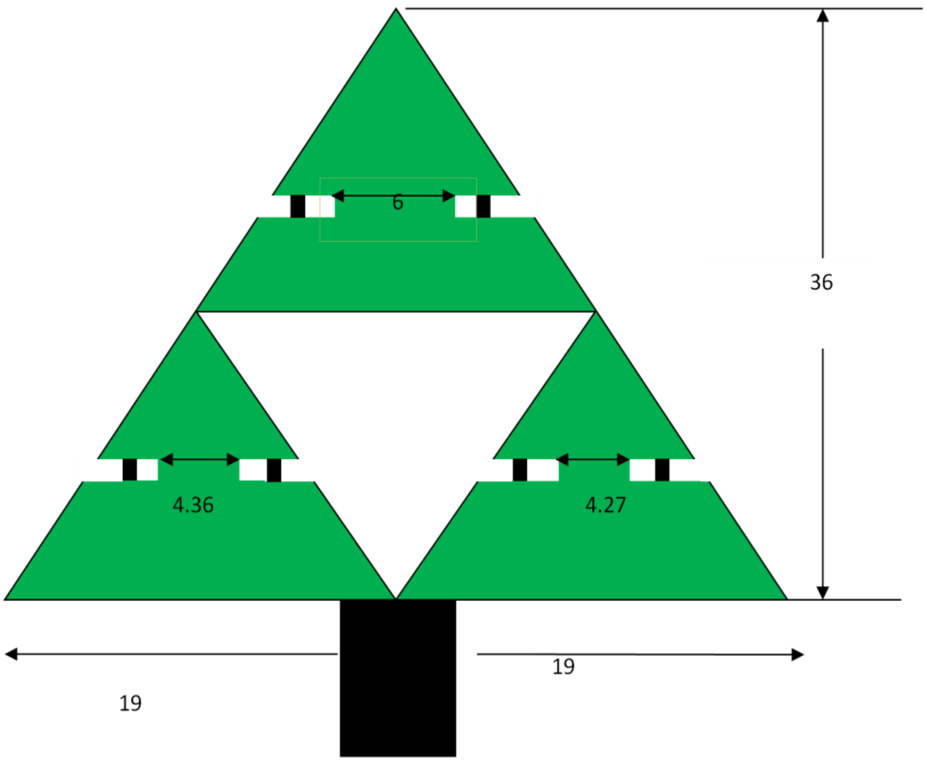


Fig. 1 Geometry of Fractal reconfigurable multiband communicating antenna for Cognitive radio (dimensions are in mm)

III. Antenna Performance

3.1 Simulation Results

The radiation performance of the proposed antenna shown in Fig.2 is simulated by using the High-Frequency Structure Simulator (HFSS) software [9]. A PIN diode model is used to simulate the switches in HFSS. The common way to model a PIN diode is that when the PIN diode is forward- biased, it is represented by a metal tape, and when the PIN diode is reverse-biased, the metal tape will be removed [8]. However, when PIN diodes are reverse biased, the measured bandwidths show a large variation in frequency as compared to simulations. That is because in this condition the diode behaves like a capacitor. Accordingly, to accurately model the behavior of a diode, another method is used in this paper, i.e. when the diode is forward-biased, it is replaced by a resistor of 1Ω, and when the diode is reverse-biased, it is replaced by a capacitor of 0.35 pF, referring to the datasheet of Philips BAP64-03. After simulations, the final geometry of the antenna with detailed dimensions is shown in Fig.2. After successfully verifying the simulated results, the prototype is fabricated, and its photograph is shown in Fig. 3.

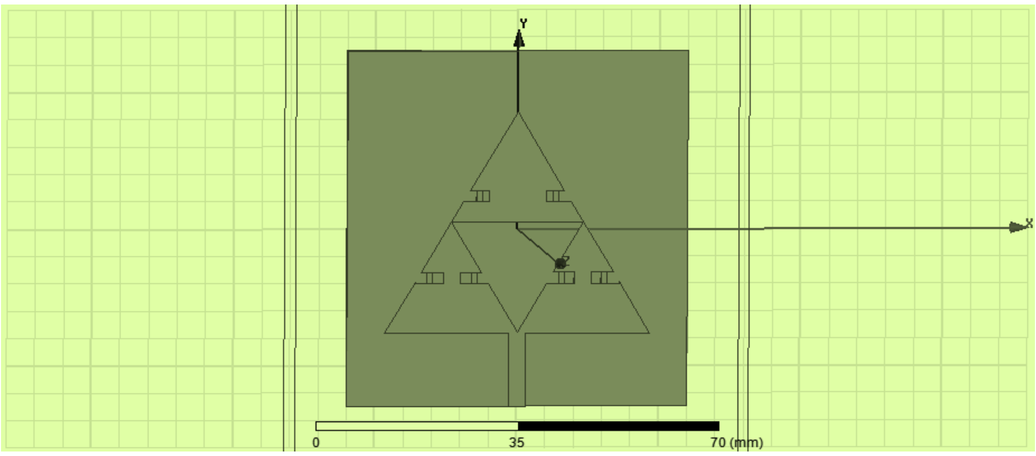


Fig. 2. Geometry of Simulated fractal reconfigurable multiband communicating antenna for Cognitive radio

The resonant frequency of an antenna is heavily determined by the length of the current path. Therefore, it is possible to adjust the length of the current path to change the resonant frequency of the antenna. The modification of the depth of the slot in each triangle has a great influence on the current path. If the switches are inserted in each slot, the resonant frequency of the antenna could be changed by controlling the states of the switches.

Fig. 3 photograph of Fractal reconfigurable multiband communicating antenna for Cognitive radio

The simulated return loss curves with optimized depths of the slot and position of the switches in the each triangle are illustrated in Fig.4. It has been observed that the resonant frequency of the proposed antenna is affected by the depth of the slot. And with the increase of the depth of the slot, the resonant frequency decreases. That is because the deeper the slot is, the longer the current path becomes.

The simulated return loss curves in various operating frequency bands are shown in Fig.4. From this figure, it can be obviously observed that the proposed antenna can achieve the frequency reconfigurable characteristic by changing the states of switches. When these switches are closed, the antenna operates at these resonant frequencies 1.6633GHz, 5.2010GHz, 7.6333GHz, 9.4020GHz, 12.0402 GHz and input reflection coefficient $\mathbf{S_{11}}$ for all the resonance frequencies are about **-**15dB.When these switches are opened, the antenna resonant frequencies are shifted to 1.6080GHz, 5.0352GHz, 7.5226 GHz, 8.9045GHz, 10.6734GHz and detailed reconfigurablity of resonance frequencies of each state of switches are as given in Table I. The states shown in this table refer to the two diodes states such that the state of Switch I is the state for two diodes of slot 1 and 2 of top triangle, the state of Switch II is the state for two diodes of slot 3 and 4 of right triangle, and the state for Switch III refers to the states for diodes of slot 5 and 6 of left triangle.

These resonant frequencies of proposed antenna are covered in L,C and X bands. The impedance bandwidths of the proposed reconfigurable antenna are about 40MHz in all operating frequency bands, which illustrates the stability of impedance bandwidth in the frequency reconfigurable antenna.

The radiation patterns of the simulated antenna in the eight states are also studied. The simulated radiation patterns in the XZ plane are shown in Fig.5. The similarity between the radiation patterns in the five resonance frequencies is comparable in both E-plane and H-plane. It is also mentionable that the radiation pattern remains same when a frequency is reconfigured for different states of the switches (the diodes turn off or on), which leads to the same pattern for the same resonance in different states. The maximum gain obtained at frequency 7.6633GHz is 2 dBi, at frequency 5.1457GHz is 3dBi and at frequency 9.2362GHz it is 3dBi and gain for all remaining frequencies is also about 2 dBi.

Table I: Proposed antenna simulated resonance frequencies for each state.

state	Switch I	Switch II	Switch III	Resonance frequencies(GHz)
State 1	ON	ON	ON	1.6633,5.2010,7.6333,9.4020,12.0402
State 2	OFF	OFF	OFF	1.6080,5.0352,7.5226,8.9045,10.6734
State 3	ON	ON	OFF	1.6633,5.1457,7.6333,9.2362,10.6181
State 4	ON	OFF	OFF	1.6080,5.0905,7.799,9.0151,10.7286
State 5	ON	OFF	ON	1.633,5.2010,7.799,9.2360,10.9753
State 6	OFF	ON	ON	1.6633,5.2010,7.7437,9.2362
State 7	OFF	OFF	ON	1.6633,5.0905,7.6884,9.2090,11.0603
State 8	OFF	ON	OFF	1.633,5.0905,7.633,10.4523

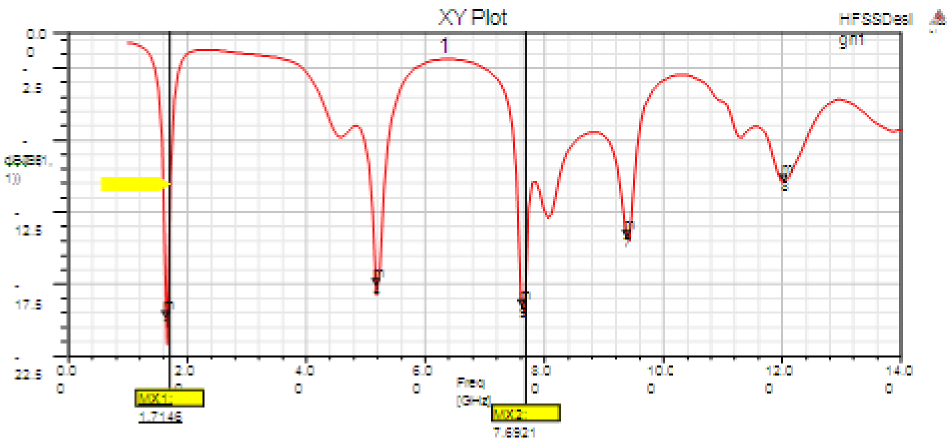


Fig. 4.a. Simulated S_{11} for the switching case State 1

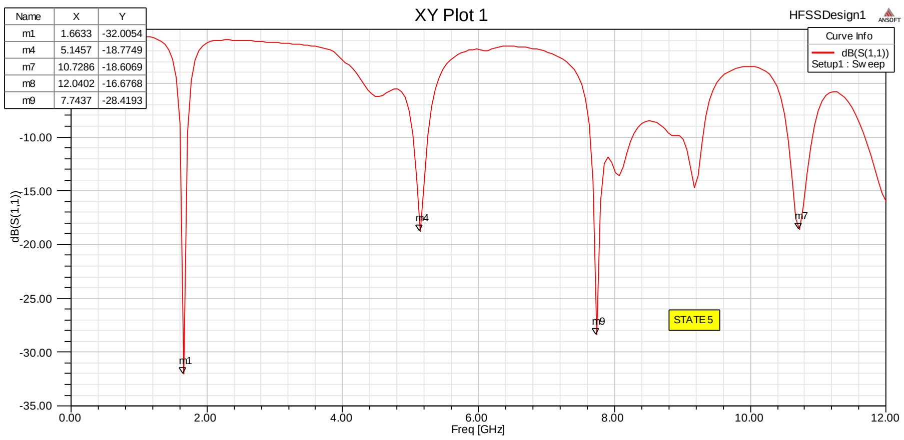


Fig. 4.b. Simulated S_{11} for the switching case State 2

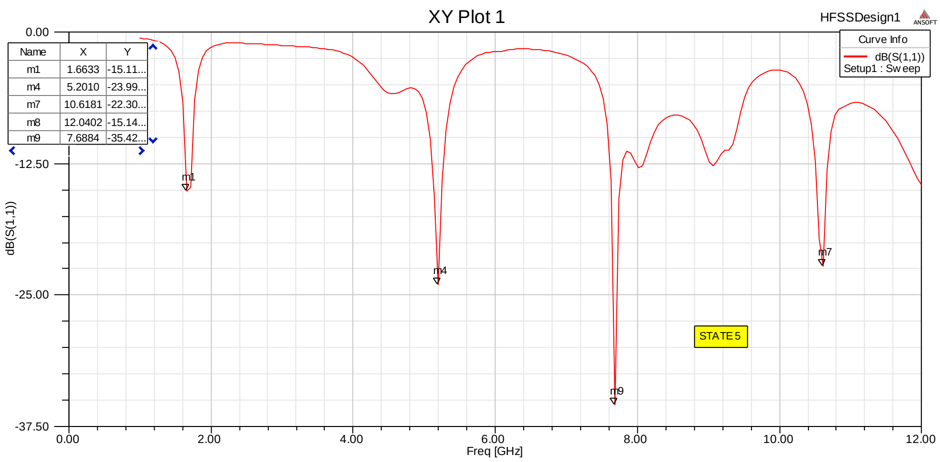


Fig. 4.c. Simulated S_{11} for the switching case State 5

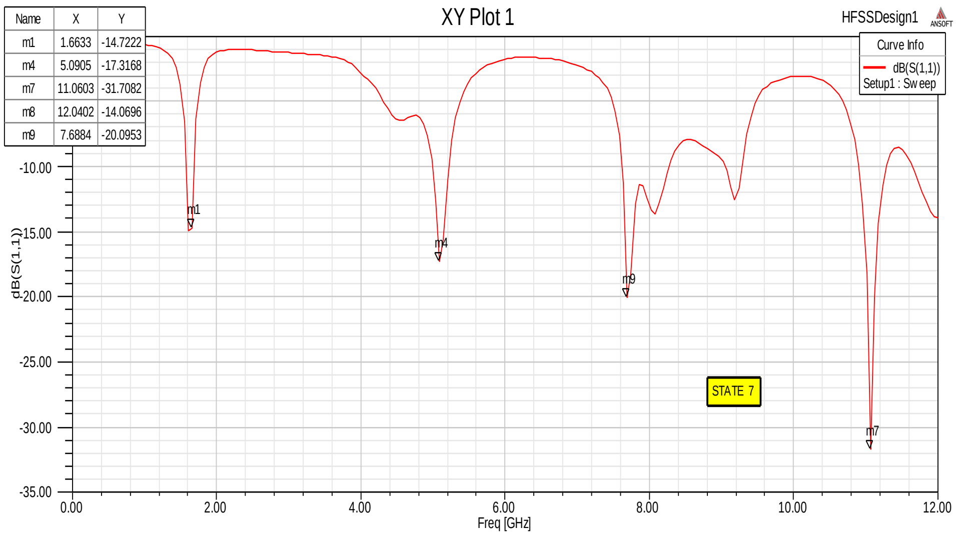


Fig.4.d. Simulated S_{11} for the switching case State 7

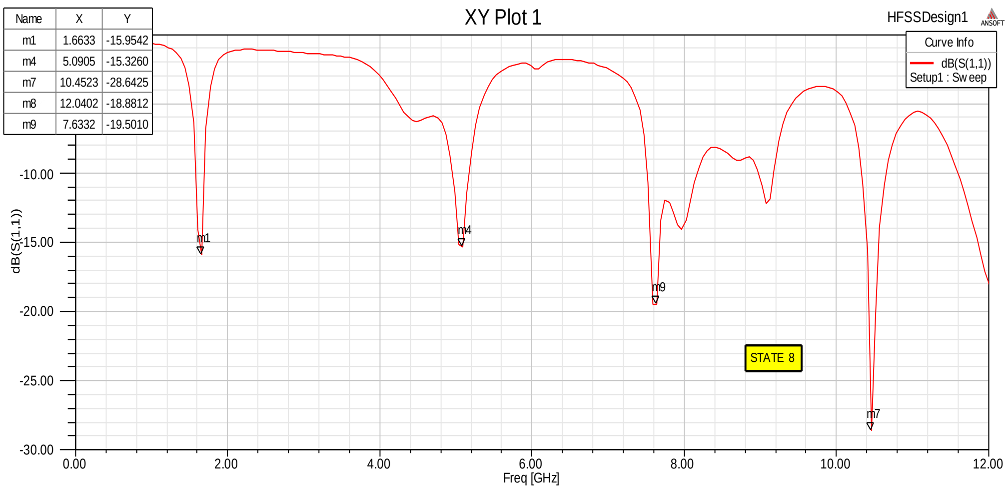
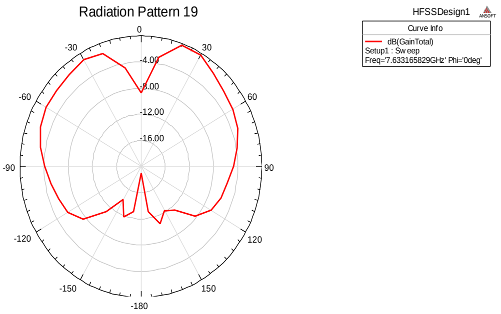
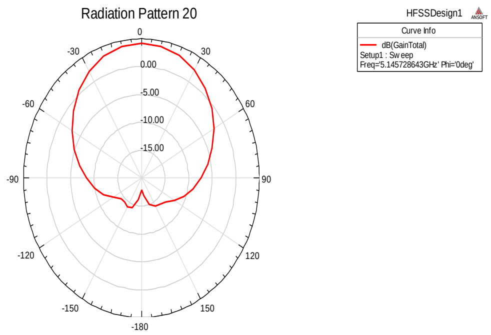


Fig. 4.e. Simulated S_{11} for the switching case State 8

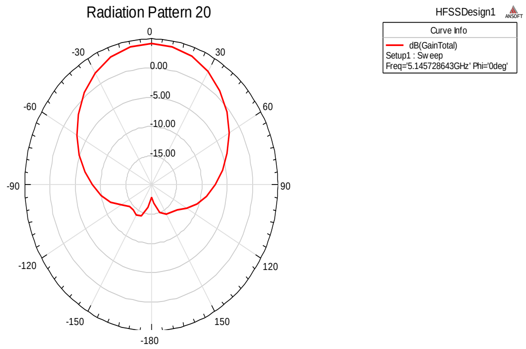
Fig. 4. Simulated S_{11} of the fractal antenna (communicating) for the various switching cases



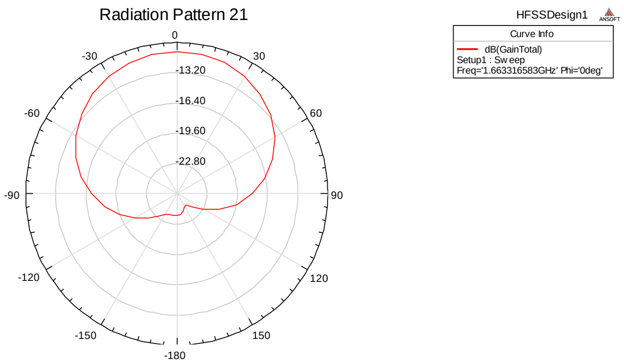
5.a. At 7.6633GHz.



5.b At 5.14572GHz.



5.c At 9.2362GHz.



5.d At 1.6633GHz.

Fig. 5. Radiation patterns of the communicating antenna at various resonance frequencies.

3.2. Experimental Results

In order to validate the simulation results, the proposed antenna has been fabricated for four switching states by placing metal strips for ON state and absence of strips for OFF state. Fabricated antenna shown in Fig. 3 is tested and return loss was measured using Agilent N5230A vector network analyzer is shown in Fig.6. The simulated values of the S_{11} of the final design shown in Fig. 4 are compared with the measured data shown in

Fig. 7. It was found that, the simulated and measured results are in good agreement. The discrepancy between the simulated and measured result might be attributed to the fabrication process.

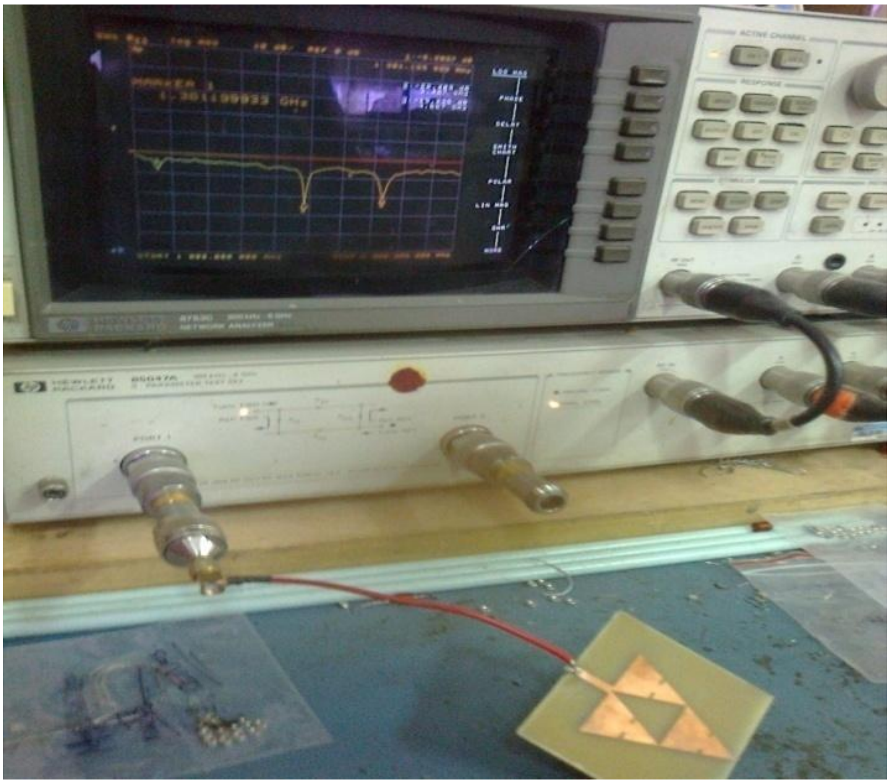


Fig. 6. Experimental set up for fabricated antenna

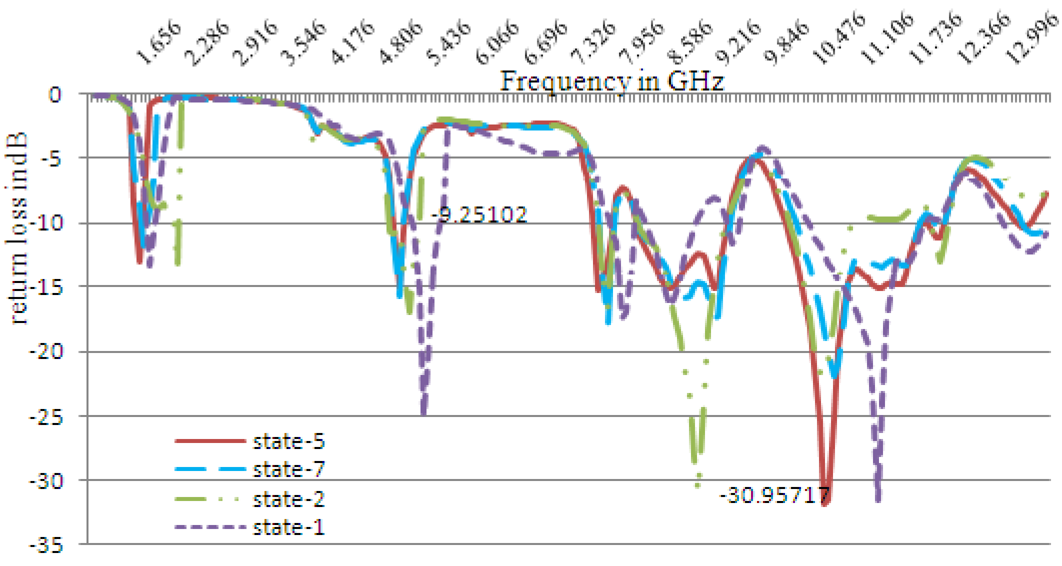


Fig. 7. Measured S_{11} for switching Cases 1, 2, 5 and 7.

IV. Conclusion

A triangular shaped fractal reconfigurable communicating antenna is presented in this paper. Simulation and test results suggest that fractal Reconfigurable antenna with multiple resonance frequencies in the various bands can be used as communicating antenna for the cognitive radio. Multiple resonant frequencies are achieved by triangular slot and reconfigurability is achieved by placing the switches in suitable location of slits.

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