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Reconfigurable Sierpinski Monopole Antenna for Cognitive Radio Applications

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Abstract- The changing scenario of the wireless connectivity has insisted the usage of the spectrum in an efficient manner which in turn demands for the new paradigms to be adopted in practice. The Cognitive Radio (CR) termed by Joseph E Mitola III in 1999, a prominent technology to overcome the above difficulty which continuously monitors the spectrum and allocates the un used portions of the spectrum to other users in a systematic approach. The most important task in this context is the design of the antenna to cater the needs of the CR networks and they must adapt the changes in the environment and must be reconfigurable.

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Reconfigurable Sierpinski Monopole Antenna for Cognitive Radio Applications

Mr.Manikya Krishna Chaitanya Durbhakula [α] & Dr.Venkata Koteswara Rao Nalam [σ]

Abstract- The changing scenario of the wireless connectivity has insisted the usage of the spectrum in an efficient manner which in turn demands for the new paradigms to be adopted in practice. The Cognitive Radio (CR) termed by Joseph E Mitola III in 1999, a prominent technology to overcome the above difficulty which continuously monitors the spectrum and allocates the un used portions of the spectrum to other users in a systematic approach. The most important task in this context is the design of the antenna to cater the needs of the CR networks and they must adapt the changes in the environment and must be reconfigurable. Besides this, the major attributes that are to be considered in the context of antenna design are the low profile, low cost, weight and size considerations, ease of integration in the system, most importantly the reconfigurability and multi band behavior. The fractal antenna technology can be best fit in these environments because of their self similarity; affinity in their structure supports the wide, multi band operation and also eases the integration of switching mechanism. This paper describes a Re-configurable monopole antenna structure which consists of two hairpin band pass filters which are switched alternatively by using two separate electro mechanical Taconic switching elements. In this design, the Sierpinski monopole antenna shows the multi band behaviour and the structure resonates at four different frequencies based on its fractal geometry. However, only two frequencies within the Ultra Wide Band (UWB) frequency, 3.1 GHz -10.6 GHz range are considered i.e 3.5 GHz and 7.5 GHz for demonstrating the reconfigurability mechanism. The complete structure was designed theoretically; analyzed using CST Microwave suite simulation tool, the same was fabricated, tested and the results were reported. This structure offers higher gains with reasonably good radiation patterns along with reconfigurability in the bands of interest and can perform both the spectrum monitoring and communication mechanisms within the UWB frequency range. As the antenna structure shows the reconfigurability, independent operation at the desired frequencies, it can be employed in the Cognitive Radio applications.

Keywords: ultra wide band, fractal geometries, sierpinski monopole, multi band behavior, hair pin band pass filters, re configurability, electromechanical switching, taconic switches, cst microwave studio, cognitive radio.

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I. Introduction

This section deals with the basic fractal antenna structures [1] ,their types, the basic configurations along with the related literature. The term Fractal was named by B.B. Mandelbrot, a French Mathematician in 1970 from the Latin word "Frangere" which means to break or to make irregular structures. The "Fractal structures" are formed by repetitive geometry of the basic structure by the number of iterations of their fundamental blocks and the fractals are considered to be the scaled versions of their basic shape. Most importantly, these structures show the self similarity, space filling properties which make the antennas so compact [2]. These antennas find many applications in the wireless communications, image compression algorithms, filtering circuits and are suitable in ultra wideband operation.

The basic fractal geometries that are in practice are Koch curve, Minkowski curve, Sierpinski carpet, Sierpinski gasket, Cohen-Minkowski etc. They are classified either into random fractal structures or deterministic structures [4]. However, they offer multi band operation and ease of integration in to the circuits, economical which makes them suitable for the design of new generation of antennas. Some of the basic geometries found more suitable in the construction of the fractal antenna structures are shown below in Fig 1.1,1.2,1.3 and 1.4.

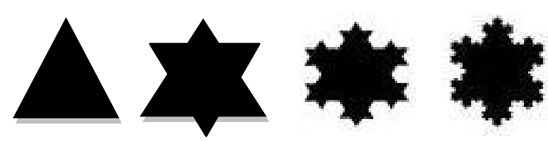

Fig.1.1: Koch Snowflake

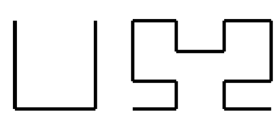

Fig.1.2: Hilbert Curve

Fig.1.3: Sierpinski Carpet

From the above Figures, it can be observed that the similarity in the construction of the fractal structures makes the antenna very compact in size at low cost. The Fig 1.1 shows the triangle shaped base structure makes the Koch structure and the same base may be used to construct the sierpinski gasket as shown in the Fig.1.4. The basic square structure is used to construct the Hilbert curve, Sierpinski carpet and is shown in Fig.1.2 and Fig.1.3 respectively.

However, the study of the fractal structures was done much earlier [3], but the verification with the antenna design was done by Kim in 1986, later they are further extended by Cohen using Koch curve. The sierpinski gasket named after polish mathematician Sierpinski and the antenna was first designed by Puente in 1998. The Sierpinski gasket is composed basically the triangular structure and the central part of was removed and the fractal shaped structure was constructed. The design of the Sierpinski monopole antenna with four iterations is explained in the later section.

II. Antenna Reconfigurability

The reconfigurability of the Antenna is the ability to change the basic operational characteristics of the antenna by inserting the additional mechanism such as switching [6]. This in turn changes the distribution of the surface currents of the antenna structure makes it to resonate at different operating frequencies with altered characteristics independently. The Re-configurability may be either in terms of frequency, pattern, and polarization or may be with the combinations of the above. However, the reconfigurability of either type may be achieved by using electrical switching, optical switching or change in the materials or by altering the physical structure. The electrical switching includes incorporates the basic switching elements like PIN diodes, Varactor diodes, RF-MEMS, Mechanical Switches etc [6] where as the optical switching employs the photo switching elements like Laser diodes, Photo diodes etc. The reconfigur ability of the antenna also can be achieved by changing the materials like ferrites; liquid crystals etc and finally the altering the physical structure of the antenna also can introduce the reconfigurability of the antenna. However, the electrical switching using PIN diodes are much in practice because of its faster switching compared to other types and they provide high isolation between the antenna elements. The other factors that are to be considered in the selection of the switching is the isolation, power consumption, operating voltages, usage of additional biasing, compensation circuitry if any needed, physical properties, electrical, magnetic properties of the materials etc.

III. Sierpinski Monopole Antenna

The sierpinski gasket is named after the polish mathematician Waclaw Sierpiñski in 1915 and the first frequency independent and multiband sierpinski was developed by Puente in 1996. The design process of a sierpinski gasket is obtained by removing the central part of the main triangle by an inverted triangle with vertices located at the midpoint of the original triangle and the same will be repeated for the next stages. The antenna shown in Fig 3.1 shows the basic design of the sierpinski monopole antenna [5] printed over Arlon Cu Clad substrate ($\varepsilon_r = 2.2$, h= 1.6 mm) and mounted over a circular ground plane of dia 15.6 cm and is fed with the co axial probe with SMA connector. The simulated Sierpinski Monopole and the fabrication of the same were depicted in Fig 3.2 and Fig 3.3 respectively.

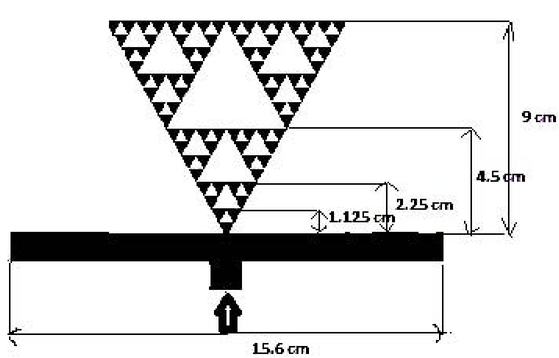

Fig.3.1: Sierpinski Gasket

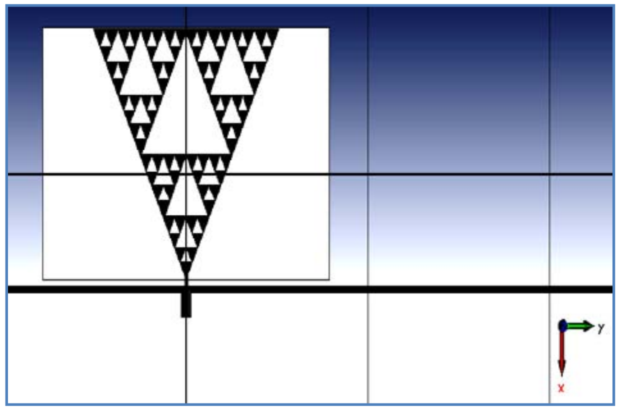

Fig.3.2: Simulation of Sierpinski Using CST

Fig.3.3: Fabricated Sierpinski Monopole Gasket

The Sierpinski antenna is designed for five iterations and appears at five different scales with a scaling factor of two such that the antenna heights are given by 9 cm, 4.5 cm, 2.25 cm, 1.125 cm and 0.5625 cm. It is expected that the structure should resonate at five different resonant frequencies with the multiple of factor two as the successive difference between the heights are considered exactly by half and is calculated using [2]

$$f_r = K \frac{c}{h} \cos\frac{\alpha}{2}\, \delta^n \qquad (1)$$

Where,

K = Constant and is 0.152 for Sierpinski Gasket for a given substrate

α= flare angle and is 60^0 for equilateral triangle

δ = scaling factor and is 2 and n= iteration number

As per the calculations using equation (1), the antenna should resonate at 0.86 GHz, 1.74 GHz, 3.46 GHz, 6.94 GHz and 13.86 GHz and the first one represents the sierpinski mode. Hence the antenna must be resonate at four frequencies other than the sierpinski basic mode in the practical measurement due to truncation effect [2]. The sierpinski gasket is simulated using CST Microwave Studio Suite software for the above dimensions as shown in Fig.3.1 and the same is fabricated manually using etching process as shown in Fig 3.3. The simulated and measured values are tabulated in the below Table 1. It gives the outlook of the resonant frequencies for both simulated and measured values

Table 1: Resonant Frequencies of the Sierpinski monopole

S.No	f_r (GHz) Resonant Frequency	
	Simulated	Measured
1	0.48	truncated
2	1.73	1.74
3	3.32	3.5
4	6.88	7.5
5	11.45	11.25

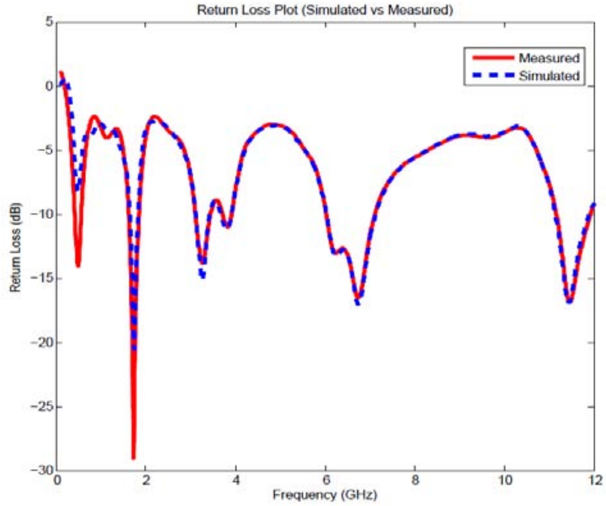

Fig.3.4: Simulated and Measured Return Loss Plot

As indicated, the designed antenna structure is radiating at 1.75 GHz, 3.5 GHz, 7.5 GHz, 11 GHz and the same was depicted in the Fig 3.4 for the Simulated and Measured values. This plot clearly shows that the Return Loss at 0.5 GHz which is the Sierpinski mode or the fundamental mode was not available in the practical measurements. The remaining frequencies are matched more or less exactly for the both Simulated and practically measured values. The radiation patterns at different resonant frequencies are shown from Fig 3.5 to Fig 3.8. Similarly the 3D radiation patterns are inserted from Fig 3.9 to 3.12.

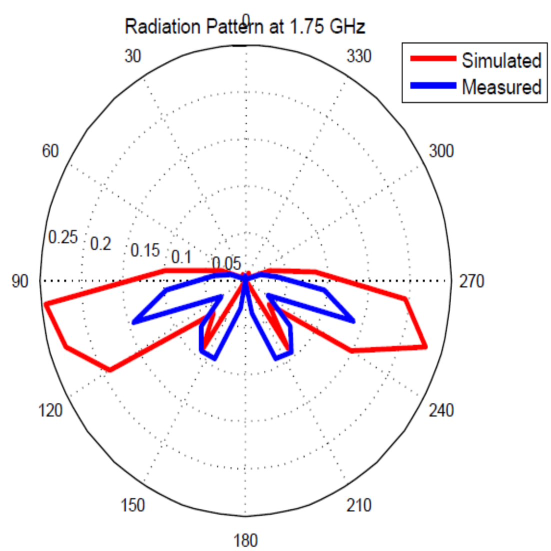

Fig.3.5: Radiation Pattern at 1.75 GHz

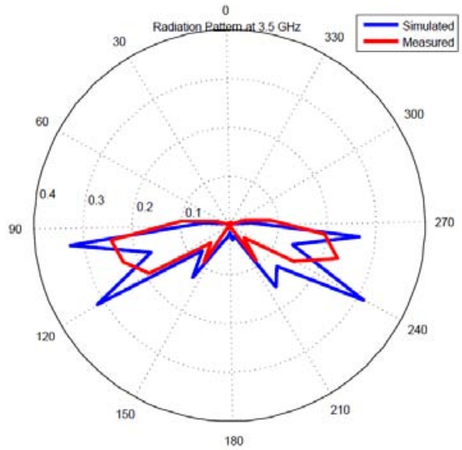

Fig.3.6: Radiation Pattern at 3.5 GHz

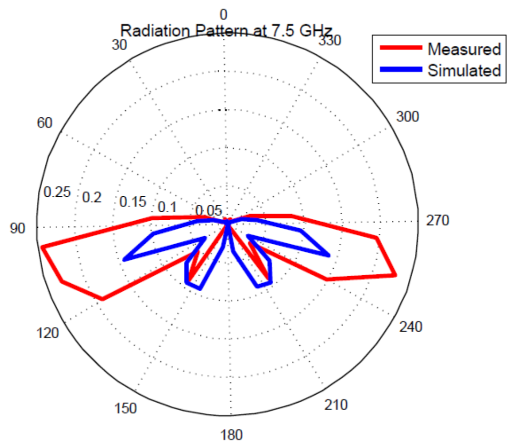

Fig.3.7: Radiation Pattern at 7.5 GHz

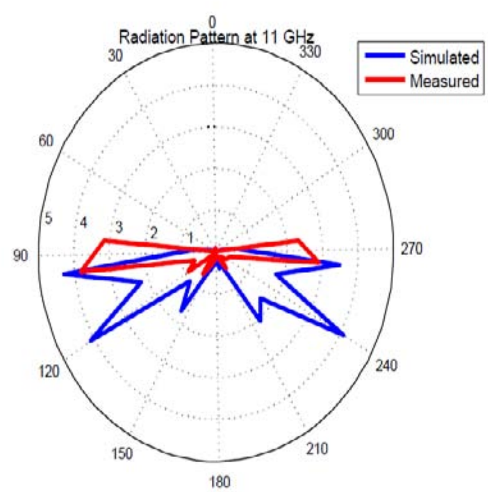

Fig.3.8: Radiation Pattern at 11 GHz

The above Polar plots are drawn with polarization dependent circular directional co-ordinate systems for different resonant frequencies. The plot for 1.75 GHz resonant frequency the main lobe magnitude

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is 3.7 dB with an angular 3 dB width of 22^0 with a side lobe level of -1.8 dB is observed. For 3.5GHz, the main lobe magnitude is about 7.58 dB with an angular 3dB width of 11.6^0 with a side lobe level of -4.9 dB is obtained. Similarly for 7.5 GHZ frequency the main lobe magnitude of 8.51 dB and with an angular width of 15.7^0 with a side lobe level of -3.3dB is obtained and for 11 GHz frequency, the main lobe magnitude at about 7.3 dB and with an angular width of 19.1^0 with a side lobe level of -6.2 dB is achieved

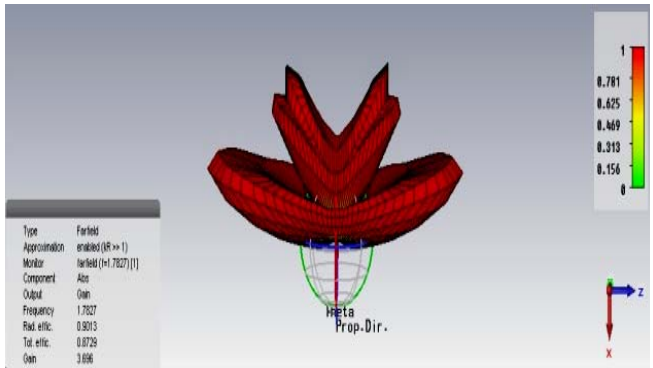

Fig.3.9: 3D Radiation Pattern at 1.75 GHz

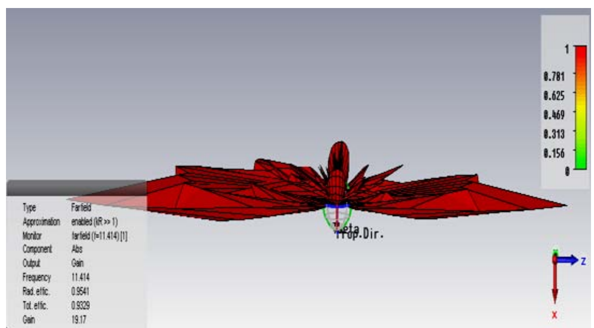

Fig.3.10: 3D Radiation Pattern at 3.5 GHz

Fig.3.11: 3D Radiation Pattern at 7.5 GHz

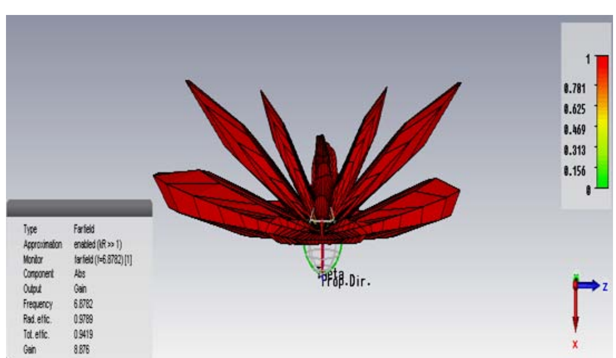

Fig.3.12: 3D Radiation Pattern at 11 GHz

From these Figures, it is clearly seen that the pattern becomes wider as the frequency with increased frequency and a gain of 3.696 dB is obtained for 1.75 GHz frequency. For 3.5 GHz the gain of 7.3dB is achieved. Similarly for 7.5 GHz, a gain of 8.876 dB is observed and for 11 GHz, the observed gain value is about19 dB.

IV. Reconfigurability Mechanism

It was observed that the Sierpinski monopole structure is having multi band operation and the above structure resonates at four resonant frequencies other than the Sierpinski mode. The reconfigurability is achieve by using suitable switching [6] mechanism along with filters of desired frequencies and it was for two frequencies in this case. The Hair Pin Band Pass Filters were designed [8] for the frequencies 3.5 GHz and 7.5 GHz on Arlon Cu clad substrate (εr = 2.2, h= 1.6 mm) and are shown below. Fig 4.1 shows the basic CST simulated model of 3.5 GHz Hairpin Filter and Fig 4.2 is the fabricated Filter. The dimensions of the Filters are calculated theoretically based on basic filter design and for 3.5 GHz Filter the width of the strip is taken as 3.16 mm and the distance between two successive hairpins is 1.86 mm and the length of the strips at the ends are taken as 5 mm. The length of each U arm is given by each arm is 41.24 mm (l_1=16.74 mm, w=7.76mm, l_2=16.74 mm) and the successive difference in between two arms is 1.44 mm. Similarly from the Fig 4.3 the dimension of the 7.5 GHz Filter is given below, the width of the strip is 2.6 mm, the separation between each U arm of the hairpin is 1.24 mm and the length of the strip at both ends is 5 mm. The length of each U arm is given by 22.24 mm (l_1=7.24 mm, w=7.76mm, l_2=7.24 mm) and the successive difference between each arm is given by 1.44 mm. The fabricated 7.5 GHz Hairpin filter is shown in Fig 4.4.

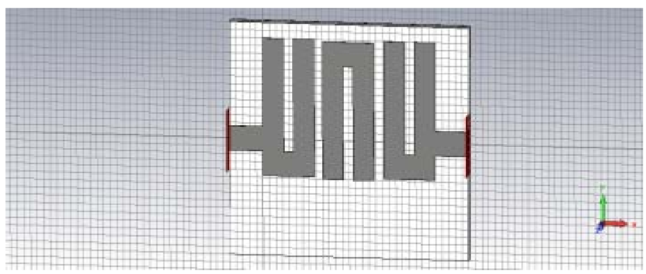

Fig.4.1: Hair Pin Filter 3.5 GHz Simulation

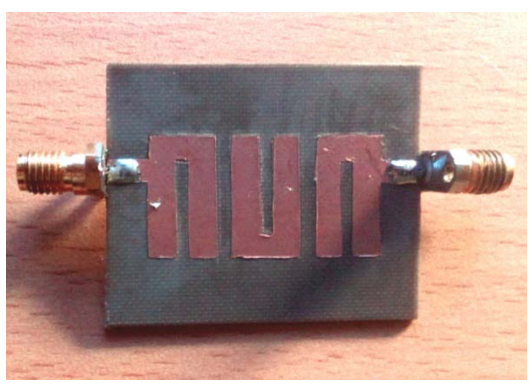

Fig 4.2: Fabricated 3.5 GHz Filter

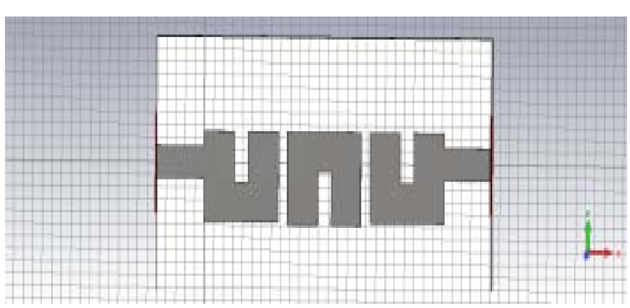

Fig.4.3: Hair Pin Filter 7.5 GHz Simulation

Fig 4.4: Fabricated 7.5 GHz Filter

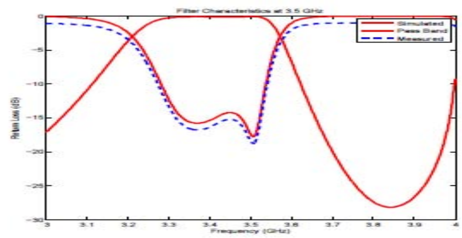

Fig 4.5: 3.5 GHz Filter Response Plot

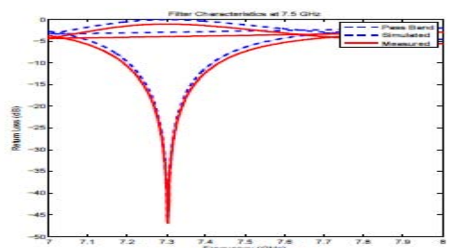

Fig 4.6: 7.5 GHz Filter Response Plot

The response of the 3.5 GHz Filter as shown in Fig 4.5 gives the pass band of the filter ranges in the given frequency range and the Fig 4.6 shows the pass band lies in the designed 7.5 GHz range.

The switching mechanism is achieved by using the electromechanical coaxial switches which have the extensive usage in the commercial and defense RF systems where low current consumption, small size, low insertion loss, high reliability are the major concern. The switch used in the design is of Teseol make from Stockholm [9], Sweden and model number is TS121 which is a "Single Pole Double Through" (SPDT) failsafe SMA stainless steel connector version. The operation of this type of switch by the requirement of holding current at only one position and the circuit is break before make and the actuating voltage is 12 V $\pm$2.4 V and actuating current is 75 mA (+20^{0}C) and the switching time is 15 ms. The Fig 4.7 shows the basic Tesoel SPDT Switches.

Fig 4.7: Teseol SPDT switches

V. Modeling of the Antenna Re – configurability

From the earlier sections, it was proposed that the Sierpinski Monopole Gasket is to be incorporated with the Switches to select the appropriate filter to attain the reconfigurability. The design was simulated, fabricated, tested and measured. The Antenna is attached to the 3.5 GHz and 7.5 GHz Filter through two different switches and were operated and controlled through the switching mechanism. The CST simulated models of the same were shown in Fig 5.1, Fig 5.2 and the fabricated model was shown in the Fig 5.3.

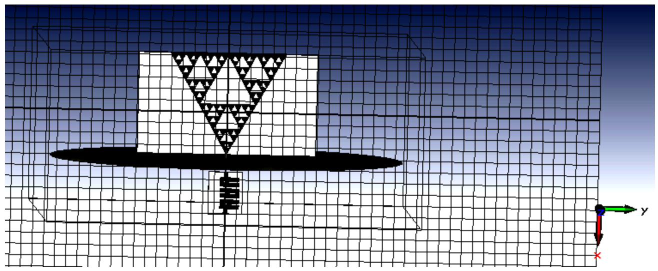

Fig.5.1: Antenna with 3.5 GHz Simulation

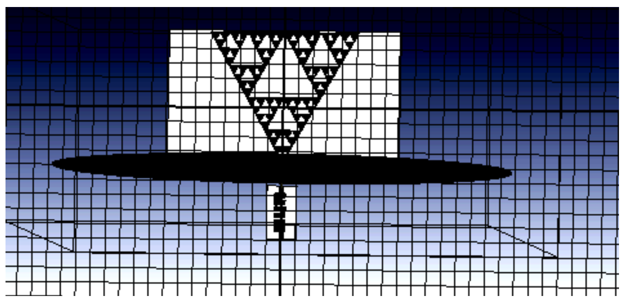

Fig 5.2: Antenna with 7.5 GHz Filter Simulation

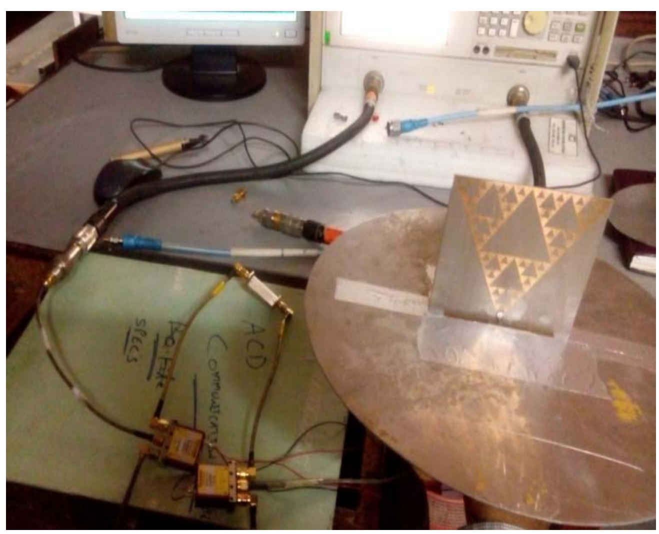

Fig.5.3: The Sierpinski Monopole Antenna along with Filters and Switches

The basic operation involved in this design was the first switch is connected to the 3.5 GHz Filter and was actuated by giving the voltage of +12 V and the other was connected to 0V. Therefore, it was observed that the antenna was resonating for 3.5 GHz only. Similarly, when the 7.5 GHz Filter was actuated through switch, the other switch was not actuated and observed that the antenna is resonating at 7.5 GHz. The responses of the individual filters according to their switching condition are shown in Fig 5.4 and Fig 5.5 respectively for 3.5 GHz and 7.5 GHz. The Radiation patterns of the individual filters are shown in the Fig 5.6 for 3.5 GHZ Filter and for 7.5 GHz Filter is shown in Fig 5.7.

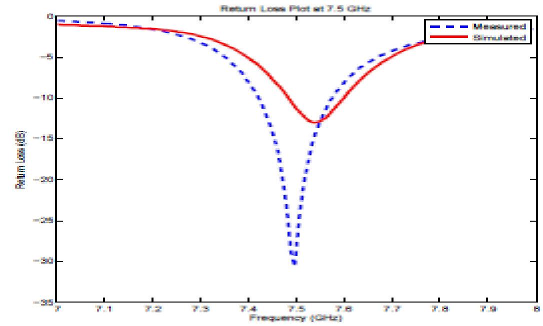

Fig.5.4: Antenna Response with 3.5 GHz Filter

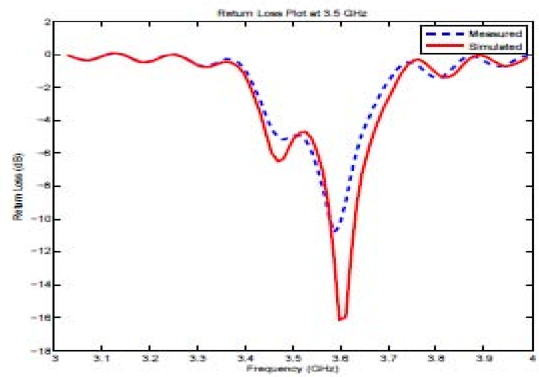

Fig 5.5: Antenna Response with 7.5 GHz Filter

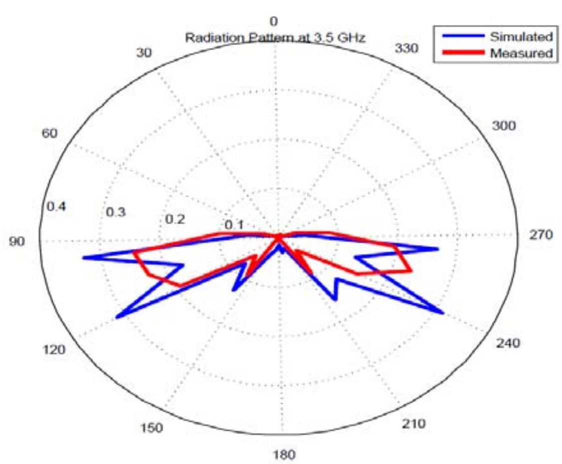

Fig.5.6: Radiation Pattern at 3.5 GHz

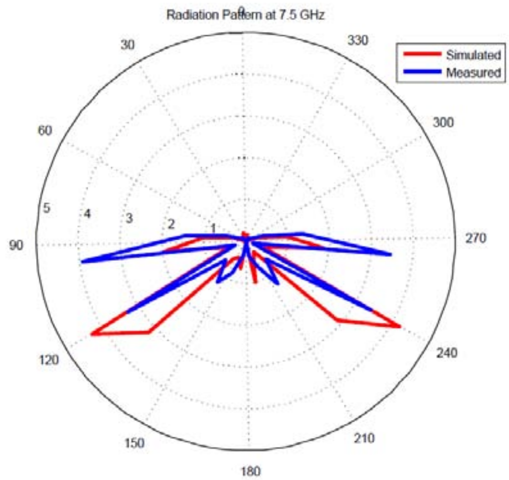

Fig 5.7: Radiation Pattern at 7.5 GHz

VI. Discussion of the Results

The basic idea of achieving the reconfigurability mechanism of the Sierpinski monopole antenna along with the 3.5 GHz and 7.5 GHZ filters with the incorporation of the Teseol electromechanical switches was shown along with the results in the previous section. Since the Sierpinski monopole gasket has been constructed through five iterations in this case, hence five scaled versions of the fractal structures has been observed on the antenna and the basic Sierpinski lower frequency was not observed practically because of the truncation effect. The Antenna was resonating at four different frequencies, since the scaling factor of the antenna is 2 (δ=2), it is observed that the resonating frequencies are also spaced by a factor of two. Due to the truncation effect of current distribution in the fractal structure, the lowest frequency is shifted closer to the next resonant frequency and therefore the basic sierpinski mode i.e the first resonant frequency was not observed practically.

Since the fractals appear at different scales, it is observed that the Sierpinski gasket would behave similarly to a triangular antenna but at different bands depends on the fractal geometry. All the plots clearly show a log periodic behavior, and the log-period (δ) is a factor of two. In particular, the antenna is matched at four frequencies, i.e. at 11, 7.5, 3.5, 1.75 GHz respectively and the fundamental mode is not visible in the measured value due to the truncation effect and the return loss plot is as shown in Fig.5.4 and Fig 5.5 for the Antenna structure with 3.5 GHz Filter and 7.5 GHz Filter respectively along with simulated and measured results. These plots clearly indicate that the antenna is resonating accordingly with the selected filtering section controlled by the appropriate switching.

The simulated and measured radiation patterns of the Sierpinski monopole along with 3.5 GHz Filter and 7.5 GHz Filter is presented in the Fig 5.6 and Fig 5.7 respectively, The patterns corresponding to the flare angle $\alpha = 60^0$, $\theta = 90^0$ it is observed that the beam becomes more wider and almost the same patterns were obtained without using the Filter sections. The H-plane pattern and almost Omni directional pattern for $\varphi = 0^0$, $\varphi = 180^0$ is traced. It is observed that the wider band width is obtained with the increase in the frequency from the radiation patterns also the gains of 3.6 - 19 dB is observed with almost 90% radiation efficiency with these structures.

VII. Conclusions

The Triangular fractal sierpinski monopole antenna along with two different Filters with suitable switching arrangement has been designed, analyzed using simulation software, fabricated, tested and the results are reported. It is observed that the antenna showed multi frequency operation resonating at the following frequencies 1.74 GHz, 3.5 GHz, 7.5 GHz & 11.25 GHz. However the antenna is made operational (along with suitable filters and switching arrangement) covering the UWB frequency range 3.1 GHz to 10.6 GHz for commercial communication applications. To achieve the frequency reconfigurability mechanism, electro mechanical switching concept using Tesoel Taconic Switches is employed and the antenna exhibits resonance at 3.5 GHz and 7.5 GHz independently. The developed antenna structure exhibited excellent gain ranging from 3.6 dB to 19 dB along with good amount of radiation efficiency, impedance bandwidth parameters making it most suitable for Cognitive Radio applications. In future, the electro mechanical switches can be replaced by electrical switching methods using PIN diodes to achieve the reconfigurability. Similarly a single reconfigurable resonator instead of different filter sections can also be employed to reduce the design in to a simple structure. Further, this concept of reconfigurability using suitable filter with multi band antenna can be extended further to any type of antenna under different communication applications.

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