Mechanically Reconfigurable Hexagonal Fractal Patch Antenna for Ambient Computing

Anita Garhwal, Mohd Riduan Ahmad, Badrul Hisham Ahmad, Sanyog Rawat, Pushpendra Singh, Kanad Ray, Anirban Bandyopadhyay

Abstract: ***Ambient computing is a rapidly growing field which requires increasing number of wireless devices. In this paper first a hexagonal shape patch antenna is designed. Fractal concept is used to achieve miniaturization. So triangle inscribed hexagon fractal patch antenna is designed. The designed antenna is simulated using Computer Simulation Technology (CST) Microwave Studio software. The proposed antenna resonates in the range of 2 GHz to 10 GHz. Mechanical tuning in frequency is achieved by varying the ground length. Good reflection coefficient less than -10dB, gain, E and H fields are observed in CST. Then fuzzy logic model is developed in MATLAB software for movable ground. Mechanical sliding ground results and fuzzy logic model results are compared. This antenna is adaptive and anticipatory, can be utilized where stable system is required because it provides more robustness. This paper explores the use of fractal reconfigurable antennas to aid the development of ambient computing.***

Index Terms: Ambient intelligence, antenna, fractal, fuzzy logic, micro strip patch, mechanical tuning, reconfigurable.

I. INTRODUCTION

Ambient computing, a new paradigm can be defined as a widespread discipline which works in the area of environment, society, security, computing, interacting, intelligence and many more. It's a future vision technique [1]. Ambient Intelligence (AmI) is next to ubiquitous computing where it senses people's presence in electronic environment. The main requirement of AmI is distribution, ubiquitous, transparent and intelligent. Now in the modern–era of ambient intelligent world, network-intelligent devices will provide all information and communication to user at any location [2].

There are five attributes of ambient intelligence. Embedded: integrated devices; context aware: situation awareness; personalized; adaptive: changes as per user and anticipatory [2, 3]. These features are similar to human behaviour as cognitive, context awareness, personal, adaptive and anticipatory.

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AmI application in smart home is described in [4]. Smart home is having basically three domains: comfort, health and security [5]. It is having application is all areas like homes, hospital (health), education, transport etc. [6]. Using AmI, climate big data is captured and analysed for dengue transmission [7]. Intelligent transportation system using AmI is developed [8], intelligent wireless Qos technology in WLAN [9], ambient concept in educational institute [10] and smart content selection for public display using AmI [11]. AmI is providing better everyday life. Ambient computing is leading to huge expansion in demand of wireless communication services. There is necessity of re configurable antennas so total number of antennas are reduced and flexibility of wireless devices is increased. Earlier antennas were designed only for one specific parameter like gain, bandwidth, radiation pattern, directivity etc. but nowadays smart antennas are designed that can handle more than one parameter at a time. For Example, cognitive radios which sense the environment and allocate the available spectrum. Reconfigurable antenna is a better choice because in this we can control antenna parameters electrically, mechanically and optically to achieve better signal to noise radio, low interference, radio spectrum utilization and improved capacity. Here we can combine many smaller front –end units to get smart antenna array, so overall size of antenna is less and implementation cost is also reduced. Re configurability can be controlled in three ways i.e. electrical, mechanical and optical.

Conventional switching method uses pin diode [12], varactors or RF-MEMS switches [13], among these pin diode is more popular in reconfigurable antenna design. These methods have low reliability, low tuning and limited power handling because solid state switches have low linearity issues. Here controlling is electrical in nature by redirecting the surface current.

Due to high power, system can heat up and burst. Alternative of this method is mechanical reconfigurable antenna, because here less signal interference and isolation issues as mechanical actuators do not require to be placed in antenna signal path. Also, mechanically tuning is slow but it is stable, high power handling capabilities and linearity. Conventional actuators were heavy, bulky and high power consuming but now with the advancement in VLSI integration methods and smart materials (electro active polymers) these are easy and cheap [14].

Applications of reconfigurable antennas are in cellular radio system, radar system, wireless communication (Wi-Fi, WiMAX etc.), satellite communication,

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airplane and smart weapon protection, cognitive radio and radio spectrum management [14]. There are three types of reconfigurable antennas:-

1. Frequency reconfigurable
2. Polarization reconfigurable
3. Radiation pattern reconfigurable

Frequency reconfigurable: - Those antennas where operating frequency is electrically controlled without altering the radiation characteristics of the design are known as frequency reconfigurable. This can be done by switched tuning or continuous tuning, where antenna resonant frequency is changed discrete in nature and continuous in nature respectively [15].

Polarization reconfigurable:- those antennas where polarization changes from horizontal to vertical, at an angle, left and right-hand polarization [13]. For example, antenna can change from right hand to horizontal. Radiation pattern reconfigurable: -here radiation pattern is tuned in terms of shape (directivity), direction and value (gain).

Advantages of reconfigurable antenna over normal antenna are reduction in size, weight, cost and complexity. It also offers secure, multiband and anti-jamming capabilities. Electrically control antennas are implemented in literature. Advantages of mechanical control over electrical are better reliability even though with slower tuning, good control over antenna and robust techniques [16]. Here some mechanical movements are involved. Optical reconfiguration is done with the help of laser and optical fibre but this technique is costly. Many mechanically reconfigurable antenna papers are presented for cognitive radio. Software controlled ground plane antenna is presented for cognitive radio where there are two fixed grounds and one moving is used. Frequency tuning is done by elevating and tilting of ground plane 5]. Mechanical tuning using electromagnetic coupling is done in [17]. Meandered line antenna is developed and fabricated by making ground plane floating [18-19]. In this the ground below the meander patch is floating and same is achieved with the help of copper wires. Resonating frequency changes as the wires are removed one by one. This antenna structure gives multi-frequency response with better radiation pattern. A sensing and reconfigurable antenna is given in [20]. To achieve frequency re configurability, antenna patch consisting five different shapes is rotated by stepper motor. Each shape resonates in different band.

Mechanical reconfiguration is also obtained by using the galinstan liquid metal in [21]. Here the same meander patch described in [20] is used. Frequency re-configurability is achieved by injecting galinstan liquid from different lengths of patch using syringe. So as the metal pressure changes frequency changes. Antenna for polarization diversity is given in [22]. One bottom substrate and second upper substrate is used. The bottom substrate have fixed L-probe feed and upper one have truncated patch that rotates in azimuth direction. A thin bolt is used for tiding two layers together. In [23] for manual reconfiguration patch of antenna is rotating and this patch consists of four different shapes. To achieve different resonating frequency patch is rotated at clockwise 450^0, anticlockwise 450^0 and 180^0 [14], [16-17], [20] having actuator based mechanical reconfiguration. In [19], [22-25] manual re configurability is achieved.

Fractal concept is acquired from Latin word “fractus” that refers to broken. Fractal is generated using recursive methods where same structure is regenerated from the base structure but smaller in size [26]. Fractal geometries have two properties, one is space filling which is utilized for antenna miniaturization where large electrical antenna length can be fit in smaller areas and second is self-similarity which is used to get multi band operation [27, 28]. Degree of miniaturization increases by changing the fractal dimension of antenna. Many fractal patch antennas with hexagonal shape are presented in literature [29-35].

This paper is further divided into 4 sections: - in section -2 methodology used, in section -3 fractal hexagonal antenna design with simulated results is presented, while section-4 has results and discussion of mechanical reconfigurable antenna, section-5 has fuzzy logic model of movable ground.

II. METHODOLOGY

1. Hexagonal-triangle fractal patch antenna is designed and simulated in CST software.

2. Antenna ground is divided into two parts: fixed and movable.

3. Movable (sliding) ground design is simulated in CST for different length positions: 1/8, 1/4, 1/2, 3/4, 4/4.

4. Fuzzy logic model is developed using MATLAB software for movable ground for applications in ambient environment/ intelligence.

5. Mechanical sliding ground results and fuzzy logic model results are compared and validated.

III. ANTENNA DESIGN

The 0^{th} iteration is a monopole hexagon antenna having side length of 8.5mm as given in fig 1. Micro strip feed of width 2.9mm is optimized to get 50 ohm impedance matching. The fractal patch is simulated on top of 28 mm by 28 mm Fr-4 glass epoxy substrate of thickness 1.59mm. The ground is 28mm * 4.5mm is considered.

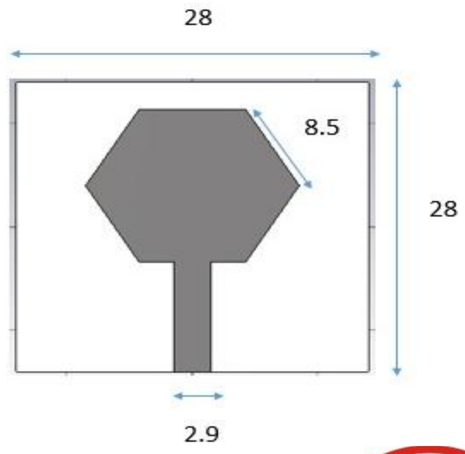


Fig 1: Antenna Geometry Iteration-0

Reflection coefficient is shown in fig 2. Surface current distribution of hexagon is shown in fig 3. The antenna resonates at frequency 3.57GHz, 6.0 GHz and 7.77 GHz with S11 of -17.13,-18.71, and -18.76.

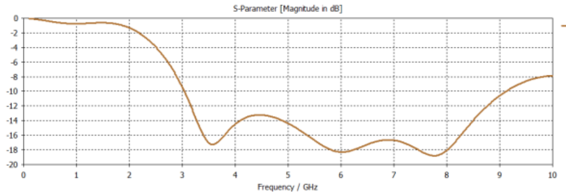
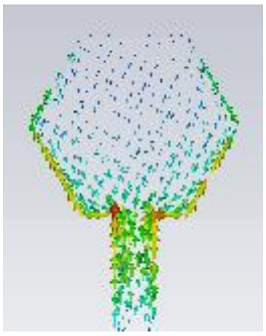
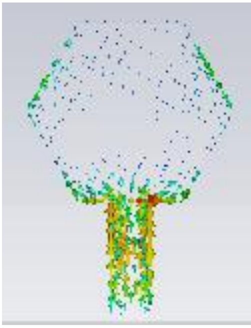


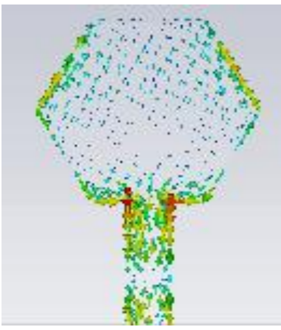
Fig 2: Reflection Coefficient of Hexagonal Patch



(a) Fr=3.57 GHz



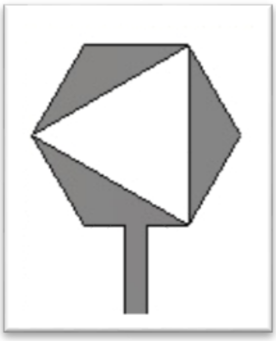
(b) Fr=6.0 GHz



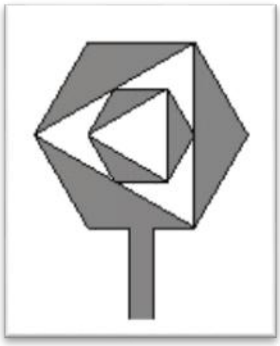
(c) Fr=7.77 GHz

Fig 3: Surface Current in Hexagon

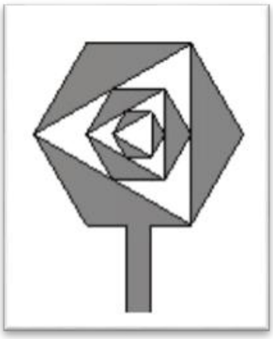
In fig 3 the current flows only at the edges of hexagon and feed line. There is no current in middle area, so we can introduce fractal geometry inside the patch. 1st iteration is achieved by removing a triangle of side length 14.5mm from alternative edges of hexagon. By doing this electrical length for current is increased so antenna size is miniaturized. To achieve 2nd iteration, first a hexagon is inscribed and later a triangle is removed of side length 8.6mm. In the similar fashion iteration-3 is achieved by inscribing a hexagon first and then removing a triangle of length 5.1mm. In this geometry space filling fractal property is applied to get miniature antenna. Different iterations are shown below in fig 4. In literature square inscribed square also known as crown square [36], Triangular wheel shape fractal [37], circle inscribed circle fractal [38], square slot in circular patch [39], square octal fractal [40] are presented. Octagon and decagon shaped fractal patch antenna presented [42]. Nature inspired and biological antennas are also presented [43-50].



(a) 1st iteration



(b) 2nd iteration



(c) 3rd iteration

Fig 4: Designing Steps of Iteration-3

Comparative reflection coefficient for different iterations is shown in fig 5. When we are applying fractal geometry and increasing iterations then resonating frequency is shifting from 3.5GHz to 3.28GHz is achieved so antenna size is reduced. Better results are achieved in iteration-3.

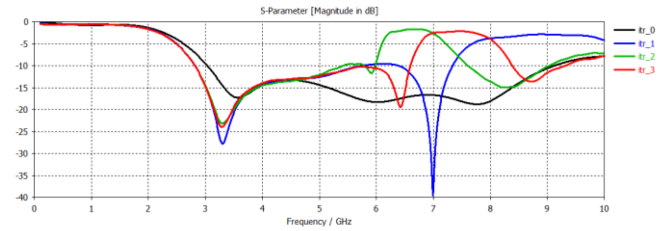


Fig 5: Reflection Coefficient for Different Iterations

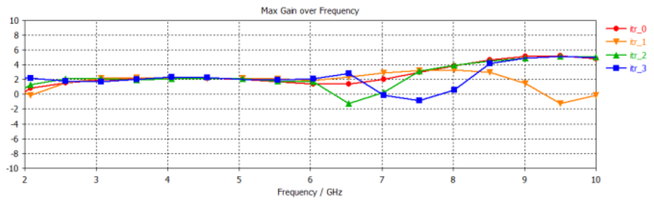


Fig 6: Gain for Different Iterations

A comparative study of return loss and gain is given in Table 1. In all iterations gain is positive at resonating frequencies. In Iteration-3 maximum gain of 4.60 dB is achieved and its increased compared to iteration-0.

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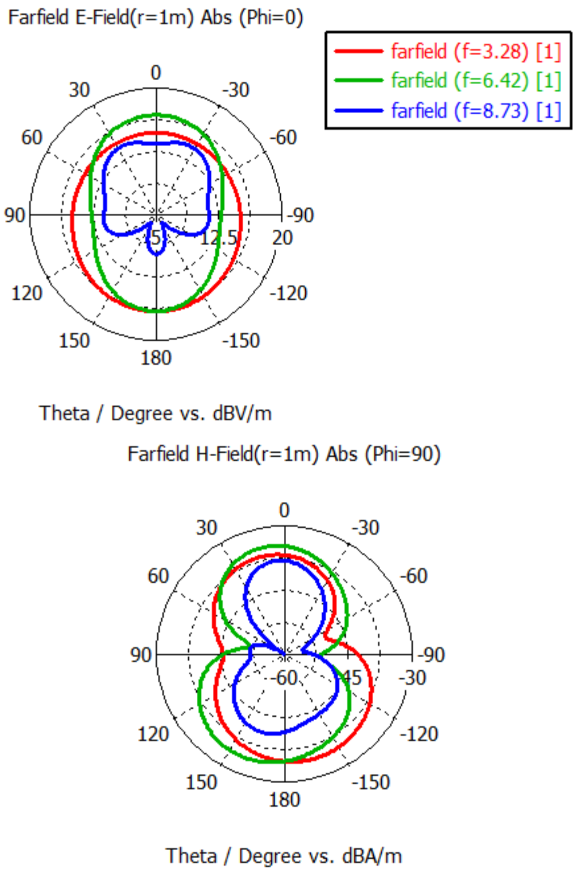
Table I: Comparative Study of Different Iterations

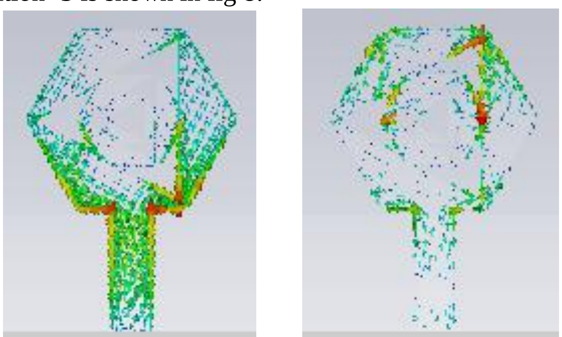
Iteration	Fr	Fl	Fh	BW %	Gain (dB)
0^{th}	3.57	3.04	9.12	35.06%	2.14
	6.0				1.38
	7.77				3.42
1^{st}	3.30	2.82	5.74	88.48%	2.06
	6.99	6.40	7.33	13.30%	2.79
2^{nd}	3.3	2.82	5.41	78.49%	2.02
	8.3	7.62	9.04	17.11%	4.26
3^{rd}	3.28	2.81	6.60	39.07%	2.02
	6.42				2.59
	8.73	8.39	9.31	10.53%	4.60



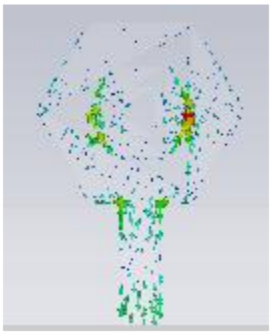
(a) E field (b) H field

Fig 7: Radiation Pattern of E and H plane

E and H plane radiation pattern for iteration-3 is shown in fig 7. E field pattern is achieved when phi=0^0 while for H plane phi=90^0. At 3.28 GHz and 6.42GHz E field radiation pattern is omni directional and H field pattern is eight shape for all resonating frequencies. Surface current distribution for iteration -3 is shown in fig 8.



(a) Fr=3.28GHz (b) Fr= 6.42 GHz



(c) Fr=8.73 GHz

Fig 8: Surface Current Distribution of Iteration -3

When resonating frequency is lower, 3.28 GHz, then maximum current flows through feed line. At 6.42GHz some current flows in outer heaxgon and maxium flows into inner ones. Current flows only in inner hexagon at 8.73 GHz. Here effective current path length is increased as compred to 3.28 GHz.

Table II: Comparison of Hexagonal Fractal Patch Antenna

Reference no.	Dimensions	Frequency and Gain
[41]	Patch =45 * 44 Gain= 2.88dB	1.9, 2.6 GHz
[27]	Radius of circle fits=18.24	3.94,6.46,13.04,14.16 Gain= - 6.85, 4.11, 3.73, 3.11 dBi respectively.
[34]	45mm*44.92 mm.	Frequency band is 3.1 to 10 GHZ. Fr=3.14GHz, 4.87GHz, 5.74GHz, 6.55GHz, 8.62GHz and 9.85GHz. Gain= 8.80, -2.74, 2.53, 3.34, 5.38 and 7.59 respectively.
Proposed Antenna	28*28 mm	(2.8- 6.4 GHz) band with resonating frequencies 3.28 GHz, 6.42GHz and (8.39-9.31 GHz) band with resonating frequency 8.73 GHz. Gain=2.0, 2.5 and 4.6 dB respectively. Bandwidth of about 39% is achieved in iteration-3.

Comparison of hexagon shape fractal patch antenna is given in table-2. The proposed antenna is having the lowest size.

IV. MECHANICAL TUNING OF GROUND

Mechnical tunning is achieved in similar fashion to [19]. Here total ground length is dvided into two parts, one is fixed and other is floting. Total ground length is 28mm. Out of which 1.0mm is kept fixed and 27mm is floting ground. Then we will slide floting ground vertically down over fixed ground. For $1/8^{th}$ ground, ground length will be 3.5mm, out of which 1.0mm is fixed so floting ground till of 2.5mm is sliding vertically.

Now when we require ¼ ground then we will slide floting ground vertically down. So the total length that is in contact with substrate is 7mm ($1/4^{th}$ of total ground). In similar manner by manually sliding floting ground plane we will get $1/2^{th}$, $3/4^{th}$ and full ground as shown in fig 9.

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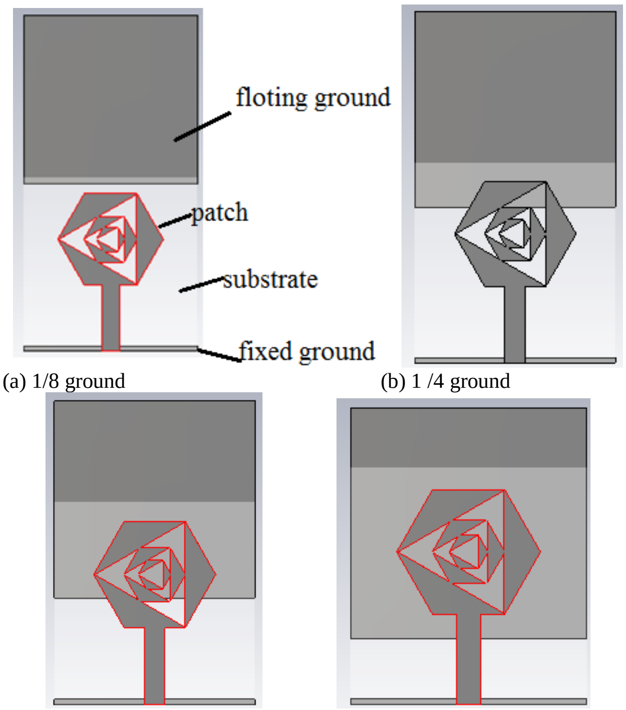

(a) 1/8 ground (b) 1 /4 ground

(c) 1 /2 ground (d) 3 /4 ground

Fig 9: Floting ground of Different Length

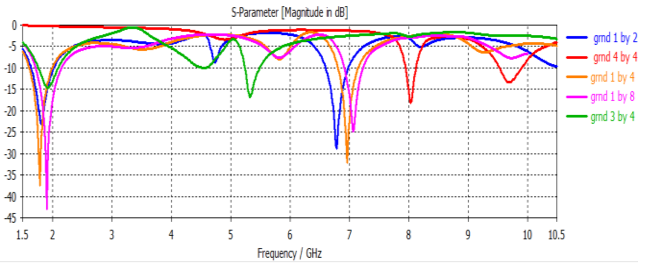

Figure 9: Tuning of Reflection Coefficient for Different Ground Lengths

Reflection coefficient for different ground length is shown in fig 10. When we are manually sliding the ground plane then contact between substrate and floting ground changes so resonating frequency also changes. Frequency re configurability is shown in table III.

Table III: Frequency and Gain for Different Ground Length

Sr.no.	Ground	Fr (GHz)	Band (GHz)	Gain (dB)
1.	1/8	1.91 7.06	1.72-2.15, 6.92-7.23	0.6 -2.1
2.	1/4	1.78 6.97	1.61-1.99 6.97-7.15	2.4 1.0
3.	1/2	1.81 6.78	1.65-2.02 6.60-6.98	1.9 1.2
4.	3/4	1.92 5.33	1.77-2.09 5.24-5.49	-1.8 1.7
5.	4/4	8.03 9.70	7.95-8.12 9.54-9.90	3.3 2.8

From the above table it is clear that the designed antenna covers frequency band of 1.61 GHz to 2.15 GHz (L band) and 5 GHz to 10 GHz (C and X band). So this antenna is useful for multiband applications. Gain for different grounds is shown in fig 11. Here gain is positive at all frequencies except at 7.06 GHz and 1.92 GHz.

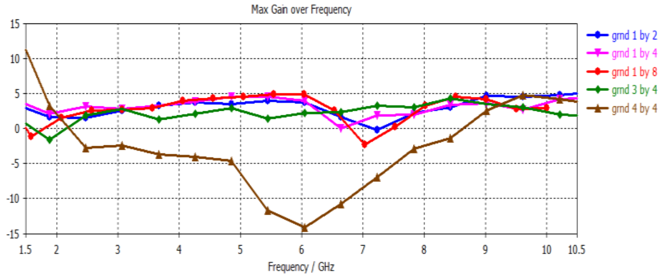

Figure 10: Gain for Different Ground Lengths

So a single antenna can be utilized for different ground lengths. This technique is cost effective and easy to implement, because instead to fabricating 5 different antennas all can be accommodated in one. When we slides the floating ground then effective length of ground is increased and different resonating frequencies are achieved. From the table 3 and return loss graph in fig 10 that when the ground length is increased then band shifts.

The designed antenna works in 1-10 GHz range, this can be used for Cognitive radio. Mechanical reconfiguration is used because system is more stable in comparison to electrical tuning although mechanical tuning is slower than electrical. This antenna can be a utilized where we require stable systems because it provides more robustness.

V. FUZZY LOGIC

Fuzzy logic is a multivalued logic system. Fuzzy logic is applied on the antenna system for applications in ambient environment. Because ambient intelligence is sensitive, adaptive and responsive to user. Fuzzy logic for ambient environment is prseneted in literature [51-53]. The propsed system can be a good candidate where a single antenna with the help of sliding ground can be utilized for many applications. The proposed system is easy to handle and cost effective.

Fuzzy logic is applied here for decision making, when a certain frequency is detected by antenna, then by sliding, movable ground should reach there. For this input membership function of fuzzy logic is “frequency” and output membership function ground length is defined in MATLAB. Fuzzy logic system is shown in figure 12, input and output membership functions are given in Table –IV. Mamadani rules are defined.

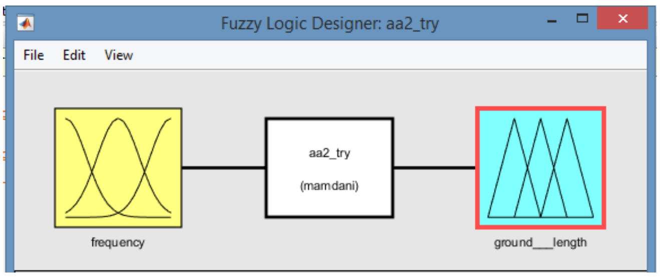

Fig 12:- Fuzzy Logic System

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Table IV: Input and Output Membership Function

Input membership function		Output membership function
Frequency	(membership function)	Ground length
1.78 GHz	Very low	1/4=0.25
1.81 GHz	Moderate low	½ =0.5
1.91 GHz	Low	3/4 =0.75
5.33 GHz	Very medium	3/4= 0.75
6.78 GHz	Medium	1/2= 0.5
6.97 GHz	High	1/4=0.25
8.03 GHz	Moderate high	4/4=1
9.70 GHz	Very high	4/4=1

If then Else rules are defined as:

1. IF ground length is very low then ground length is 1/4.
2. IF ground length is moderate low then ground length is 1/2.
3. IF ground length is low then ground length is 3/4.
4. IF ground length is very medium then ground length is 3/4.
5. IF ground length is medium then ground length is 1/2.
6. IF ground length is high then ground length is 1/4.
7. IF ground length is moderate high then ground length is 4/4.
8. IF ground length is very high then ground length is 4/4.

Fuzzy system output graph between frequency and ground length is shown in figure 13. The output of fuzzy logic system is comptble with mechanical sliding ground results shown in below table V.

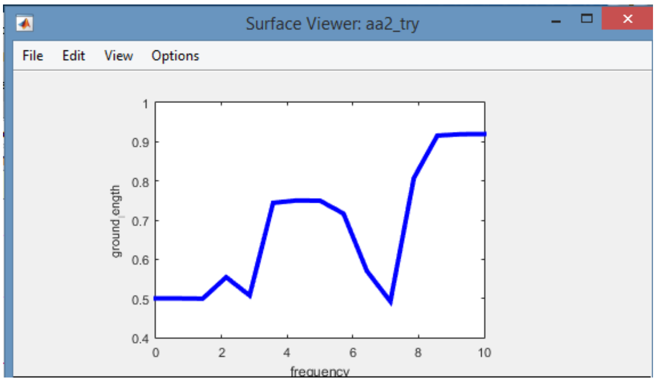

Figure 13:- Graph Between Frequency and Ground Length

Table V: Comparison of Output of Fuzzy Logic and Mechanical Sliding

Expected output (Fuzzy Logic system)		Actual output (Mechanical Sliding ground)	
Frequency	Output Ground length (membership function)	Ground length	Range
1.78 GHz	1/4 =0.25	0.497	> 0.25 , <0.5
1.81 GHz	1/2 =0.5	0.496	~ 0.5
1.91 GHz	3/4 =0.75	0.53	>0.5, <0.75
5.33 GHz	3/4= 0.75	0.745	~ 0.75
6.78 GHz	1/2= 0.5	0.47	>0.25, <0.5
6.97 GHz	1/4=0.25	0.478	>0.25, <0.5
8.03 GHz	4/4=1	0.86	>0.75, <1
9.70 GHz	4/4=1	0.92	>0.75, <1

VI. CONCLUSION

A novel fractal patch antenna with hexagon inscribed triangle is presented which can aid in development of ambient computing. The antenna is mechanically reconfigurable. It gives different bands for different ground lengths. The main emphasis of this paper is to achieve a system which provides frequency tuning and cost effective. This mechanical reconfigurable antenna has the ability to be context aware, adaptive and anticipatory. Ambient computing environment such as a smart home, mostly consists of large number of small devices. These devices require an antenna which can provide flexibility, can be miniaturized easily and is cost effective. The antenna concept presented in this paper can be adapted for ambient computing.

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