Design and Simulation of Koch Snowflake Fractal Antenna for GPS, WiMAX and Radar Application

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***Abstract* — This paper represents, design and simulation of micro strip patch antenna having Koch Snowflake Geometry. The antenna has been designed by increasing the perimeters of triangular shape patch by using self-similarity property. The multiband nature is obtained, by designing antenna up to second iteration. The designed antenna operates in four frequency bands for different applications. First frequency band is 1.41GHz - 1.65GHz which covers the GPS operating band, second band is 3.41GHz - 3.81GHz & third is 5.41GHz - 5.80GHz both band covers the WiMAX operating range , 7.75GHz - 8.13GHz is the last band which covers the X-band. X-band is used in radar application. The antenna is designed and simulated using CAD FEKO electromagnetic simulation software. The designed antenna is fed by a 50-Ω co-axial line and fabricated on a low-cost FR4 substrate having dimension 80(L) × 80(W) × 1.6(h) mm^3 with ϵ_r =4.4 and tanδ= 0.025. This antenna shows acceptable gain with directional radiation patterns in the frequency bands for wireless applications.**

Keywords— CAD FEKO, Co-axial, Koch Snowflake

I. Introduction

The wireless communication between two points in a space is possible only with antenna. An antenna is defined by Webster's Dictionary as 'a usually metallic device (as a rod or wire) for radiating or receiving radio waves'. The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) defines the antenna or aerial as 'a means for radiating or receiving radio waves [1]. Due to tremendous increase in wireless communication systems there is a great demand for wideband and small sized antennas. We know that conventional antenna can operate at single or dual frequency band, based on this logic each application will require separate antenna which is not feasible. As this will make the bulky system as well as the costs associated will be higher. In many applications Microstrip patch antennas are widely used. They have some good characteristics such as small size, light weight, cost effective, highly efficient and easy circuit integration. These antennas are suitable for wireless applications which require low impedance bandwidth. As microstrip antennas have low impedance bandwidth they are not suitable for modern wireless communication systems. To overcome above problems there is a need to design small sized and multiband/wideband antenna. In past, many techniques were available for reducing size of the patch antenna. One of them is the use of high dielectric constant substrate material, but due to surface wave excitation it gives narrow bandwidth and low efficiency. Also cost of high dielectric constant material is high. The good solution for these problems is to construct a multiband antenna is by applying fractal geometry.

Fractal antenna has been proved to be an effective technique to design small and multiband antennas. Fractal antenna geometry represents self similarity and repeats itself in different dimensions filling the space effectively [2-3].
The fractal geometry provide many advantages such as multiple electric dimensions, self loaded to 50 ohm, auxiliary reactance and capacitance not needed, mutual coupling between array elements can be reduced substantially and many more. Recently several fractal geometries are available like Helix, Koch curve, Hilbert curve and Sierpinski carpet etc. The objective of this paper is to increase bandwidth of the fractal antenna. This paper represents the design and simulation of Koch snowflake fractal antenna up to second iteration. This reduced size of antenna by fitting larger electrical length in to small physical volume.To increase bandwidth of fractal antenna suspended technique is used. So designed antenna exhibits some attractive features like small size multiband and broadband which fulfill the requirement of modern wireless communication systems.

II. Antenna Design And Geometry

A. Koch Snowflake Fractal Geometry

Koch Snowflake fractal geometry is the best example of self similarity and space filling properties of fractal antenna. Three Koch curves make Koch Snowflake.

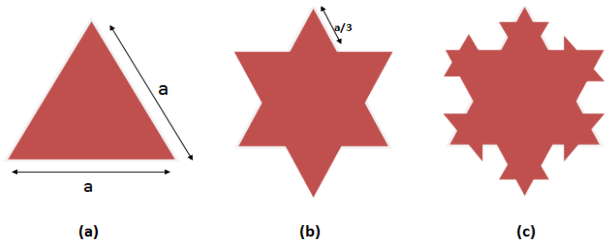

Fig. 1. Koch Snowflake Fractal Antenna Geometry
(a) Simple Triangular Patch Antenna (TMSA)
(b) 1st Order Iteration (c) 2nd Order Iteration

The design of Koch snowflake starts with the simple equilateral triangular patch which is termed as 0th order iteration. For the design of triangular patch three parameters are required i.e. resonant frequency (Fr), dielectric constant (ϵ_r) and side length of equilateral triangle (a). The resonant frequency chosen here is 1.6 GHz. The antenna is designed using a low cost FR4 substrate (ϵ_r=4.4). The side length of equilateral triangle patch (a) is calculated as,

$$a=3c/Fr\sqrt{\epsilon_r} \qquad (1)$$

Where
Fr =1.6 GHz
ϵ_r = dielectric constant of substrate =4.4
C = speed of light

The Koch Snowflake is designed by adding smaller triangles to the original triangle. After designing the main triangle, another triangle of same size is placed on it but in inverted form, this makes star shape patch as shown in fig. 1(b) and is termed as 1st order iteration. [4]

The star shape patch contains six small triangles. The same procedure will be repeated on all these triangles i.e. six inverted triangles will be placed on these six triangles. This is termed as 2nd order iteration as shown in fig. 1(c). Total perimeter after nth no. iteration is given by equation (1) ,

$$ln = 3a(4/3)^n \qquad (2)$$

Where
a = Side length of equilateral triangle patch
n = No. of Iteration

III. Simulation Results

The design and simulation of antenna is carried out by using CAD FEKO simulation software. The fig. 2 shows the design of antenna modeled in CAD FEKO software

A. Simple Triangular Microstrip Patch Antenna(TMSA)

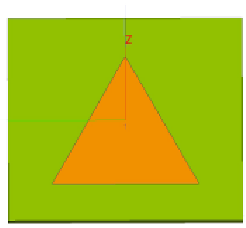

Fig. 2. Simple Triangular Microstrip Patch Antenna (TMSA)

Above fig. 2 shows the basic design of triangular patch. After simulating this patch we get frequency response as shown in fig. 3.

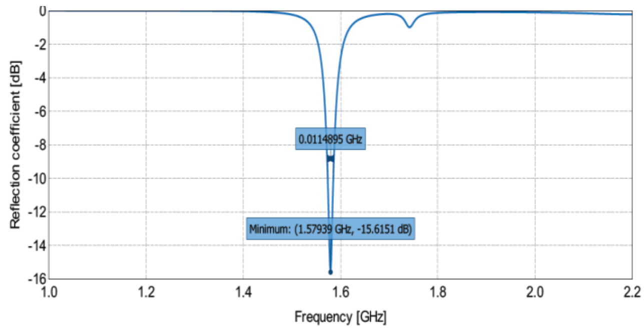

Fig. 3. Return loss Vs frequency graph of simple triangular patch antenna

The graph represents return loss of the simple triangular patch antenna. Here the antenna operates over the bandwidth of 25.25 MHz with a return loss of -15.61db which is less than -10db. The resonant frequency of the antenna occurs at 1.57GHz.

B. 1st Order Iteration of Koch Snowflake Fractal Antenna

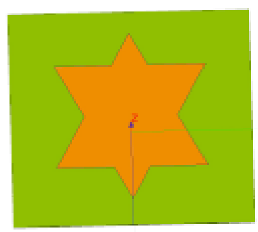

Fig. 4. 1st Order Iteration of Koch Snowflake Fractal Antenna

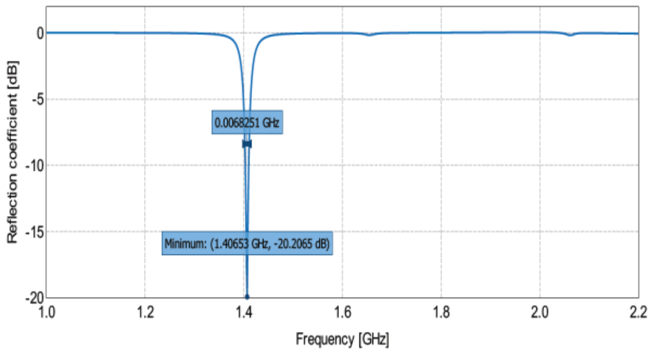

Fig. 5. Return loss Vs frequency graph of 1st iteration of Koch snowflake fractal antenna

The corresponding return loss of first iteration of Koch snowflake fractal antenna is as shown in fig. 5. It is seen that antenna resonate at 1.4GHz having 20.04MHz bandwidth with -20.20 db return loss. In first iteration perimeter of the patch increases because of this the fundamental resonant frequency shifted towards the lower side.

C. 2nd Iteration of Koch Snowflake Fractal Antenna

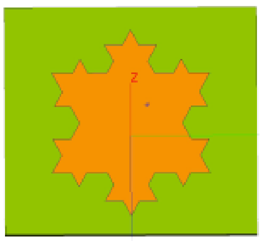

Fig. 6. 2nd Order Iteration of Koch Snowflake Fractal Antenna

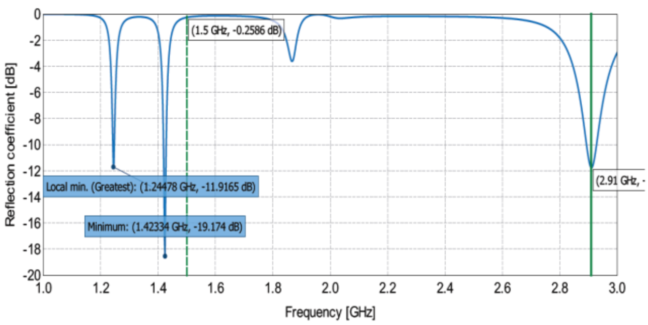

Fig.7. Return loss Vs frequency graph of 2nd iteration of Koch snowflake fractal antenna

Above fig. 7 shows the return loss of 2nd iteration of Koch snowflake fractal antenna. In 2nd iteration antenna resonate at three different frequencies first at 1.24GHz, second at 1.4GHz and third at 2.91 GHz with 7.88MHz, 10.43MHz and 41.22MHz of bandwidth.

TABLE 1

Simulation results of simple TMSA, 1st iteration and 2nd iteration of Koch snowflake fractal antenna

Types of MSA	Fr (GHz)	BW (MHz)	Return Loss (dB)	VSWR	Gain (dB)	Imp (Ohm)
TMSA	1.57	25.25	-15.61	1.39	3.42	47.12
1st Iteration	1.4	20.04	-20.2	1.27	4.95	42.54
	1.24	7.88	-11.91	1.67		53.9
2nd Iteration	1.42	10.43	19.17	1.24	3.36	47.83
	2.91	41.22	-11.9	1.68		53.12

Above table 1 summarized all the simulated parameters of antenna of simple triangular patch antenna, 1st iteration of Koch snowflake fractal antenna and 2nd iteration of Koch snowflake fractal antenna. From table, it is observed that the simple triangular patch antenna, 1st iteration and 2nd iteration of Koch snowflake fractal antenna give very narrow bandwidth and low gain.

In order to increase bandwidth and gain of antenna we have to design suspended Koch fractal antenna. The design and simulation results of suspended Koch fractal antenna are as shown below.

IV. Design And Simulation Results of Suspended Koch Snowflake Fractal Antenna

A. Antenna Design

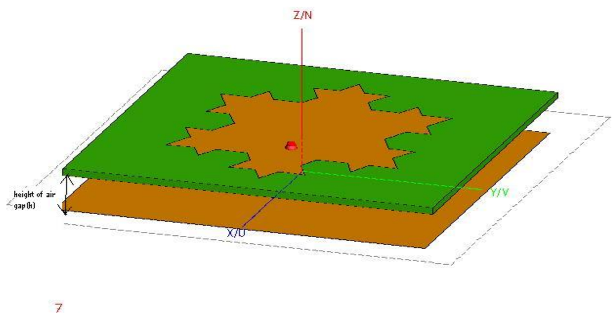

Fig. 8 Suspended Koch Snowflake Fractal Antenna

The structure of Suspended Koch Snowflake Fractal Antenna is shown in fig 8. In suspended technique an air gap is introduced between substrate and ground plane. Because of this, effective dielectric constant decreases and this will improve the bandwidth and gain of the antenna. Suspended Technique is mainly used to enhance bandwidth of antenna.

Suspended Technique is mainly used to enhance bandwidth of antenna. Koch Snowflake Fractal antenna with air gap of 9 mm with suspended ground plane is as shown in above figure.

B. Simulation Results

Return Loss indicates the amount of power that is lost to load and does not return as reflection. The simulated return loss for Suspended Koch Snowflake Fractal antenna as shown:

Fig.9 Return Loss Vs Frequency graph of suspended Koch snowflake antenna

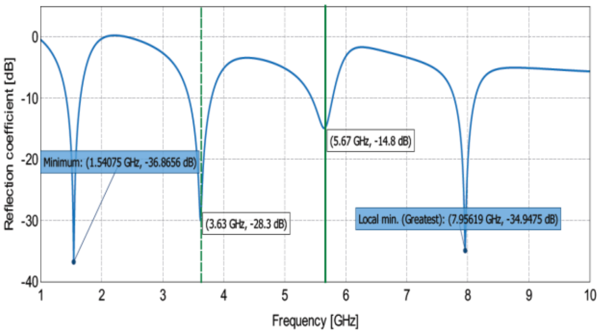

Fig. 9. Return Loss Vs Frequency graph of suspended Koch snowflake fractal antenna

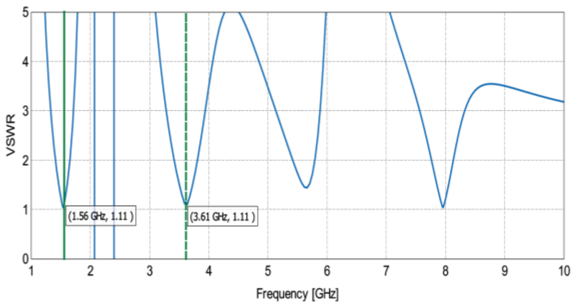

Fig. 10. VSWR Vs Frequency graph of suspended Koch snowflake fractal antenna

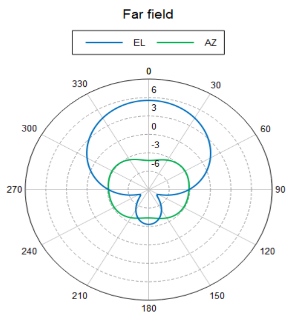

Fig. 11. Radiation pattern of suspended Koch snowflake fractal antenna at 1GHz

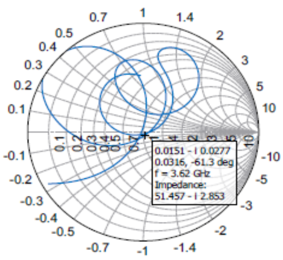

Fig. 12 Smith chart of suspended Koch suspended fractal antenna

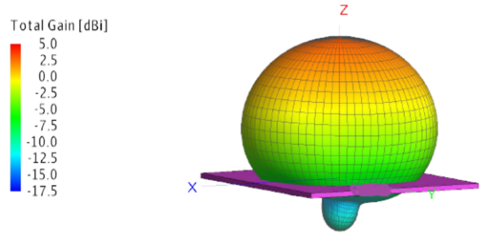

Fig 13. D total gain of final suspended Koch Fractal Antenna

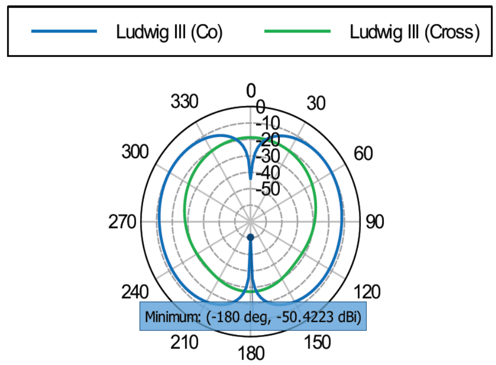

Fig. 14. Cross and Co polarization of suspended Koch fractal antenna at 1.52 GHz

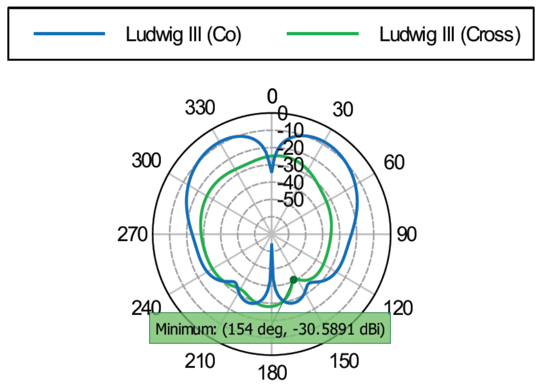

Fig. 15. Cross and Co polarization of suspended Koch fractal antenna at 3.63 GHz

The simulated results for final suspended fractal antenna are shown above. Fig. 9 shows the return loss of suspended antenna in which antenna operates in four frequency band. First band is 1.41GHz-1.65GHz having 249MHz bandwidth which covered the GPS application range, second band is 3.41-3.81GHz & 5.41GHz-5.80GHz with 398.2MHz &386MHz bandwidth which covered the WI-MAX operating range and 7.75GHz - 8.13GHz having 389.3 MHz bandwidth which covered X-band application band. Fig. 11 shows the radiation pattern of suspended fractal antenna. In E-plane antenna give directional radiation pattern with 5.527 db total gain. Smith chart shows good impedance matching. Fig. 14 & 15 show cross and co polarization graph at 1.52 GHz & 3.63 Hz with acceptable values of cross and co polarization values.

TABLE 2

Comparison between results of suspended Koch Snowflake fractal antenna with results of simple TMSA, 1st iteration and 2nd iteration of Koch snowflake fractal antenna

Iteration	Fr (GHz)	Return Loss (dB)	VSWR	Gain (dB)	BW (MHz)	Imp (ohm)
0	1.57	-15.61	1.39	3.42	25.25	47.12
1	1.4	-20.2	1.27	4.95	20.04	42.54
2	1.24	-11.91	1.67	3.36	7.88	53.9
	1.42	-19.17	1.24		10.43	47.83
	2.91	-11.9	1.68		41.22	53.12
Final Suspended Fractal Antenna	1.54	-36.86	1.11	5.52	249	50.82
	3.63	-28.3	1.11		398.2	50.1
	5.67	-14.8	1.45		386.1	50.7
	7.95	-34.94	1.05		389.3	52.1

The above table shows that as iteration increases the fundamental frequency is shifted to the lower side and which is used for multiband applications. The comparative table shows Final suspended Koch Fractal antenna, which gives good results in comparison to all iterations.

Final Suspended antenna has minimum VSWR, improvement in reflection coefficient, four frequency bands with broad bandwidth and high gain compared to first two iterations.

CONCLUSION

In this work, the design of Koch snowflake fractal antenna presented and simulation results are evaluated. The simulation results show that this antenna can be efficiently operated as a multiband antenna and bandwidth improvement is achieved using suspended technique. The final suspended Koch snowflake fractal antenna achieved some favorable characteristics such as multiband/broadband with acceptable gain, compact size, good impedance matching, low VSWR and improved return loss. The final suspended Koch snowflake fractal antenna has four resonance bands at frequencies 1.54GHz, 3.63GHz, 5.67GHz and 7.95GHz. According to these frequencies, this antenna can operate as a multiband antenna which covers GPS, WiMAX and Radar application.

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