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Study and Simulation of Koch Snowflake and Sierpinski Gasket fractal geometries

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Abstract*— - As the technology has undergone different phases of development ever since its inception. There have been numerous design changes of antenna with thousands of published documents relating to its design and analysis. Over the period new design concepts have been introduced. The present study is based on one such new trend known as "Fractal Antenna". Fractal geometries are characterized by series of built-in self similarities. Fractals antennas are the most successful implementation of fractal geometry. This thesis addresses the study and simulation of Sierpinski Gasket antenna and Koch Snowflake antenna in order to identify multiband/broadband behavior of fractal antenna. Due to self similar design Sierpinski Gasket fractal antenna and Koch Snowflake employ less area. The proposed approach is implemented using 4NEC2X antenna design software at designing frequency of 400 MHz, 600 MHz and 800 MHz .The results of the study indicate that these antennas resonate at different frequency. The 4NEC2X software has been used to simulate the antenna and observed that increase in iterations led to increases in resonant frequency. The performance of Sierpinski Gasket and Koch Snowflake is estimated in terms of its VSWR, Reflection coefficient and gain. The results of the study indicate that single antenna which is showing multiband behavior can be used for military and commercial applications.

***Keywords*— Fractal Antenna, Koch Snowflake, multiband/broadband, Sierpinski Gasket, 4NEC2X**

I. INTRODUCTION

As a result of progress in modern tele- communication systems compact size, multiband, broadband and low profile antennas are in requirement for commercial and military applications Fractal geometry is a very good option in designing of multiband and broadband antenna [1]. Fractals are geometric shapes that have inherent properties of space filling and self-similarity. For such mathematical shapes B.Mandelbrot introduced the term of "fractal curve". Such a name is used to describe a family of geometrical objects that are not defined in standard Euclidean geometry. Fractal geometry is united with electromagnetic theory to meet the target of investigating radiation, scattering and propagation problems so, that it is used in antenna design. Kim and Jaggard firstly introduced application of fractals to the field of antenna theory [2] with an increase of the wire length of a fractal there is a resonant frequency which results due to the coupling between sharp angles. Each angle not only radiates, but also receives the signal radiated by other angles. As the consequence, part of the signal does not follow the wire path but takes shortcuts [3]. In this paper fractal antenna is designed using Sierpinski gasket and Koch snowflake fractal geometries. The simulations of antenna are carried out using windows based 4NEC2X antenna modeler. The characteristics that are usually of interest in the antenna are Gain, resonant frequency, Reflection coefficient, VSWR. The simulation results show that the Sierpinski gasket and Koch snowflake design shows multiband/broadband behavior when iterated. These antennas can be used in military and commercial applications.

II. ANTENNA PARAMETERS

The performance of an antenna is described in terms of following parameters. These parameters specify physical and electrical characteristics of an antenna [4].

- **Resonant frequency:** The "resonant frequency" is related to the electrical length of an antenna. The electrical length is usually the physical length of the wire divided by its velocity factor (the ratio of the speed of wave propagation in the wire to the speed of light in a vacuum). Typically an antenna is tuned for a specific frequency, and is effective for a range of frequencies that are usually centred on that resonant frequency.
- **Gain:** Gain as a parameter gives the measure of how much power is transmitted in the direction of peak radiation to that of an isotropic source.
- **Directivity:** The maximum directive gain is called as the directivity of an antenna and is denoted by D. it is the ratio of Maximum radiation intensity to its average radiation intensity.
- **Radiation Pattern:** It is a graphical representation of the radiation properties of the antenna as a function of space coordinates.

- **Voltage Standing Wave Ratio (VSWR):** The voltage standing wave ratio (VSWR) is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to. VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna
- **Bandwidth:** The bandwidth of an antenna is the range of frequencies on either side of centre frequency where the antenna characteristics are within an acceptable value.
- **Reflection Coefficient:** A reflection coefficient defines the amplitude or the intensity of a reflected wave relative to an incident wave.

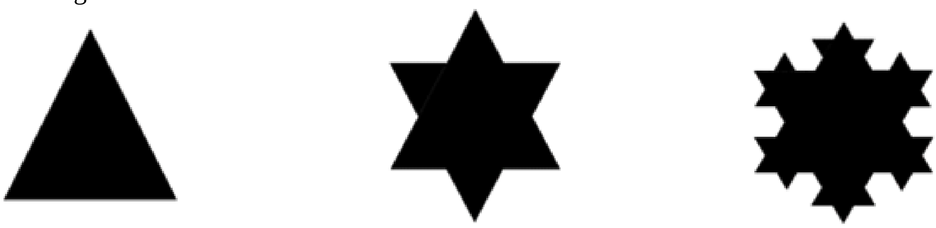
III. FRACTAL ANTENNNA

As mentioned earlier fractal antenna geometries are nature inspired geometries they exhibit properties of fractals existing in nature. The first geometry that will be considered is the popular Sierpinski gasket .The first few stages in the construction of the Sierpinski Gasket are shown in figure 1

Iteration 0 Iteration1 Iteration2 Iteration 3

Figure 1 Stages of Sierpinski Gasket fractal

Another popular fractal is known as the Koch Snowflake. This fractal also starts out as a solid equilateral triangle in the plane, as illustrated in figure 2.



Iteration 0 Iteration 1 Iteration 2

Figure 2 Stages of Koch Snowflake fractal

IV. SIERPINSKI GASKET GEOMETRY

Sierpinski Gasket design is named after the polish mathematician Sierpinski. The original Sierpinski fractal is illustrated in Figure .In this case, the antenna geometry is in the form of a classical Sierpinski Gasket. We start with an equilateral triangle and we subdivide it into four smaller triangles using lines joining the midpoints of the sides. The middle triangle, which is rotated 180 degrees compared to the other triangles, is subtracted. So the gasket antenna is composed of one substructure which is a replica of the whole gasket scaled down by a factor of two [5]. Properties that can be utilized in antenna construction are space saving property and self-similarity. Fractals have self-similarity in their geometry, which is a feature where a section of the fractal appears the same regardless of how many times the section is zoomed in upon. This can lead to multiband characteristic, which is displayed when an antenna operates with a similar performance at various frequencies.

V. KOCH SNOWFLAKE GEOMETRY

The Koch Snowflake (also known as the Koch star and Koch island) is a mathematical curve. It is based on the Koch Curve. In 1998 the von Koch monopole [6] became the first reported fractal small antenna that improved the features of some classical antennas in terms of bandwidth, resonance frequency, and radiation resistance. The Koch loop can be used both as self similar and space-filling geometry for designing wideband or multiband and miniaturized antennas. The features of this geometry, when incorporated into antenna design can overcome the limitations of small antennas. The Koch Snowflake can be constructed by starting with an equilateral triangle, then recursively altering each line segment as follows:

1. Divide the line segment into three segments of equal length.

2. Draw an equilateral triangle that has the middle segment from step 1 as its base and points outward.

3. Remove the line segment that is the base of the triangle from step 2.

4. The Koch Snowflake is the limit approached as the above steps are followed over and over again. The Koch curve originally described by Koch is constructed with only one of the three sides of the original triangle. In other words, three Koch curves make a Koch snowflake.

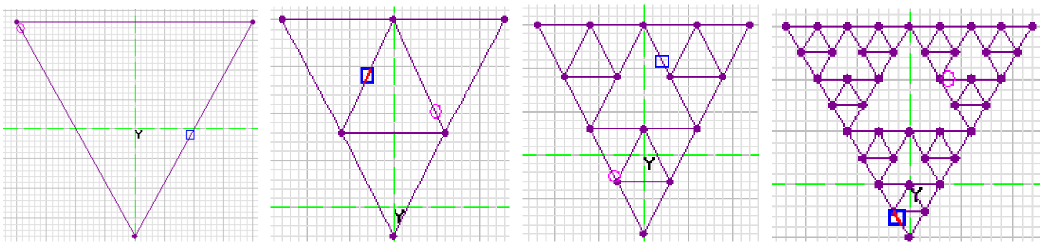
VI. RESULT AND DISCUSSION

SIERPINSKI GASKET GEOMETRY

- At 400MHz frequency for iteration 2 antenna operates at three resonant frequencies of 5200MHz, 4900MHz and 10 GHz .For iteration 3 this antenna operates at resonant frequency of 10.4 GHz and band is wider from 10.8GHz to 11.3 GHz

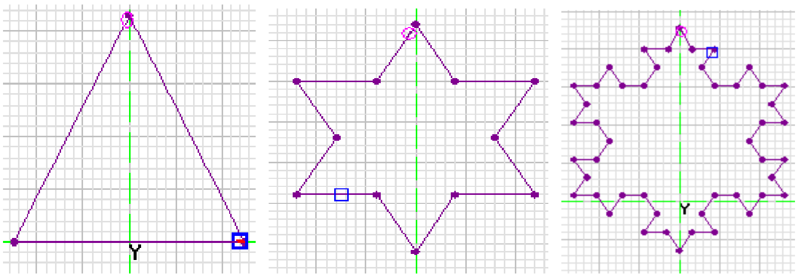
- At 600MHz frequency for iteration 2 Sierpinski Gasket antenna is operates at three resonant frequencies i.e. at 4000 MHz, 8000MHz and 9400MHz and for iteration 3 this antenna operates at resonant frequency of 14.8 GHz and band is wider from 15.4GHz to 16.2GHz.

- At 800MHz case for iteration 2 antenna operates at three resonant frequencies i.e. at 3300MHz, 12700MHz and 13100MHz and for iteration 3 band is wider from 24.2GHz to 27 GHz



First three iteration of sierpinski gasket

KOCH SNOWFLAKE GEOMETRY



First two iteration of Koch snowflake

- At 400MHz frequency for iteration 2 band is wider from 5.9 to 6.1 GHz.

- At 600MHz frequency for iteration 2 this antenna operates at resonant frequency of 1600MHz and band is wider from 8300MHz to 8800MHz.

- At 800MHz frequency for iteration 2 Koch snowflake antenna operates at resonant frequency of 3800MHz and band is wider from 13.6GHz to 14.6GHz.

At these resonant frequencies the designed antennas have VSWR < 2 and Reflection Coefficient < -10dB (parameters defined for practical antennas) [7] [8].

Table 1 Sierpinski Gasket designed at designing frequency (400MHz) from iteration 0 to 3

Iteration	Resonant Frequency	Reflection coefficient(dB)	Gain(dBi)	SWR
0	1200 MHz	-11.75	4	1.69
1	2600 MHz	-24.43	5.45	1.12
2	4900MHz	-32.28	5.43	1.04
	5200 MHz	-15.79	4.89	1.38
	10000 MHz	-12.72	3.16	1.6
3	10.4 GHz	-13.09	5.1	1.56
	10.8 GHz to 11.3 GHz	-19.6 -18.27	10.5 6.3	1.23 1.27

Table 2 Sierpinski Gasket designed at designing frequency (600MHz) from iteration 0 to 3

Iteration	Resonant frequency	Reflection coefficient(dB)	Gain(dBi)	SWR
0	1900 MHz	-10.1	3.4	1.9
1	4200MHz	-19.4	3.24	1.23
2	4000 MHz	-14.8	3.71	1.44
	8000 MHz	-15.68	4.22	1.39
	9400 MHz	-20.7	6.04	1.2
3	14.8 GHz	-19.85	12.8	1.22
	15.4 GHz to 16.2 GHz	-11.83 -10.47	5.29 4.93	1.68 1.85

Table 3 Sierpinski Gasket designed at operating frequency (800MHz) from iteration 0 to 3

Iteration	Resonant Frequency	Reflection coefficient(dB)	Gain(dBi)	SWR
0	2700 MHz	-13.11	4.5	1.56
1	5700 MHz	-14.4	3.76	1.46
2	3300MHz	-13.7	3.45	1.52
	12700 MHz	-23.9	5.57	1.13
	13100 MHz	-22.2	3.35	1.16
3	24.2GHz to 27GHz	-10.23 -11.11	5.79 3.26	1.88 1.7

Table 4 Koch Snowflake antenna designed at operating frequency (400MHz) from iteration 0 to 2

Iteration	Resonant Frequency	Reflection coefficient(dB)	Gain(dBi)	SWR
0	2800MHz	-10	3.27	1.92
1	2300MHz	-11.6	5.93	1.7
2	5900MHz to 6100MHz	-10.1 -12.1	4.91 3.9	1.89 1.65

Table 5 Koch Snowflake antenna designed at operating frequency (600MHz) from iteration 0 to 2

Iteration	Resonant Frequency	Reflection coefficient(dB)	Gain(dBi)	SWR
0	3800MHz	-15.8	3.57	1.38
1	2900 MHz	-12.7	5.3	1.6
2	1600 MHz	-10.8	3.02	1.8
	8300 MHz to 8800 MHz	-12.6 -10.4	4.65 4.67	1.6 1.85

Table 6 Koch Snowflake antenna designed at operating frequency (800MHz) from iteration 0 to 2

Iteration	Resonant frequency	Reflection coefficient(dB)	Gain(dBi)	SWR
0	5700MHz	-10.23	4.03	1.88
1	4600MHz	-16.8	4.59	1.33
2	3800MHz	-11.2	3.12	1.75
	13600MHz to 14600MHz	-10.9 -10.7	3.76 3.86	1.79 1.81

V. CONCLUSIONS

- Sierpinski gasket antenna geometry and Koch snowflake shows multiband/broadband behavior thus they can be used as multiband/broadband antennas. Sierpinski gasket antenna is designed up to 3rd iteration and because of complexity Koch snowflake is designed up to 2nd iteration.

- Sierpinski gasket antenna and Koch snowflake antenna are small in size thus can be used in small wireless communication devices and in defence sector.

- The Sierpinski gasket antenna for iteration 2 operates at three resonant frequencies of 5200MHz, 9500MHz and 10 GHz and for iteration 3 this antenna operates at resonant frequency of 10.4 GHz and band is wider from 10.8GHz to 11.3 GHz. At 600MHz for iteration 2 Sierpinski Gasket antenna is operates at two resonant frequencies i.e. at 4000MHz, 8000MHz and 9400MHz and for iteration 3 this antenna operates at resonant frequency of 14.8 GHz and band is wider from 15.4GHz to 16.2. At 800MHz for iteration 2 Sierpinski Gasket antenna operates at three resonant frequencies i.e. at 3300MHz, 12700MHz and 13100MHz and for 3rd iteration band is wider from 24.2GHz to 27GHz. These frequencies are not only suitable for LTE/WiMAX, ISM/WLAN/Bluetooth applications [9] but also suitable for defence/intelligence sector. Thus this particular antenna design can be used for fabricating an antenna that can support commercial and military applications.

The typical frequency bands of the different applications are the following:

- 1164-1215MHz (Band used for Aeronautical radio navigation systems to control civilian and military aircraft in the National Air Space)

- 2500-2655MHz (The military agencies use this band for tactical communication system)

- 5150-5250MHz (Band used for weather precision landing system at civilian and military airports)

- 10-10.45GHz Amateur radiolocation (used by military for weapons control radar systems)

- 10.7-11.7GHz (military agencies operate communication satellite earth station for voice, data and video signals)

- 4200-4400MHz (This band is used by pulse radar altimeters operating on military aircraft)

- 9300-9500 MHz (The military agencies operate mobile and transportable radar systems in this band)

- 15.4-15.43GHz (The military agencies use this band for mobile or transportable tactical aircraft landing systems

- on shore and ship borne)

- 15.7-17.3GHz (The Army uses this band for Unmanned Aerial Vehicles)
  Like in similar way other bands are used in military applications.

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