ISSN: 2395-1680 (ONLINE)
DOI: 10.21917/ijme.2020.0160

DESIGN AND ANALYSIS OF KOCH FRACTAL ANTENNA FOR WLAN APPLICATIONS

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Abstract

In this paper, a Koch fractal antenna is designed for Wireless Local Area Network (WLAN) applications. Koch snowflake design is symmetrical and self-similar structure that induces space filling capability and improves the surface current on the antenna. The overall fractal antenna structure consist of a copper foils (Patch and Ground Plane) mounted on either sides of the dielectric material (Flame Retardant-4 (FR-4) with permittivity ε_r =4.4 and loss tangent δ=0.02). The antenna is fed using a microstrip line feed. The dimensions of the Koch fractal antenna are 30×30×1.6mm^3 which is compact sized design made on High Frequency Structure Simulator (HFSS) platform. The simulation outputs are internally compared with different iterations implemented on the patch using Iterated Function System (IFS) and the difference in the radiating frequency, return loss, bandwidth, gain and directivity of all three different iterations. The resonating frequency for three iterations ranges from 5.8GHz to 7.47GHz which can be used in WLAN applications. Thus, the proposed Koch snowflake fractal antenna design provides improvements in the antenna parameters on increasing scale of iteration such as S_{11} from -21.35dB to -36.32dB, average gain of 3dB and Impedance Bandwidth of 25.90%.

Keywords:

Antenna Design, FR-4, Ground Plane, Koch Snowflake, Patch, WLAN Application

1. INTRODUCTION

The MPA can be fabricated easily by using modern printed circuit technology and it is a low profile antenna [1]. It is used in mobile, radio and wireless communication systems to enhance the bandwidth. It is often used in microwave frequencies. A microstrip patch antenna has a patch of metal foil which can be of different shapes on the surface of a PCB, with a ground plane made up of metal foil on the other side of the board. A microstrip antenna consists of a patch that can be of various shapes, a ground plane on the opposite side of the board and a substrate [2]. The main advantages of Microstrip antenna is they are light weight, has low volume, cheaper and the most important one is its dimension is small, so that we can use this type of antenna in phone, dongles, etc. [3] [4].

The IEEE 802.11 standard was proposed in 1997 for WLANs application. After few years new standard was proposed operating on the 2.4 GHz ISM band is called 802.11b, which provides a data rate up 11Mbps.The IEEE 802.11y standard was approved in 2008, operating on the 3.6 GHz frequency. The IEEE 802.11a standard was approved in 1999, operating on the 5 GHz ISM band. The change in the band shows that the products of 802.11a and 802.11b are not compatible. Due to this the IEEE proposed 802.11g which was compatible with both 802.11b and 802.11a technology. Fractal means broken or irregular fragments [5] [6].

Fractal MPA is an antenna which uses self-similar designs to increase the perimeter of the antenna and to maximize the effective length [7]-[9]. It can be able to transmit receive electromagnetic radiation within a given surface. The advantage of fractal MPA are larger bandwidth, improved VSWR. Fractal antennas are mostly compacting, multiband or wideband, and used in applications such as cellular telephone and microwave communications. Fractals are mostly used for its size reduction [10]-[12]. The Koch snowflakes constructed by a sequence of iterations. The first iteration is a rectangle, and then each successive iterations can be constructed by adding outward bends to each side of the previous iterations, so that the smaller rectangles will be obtained [13]-[15]. Accordingly, the snowflake confines a finite amount of area and it also has an infinite perimeter.

FR-4 is a composite material which can be made up of woven fiber glass cloth with an epoxy resin bind and it also acts as a flame resistant. FR-4 is a commonly used material for printed circuit boards (PCB) [16] [17]. A thin layer of copper foil is covered either to one or both sides of an FR-4 glass epoxy panel. These are often referred to as copper clad laminates. Ansys HFSS is used to design and simulate high-frequency electronic products like antennas, array of antennas and PCB [18]. Normally, engineers across the world use Ansys HFSS to construct high-frequency; high-speed electronics so that it can boosts the communications systems, radar systems, ADAS, satellites, IoT products and other high-speed RF and digital devices. It helps in reducing the time for designing cycle time to and boosts the product's reliability and performance.

Microstrip patch antenna fulfills all specifications, and antennas are designed for use in mobile communication systems. Well into the category of satellite communication circularly polarized radiation patterns are necessary and can be implemented using either a square or circular patch with one or two feed points.

Hereby, antenna's structural parameters are follows: section 2 explains the structural geometry of the constructed Koch fractal antenna. Section 3 brings out antenna parameters through simulation outputs. Section 4 concludes the paper.

2. ANTENNA STRUCTURE

The Koch fractal antenna design consists of three different layers. The layer 1 is a patch and layer 3 is a Ground plane, both are made of metal sheet which are mounted on the either sides of the 1.6 mm thicker FR-4 substrate. The Fig.1 shows the overall structure of Koch Snowflake antenna with microstrip feed.

2.1 KOCH SNOWFLAKE FRACTAL STRUCTURE

The Koch Snowflake construction starts with a square. This square is divided into four pieces which are identical. The smallest square in the middle is far from the first bigger square. The Table.1 show the Stages of Koch Snowflake Fractal geometry. A pattern of Koch Snowflake is observed on repeating this cycle using Iterated Function System (IFS). The design of the microstrip Koch Snowflake fractal antenna follows the approach of various considerations.

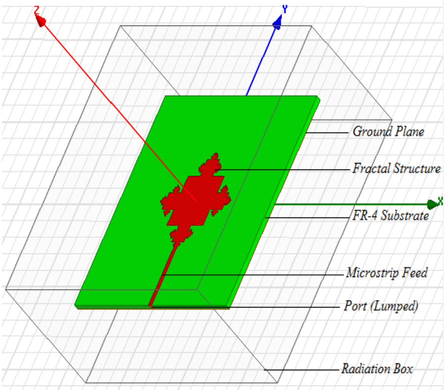

Fig.1. Structure of Koch Fractal antenna

Table.1. Stages of Koch fractal geometry

Iterations	Dimensions
0^{th} Iteration	None
1^{St} Iteration	$5\times5mm^2$
2^{nd} Iteration	$1.6\times1.6mm^2$
3^{rd} Iteration	$0.55\times0.55mm^2$

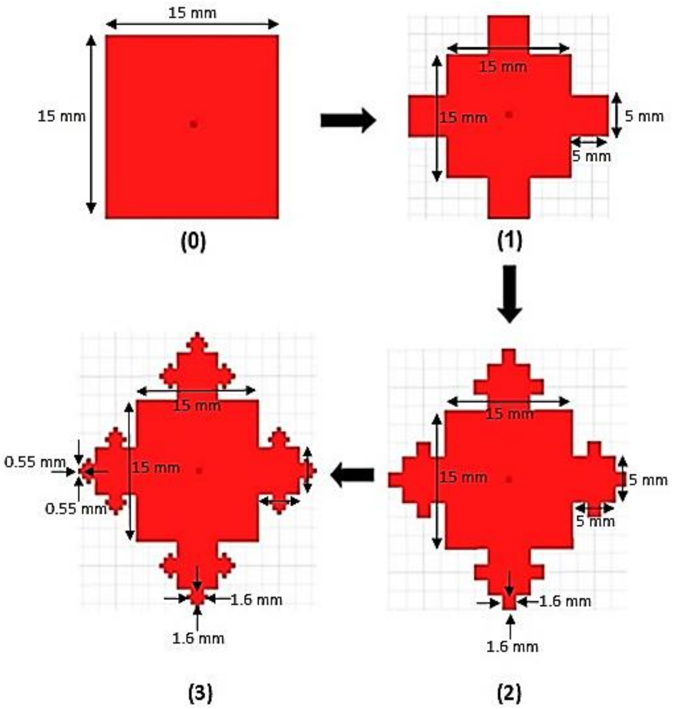

Fig.2. Different iterations of Koch Fractal structure

Koch Snowflake geometry provides improved results compared to planar which includes: it has an excellent design at arbitrarily minute scale and estimated in traditional Euclidean geometry. Also, it enhances electrical area of antenna and improves radiation efficiency. Here, the Fig.2 gives the list of different iterations of Koch Snowflake Fractal structure.

2.2 METHODOLOGY AND DESIGN

Width of Patch (*W*):

$$W = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where,

c is the velocity of light,

f_r is the radiating frequency and

ε_r is the dielectric constant

Effective Dielectric Constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-0.5} \tag{2}$$

Patch Length Extension:

$$\Delta L = 0.412h\left(\frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} + 0.259}\right)\left(\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right) \tag{3}$$

where, *h* is the height of the substrate.

Effective Patch Length:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

Patch Length:

$$L = L_{eff} - 2\Delta L \tag{5}$$

Substrate width or ground plane width:

$$W_s = W_g = 6h + W \tag{6}$$

Substrate length or ground plane length:

$$L_s = L_g = 6h + L \tag{7}$$

The Table.2 lists the dimensions of antenna structure and Fig.3 shows the Koch Snowflake Fractal structure with microstrip feed.

Table.2. Dimensions of antenna structure

Antenna Part	Design (symbols)	Dimensions
Substrate	Length (L_s)	30 mm
	Width (W_s)	30 mm
	Height (h)	1.6 mm
Patch	Length (L)	15 mm
	Width (W)	15 mm
Feed line	Length (f_l)	7.6 mm
	Width (f_w)	1.3 mm
Ground plane	Length (L_s)	30 mm
	Width (W_s)	30 mm

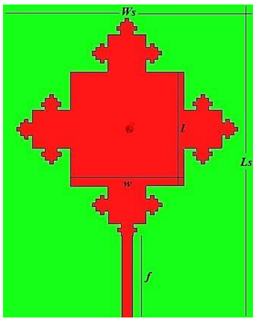

Fig.3. Koch Curve with Microstrip feed

2.3 SUBSTRATE AND GROUND PLANE

For this model, the dielectric material used is FR-4, with a standardized geometry. The ground plane which is made of perfect electric conductor is also designed using the same methodology. FR-4 is an electrical insulator that has considerable mechanical strength because of its zero water absorption capability. It has good electrical mechanical values, fabrication characteristics. A ground plane is a surface that is electrically conductive and typically connected to electrical ground.

In theory of antennas, a ground plane can be a large conductive surface relative to the wavelength, which is attached to the ground wire of the transmitter and is a reflective surface for radio waves. A ground plane in computer circuit boards has a wide area of copper foil on the board that can be connected to the ground terminal supply facility and is a return route for current from different components on the board.

3. SIMULATION RESULTS

There are four Iterative level antennas designed in HFSS platform. The first antenna contains no fractal design which is a normal square patch antenna whose resonating frequency is obtained as 7.48GHz. The second antenna is Iteration 1 in Koch fractal with dimension 5×5mm^2 whose resonating frequency is 6.42GHz. The third antenna is Iteration 2 (1.6×1.6mm^2) whose resonating frequency is 6.08GHz. The fourth antenna is Iteration 3 (0.55×0.55mm^2) with the resonating frequency of 5.79 GHz.

3.1 RETURN LOSS

Return loss is the ratio of power reflected from the antenna to the power fed to the antenna through a transmission line. The Return Loss of an antenna indicates the amount of radio waves reaching the antenna input that are rejected as reflection. The outputs of the fractal antenna are listed in Table.3.

Table.3. Return Loss for different Iterations

Iterations	Resonating frequency	Return Loss
0th Iteration	7.48 GHz	-21.357 dB
1st Iteration	6.42 GHz	-22.981 dB
2nd Iteration	6.08GHz	-31.572 dB
3rd Iteration	5.79 GHz	-36.320 dB

3.2 BANDWIDTH

The frequencies over which the antenna can operate are called as bandwidth. The slots which are used in the proposed antenna will provide an enhanced bandwidth with a good gain and directivity values. The Table.4 shows the bandwidth assessments for iterations of fractal structure.

Table.4. Bandwidth for different Iterations

Iterations	Lower Frequency	Higher Frequency	Bandwidth
0thIteration	7.25 GHz	7.48 GHz	220 MHz
1stIteration	6.33 GHz	6.51 GHz	180 MHz
2ndIteration	6.08 GHz	6.16 GHz	160 MHz
3rdIteration	5.71 GHz	5.86 GHz	150 MHz

3.3 VSWR

Voltage Standing Wave Ratio refers to the ratio of matched load impedance to the characteristic impedance of a transmission line. VSWR is a way to measure the imperfection in the transmission line. It is a measure which numerically describes how well the antenna impedance is matched to the transmission line. The Table.5 shows the VSWR of different iterations in the Fractal antenna.

Table.5. VSWR for different Iterations

Iterations	VSWR
0thIteration	1.187
1stIteration	1.152
2ndIteration	1.054
3rdIteration	1.031

3.4 GAIN AND DIRECTIVITY

Gain in an antenna mentions the performance by combining the directivity and electrical efficiency of an antenna. Gain of an antenna is the ability to change electrical waves into radio waves. Directivity is used to calculate the radiation of density of power by an antenna in the direction of its strongest emission. The Table.6 represents the Gain and Directivity of the fractal antenna iterations respectively.

Table.6. Gain and Directivity for different Iterations

Iteration	Gain	Directivity
0thIteration	2.942 dB	3.561 dB
1stIteration	3.058 dB	3.539 dB
2ndIteration	3.083 dB	3.623 dB
3rdIteration	3.192 dB	3.798 dB

A Koch Snowflake fractal antenna structure is designed using HFSS software and obtained an optimized output for all four iterations. In 0th iteration, a normal microstrip patch antenna has been designed for 7.48GHz.

In first iteration, a simple square of size 5×5mm^2 has been added to the patch and considered as the first step for the antenna which produces a 6.42GHz. In second iteration, there are four square slots of size 1.6×1.6mm^2 has added on to four sides of the square, and then the outputs have been observed at 6.08GHz. In third iteration, the same has been repeated with dimension 0.55×0.55mm^2 which leads to 5.79GHz. Hence, the simulated output for the Koch Snowflake fractal structure is listed in Table.7.

Table.7. Simulated output for Koch Fractal antenna

Iterations	Parameters				
	Return loss (dB)	VSWR	Bandwidth (MHz)	Gain (dB)	Directivity (dB)
Iteration 0 (f_r=7.48GHz)	-21.35	1.187	220	2.94	3.56
Iteration1 (f_r=6.42GHz)	-22.98	1.152	180	3.05	3.53
Iteration 2 (f_r=6.08GHz)	-31.57	1.054	160	3.08	3.62
Iteration 3 (f_r=5.79GHz)	-36.32	1.031	150	3.19	3.79

4. CONCLUSION AND FUTURE WORK

A fractal antenna for the Koch Snowflake was planned and analyzed for WLAN application. A fractal structure is a self-like structure that improves the effective length of the patch transmitting/receiving electromagnetic radiation. The proposed antenna has three layers namely Patch Dielectric material and Ground and it is fed using a quarter wavelength transmission lines for better input impedance. The overall geometry of the fractal antenna is 30×30×1.6mm^3 and it is designed and simulated in HFSS platform. The output has been analyzed for three different iteration made on the radiating patch, the difference in the radiating frequency, return loss, bandwidth, VSWR, gain and directivity has been compared. The radiating frequencies for three different iterations are 6.42GHz, 6.08GHz and 5.79GHz, which is suitable for WLAN applications. The designed Koch Snowflake fractal antenna using Iterated Function System (IFS) shows improvements in the simulation parameters while increasing iteration. Therefore, the Koch Snowflake fractal antenna design provides an improvement in the antenna parameters on increasing scale of iteration such as S_{11} from -21.35dB to -36.32dB, average gain of 3dB and Impedance Bandwidth of 25.90%.

In future, the Koch Snowflake design will be fabricated and measured output parameters of the fabricated antenna will be compared with the simulated results.

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