Design, Simulation, Fabrication and Measurement of a 900MHZ Koch Fractal Dipole Antenna

S. A. Hamzah, M. K. Raimi, N. Abdullah, M. S. Zainal
Department of Communication Engineering (JEP)
Faculty of Electrical and Electronic Engineering (FKEE)
Kolej University Technology Tun Hussien Onn (KUiTTHO)
86400 Parit Raja, Batu Pahat, Johor, Malaysia
Email: shipun@kuittho.edu.my, koi@comic.com

Abstract - **This paper present the design and fabrication of the Koch fractal dipole antenna. A multi-band element has been designed based on the Koch fractal which operates over two frequency band. The property of antennas such as return loss, S11 has been investigated at frequency of 900MHz for GSM band. Wide bandwidth with input return loss of –10 dB has been achieved from 0 to 8 GHz using this fractal antenna. The size of fabricated antenna is reduced around 64% compare to conventional dipole antenna at these frequencies.**

Keyword: **Fractal Antenna, Koch Fractal, 900MHz, Dipole Antenna**

I. INTRODUCTION

For a current world of wireless communications, there has required compact and wider bandwidth antenna. A lot number of antenna researches in many ways have been done and by using fractal shaped antenna elements [1] [2] [3] [4] is one of it.

A. Fractal Geometry

Fractals are a class of shapes which have no characteristic size. Each fractal is composed of multiple iterations of a single elementary shape. The iterations can continue infinitely, thus forming a shape within a finite boundary but of infinite length or area. This shows fractal shapes are compact, meaning that they can occupy a portion of space more efficiently than other antenna types. In the previous literature [1] [2], it has been discovered that fractal shapes radiate electromagnetic energy well and also been demonstrated that fractal antennas exhibit compressed resonance and multi-band behavior, which can radiate signals at multiple frequency bands when their impedance properties are compared to those of Euclidean antennas having the same overall size. Fractal antennas have also been shown to exhibit lower resonant frequencies than Euclidean antennas of the same overall size. All the properties discovered that fractal shapes are advantageous over traditional antenna types can be helpful in application requiring reduced size antennas like mobile wireless communication because smaller receivers could be produced.

B. Koch Fractal Curve

From ref. [3], the Koch curve fractal geometries were originally introduced by the Swedish mathematician Helge von Koch in 1904. Fig. 1 shows the geometrical construction of standard Koch curve. The initial straight line (K0) is called the initiator. First iteration of Koch curve or called the generator achieved by partitioned the initiator into three equal parts and replaced the segment at the middle with two others of the same length at certain angle. The method reused in generation of second and higher iterations.

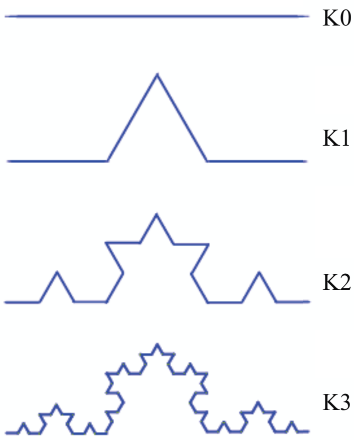

Fig. 1. Iterations of the standard Koch curve [2].

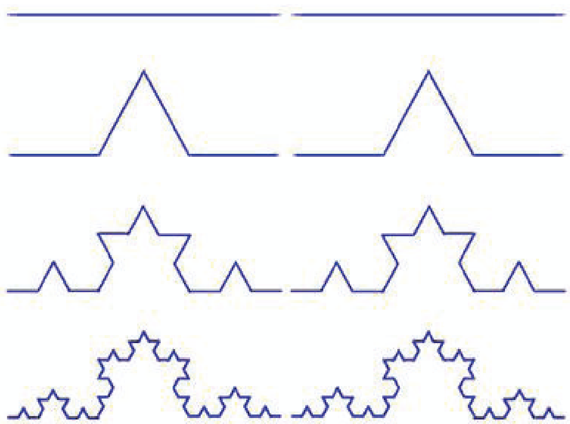

Fig. 2. Iterations of the Koch fractal dipole.

Two Koch fractal dipoles are printed on the substrate parallel to the ground plane, so as to face each other at one of their end, to form the dipole configuration. Two feeds are required for the two geometries. Low dielectric constant substrate FR-4 is used as the substrate material. Fig. 2 shows zero to third iteration of Koch fractal dipole.

II. KOCH FRACTAL ANTENNA

A. Koch Fractal Description

From ref. [1] [2] [3] [4], the explanation of Koch fractal antenna is covered. Many useful fractals can be generated by Iterated Function Systems (IFS) [2] [4]. Briefly, IFS work by applying a series of affine transformations *w* to an elementary shape *A* over much iteration [2]. IFS can be effectively used to generate the basis of the Koch fractal antenna as shown in Fig. 3. The affine transformation in the plane ω, comprising rotation, scaling and translation, is given by:

$$\omega\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} = Ax + t \quad (1)$$

Short form of affine transformation:

$$\omega = [a, b, c, d, e, f] \quad (2)$$

The matrix A :

$$A = \begin{pmatrix} \frac{1}{s}\cos\theta & -\frac{1}{s}\sin\theta \\ \frac{1}{s}\sin\theta & \frac{1}{s}\cos\theta \end{pmatrix} \quad (3)$$

where scaling factor, $1/s$ is angle dependent and is given by:

$$\frac{1}{s} = \frac{1}{2(1+\cos\theta)} \quad (4)$$

The first iteration of Koch curve is then obtained as:

$$A_1 = \omega(A) = \omega_1(A) \cup \omega_2(A) \cup \omega_3(A) \cup \omega_4(A) \quad (5)$$

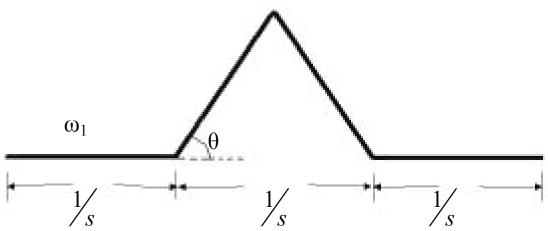

Fig. 3. The four segments that form the general basis of the Koch fractal antenna.

For this fractal geometry;

Let
- c is the speed of light
- l is the effective length
- h is the antenna height
- n is the number of iteration
- θ is the indentation angle
- D is the dimension
- f_r is the frequency resonance
- s is the scaling factor

For conventional antenna:

$$h = \frac{\lambda}{4} \quad (6)$$

Then

$$l = h\left(\frac{4}{3}\right)^n \quad (7)$$

$$D = \frac{\log(4)}{\log(1 + 2\cos\theta)} \quad (8)$$

$$f_r = \frac{c}{4l} \quad (9)$$

$$s = 2(1+\cos\theta) \quad (10)$$

By using these equations and some consideration parameters the design process is started.

III. DESIGN AND FABRICATION METHODS

A. Microstrip Dipole Antenna

Microstrip dipole antenna is based on rectangular patch antenna design consideration [5]. The microstrip patch antenna has become one of the most versatile radiating element solutions for a large variety of systems. Microstrip patches are basically conductive radiating elements etched on a thin dielectric layer. A ground plane is etched on the opposing side of the dielectric layer from the radiating element. An advantage of microstrip antennas is that they can be easily and low fabrication cost using commonly available printed circuit board (PCB) technology. This antenna can thus also be produced at small size and profile [2]. For the microstrip dipole, resonant length, *L* is given by:

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{re}}} \quad (11)$$

where
f_r = resonant frequency of the antenna
ε_{re} = effective dielectric constant of the microstrip line for the microstrip

B. Koch Fractal Dipole Antenna

This antenna has been designed based on iterated Koch fractal geometrical principals using Microwave Office software with rotation angle $\theta = 60°$, scaling factor $1/s = 1/3$ and maximum iterations of three. It is assumed that this antenna will be designed for an application that needs a fairly small antenna that can effectively model quarter wave dipole. The antenna is fabricated to operate in 900MHz frequency band and its measurability in the antenna chambers of FKEE, KUiTTHO with a total height of 36% less than conventional calculation. This antenna is printed onto FR-4 substrate with a relative dielectric constant of 4.5, and trace line thickness is 1 mm. The final design and fabricated of the antenna is depicted in Fig. 4 and Fig. 5 respectively.

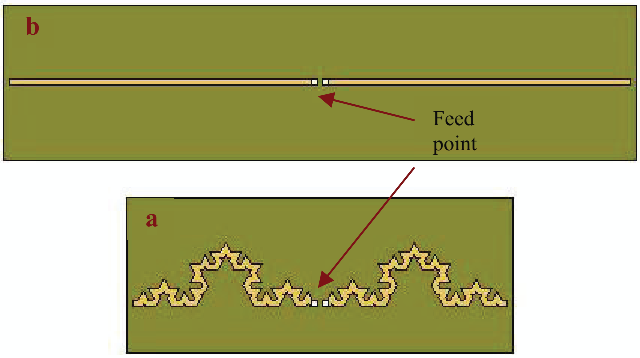

Fig. 4. Final design of Koch fractal dipole (a) compared to microstrip dipole (b).

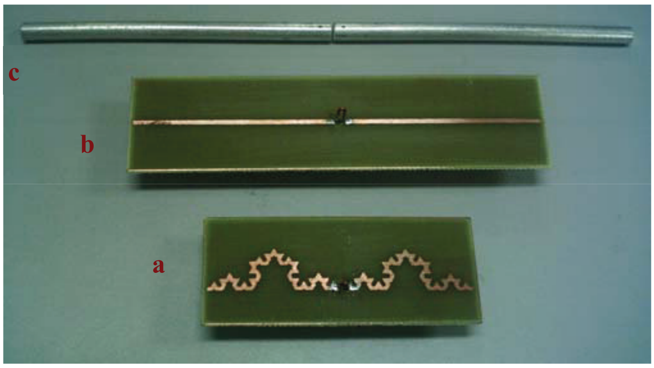

Fig. 5. Fabricated Koch fractal dipole antenna (a) compared to microstrip dipole (b) and conventional dipole antenna (c).

IV. Measurement Result

A. Input Return Loss, S_{11}

Measurement of microstrip dipole:

(i)

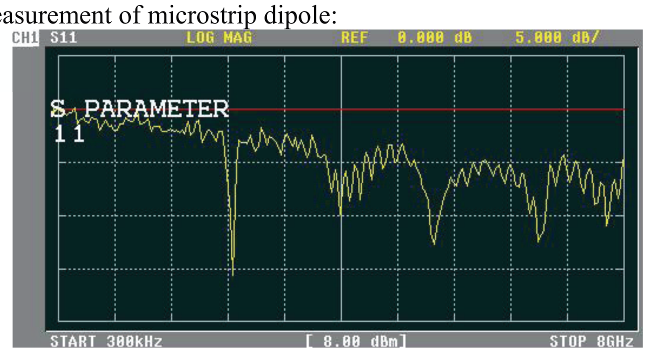

Fig. 6. Input return loss of microstrip dipole antenna from 300 kHz – 8 GHz.

(ii)

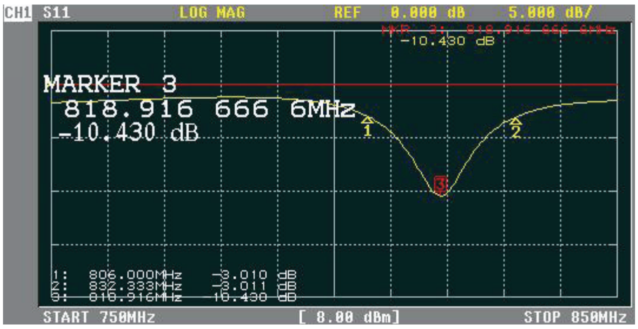

Fig. 7. Input return loss of microstrip dipole antenna from 750 MHz – 850 MHz.

B. Measurement of Koch fractal dipole:

(i)

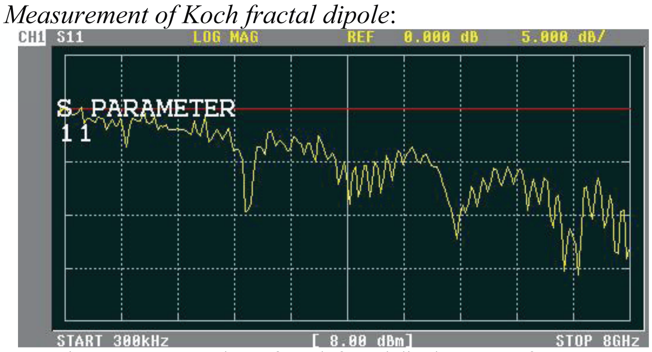

Fig. 8. Input return loss of Koch fractal dipole antenna from 300 kHz – 8 GHz.

(ii)

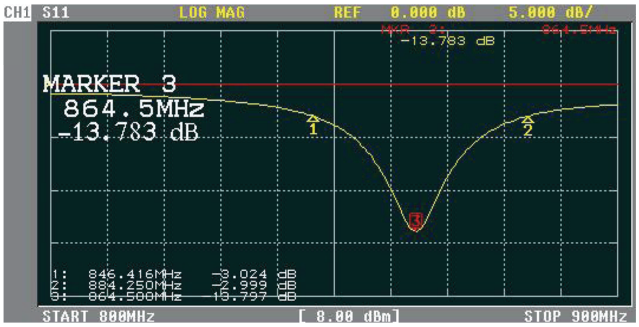

Fig. 9. Input return loss of Koch fractal dipole antenna from 800 MHz – 900 MHz.

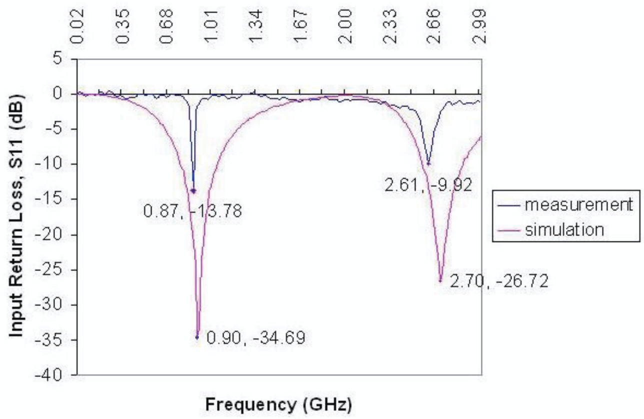

Fig. 10. Comparison between measurement and simulation of input return loss of Koch fractal dipole from 300 kHz – 3 GHz.

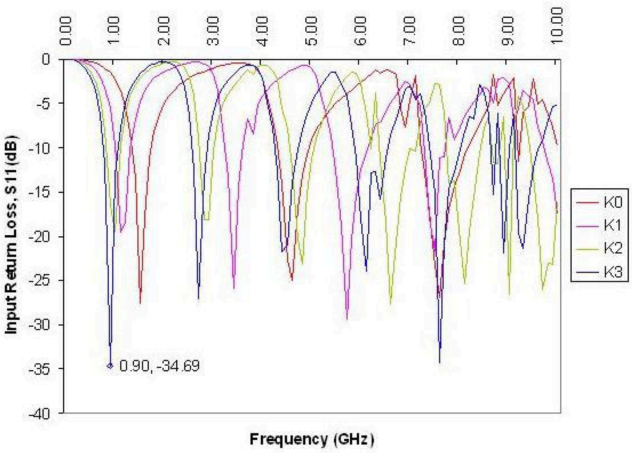

Fig. 11. Input return loss of 0 – 3rd iteration Koch fractal dipole.

From Fig. 11, the typical behavior of Koch fractal dipole can be proved [3]. As the higher the number of iteration, *n* of Koch fractal dipole, it can be observed that:

(i) The higher the number of resonant frequencies
(ii) The wider the bandwidth of the center frequency
(iii) The lower the first resonant frequency

TABLE 1
EXPERIMENT RESULT PARAMETERS OF KOCH FRACTAL DIPOLE AND MICROSTRIP DIPOLE ANTENNA

Antenna	Microstrip dipole	3rd iteration Koch fractal dipole
Length (mm)	100	60
Trace line thickness (mm)	1	1
Resonant frequency (MHz)	818.92	864.5
S11 (dB)	– 10.43	– 13.78
Bandwidth (MHz)	806.00 – 832.33	846.42 – 884.25
SWR	1.854	1.522
Compactness (compare to conventional dipole*)	100/166.67 = 60%	60/166.67 = 36%

*length of 900 MHz conventional dipole, λ/2 = 166.67 mm

V. CONCLUSION

A Koch fractal dipole antenna was constructed using fractal geometry for 900MHz band operation. The initial design is started by using a single element equation of patch antenna with scaling factor 1/3. In this design the iteration is at 3rd iteration with a return loss around –34 dB (simulation). This is the highest iteration for the antenna following it specification. The result shows that the antenna can be operate at multiple band of resonant frequency. The return loss less than -10 dB will cover a frequency range from 0 – 8 GHz and the size antenna is reduced around 64% than conventional is the main achievement of this study.

VI. REFERENCES

[1] Best, S.R. (2005). "The Koch Fractal Monopole Antenna: The Significant of Fractal Geometry in Determining Antenna Performance." Technical Report. Manchester, NH: Cushcraft Corporation.
[2] Simedra, P. (2004). "Design and Implementation of Compact Microstrip Fractal Antennas." Project Report. London, Ontario: The University Of Western Ontario.
[3] Vinoy, K.J. (2002). "Fractal Shaped Antenna Elements for Wide- and Multi-Band Wireless Applications." : Pennsylvania State University.
[4] Schulwitz, L. (2005). "The Small Koch Fractal Monopole: Theory, Design and Applications." : University of Michigan.
[5] Ramesh Garg, Prakash Bhartia, Inder Bahl and Apisak Ittipiboon (2001). "Microstrip Antenna Design Handbook". London: Artech House, Inc.