CHAPTER 2

DEVELOPMENT OF SELF-AFFINE FRACTAL ANTENNA
FOR MICS BAND WIRELESS APPLICATIONS

This chapter discusses the design of a self-affine fractal antenna for Medical Implants Communication Services (MICS) band wireless applications. The iterative function formulation, fabrication, and testing procedures are discussed.

2.1 INTRODUCTION

Generally, conventional microstrip antennas are a conducting patch, printed on a microwave substrate with ground plane on the other side. The features of microstrip antenna are low profile, light weight, less volume, easy to manufacture, conformal to host and operates for multiple bands with two polarizations. The inherent nature of microstrip antenna is to offer very narrow bandwidth, low efficiency, and low gain. It requires complex feed structures with many arrays. But compactness and bandwidth enhancement is usually needed for all practical applications.

In addition, present-day wireless markets require antennas which are small in size to meet the miniaturization requirements of wireless mobile systems. Thus, miniaturization and multiband operation are the major issues for any RF applications. For this reason, compact and broad band operations of microstrip antennas have greatly increased.
Han hua-Yang et al (2008) designed and investigated a modified aperture coupled fractal antenna on a RT duroid substrate. It is realized as multilayer and exposed a return loss of -41dB with change in frequency separation between iterations.

The generations of fractals were suitably expressed in a flexible manner through Iterative Function Systems (IFS). Fractals have no definite size and are usually composed of many copies of initial stage at various scales. Realization for Sierpinski gasket, Koch snowflake, Hilbert curve, Sierpinski gaskets, carpets, fractal trees and frequency selective systems are reported (Wener and Ganguly 2003). Fractal antennas are advantageous compared to wire antennas by providing strong radiation, directional characteristics and ease of fabrication and low cost (Jaggard 1990).

A dipole, monopole and loop shall be easily realized in terms of smaller version. This requires significant loading of elements which tends to complex structure. Fractals antennas are patterned after self-similar geometries which eliminates the loading with discrete components (Cohen 1997). A self-complementary Hilbert-curve fractal antenna with balun structure and loading, exhibits a return loss of -25 dB. The improvement in performance is achieved through meander line (Dau Chyrh et al 2008). A ceramic fractal antenna proposed by Bin, maintains a VSWR less than 2. The fractal antenna with a variety of relative permeability promotes a return loss of -19.23 dB (Bin Lin et al 2008).

A Uniplanar coupled Planar Inverted F Antenna (PIFA) is designed for Wireless Local Area Network (WLAN)/World wide Interoperability Microwave Access (WiMAX) to implement in laptop computers. It operates for 2.4 GHz, 5.2 GHz WLAN applications and 2.5 GHz, 3.5 GHz and 5.5 GHz WiMAX applications. PIFA coupling feed provides two wide
operating bands for WLAN applications. In PIFA antenna slots are embedded of length \( \frac{1}{4} \) for 4 GHz, through which band notching characteristics are achieved. These designs are developed on a FR4 substrate. The ground plane measures 260 mm in length, and 200 mm in width are chosen (Cheng-Tse Lee and Kin-Lu Wong 2009). The antenna designed for Wireless Fidelity (Wi-Fi) applications are grown on a Printed Circuit Board (PCB) is spline shaped. The substrate is an Arlon, which is analyzed to review the usefulness of the antenna in terms of Voltage Standing Wave Ratio (VSWR). The antenna operates for 2.448 GHz and 5.512 GHz (Leonard Lizzi et al 2009). The multiband performance is concerned, and there after it is frequently obtained by appropriately modifying the orientation of geometry and fitting radiation element. Examples of such a design procedure can be found in literature (Guo et al 2003a).

Low cost printed circuit board waveguide knowledge is employed to build up novel waveguide-fed microstrip antenna arrays. It consists of low profile, light weight and maintains high efficiency. The structure has two parts namely microstrip line and antenna layer. They are used to form 2 × 4 subarray of circularly polarized microstrip patch antennas (Amir Borji et al 2009a). Highly efficient antenna array for “Ku” band applications is presented. These structures are scheduled on pinnacle side, sub arrays of circularly polarized microstrip patches printed on a thin FR4 substrate are estranged from the ground plane with a slab of foam. It enhances their gain, and bandwidth (Amir Borji et al 2009 b).

The fractal geometries have been introduced in the design of antennas for dropping the size of antenna. It has been exposed that fractal wrought antennas, display characteristics that are linked with the geometric properties of fractals. Fractal geometries have two widespread properties such as space filling and self-similarity. The self-similarity properties of
certain fractals effect in a multi-band behavior. These properties of fractal antenna can be designed to receive and transmit over an extensive range of frequencies. The space filling properties of fractal makes it possible to diminish the size of antenna (Kwaon Kim et al 2002).

In fractal geometries, the isotropic self-similar scaling behaviour is commonly used to embrace the self-structure inside a large scale whereas the self-affine substance, is well defined in proposed structures. They have different scaling factors in each direction (Lapique et al 2002). In the midst of the proceedings of wireless communication systems and increasing significance of other wireless applications, wideband, and lowprofile antennas are in great demand for both commercial and military applications. Multiband and wideband antennas are desirable in personal communication systems, small satellite communication terminals, and other wireless applications (Tian Tiehong and Zhou Zheng 2003).

A novel fractal antenna which is irregular in shape is presented. The antennas are based on two-dimensional pseudorandom fractal bunch. The antenna presentation is studied by means of numerical analysis. The algorithm of generating fully reproducible uneven fractal structure is developed. The algorithm is based on hierarchical cluster to cluster aggregation computer model (Thouy and Jullien 1994). The current distribution on the Sierpinski gasket shows that most of the current density concentrates on the joints and edges of the different triangle clusters that make up the Sierpinski gasket (Puente et al 1998).

Several technical manuscripts have become visible to improve the bandwidth of microstrip antenna. The bandwidth of microstrip antenna increases when the thickness of the substrate is increased and by lowering the dielectric constant. Using the coupling resonant antenna is also the strong
technique to increase the bandwidth of microstrip antenna (Dubost et al 1986, Garg 2001, and Shackelford et al 2003). Fractal shaped antennas have a few unique characteristics that are linked to the geometrical properties of fractals.

The self similarity property of fractals makes them especially appropriate to design multi frequency antennas. Some fractal shapes have complex and convoluted shapes that can enhance radiation when used as antennas. For instance, some fractal loops can be designed to enclose a finite surface with an arbitrarily large perimeter. Certain monopoles can be designed to have an arbitrarily large length, although they can be considered to fit a given volume. Therefore, it is possible to design small antennas that occupy the same volume than other Euclidean counterparts, but much longer (Baliarda et al 2000, Best 2003, Werner et al 2003 and Zhu et al 2003).

In open literature, many techniques have been reported for a good candidate. This chapter addresses a self affine fractal geometry on a low cost, lossy substrate to solve the needs of frequency operating in MICS band wireless applications quantitatively.

2.2 SELF-AFFINE FRACTAL GEOMETRY - AN MINKOWSKI TYPE

Hermann Minkowski introduced Minkowski fractal first and later the geometries were defined by Strobl, Schwemer and many others (Strobl 1985, Schwemer 1991). The proposed geometry is a self-affine structure.

The structure consists of many groups of islands hidden behind the main geometry. It results in Minkowski self-affine fractal geometry. Figure 2.1 depicts affine transformation of the geometry.
2.2.1 Iterative Function Systems

The IFS were conveniently described by Michael Barnsley who formulated iterative function systems as the easiest way of representation of fractal geometry for a wide variety of structures such as Hilbert curve, Sierpinski gasket, Sierpinski carpet, and fractal tree (Barnsley 1993). These are based on the self-affine transformations.

The set and subset are assumed to be in anticlockwise direction for convenience.

Let \( W(A) \) be a set, where \( A \) is the initiator

\[
W(A) = \bigcup_{i=1}^{9} A_i \tag{2.1}
\]

where, \( W(A) \) is called as Hutchinson operator (Peitgen 1992) which is spanned by,
\[ w(A_1), w(A_2), \ldots, w(A_n) \quad (2.2) \]

where, \( n = 9 \) which is known as subsets of \( w(A) \) (equation 2.1).

Equation (2.2) holds true for the remaining subsets \( w(A_1, \ldots, A_n) \).

\[ W(A_i) = \bigcup_{i=1}^{9} A - (A_4 + A_5 + A_7 + A_9) \quad (2.3) \]

Repetition holds true for values of \( A_1, A_2, \ldots, A_n \) (except), \( A_4, A_5, A_7, A_9 \),

\[ W(A_1) = \begin{bmatrix} 0 \mid 0 \\ \frac{x}{3} \mid \frac{y}{3} \\ 0 \mid \frac{y}{3} \\ \frac{x}{3} \mid \frac{y}{3} \end{bmatrix} \quad (2.4) \]

\[ W(A_2) = \begin{bmatrix} \frac{x}{3} \mid 0 \\ \frac{2x}{3} \mid \frac{2x}{3} \\ 0 \mid \frac{y}{3} \\ \frac{x}{3} \mid \frac{y}{3} \end{bmatrix} \quad (2.5) \]

\[ W(A_3) = \begin{bmatrix} \frac{2x}{3} \mid 0 \\ \frac{y}{3} \mid \frac{2x}{3} \\ \frac{x}{3} \mid \frac{y}{3} \end{bmatrix} \quad (2.6) \]

\[ W(A_4) = \begin{bmatrix} \frac{x}{3} \mid \frac{y}{3} \\ 2x \mid \frac{2x}{3} \\ \frac{y}{3} \mid \frac{2y}{3} \\ \frac{x}{3} \mid \frac{2y}{3} \end{bmatrix} \quad (2.7) \]

\[ W(A_5) = \begin{bmatrix} \frac{x}{3} \mid \frac{y}{3} \\ \frac{2x}{3} \mid 0 \\ \frac{2x}{3} \mid \frac{y}{3} \\ \frac{x}{3} \mid \frac{y}{3} \end{bmatrix} \quad (2.8) \]

\[ W(A_6) = \bigcup_{i=1}^{9} A - (A_4 + A_6 + A_7 + A_9) \quad (2.9) \]

\[ W(A_7) = \begin{bmatrix} 0 \mid 0 \\ \frac{x}{9} \mid \frac{y}{9} \\ \frac{x}{9} \mid \frac{y}{9} \end{bmatrix} \quad (2.10) \]
Using the IFS coefficient, the remaining iterations are obtained from the initial geometry. The scaling factor of the self-affine geometry are given as

\[ W(A_{12}) = \begin{bmatrix} \frac{x}{9}, 0 \, \frac{2x}{9}, 0 \, \frac{2x}{9}, \frac{y}{9} \end{bmatrix} \] \tag{2.11}

\[ W(A_{13}) = \begin{bmatrix} \frac{2x}{9}, 0 \, \frac{x}{3}, 0 \, \frac{x}{3}, \frac{y}{9} \end{bmatrix} \] \tag{2.12}

\[ W(A_{15}) = \begin{bmatrix} \frac{x}{9}, \frac{y}{9} \, \frac{2x}{9}, \frac{y}{9} \, \frac{2x}{9}, \frac{y}{9} \end{bmatrix} \] \tag{2.13}

\[ W(A_{18}) = \begin{bmatrix} \frac{x}{9}, \frac{2y}{9} \, \frac{2x}{9}, \frac{y}{9} \, \frac{2x}{9}, \frac{y}{9} \end{bmatrix} \] \tag{2.14}

\[ W(A_{22}) = \bigcup_{i=1}^{9} A_{2i} - (A_{24} + A_{26} + A_{27} + A_{29}) \] \tag{2.15}

\[ W(A_{33}) = \bigcup_{i=1}^{9} A_{3i} - (A_{34} + A_{36} + A_{37} + A_{39}) \] \tag{2.16}

\[ W(A_{55}) = \bigcup_{i=1}^{9} A_{5i} - (A_{54} + A_{56} + A_{57} + A_{59}) \] \tag{2.17}

\[ W(A_{88}) = \bigcup_{i=1}^{9} A_{8i} - (A_{84} + A_{86} + A_{87} + A_{89}) \] \tag{2.18}

\[ D = \frac{\log 5}{\log 3} = 1.465 \] \tag{2.19}

where, \( D \) is a Hutchinson operator dimension (Falconer 1990).
The above equation symbolizes the class of fractals. Five copies of squares are obtained through repeated iteration scaled to one third, down from the set and subset. The outline is shown in Figure 2.1.

The basic geometry is called as initiator, a rectangular patch. The basic geometry is scaled down by a factor of three along the length, and three along the width which leads to nine rectangles. The ensuing rectangles are equal in dimension, as governed by IFS. The regions towards left and right shown in the diagram are eliminated thereby retaining the remaining five regions, and the process is repeated in succession. The method of IFS conveys that the volume reduction is achieved through these fractals.

2.3 SELF-AFFINE FRACTAL GEOMETRY FOR MICS BAND APPLICATIONS

2.3.1 Introduction

The growth of wireless systems, the demand in wireless telemedicine applications in health care and patient monitoring systems is increasing day by day. These MICS band antennas have been used for body sensor networks in order to monitor patients at remote area in order to provide better healthcare by transmitting physiological, and pathology parameters. The frequency intended for these MICS band applications are 402 MHz – 405 MHz. It incorporates the fractal antennas on wireless boards. The transfer of parameters shall be achieved through wireless boards. It is a store and forward concept by which tele-consultation to more than one doctor shall be obtained. Apart from that, a second opinion is also possible. The Federal Communication Commission (FCC) determines that the 402 MHz - 405 MHz frequency band meets the technical requirements compared to other available frequencies. Here, the study of self-affine fractal cantor at various iteration has been proceeded through simulation software Advanced Design
Systems (ADS) 2008. As a continuous factor, the effectiveness reduction is carried out to know the performance of candidate for MICS band wireless applications.

2.3.2 Generation of Self-Affine Fractal Cantor Antenna for MICS Band Applications

The self-affine antenna structure is developed on a FR4 substrate whose thickness is 1.6 mm, ε_r = 4.4 and tan δ = 0.01 with ground plane at the bottom of the substrate. Figure 2.2 depicts the various iterations of self-affine fractal geometry.

Figure 2.2  Generation of self-affine fractal antenna  (a) Initiator K0 (b) First iteration K1 (c) Second iteration K2 and (d) Third iteration K3
The patch antenna initially started with K0 measures 223 mm × 174 mm × 1.6 mm in dimension resonates at 405 MHz. Then, the initiator is iterated into segments governed by IFS up to K3 as revealed in Figure 2.2. The performance of the antenna at various iterations has been investigated using Agilent ADS momentum.

Figure 2.3 Simulated return loss of self-affine fractal antenna (a) Initiator K0 and (b) First iteration K1
Figure 2.4 Simulated return loss of self-affine fractal antenna
(a) Second iteration K2 and (b) Third iteration K3
Figures 2.3 and 2.4 depict a return loss of self-affine fractal antenna at various iterations. Table 2.1 and Table 2.2 correspond to the simulated values of self-affine fractal cantor antenna. The initiator resonates at 403 MHz with -41dB return loss ($S_{11}$). For an antenna, the simulated values are referred with respect to a reference level of $<-10$ dB which when converted to VSWR it is equivalent to 1.924 as per microwave theory and standard, the value of VSWR should be between 0 and 2. When return loss measured $<-10$ dB, can be accepted. For remaining iterations K1, K2 and K3 it exhibits 405 MHz, 406.6 MHz and 403 MHz with return loss of -15 dB, 35.5 dB and -40 dB respectively.

**Table 2.1** Simulated return loss of a self-affine fractal antenna for initiator and first iteration

<table>
<thead>
<tr>
<th>S.No</th>
<th><strong>K0</strong></th>
<th><strong>K1</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency in MHz</td>
<td>$S_{11}$ in dB</td>
</tr>
<tr>
<td>1</td>
<td>403</td>
<td>-41</td>
</tr>
</tbody>
</table>

**Table 2.2** Simulated return loss of a self-affine fractal antenna for second iteration and third iteration

<table>
<thead>
<tr>
<th>S.No</th>
<th><strong>K2</strong></th>
<th><strong>K3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency in MHz</td>
<td>$S_{11}$ in dB</td>
</tr>
<tr>
<td>1</td>
<td>404.6</td>
<td>-35.5</td>
</tr>
</tbody>
</table>
As number of iterations increase, the pillars like projections also increase from centre. This is governed by IFS and reveals the self-affine transformation of fractal geometry. A shift in frequency shall be visualized which reveals the electrical length of the original cantor which has increased simultaneously. Figure 2.5 depicts the prototype of a self affine fractal antenna. Figure 2.6 shows the measured return loss of a self-affine fractal antenna using network analyzer.

To evaluate the designed antenna, a few physiological parameters such as temperature, heart rate, and blood pressure is acquired using suitable sensors. They are fed into electronic gadgets to transfer the data through a Global System for Mobile communication (GSM) network. A rabbit processor is chosen which has an inbuilt GSM module (WCF 12) wireless compact flash card. The rabbit processor works on dynamic C platform,
where prerequisite senders, System Identification Mobile (SIM) is fed to have one to one communication. Figure 2.8 depicts the pictorial view of a rabbit processor, which is developed by Rabbit semiconductors.

![Graph](image)

**Figure 2.6** Measured return loss of self-affine fractal antenna for third iteration

In GSM module, the monopole antenna is detached and the developed prototype antenna is replaced. The physiological parameters are transferred using gadgets through a GSM network. The transferred data are collected using Rabbit processor GSM module. The data are visualized in Rabbit processor using inbuilt liquid crystal display.
Figure 2.7 Prototype of Rabbit processor

Figure 2.8 Prototype of third iterated self-affine fractal antenna with Rabbit processor
The Rabbit processor board is used to demonstrate the developed antenna which is capable of transmitting signals. Figure 2.7 depicts the prototype of Rabbit processor. Figure 2.8 depicts the Rabbit processor along with the developed prototype model used for transmission.

2.3.3 Results and Discussion

A self-affine fractal antenna measures 223 mm × 174 mm × 1.6 mm on a FR4 substrate. The substrate has a relative permeability 4.4, thickness 1.6 mm and loss tangent 0.02 has been tested using Agilent Vector Network Analyzer. The prototype exhibits wideband, starting from 370 MHz to 460 MHz. The bandwidth of self-affine fractal antenna is 90 MHz, and VSWR is almost equal to one. The self affine fractal geometry is etched using eight portion of ferric chloride and two portion of hydrochloric acid. The developed prototype has been validated using Rabbit processor by transferring physiological parameters.

2.4 SUMMARY

i) The resonant frequency selected are in terms MHz. The terms of free space wavelength, length and width measures 221.34 mm × 172.68 mm.

ii) The size of the initiator has increased due to lower design frequency in MHz. Thus, selection of resonant frequency in microwave range decreases the size of the initiator.

iii) The self-affine fractal antennas exhibit a wide bandwidth. The wide bandwidth is mainly due to the effect of fractal slots.
The slot like projections grow from iteration to another. Therefore, the total volume gets reduced.

iv) In the simulated values, the VSWR is almost equal to 1 and their ratios are 1.017:1, 1.432:1, 1.034:1 and 1.02:1 respectively.