CHAPTER 3

DEVELOPMENT OF SELF-AFFINE WIDEBAND
FRACTAL CANTOR ANTENNA FOR WIRELESS
APPLICATIONS

This chapter addresses the development of self-affine wideband fractal cantor antennas for wireless applications. The design issue is outlined in the introduction. Later, the chapter discusses a compact self-affine antenna and concludes with Multiple-Input-Multiple-Output antennas for Wireless Local Area Networks.

3.1 INTRODUCTION

An important alteration of Long Term Evolution (LTE) service is that it supports better mobile communication and quality of service compared to Global System for Mobile communications (GSM) and Universal Mobile Telecommunication System (UMTS). The proposed antenna also covers LTE standards at the same time. A vital prerequisite for these systems is to have a compact size with wide bandwidth in nature (Chaun-Ling Hu et al 2010). It is very important to Wireless Local Area Network (WLAN) with the aid of IEEE 802.11, to establish connectivity for devices within short range. For these connectivities, low profile antennas are mandatory. The designed antenna measures 35 mm × 31 mm on a FR4 substrate. It operates in triband which consists of meander like monopole antenna on one side and three
parasitic strips on the other side. Through these designs, 50% bandwidth is achieved by mutual coupling (Rong Lin Li et al 2007).

The designed antenna measures $18 \text{ mm} \times 7.2 \text{ mm} \times 0.254 \text{ mm}$ on a RT Duroid substrate. These antennas are tuned for Global Positioning Systems (GPS), Digital Communication Service (DCS-1800), International Mobile Telecommunications (IMT-2000) and WLAN handsets by varying the “s” strip, and the height of the antennas (Renzo 2009). Compact antenna designed for integrated mobile device, illustrates a multiband resonance with help of dual strips. It measures $60 \text{ mm} \times 36 \text{ mm}$. The designed antenna covers complex radiating meander structures and capacitive coupling (Liao 2010). Gianvittoria and Rahmat Sammi (2004) proposed a self-affine fractal geometry which is a Sierpinski based yagi antenna. This self-affine fractal geometry is intended to operate for “S” and “C” band wireless applications. The designed antenna is fabricated on a material whose dielectric constant is 2.2. To achieve stable radiation pattern, filters are used on one side of the substrate and the copper is removed on the other side. The antenna measure $30.5 \text{ mm} \times 29.8 \text{ mm}$ with reflector spacing of 8.89 mm.

In the last years, several design concepts were proposed by research scholars. The researchers designed the miniaturized compact antennas and it is achieved through slots, shorting pins, and folded geometries. These were to appear until the birth of fractal geometries. Fractal geometries are considered as the promising way of designing compact miniaturized antennas (Wang et al 2004, Khodaei et al 2008).

In fractal geometry, self-similar structures have paved way for size reduction when compared to the conventional loop antennas. Minkowski fractal is a good candidate for size reduction which are recognized for its compactness and miniaturization (Cohen 1995). Mutual coupling reduction is
achieved without altering the bandwidth by closely placing these structures (John Gianvittoria and Rahmat Samii 2002).

Sinha and Jain (2007) examined self-affine property of fractals and evaluated the multiband characteristics. They implemented these self-affine fractal antenna with microstrip feed line, on a substrate whose relative permeability is 2.2 and thickness is 1.5748 mm. The reasonable bandwidth is achieved through 3 mm air gap between the substrate and ground plane. A microstrip feed line on one substrate and the radiating element on the other substrate is realized to obtain these bandwidth. The finite ground plane measures a length of 85 mm × 85 mm with aperture coupling to cover frequency bands at 2.435 GHz, 4.885 GHz, and 10 GHz with 130 MHz, 580 MHz and 690 MHz bandwidth in that order. Also, the cost of RT-Duroid substrate is too high when compared to FR4 substrate.

Currently, higher bit rate transmission is required for wireless communication systems. The wireless system holds various multimedia services to uplift coverage, frequency reuse, low power and bandwidth efficiency. A Multi-Input Multi-Output (MIMO) system is considered as a capable solution to solve the problems with the increase in number of antennas (Gesbert et al 2003 and Kim et al 2006).

The channel capacity shall be increased without sacrificing spectrum efficiency, without additional transmitted power (Guterman et al 2004). The compact antenna elements have to be significantly arranged. For an MIMO system, the order of arrangement is performance of antenna, systems requirements, mutual coupling or isolation between the elements is an open issue (Naguib et al 1994, Chiu et al 2003, Xiang Zhou 2012 and chen et al 2012).
This chapter concentrates on the performance of self-affine fractal cantor antennas for wideband wireless applications. Later, the chapter deals with WLAN MIMO wireless applications. A detailed study of the generation of compact Minkowski type of fractal cantor antennas and their implementation on microstrip platform are evaluated. In a nutshell, the proposed work is presented in this category.

3.2 COMPACT SELF-AFFINE WIDEBAND FRACTAL CANTOR ANTENNA

This module opens with a discussion of preamble, followed by self-affine fractal geometry, design approach, fabrication, and testing.

3.2.1 Preamble

This section involves in designing a compact wide band fractal cantor antennas, for wireless applications such as LTE and WLAN operation. Presently, a mobile device capable of operating at multiband with small size is needed. This module deals with a compact antenna which covers a wideband of frequency.

In open literature, numerous techniques have been reported for a good candidate on a wide variety of substrates. Copious attempts have been made by research scholars and RF design engineers to improve the bandwidth and to reduce the size of the antenna elements.

This section aims at the appraisal of self-affine fractal geometry on a low cost and lossy substrate to solve the needs of wireless markets. The self-affine fractal geometry exhibits a good agreement of size reduction for microwave range of design frequency. The substrate FR4 is chosen for implementation which is cost effective.
3.2.2 Self-Affine Fractal Geometry

Self-affine fractal geometry is a class of fractal family. In antennas, self-affine fractal geometry finds a wide range of applications. The characteristics of self-affine fractal geometries are simplicity and compactness. Self-affine geometries are outsized classes of fractals. These geometries have the chattels that are closely self-affine. When these geometries are divided into N number of parts, each of these geometries is slender. The reflected editions of these geometries look inventive. Figure 3.1 portrays a self-affine transformation of fractal geometry.

![Figure 3.1 Generation of self-affine fractal geometry](image)
3.2.3 Iterative Function Systems

A convenient way of representing fractal geometry is described by Iterated Function Systems (IFS). Self-affine fractal set looks similar in all possible ways. In the proposed design, set and subset are assumed to be in anticlockwise direction for convenience.

Let \( W(A) \) be a set, where \( A \) is the initiator, and is given in equation (3.1). Equations (3.2) upto (3.37) describes the approach of IFS for the fractal geometry.

\[
W(A) = \bigcup_{i=1}^{6} A_i \quad (3.1)
\]

where, \( W(A) \) is called as Hutchinson operator (Peitgen 1992)

\[
W(A_1) = [(0,0), \left( \frac{x}{3}, 0 \right), \left( \frac{x}{3}, \frac{y}{2} \right), \left( 0, \frac{y}{2} \right)] \quad (3.2)
\]

\[
W(A_2) = \left[ \left( \frac{x}{3}, 0 \right), \left( \frac{2x}{3}, 0 \right), \left( \frac{2x}{3}, \frac{y}{2} \right), \left( 0, \frac{y}{2} \right) \right] \quad (3.3)
\]

\[
W(A_3) = \left[ \left( \frac{2x}{3}, 0 \right), (x,0), \left( \frac{y}{2} \right), \left( \frac{2x}{3}, \frac{y}{2} \right) \right] \quad (3.4)
\]

\[
W(A_4) = \left[ \left( 0, \frac{y}{2} \right), \left( \frac{x}{3}, \frac{y}{2} \right), \left( \frac{x}{3}, y \right), (0, y) \right] \quad (3.5)
\]

\[
W(A_5) = \left[ \left( \frac{2x}{3}, \frac{y}{2} \right), \left( \frac{x}{3}, y \right), \left( x, \frac{2x}{3}, y \right) \right] \quad (3.6)
\]

\[
W(A_6) = \left[ \left( \frac{2x}{3}, \frac{y}{2} \right), \left( \frac{x}{3}, y \right), \left( \frac{x}{3}, \frac{2x}{3}, y \right) \right] \quad (3.7)
\]

\[
W(A_{11}) = \bigcup_{i=1}^{6} A_i - A_{15} \quad (3.7)
\]
\[ W(A_{11}) = \begin{pmatrix} 0,0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \\ \frac{y}{9},0 & \frac{2x}{9},0 & \frac{2x}{9} & \frac{y}{4} \\ \frac{2x}{9},0 & \frac{x}{3},0 & \frac{x}{3} & \frac{2x}{9} & \frac{y}{4} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.8)

\[ W(A_{12}) = \begin{pmatrix} \frac{x}{9},0 & \frac{2x}{9},0 & \frac{2x}{9} & \frac{y}{4} \\ \frac{2x}{9},0 & \frac{x}{3},0 & \frac{x}{3} & \frac{2x}{9} & \frac{y}{4} \\ \frac{x}{3},0 & \frac{4x}{9},0 & \frac{4x}{9} & \frac{y}{4} \\ \frac{4x}{9},0 & \frac{5x}{9},0 & \frac{5x}{9} & \frac{y}{4} \end{pmatrix} \] (3.9)

\[ W(A_{13}) = \begin{pmatrix} \frac{2x}{9},0 & \frac{x}{3},0 & \frac{x}{3} & \frac{2x}{9} & \frac{y}{4} \\ \frac{x}{3},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.10)

\[ W(A_{14}) = \begin{pmatrix} \frac{0}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \\ \frac{x}{9},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.11)

\[ W(A_{16}) = \begin{pmatrix} \frac{2x}{9},0 & \frac{x}{3},0 & \frac{x}{3} & \frac{2x}{9} & \frac{y}{4} \\ \frac{x}{3},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.12)

\[ W(A_{22}) = \bigcup_{i=1}^{6} A_{2i} - A_{25} \] (3.13)

\[ W(A_{21}) = \begin{pmatrix} \frac{x}{3},0 & \frac{4x}{9},0 & \frac{4x}{9} & \frac{y}{4} \\ \frac{4x}{9},0 & \frac{5x}{9},0 & \frac{5x}{9} & \frac{y}{4} \\ \frac{5x}{9},0 & \frac{2x}{3},0 & \frac{2x}{3} & \frac{y}{4} \end{pmatrix} \] (3.14)

\[ W(A_{22}) = \begin{pmatrix} \frac{4x}{9},0 & \frac{5x}{9},0 & \frac{5x}{9} & \frac{y}{4} \\ \frac{5x}{9},0 & \frac{2x}{3},0 & \frac{2x}{3} & \frac{y}{4} \\ \frac{2x}{3},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \end{pmatrix} \] (3.15)

\[ W(A_{23}) = \begin{pmatrix} \frac{5x}{9},0 & \frac{2x}{3},0 & \frac{2x}{3} & \frac{y}{4} \\ \frac{2x}{3},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.16)

\[ W(A_{24}) = \begin{pmatrix} \frac{x}{3},0 & \frac{4x}{9},0 & \frac{4x}{9} & \frac{y}{4} \\ \frac{4x}{9},0 & \frac{5x}{9},0 & \frac{5x}{9} & \frac{y}{4} \\ \frac{5x}{9},0 & \frac{2x}{3},0 & \frac{2x}{3} & \frac{y}{4} \end{pmatrix} \] (3.17)

\[ W(A_{25}) = \begin{pmatrix} \frac{5x}{9},0 & \frac{2x}{3},0 & \frac{2x}{3} & \frac{y}{4} \\ \frac{2x}{3},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.18)

\[ W(A_{26}) = \begin{pmatrix} \frac{5x}{9},0 & \frac{2x}{3},0 & \frac{2x}{3} & \frac{y}{4} \\ \frac{2x}{3},0 & \frac{y}{9},0 & \frac{y}{9} & \frac{2x}{9} \\ \frac{y}{9},0 & \frac{x}{9},0 & \frac{x}{9} & \frac{y}{4} \end{pmatrix} \] (3.18)
\[ W(A_{3j}) = \bigcup_{i=1}^{6} A_{3j} - A_{35} \quad (3.19) \]

\[ W(A_{31}) = \begin{bmatrix} 2x \ 0 \ \frac{7x}{3} \ \frac{y}{9} \ \frac{y}{4} \ \frac{2x}{3} \ \frac{y}{4} \end{bmatrix} \quad (3.20) \]

\[ W(A_{32}) = \begin{bmatrix} \frac{7x}{3} \ 0 \ \frac{8x}{9} \ \frac{y}{9} \ \frac{y}{4} \ \frac{7x}{3} \ \frac{y}{4} \end{bmatrix} \quad (3.21) \]

\[ W(A_{33}) = \begin{bmatrix} \frac{8x}{9} \ 0 \ | x,0 | \ x,\frac{y}{3} \ 0 \ y,\frac{y}{4} \end{bmatrix} \quad (3.22) \]

\[ W(A_{34}) = \begin{bmatrix} 2x \ y \ 2x \ y \ \frac{7x}{3} \ \frac{y}{9} \ \frac{y}{4} \ \frac{2x}{3} \ \frac{y}{2} \end{bmatrix} \quad (3.23) \]

\[ W(A_{35}) = \begin{bmatrix} \frac{8x}{9} \ y \ 8x \ y \ | x,\frac{y}{3} \ 0 \ y,\frac{y}{4} \end{bmatrix} \quad (3.24) \]

\[ W(A_{36}) = \bigcup_{i=1}^{6} A_{3i} - A_{35} \quad (3.25) \]

\[ W(A_{41}) = \begin{bmatrix} 0,\frac{y}{3} \ x,0 \ | x,\frac{3y}{9} \ y,\frac{3y}{9} \end{bmatrix} \quad (3.26) \]

\[ W(A_{42}) = \begin{bmatrix} x,0 \ | 2x,0 \ 2x,\frac{3y}{9} \ y,\frac{3y}{9} \end{bmatrix} \quad (3.27) \]

\[ W(A_{42}) = \begin{bmatrix} \frac{x}{9} \ 0 \ | 2x,0 \ 2x,\frac{3y}{9} \ y,\frac{3y}{9} \end{bmatrix} \quad (3.28) \]
Using the IFS coefficient, the remaining iterations are obtained from the initial geometry. The scaling factor of the self-similar geometries are given in equation (3.38), as

\[
D = \frac{\log 5}{\log 3} = 1.464
\]  

where, \( D \) is called as Hausdorff dimension (Falconer 1990).
From the above equation, it is apparent that five copies are retained, which is scaled down by a rectangle of three along its width and length. The constant D is equal to 1.464 which is the minimum value of geometry. The scaling factor can be implemented to the maximum in the initial geometry. Later, the dimension of the fractal geometry does not exist.

3.2.4 Generation of Self-Affine Compact Fractal Cantor Antenna for Wideband Wireless Applications

The self-affine fractal geometry discussed earlier, is considered for designing WLAN antennas. The corresponding IFS accepts designing WLAN antennas.
Figure 3.2  Generation of self-affine fractal antenna (a) Initiator K0 (b) First iteration K1 (c) Second iteration K2 and (d) Third iteration K3 (All dimensions are in mm)

Table 3.1 Size of fractal geometry

<table>
<thead>
<tr>
<th>S.No</th>
<th>Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a 38.734  b 28.757  c 12.9  d 5</td>
</tr>
<tr>
<td>2</td>
<td>e 4  f 4  g 35  h 0.569</td>
</tr>
<tr>
<td>3</td>
<td>i 0.5  j 2.276  k 0.099  l 29.979 × 13.525</td>
</tr>
</tbody>
</table>

The fractal cantor antenna, developed on a microstrip platform for frequency operating at 2.4 GHz, which is intended for WLAN wireless application is chosen. Figure 3.2 highlights the various stages of self-affine fractal antennas. The corresponding optimized values are tabulated in Table 3.1. The alphabets “a to l” refer to optimized dimensions of fractal geometry. The design is full-fledged on a FR4 substrate whose relative dielectric constant is 4.4, loss tangent = 0.02, and thickness 1.6 mm. The initiator has divided itself into a number of iterations, governed by the IFS. The antenna measures 29.979 mm × 13.525 mm × 1.6 mm thickness. These structures are simulated, fabricated, and measured. The geometry looks similar in all possible views. It projects the self-affinity of fractal geometry. The slots like projections raise from the centre towards the edges, and it has a control over the bandwidth.
Figure 3.3 Simulated return loss of self-affine fractal geometry
(a) Initiator K0 (b) First iteration K1 (c) Second iteration K2 and (d) Third iteration K3

Figure 3.3 portrays simulated return loss of a self-affine fractal geometry. The corresponding values are tabulated in Tables 3.2 and 3.3. Initially, the designed patch K0, resonates at 2.396 GHz ≤ 2.45 GHz with $S_{11} < 14.25$ dB. VSWR obtained by using coaxial feed technique for this geometry is 1.48%. Followed by that, the initiator K0 is iterated into segments from K1 to K3 as governed by the iterative function coefficient. This results in various stages of geometry and a fractal geometry which resembles the initiator is obtained. The consonant, a self-affine fractal geometry is depicted in the above figure. The above Figure 3.2 reveals the
self-affine property of fractal geometry. The first column represents the centre frequency, the second column represents the return loss (S11 in dB), and the third column represents the bandwidth. From all the simulated values, it is pragmatic that size reduction of 16.13%, 16.84% and 15.7% are achieved in all iterations namely K1, K2, and K3 respectively.

Table 3.2  Simulated return loss of Initiator K0 and First iteration K1 of self-affine antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>K0</th>
<th>K1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency in GHz</td>
<td>S11 in dB</td>
</tr>
<tr>
<td>1</td>
<td>2.4</td>
<td>-14.25</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>-5.17</td>
</tr>
<tr>
<td>3</td>
<td>3.7</td>
<td>-17.668</td>
</tr>
</tbody>
</table>

Table 3.3  Simulated return loss of Second iteration K2 and Third iteration K3 of self-affine antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>K2</th>
<th>K3</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Frequency in GHz</td>
<td>S11 in dB</td>
</tr>
<tr>
<td>1</td>
<td>1.7</td>
<td>-17.75</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>-13.28</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>-11.6</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2.71</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>2.769</td>
</tr>
</tbody>
</table>
The graph gives a clear idea that the return loss $<-20$ dB approximately with wideband characteristics is visualized in all the iterations with multiple resonances. Figures 3.4 and 3.5 relate the graph showing the number of resonances which is shown by the self-affine structure along x axis, and resonant frequency in y axis. The initiator, first iteration, and second iteration brings out three resonances for the resonant frequencies which is obtained and is shown in the above tables. The third iteration exhibits five resonances starting from 1.8 GHz to 2.769 GHz as shown in Figure 3.5.

![Graph](image)

**Figure 3.4** Number of resonances exhibited by self-affine structure for $K0$, $K1$ and $K2$ iterations

The return loss of self-affine fractal cantor antenna values are within the microwave standard. The number of resonance has been increased from second to third iterations. These increases are mainly due to the fractal...
structure. The transmission line has taken a longest electrical path, so that the signals have penetrated along the edges of the conductors. Figure 3.6 demonstrates the simulated gain of third iterated fractal antenna. The gain is shown as maximum at the lower values of resonance and simultaneously a gradual decrease occurs, when there is increase in frequency. The variation gained is mainly due to the elimination of conductor area. At design frequency, the self-similar antenna divulges a gain of 5.05 dBi. Figure 3.7 represents the current plot of third iterated self-affine fractal cantor antennas. These antennas are obtained in Agilent Advanced Design Systems (ADS) display window. Figure 3.8 represents the prototype of third iterated fractal cantor antennas.

![Graph showing S11 in dB versus Number of Resonances](image)

**Figure 3.5**  Number of resonances exhibited by self-affine structure for K3 iterations
3.2.4.1 Consequence of slots on the fractal geometry

The slots on the fractal geometries are governed by the iterative coefficients along with \( x \) and \( y \) coordinates. The structure is scaled down to the maximum number of possible iterations so that the volume of the geometry gets reduced by maintaining its individuality. The antenna design on these concepts, tends to reduce in size, and a occupies less space. When visualized, the design of fractal antennas using these self-affine transformations, looks similar on all the subsets.

![Graph showing gain in dB vs frequency in GHz]

**Figure 3.6** Simulated gain of the proposed self-affine cantor antenna
Figure 3.7 3D Geometry of third iterated self-affine fractal cantor antenna

Figure 3.8 Prototype of third iterated self-affine fractal cantor antenna
Figure 3.9 Measured return loss of a third iterated self-affine fractal cantor antenna

Table 3.4 Measured return loss of a self-affine fractal cantor antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Frequency in GHz</th>
<th>S11 (dB)</th>
<th>f₁ in GHz</th>
<th>f₂ in GHz</th>
<th>BW in MHz</th>
<th>% BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.864</td>
<td>-22.584</td>
<td>1.761</td>
<td>1.95</td>
<td>189</td>
<td>10.14</td>
</tr>
<tr>
<td>2</td>
<td>2.496 ± 2.5</td>
<td>-27.009</td>
<td>2.391</td>
<td>2.57</td>
<td>179</td>
<td>7.17</td>
</tr>
<tr>
<td>3</td>
<td>2.1377</td>
<td>-30.729</td>
<td>2.066</td>
<td>2.328</td>
<td>262</td>
<td>12.25</td>
</tr>
<tr>
<td>4</td>
<td>2.177</td>
<td>-22.584</td>
<td>2.584</td>
<td>2.654</td>
<td>70</td>
<td>3.22</td>
</tr>
<tr>
<td>5</td>
<td>2.833</td>
<td>-22.584</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.5 Calculated Voltage Standing Wave Ratio and reflection coefficient of a self-affine fractal cantor antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Frequency in GHz</th>
<th>S11 (dB)</th>
<th>VSWR</th>
<th>VSWR in ratio</th>
<th>Reflection coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.864</td>
<td>-22.584</td>
<td>1.16</td>
<td>1.16:1</td>
<td>0.074</td>
</tr>
<tr>
<td>2</td>
<td>2.496 ± 2.5</td>
<td>-27.009</td>
<td>1.093</td>
<td>1.093:1</td>
<td>0.044</td>
</tr>
<tr>
<td>3</td>
<td>2.1377</td>
<td>-30.729</td>
<td>1.0591</td>
<td>1.0591:1</td>
<td>0.029</td>
</tr>
<tr>
<td>4</td>
<td>2.177</td>
<td>-22.584</td>
<td>1.16</td>
<td>1.16:1</td>
<td>0.074</td>
</tr>
</tbody>
</table>

Figure 3.10 Comparison of simulated and measured return loss of a third iterated self-affine fractal cantor antenna
Figure 3.11 Simulated radiation patterns of self-affine fractal cantor antenna (E₀, co pol and E₀, cross pol)

1.8 GHz
Figure 3.12 Simulated radiation patterns of self-affine fractal cantor antenna ($E_\text{co pol}$ and $E_\text{cross pol}$)
Figure 3.13 Measured radiation pattern of self-affine fractal cantor antenna ($E_\| \text{co pol}$ and $E_\varphi \text{cross pol}$)
3.2.5 Results and Discussion

The simulated self-affine fractal cantor antenna has been fabricated with eight portion of ferric chloride and two portion of dilute hydrochloric acid on a FR4 substrate. The thickness of the substrate is 1.6 mm, \( \varepsilon_r = 4.4 \), \( \tan \delta = 0.02 \) and the optimized antenna size is 38.734 mm × 28.757 mm × 1.6 mm.

The resonant frequency of the proposed antenna is listed in Table 3.4. The resonant frequencies are obtained using Agilent vector network analyzer E5062A. The analyzer measures from 300 KHz to 3 GHz. The return loss (S11) < -10 dB as reference is obtained using Figure 3.9. For a planar antenna, the port S11 parameters are sufficient to evaluate the performance of the prototype. The simulated and measured return loss matches as shown in Figure 3.10.

Initially, simulations are computed at mesh, to evaluate the fractal geometry upto 6 GHz sample size which is low mesh in Agilent momentum.
Later, the simulations are incorporated using high mesh. The third iterated structure is computed and fabricated which convolves for all possible combination of mesh.

To start with, the resonant frequency is 1.864 GHz with 10.14% impedance bandwidth [about $\lambda_0 = 16.09 \text{ cm (0.1609 m / 160.9 mm)}$; 0.2407 $\lambda$]. The second resonant frequency is 2.496 GHz with 7.17% impedance bandwidth [about $\lambda_0 = 12.01 \text{ cm (0.120 m / 120.01 mm)}$; 0.3225 $\lambda$]. The third resonant frequency is 2.1377 GHz with 12.25% impedance bandwidth [about $\lambda_0 = 14.033 \text{ cm (0.1403 m/140.38 mm)}$; 0.275 $\lambda$] is reported.

The VSWR of the resonant frequencies are listed in Table 3.5. The VSWR and reflection coefficient are calculated using the return loss. From the table, it is found that the values are within microwave standards. The VSWR is almost equal to one. The reflection coefficient is minimum. At design frequency, the gain of the antenna is 1.97 dBi.

The prototype eliminates the complications which are involved in tuning the main patch, due to which coaxial feed technique is adopted. A few comparisons are listed in the survey with which the proposed self-affine fractal cantor antenna is displayed in Table 3.6. The model on a lossy low cost substrate is realized which will serve the current trends. The prototype designed for WLAN applications has a tendency of crowning wideband wireless applications which include ISM band, Bluetooth IEEE 802.11, IEEE802.15, Personal Communication Service (PCS 1900), International Mobile Telecommunication (IMT 2000), GSM lowerband, DCS, Universal Mobile Telecommunication System (UMTS 2100), Worldwide Interoperability for Microwave Access (WiMAX), Wireless Wide Area Network (WWAN) and LTE(2300/2500) fulfills the requirements of wireless standards and applications.
<table>
<thead>
<tr>
<th>S.No</th>
<th>References</th>
<th>Substrate/Size</th>
<th>Frequency in GHz/Bandwidth/Return loss</th>
<th>Mode/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A Compact Broadband Planar Antenna for GPS, DCS-1800, IMT-2000, and WLAN applications</td>
<td>FR4 Size: 35 mm × 31 mm</td>
<td>Triband, 50% bandwidth</td>
<td>1. Mutual Coupling 2. Monopole and three parasitic strips</td>
</tr>
<tr>
<td>2</td>
<td>A Hybrid Prefractal Three band Antenna for Multistandard Mobile Wireless Applications</td>
<td>RT Duroid Size: 18 mm × 7.2 mm × 0.254 mm</td>
<td>Dual band</td>
<td>Monopole antenna</td>
</tr>
<tr>
<td>3</td>
<td>A compact planar multiband antenna for integrated mobile devices</td>
<td>FR4 Size: 60 mm × 36 mm × 0.8 mm</td>
<td>Multiband</td>
<td>Dual strips complex radiating meander structures and capacitive coupling</td>
</tr>
<tr>
<td>4</td>
<td>Fractal antennas: A Novel Antenna Miniaturization Technique, and Applications</td>
<td>RT Duroid Size: 30.5 mm × 29.8 mm with reflector spacing of 8.89 mm</td>
<td>S and C band</td>
<td>Copper on one side is removed and filters are used</td>
</tr>
<tr>
<td>5</td>
<td>A Self-Affine Fractal Multiband Antenna</td>
<td>RT Duroid and thickness 1.5748 mm Size: 85 mm × 85 mm</td>
<td>2.435 GHz, 4.885 GHz, and 10 GHz with 130 MHz, 580 MHz and 690 MHz</td>
<td>1. 3mm air gap between the substrate and ground plane, 2. Aperture coupling</td>
</tr>
<tr>
<td>6.</td>
<td>Proposed self-affine fractal cantor antenna</td>
<td>FR4 substrate Size: 38.734 mm × 28.757 mm × 1.6 mm</td>
<td>1.864 GHz, 2.496 GHz, 2.1377 GHz and 2.177 GHz</td>
<td>Coaxial feed technique</td>
</tr>
</tbody>
</table>
3.2.6 Self-Affine Compact Antennas for Dual band Wireless Local Area Network Multiple-Input Multiple-Output Wireless Applications

Figure 3.15 reveals schematic arrangement of various systems, which operates for Single-Input Single - Output (SISO), Single- Input Multiple Output (SIMO), Multiple- Input Single- Output (MISO), and Multiple- Input Multiple- Output (MIMO) respectively.

![Schematic arrangements of Various Input-Output antennas](image)

Figure 3.15 Schematic arrangements of Various Input-Output antennas
Figure 3.16 Self- affine compact fractal antennas for Wireless Local Area Network Multiple-Input Multiple- Output systems

Figure 3.17 Simulated return loss of a self- affine compact fractal antennas for Wireless Local Area Network Multiple-Input Multiple - Output systems
In wireless systems, the need for compact array capable of acquainting dual band is essential for MIMO wireless system. WLAN MIMO antenna is one system, which needs dual input, for signal propagation. This wireless system necessitated in realizing a self-affine fractal antenna in the form of an array. The optimized geometry discussed in the section 3.2.2, is viewed as 2 × 1 arrays. The input to the two elements is fed through a coaxial feed technique. Figure 3.16 interprets a dual input array, spaced at a distance of 0.75λ between the first element, and the second element. The background in black color with yellow line represents a finite ground plane. The red color shown in the centre of the figure is the main radiating element.

Figure 3.17 reveals the simulated return loss of self-affine compact fractal antennas for WLAN MIMO systems. The graph shown in green and blue colors are the two resonant frequencies exhibited by the structure. There is a slight deviation for the second structure about 70 MHz and almost same at the other frequencies. The array band rejects signals from 2.48 GHz to 2.78 GHz and has a return loss of -23 dB at 2.35 GHz and -21 dB at 2.9 GHz respectively.

3.3 SUMMARY

i) The self-affine fractal geometry designed for WLAN wireless applications are full-blown on a lossy substrate whose relative dielectric constant is 4.4, loss tangent = 0.02, and the thickness of the substrate is 1.6 mm. The optimized antenna measure 38.734 mm × 28.757 mm × 1.6 mm. These antennas are compact when compared to the manuscripts presented in the survey.
ii) Initially, the design is evaluated intentionally for the performance of the patch antenna /initiator using coaxial feed technique. The initiator is segmented into subsets. They are governed by IFS for first, second, and third iterations. The antennas admit a volume reduction from one stage to another. Therefore, the antennas maintain its uniqueness.

iii) The simulated structure proclaims a miniaturization of 16.845% for second, and 15.719% for third iterations respectively. The shift in resonant frequency and lowering of return loss were observed in all the iterations. It is chiefly done to attain the outcome of lengthy discontinuous transmission line. These lines occur due to IFS of fractal geometry.

iv) In preamble section, the appraisal of various design issues, and techniques which is involved in antenna design has been briefed. The self-affine prototype model, with simple coaxial feed technique is presented. The monopole antenna considerably increases the length of transmission feed, with main radiating element. The complications addressed in the survey are eliminated in the proposed structure.

v) The self-affine fractal antenna parameters is measured and tabulated. For WLAN applications, it is observed that VSWR and reflection coefficient values are maintained within the microwave standard. All the resonances undergone by the antenna is within the verge range of VSWR, and the reflection coefficient. The antenna presents a multiplicity of resonance, covering the adjacent frequency bands. It is due to the innate of the fractal geometry.
vi) The radiation patterns are measured in an anechoic chamber of 8 m × 4 m × 4m, which is rectangular. The radiation patterns of electric and magnetic fields are calculated using Agilent Vector Network Analyzer N5230A. The pyramidal horn antenna operates from 450 MHz to 6 GHz which is chosen as standard antenna. The prototype of novel antenna is assumed as reference antenna.

vii) The measurements are obtained for E_r and E_θ planes which correspond to co polarization, and cross polarization. It is pragmatic that radiation characteristics of antenna has directional pattern with a gain of 1.97 dBi. The patterns with variations along the edges are visualized; due to a lossy substrate.

viii) Simulation treatment has been given for WLAN MIMO systems in which simulated return loss is presented.