CHAPTER 4

DEVELOPMENT OF A USER DEFINED

FRACTAL ANTENNA

In this chapter a newly shaped fractal geometry using PSO and BFO with curve fitting is presented. The aim of using these biologically inspired optimization techniques is to find the geometrical descriptors of the antenna for the required user defined frequency. In order to assess the effectiveness of the presented method, a set of representative simulations had done and the results were compared with the measurements from experimental prototypes fabricated as per the design specifications obtained from the optimization procedure. The antenna characteristics have been studied using extensive numerical simulations and were experimentally verified.

4.1 Introduction

The inspired combination of fractal geometry with the electromagnetic theory has led to the development of a new class of antennas, the fractal antennas [89]. In the quest for compact and multiband antennas, fractals have played a major role and several fractal antennas have been studied extensively in recent studies [102]. Fractal antennas are extensively utilized in wireless communication systems by exploiting their low-profile features [49], [78]. Fractal antennas use the self-similarity property of fractal geometries to resonate the antenna at a number of frequency bands [21], [24]. Whereas, in order to be a useful radiator, it is necessary for the fractal antennas to resonate at user-defined frequencies. However, some techniques have been
proposed to shift the resonant frequencies of the fractal shaped antennas, but it is a challenging task to design the fractal antenna shape according to user-defined frequencies. The challenge is to determine the geometric parameters of the antenna, such as the antenna dimensions and the feed position, to achieve the best design that satisfies a certain criterion. In recent years, many efforts have been expanded on the parametric study of various fractal antennas. As a result, irregular structures are gaining popularity due to their ability to achieve large bandwidth or multi-band operation [35], [63], [118]. But, these studies are not systematic and the conclusions are highly dependent on the antenna under investigation. Consequently, a trial-and-error process is inevitable in most fractal antenna designs [116], [169]. Over the years, biologically inspired computational techniques have gained popularity among scientists in every branch of engineering. Scientists have tried various techniques such as the artificial neural network, Particle-Swarm Optimization, the genetic algorithm (GA), bacteria-foraging optimization (BFO), and many others for finding an easy solution to their problem. The robustness of these techniques has been tested in problems encompassing every engineering field. For the last decade or so, microwave engineers have frequently used these techniques [128]. However, available studies have shown lengthy optimization procedures for such type of designs. It is interesting to find that evolutionary algorithms (EAs), such as PSO and BFO are also used in planar antenna design. The PSO’s simplicity, ease of implementation, and flexibility make it extremely appealing for multi-dimensional electromagnetic designs [105]. BFO has drawn the attention of researchers and engineers because of its efficiency in solving real-world optimization problems arising in several application areas. The PSO and BFO are used in conjunction with the numerical electromagnetic solver and are found to be a revolutionary approach to antenna design and optimization. This
procedure was adopted to bypass the repeated use of the simulator for analysis of the fractal structure. It needs hundreds of simulations in order to find an optimized structure of the antenna to resonate at user-defined frequencies [65], [66].

This work demonstrates design and fabrication of new fractal antenna using PSO and BFO algorithms, for wireless communication and their application in health care. Telemedicine facilitates the provision of medical aid from a distance. Decision makers in the healthcare industry are shifting to mobile and wireless technology, to improve the quality of their patient care in critical applications [107]. Correct and timely transmission of medical data and information is necessary for the safety and effectiveness of both wired and wireless medical systems [37], [147]. In recent years, various Electromagnetic simulation software are available for designing of fractal antennas, amongst, the one of the powerful electromagnetic simulation software is IE3D. In this work full wave IE3D simulator was used to predict the performance of antenna.

4.2 Design Implementation

New fractal geometry for patch antenna is presented in this work. Figure 4.1 shows the zero, first and second iteration of the proposed antenna structure. Fractal antenna of different iteration orders can be designed by dropping same structured elements on the patch, whose scale factor is 1/3 without changing the physical parameters of the antenna. In this presented work only the first and the second iterations are considered since high order iterations do not make significant effect on antenna properties. The antenna is designed on FR4 substrate with dielectric constant, $\varepsilon_r = 4.4$. A 50Ω CPW fed transmission line which consists of a single strip is used to feed the antenna. Two finite ground planes with the same size are placed symmetrically at both sides of CPW line. The patch size is characterized by the length
$L$, width $W$ and thickness, $h$. The dimensional parameters of the proposed antenna are detailed in Table. 4.1. There is a technique to produce the fractals called initiator-generator construction. This technique begins with a specified initiator, and a generator which is applied repeatedly in a lower scale to form the fractal geometries [23], [24].

Table 4.1 Dimensional Parameters of Proposed Antenna

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant, $\varepsilon_r$</td>
<td>4.4</td>
</tr>
<tr>
<td>Width of the antenna, $W$</td>
<td>24 mm</td>
</tr>
<tr>
<td>Width of feed strip</td>
<td>3 mm</td>
</tr>
<tr>
<td>Gap between strip and ground plane</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Space between patch and ground plane, $g$</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Length of ground plane, $L_p$</td>
<td>21.6 mm</td>
</tr>
<tr>
<td>Width of ground plane, $W_p$</td>
<td>31.5 mm</td>
</tr>
</tbody>
</table>

Figure 4.1 Geometry of the proposed fractal antenna (a) zero iteration (b) first iteration (c) second iteration
4.2.1 IFS Algorithm for Fractal Geometry

An iterative function system (IFS) can be effectively used to generate the standard fractal geometry. A set of affine transformations forms the IFS for its generation [21, 22]. The transformations for different iterations can be achieved using Equation 4.1.

\[
\begin{pmatrix}
X \\
Y
\end{pmatrix} = \begin{pmatrix}
a & b \\
c & d
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \begin{pmatrix}
e \\
f
\end{pmatrix}
\] (4.1)

where a, b, c, d, e and f are real numbers, such that a, b, c and d control rotation and scaling, while e and f control linear translation. The transformations to obtain the segments of the generator are:

\[
\begin{pmatrix}
x' \\
y'
\end{pmatrix} = \begin{pmatrix}
\frac{1}{3} & 0 \\
0 & \frac{1}{3}
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix}
\] (4.2)

\[
\begin{pmatrix}
x' \\
y'
\end{pmatrix} = \begin{pmatrix}
\frac{1}{3} & 0 \\
0 & \frac{1}{3}
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \begin{pmatrix}
0 \\
\frac{2}{3}
\end{pmatrix}
\] (4.3)

\[
\begin{pmatrix}
x' \\
y'
\end{pmatrix} = \begin{pmatrix}
\frac{1}{3} & 0 \\
0 & \frac{1}{3}
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \begin{pmatrix}
\frac{2}{3} \\
\frac{2}{3}
\end{pmatrix}
\] (4.4)

\[
\begin{pmatrix}
x' \\
y'
\end{pmatrix} = \begin{pmatrix}
\frac{1}{3} & 0 \\
0 & \frac{1}{3}
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \begin{pmatrix}
\frac{2}{3} \\
0
\end{pmatrix}
\] (4.5)

where \(w_1, w_2, w_3\) and \(w_4\) are set of affine linear transformations, and let \(M\) be the initial geometry then the generator is obtained as:
This procedure can be repeated for all higher iterations of the structure. Scale factors in these transformations are such that they lead to a self-similar structure, a fact that is visually apparent from Figure 4.1. The similarity dimension can be interpreted as a measure of the space filling properties and complexity of the fractal shape. The fractal similarity dimension is given by the Equation 4.7, where ‘n’ is the total number of distinct copies and ‘r’ is the scale factor of the consecutive iteration. The similarity dimension of the geometry can, thus, be calculated as [158]:

$$D = \frac{\log n}{\log \frac{1}{r}} = \frac{\log 4}{\log 3} = 1.261$$  \hspace{1cm} (4.7)

### 4.2.2 Curve Fitting Implementation

The MATLAB software has been used for curve fitting method to form a relationship between the design parameters \((h, L)\) and the corresponding resonant frequency \((f)\) of the proposed fractal geometry. In case of fractal geometries their resonant properties depend on the dimensions of the structure. EM simulator has been used to generate data sets by varying the height and length of the antenna and after applying these values, following equation was obtained that represents the mapping of resonant frequency with these design parameters:

$$f = (0.063 h^2 - 0.001318 L^2 - 0.8472 h + 0.03632 L + 7.212)$$  \hspace{1cm} (4.8)

### 4.2.3 PSO Implementation

The basic concept of PSO lies in accelerating each particle toward its pbest and the gbest locations, with a randomly weighted acceleration at each time step as shown in Figure 4.2 [66, 71]. The role of the PSO was to find the optimized values of the length and height which defines the best fractal structure for the specific frequency of operation. These two parameters were defined with suitable lower and
upper bounds that gives two-dimensional solution spaces for which PSO searched for the optimal parameters of the proposed fractal structure. Then a fitness function was developed that gives a single number after taking the values of these parameters [64-66]. The following fitness function was formed to find the structure of the fractal geometry to work at the user defined frequency.

\[
\text{Fitness function} = (5.8 - f)^2
\]  

(4.9)

The instantaneous frequency \( f \) was developed using curve fitting method.

Figure 4.2 Basic concept of PSO

The particles position can be modified according to the following equations [128]:

\[
S_{N+1} = S_N + V_{N+1},
\]

(4.10)

\[
V_{N+1} = w V_N + c_1 r_1 (P_{\text{best}} - S_N) + c_2 r_2 (g_{\text{best}} - S_N)
\]

(4.11)

where \( V_N \) is the particle velocity; \( S_N \) is the particle displacement, \( P_{\text{best}} \) is particle best position; \( g_{\text{best}} \) is global best position, \( w \) is inertial weight. On completion of the iterative process, by terminating the optimizer iteration when it reaches the global margin of \( 2 \times 10^{-4} \), the PSO produces the optimized values of the two parameters \( h \) and
For the present problem, the input parameters taken for PSO are detailed in Table 4.2 and the pseudo code for the PSO is presented Figure 4.3

Table 4.2 Input parameters of PSO.

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Population size</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Inertial weight, $w$</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>Acceleration terms, $c_1$ and $c_2$</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Random numbers, $r_1$, $r_2$</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>Number of iterations</td>
<td>100</td>
</tr>
</tbody>
</table>

For each particle
{
    Initialize particle
}

Do until maximum iterations or minimum error criteria
{
    For each particle
    {
        Calculate Data fitness value
        If the fitness value is better than pBest
        {
            Set pBest = current fitness value
        }
        If pBest is better than gBest
        {
            Set gBest = pBest
        }
    }
    For each particle
    {
        Calculate particle Velocity
        Use gBest and Velocity to update particle Data
    }

Figure 4.3 Pseudo code for the PSO [128]
4.2.4 BFO Implementation

In the BFO optimization technique variable need to optimize can take as the location of bacterial in the search. The main purpose of the BFO in this case is to find the optimized values of the length of the antenna \( (L) \) and height of substrate \( (h) \) that defines the best fractal geometry to make it resonate on required frequency. The goal of parameter estimation is to find the best values for a set of model parameters. In order to start the BFO process these parameter \( (h, L) \) was initialized with suitable lower and upper bound that defines a solution space in which the BFO searches for the optimal design parameter of the geometry. The input variables of BFO for the proposed antenna are detailed in Table 4.3 and pseudo code of BFO algorithm [109] is given in Figure 4.5. The fitness function for the present problem is given by Equation 4.12.

\[
\text{Fitness function} = (5.8 - f)^2
\]

(4.12)

Where \( f \) is the processed output from cost function, corresponding to the required frequency of the antenna.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Details of Parameters</th>
<th>Values of Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S )</td>
<td>Total number of bacteria in the population</td>
<td>10</td>
</tr>
<tr>
<td>( N_c )</td>
<td>Number of chemotactic step</td>
<td>25</td>
</tr>
<tr>
<td>( N_s )</td>
<td>Swimming length</td>
<td>4</td>
</tr>
<tr>
<td>( N_{re} )</td>
<td>Number of reproduction steps</td>
<td>4</td>
</tr>
<tr>
<td>( N_{ed} )</td>
<td>Number of elimination-dispersal events</td>
<td>4</td>
</tr>
<tr>
<td>( P_{ed} )</td>
<td>Elimination-dispersal probability</td>
<td>0.25</td>
</tr>
</tbody>
</table>

4.2.5 Design Steps of Proposed Antenna

The step-by-step design procedure may be summarized as follows:

Step1. Input the desired frequency.
**Step 2.** Optimization loop, with the use of curve fitting relation, determines the design dimensions of the new fractal antenna.

**Step 3.** If the antenna resonates on the desired frequency the design process is terminated.

**Step 4.** Use the optimized dimensions to fabricate the antenna for experimental validations.

Figure 4.4 shows the flow graph of the entire design process of new fractal antenna design.

![Flow graph of the entire design process of new fractal antenna design](image-url)
Initialization

For : $i = 1: N_{ed}$
   For : $j = 1: N_{re}$
      For : $k = 1: N_c$
         For : $n = 1: S$
            $j_{last} = j(n)$
            Generate a tumble angle for bacterium $n$:
            Update the position of bacterium $n$;
            Recalculate the $j(n)$
            $m = 0$
            While ($m < N_s$)
               If $j(n) < j_{last}$
                  $j_{last} = j(n)$;
                  Run one more step;
                  Recalculate the $j(n)$;
                  $m = m + 1$;
               Else
                  $m = N_s$;
               End if
            End while
            Update the best value achieved so far;
         End for
      End for
   End for
   Sort the population according to $j$;
   For : $m = 1: S/2$
      Bacterium ($k + S/2$) = Bacterium ($k$);
   End For
End for

For : $l = 1:S$
   If (rand < $P_e$)
      Move Bacterium $l$ to a random position
   End if
End for

Figure 4.5 Pseudo code of BFO algorithmic [109]:

[Image of text content]
4.3 Results and Discussion

4.3.1 Resonant Parameters of Proposed Fractal Structure

In order to access the effectiveness of the proposed design, developed methodology were used to draw the structure of antenna. The simulation tool adopted for evaluating the performance of the fractal antenna is IE3D software, which exploits the method of moments to solve the electric field integral equations. Figure 4.6 shows the $S_{11}$-parameter for all the three iterations of proposed fractal antenna that is zero, first and second iteration. S-parameters describe the input and output relationship between ports or terminals in an electrical system. The most commonly used parameter with regards to antennas is $S_{11}$. It indicates how much power is reflected from the antenna. If the value of $S_{11}$ is equal to zero dB, then all the power is reflected from the antenna and nothing is radiated. If the value $S_{11}$ is equal to -10 dB, this means that if 3 dB of power is delivered to the antenna and -7 dB is the reflected power. The remainder of the power was delivered to the antenna. This accepted power is either radiated or absorbed as losses within the antenna system. Generally antennas are designed to be low loss and ideally the majority of the power delivered to the antenna is radiated [16].

As expected, it was illustrated that with increase in the iterations, resonant frequency decreases and this satisfy the self-similarity property of fractal geometries. The simulated resonant characteristics of the proposed antenna are reported in Table 4.4. It can be noticed that there is an increase in the impedance bandwidth of the proposed structure when the iterations of the fractal antenna increases, with substantial improvement in the impedance matching of the antenna.
Table 4.4 Resonant performance characteristics of proposed antenna

<table>
<thead>
<tr>
<th>No. of Iterations</th>
<th>Resonant Frequency (GHz)</th>
<th>Reflection Coefficient (dB)</th>
<th>Bandwidth (%)</th>
<th>Input Impedance (ohms)</th>
<th>Antenna Efficiency (%)</th>
<th>Radiation Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>6.09</td>
<td>-25.21</td>
<td>13.73</td>
<td>44.80</td>
<td>54.47</td>
<td>55.33</td>
</tr>
<tr>
<td>First</td>
<td>6.03</td>
<td>-18.95</td>
<td>15.91</td>
<td>52.84</td>
<td>61.42</td>
<td>61.44</td>
</tr>
<tr>
<td>Second</td>
<td>5.727</td>
<td>-35.87</td>
<td>22.41</td>
<td>51.54</td>
<td>85.02</td>
<td>85.08</td>
</tr>
</tbody>
</table>

4.3.1.1 Input Impedance

As EM waves travel through the different parts of the antenna system, from the source to the feed line to the antenna and finally to the free space, they may encounter differences in impedance at each interface. The input impedance is the ratio between voltage and currents at antenna ports [16]. The impedance of the antenna has been adjusted through the design process to be matched with the feed line and have less reflection to the source. A typical input characteristics \( Z_{in} = Re_{in} + jIm_{in} \) of the first three iterations for the proposed fractal antenna are shown in Figure 4.7 and Figure 4.8, where \( Z_{in} \) is the input impedance, \( Re_{in} \) is the real part of the impedance.
(resistance) and \( Im_{in} \) is the imaginary part of the impedance (reactance). And it is illustrated that with increase in iterations, the input impedance is improving significantly, which means that the input impedance of the proposed antenna is getting better corresponding to the resonating frequency with every next iteration.

Figure 4.7 Simulated real input impedance of proposed antenna for zero, first and second iteration.

Figure 4.8 Simulated imaginary input impedance of proposed antenna for zero, first and second iteration.
4.3.1.2 Voltage Standing Wave Ratio (VSWR)

The voltage standing wave ratio is also known as standing wave ratio and it is a function of the reflection coefficient, which describes the power reflected from the antenna [16]. The VSWR of the proposed antenna for zero, first and second iteration is shown in Figure 4.9. The presented results shows that the value of VSWR for the resonating frequency band of all the three iterations is less than 2, which is the requirement of an efficient antenna and reveals that the antenna is well matched.

![Simulated VSWR of proposed antenna for zero, first and second iteration.](image)

Figure 4.9 Simulated VSWR of proposed antenna for zero, first and second iteration.

4.3.1.3 Antenna Efficiency and Radiation Efficiency

The antenna efficiency is associated with the power delivered to the antenna and the power radiated or dissipated within the antenna system [11]. The antenna efficiency and radiation efficiency of the proposed antenna is shown in Figure 4.10 for all the three iterations and it is found that with increase in iteration, the antenna and radiation efficiency increases for the respective resonating frequency.
Figure 4.10 Antenna and Radiation efficiency of proposed antenna for (a) zero iteration (b) first iteration and (c) second iteration
4.3.1.4 Smith chart

The smith chart is a graphical method of displaying the impedance of an antenna, which can be a single point or range of points to display the impedance as a function of frequency. The smith chart of the proposed antenna for all the three iterations is shown in Figure 4.11. It may be illustrated that impedance of the proposed antenna is getting better with increase in iterations of the proposed antenna.

(a)  
(b)  
(c)  

Figure 4.11 Smith chart of the proposed antenna for (a) zero iteration (b) first iteration and (c) second iteration
4.3.2 Results of Optimization

The design of the proposed antenna has been formulated in terms of an optimization problem by defining and imposing suitable constraints on resonant frequency. To obtain a database from simulator for obtaining fitness function, the height of the substrate \((h)\) and length of the antenna \((L)\) has been varied. The relationship between these designs parameters and the required frequency was generated by Curve-fitting method. In order to illustrate the impact and to increase the confidence in optimization techniques, the proposed antenna was synthesized with PSO and BFO. The motive behind using these optimization techniques are their inherent simplicity and cooperative knowledge, compared to the competitive mode in the other algorithms. The BFO and PSO are quite similar in approach with subtle differences. Though PSO is a good optimization algorithm, it can be trapped in local minima and may converge prematurely. However, BFO algorithm attempts to make a judicious use of exploration and exploitation abilities of the search space and therefore likely to avoid false and premature convergence in most of the cases. The graphical comparison for average best solution by varying number of iterations, using both the techniques is shown in Figure 4.12 and obtained results reveals that BFO outperforms PSO for most of the iterations. The advantage of BFO is that it is generalized in nature and for any small patch antenna and higher dielectric constant \((\varepsilon_r < 10)\), the resonance frequency can be calculated accurately [133]. It concludes that the BFO algorithm has an edge over PSO in terms of final accuracy and robustness. To make the comparison fair, population for both the competitor algorithms were initialized using the same random seed. The second iteration of proposed antenna has been optimized to resonate at user defined frequency of 5.8 GHz. Figure 4.13 gives the graphical comparison of s-parameters between BFO and
PSO. Based on these studies it is observed that the BFO not only provides more accurate results in terms of required resonating frequency but also outperform in antenna performance characteristics such as reflection coefficient, radiation efficiency and bandwidth, than PSO, which is a primary motive for optimization of the proposed geometry. However, the computational time for PSO is less than BFO. The various antenna parameters and their simulated results using both the optimization techniques have been detailed in Table 4.5. It is interesting to note from Table 4.5, that for most of the cases the BFO algorithm beats its nearest competitor PSO in a statistically meaningful way.

![Graph showing fitness function vs iterations for PSO and BFO](image)

**Figure 4.12 Average best solutions found using PSO and BFO**

**Table 4.5 Comparison of PSO and BFO results for proposed PHFT antenna.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Lenght, $L$ (mm)</th>
<th>Height, $h$ (mm)</th>
<th>Resonant Frequecy (GHz)</th>
<th>Reflection Coeffici (dB)</th>
<th>Bandwidt h (%)</th>
<th>Radiatio n Efficienc y (%)</th>
<th>Compu tational Time (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSO Results</td>
<td>32.3</td>
<td>1.8</td>
<td>5.70</td>
<td>-35.01</td>
<td>22.50</td>
<td>79.10</td>
<td>1.08</td>
</tr>
<tr>
<td>BFO Results</td>
<td>31.8</td>
<td>1.6</td>
<td>5.78</td>
<td>-36.86</td>
<td>24.34</td>
<td>82.90</td>
<td>8.80</td>
</tr>
</tbody>
</table>
4.3.3 Experimental Results

As the BFO provides better required results than PSO so antenna dimensional parameters obtained using it, is considered further for fabrication process. The optimized antenna is fabricated using the FR4 substrate having the dielectric constant of 4.4 and measured to test the accuracy of the proposed structure. The optimized length and height of the designed antenna are, \( L = 31.8 \) mm and \( h = 1.6 \) mm respectively. The photograph of the fabricated antenna prototype is shown in Figure 4.14. The experimental \( S_{11} \) plot obtained using HP 8720B (130 MHz – 20 GHz) network analyzer, is overlapped with the simulated plot for comparison purpose. The measured results are in good agreement with the simulated results as shown in Figure 4.15, despite a slight frequency shift of 1.3% from the simulated results. This frequency shift is mainly because of the fabrication imperfections. The proposed fractal antenna resonates at 5.8 GHz of ISM (Industrial Scientific and Medical band, 5.725 – 5.875 GHz) which is suitable for wireless Telemedicine applications.
4.3.4 Radiation Patterns

Radiation pattern measurements were completed in the frequency domain for the second iteration in an anechoic chamber. Measurements were sampled in magnitude and phase. All trials were completed in receive mode and the appropriate calibration calculations were completed to reduce free space losses, chamber effects, and the contributions of the reference antennas. The testing setup and photograph of proposed antenna in anechoic chamber for measurement of radiation patterns are shown in Figure 4.16 and Figure 4.17 respectively.
The radiation characteristics of simulated and fabricated antenna were checked in order to verify the fractal behavior. Figure 4.18 to Figure 4.20 gives the simulated radiation patterns for all the three iterations and Figure 4.21 showed the measured radiation patterns for second iteration. It is observed that the proposed antenna
exhibits omnidirectional radiation patterns at the y-z plane (H-plane) and “8-shape” radiation patterns at the x-z plane (E-plane), similar to those of an ideal dipole antenna. It is illustrated that simulated and measured radiation characteristics are in good agreement and the proposed antenna is linearly co-polarized antenna.

Figure 4.18 Simulated radiation patterns for zero iteration at 6.09 GHz (a) H-plane (b) E-plane

Figure 4.19 Simulated radiation patterns for first iteration at 6.03 GHz (a) H-plane (b) E-plane
Figure 4.20 Simulated radiation patterns for second iteration at 5.727 GHz (a) H-plane (b) E-plane

Figure 4.21 Measured radiation patterns for second iteration at 5.80 GHz (a) H-plane (b) E-plane

4.3.5 Gain v/s Frequency Plot

The ability of an antenna to direct the radiated power in a given direction is specified in terms of its gain. The Gain v/s Frequency is one of the ways to assess the antenna performance. The measured and simulated gain of the proposed antenna is in good agreement as shown in Figure 4.22. The achievable measured gain at the desired resonant frequency (5.8 GHz) is 4.6 dBi.
4.4 Conclusion

In this chapter, a fast, flexible and accurate procedure for making fractal antenna is proposed, which is easy to use from the designer's point of view. The antenna geometry is based on a new planar fractal antenna, whose geometrical descriptors are determined by means of PSO and BFO. The goal of this work was to give a conceptual overview of these optimization techniques into the electromagnetic community. In the presented work, PSO and BFO programs was developed using equation obtained by curve fitting technique. The BFO out performs in terms of accuracy and antenna performance than PSO, whereas PSO converges faster than BFO. An antenna prototype has been successfully implemented in order to assess the effectiveness and the reliability of the proposed designed geometry. Numerical and experimental analyses have been carried out, and some representative results are reported to give an overview of the prototype performance. The measured electrical parameters confirm the reliability of the antenna and make it feasible for wireless telemedicine applications.