A Polygonal Shape Patch Antenna with Triangular Mini-Fractals for Wideband Wireless Local Area Network Applications

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Abstract—This paper presents a miniaturized hexagonal fractal antenna. The mini triangular fractals of self-duplicating structures are inserted for the bandwidth improvement. The antenna is designed for Wireless Local Area Network (WLAN) application at 2.4 GHz. The antenna middle dimensions are: length is 28 mm and the breadth is 40 mm. The design is simulated and optimized with a ZEELAND IE3D package. There is bandwidth enhancement of 700 MHz at -16db return loss. We also obtained moderately high gain of 4.0 dB. Several iterations are carried out to achieve better performance.

Key words: Hexagonal Fractal; Bandwidth; ZEELANDIE3D; Directivity; Wireless Local Area Network (WLAN)

I. INTRODUCTION

The geometry generating method of a patch antenna begins with a basic calculation of dimensions of a patch antenna [1]. Then inserting the self-similar fractal slots [6, 7]. Elementary buildings blocks of a fractal cannot be differentiated as a result of they are scaled versions of the leader [1, 2, 3]. The present vibrant area of research in the field of antenna is that the immoderate broadband response with miniaturized size that may be mounted on two-dimensional surfaces. Wireless LAN, Wi-Fi, satellite and alternative broadband applications are attracting the researchers. Shrinking the antenna size [2] while not adversely affecting the antenna performance is an art of the researchers, and a method to do this is to implement the fractal geometry. Fractal geometries structure the antenna with little space and geometry resistance within the structure. Fractals can be of any shape, like triangular [4], Star, hexagons etc. in this paper we have created a hexagonal shape patch antenna with the triangular fractals leading to augmented bandwidth, higher performance and ease of Use. The major factor to maximize the response of antenna is to match the line impedance to the antenna input impedance [3] for maximum power transfer. One way of doing this is to introduce a Quarterwave transformer [1].

The paper includes the following concepts:

- Mathematical steps for designing a simple patch antenna.
- Significance of fractal geometries.
- Quarter wavetransformer for impedance matching.
- Implementation of proposed antenna in ZEELAND IE3D.
- Optimization and tuning of proposed antenna.
- Software Results and discussions.
- Hardware implementation and testing of antenna using antenna measurement system.

II. DESIGN OF A SIMPLE PATCH ANTENNA

Before we proceed to construct any type of antenna, we must calculate the dimensions of simple patch antenna [1, 2, 3]. The design follows the following steps. Because of fringing field effect the length of ground plane is taken somewhat greater than the actual size of antenna.

1) Step 1:
The width of a patch is calculated using the formula,

\[ \frac{w_p}{c} = \frac{2}{f \sqrt{\varepsilon_r + 1}} \]

Where \( \varepsilon_r \) the dielectric constant, \( c \) is velocity of light and \( f \) is the resonant frequency of antenna.

2) Step 2:
The next step is to compute the effective dielectric constant by using equation below,

\[ \varepsilon_{ref} = \frac{\varepsilon_r + 1}{\varepsilon_r - 1} + \frac{1}{1 + \frac{12h}{w}} \]

Where \( h \) is the height of substrate and \( w \) is width of the patch.

3) Step 3:
Calculation of effective length

\[ L_{eff} = \frac{c}{2f \sqrt{\varepsilon_{ref}}} \]

4) Step 4:
Determining the length extension \( \Delta L \)

\[ \Delta L = h \times 0.412 \left[ \frac{\varepsilon_{ref} + 0.300}{\varepsilon_{ref} - 0.258} \right] \left[ \frac{w + 0.262}{w + 0.813} \right] \]

5) Step 5:
Deciding actual length of a patch antenna.

\[ L_p = L_{eff} - 2\Delta L \]

6) Step 6:
Calculating the ground plane dimensions \( L_g \) and \( w_g \). Length of ground plane is given as:

\[ L_g = L + 6h \]

Width of ground plane is given as:

\[ w_g = w + 6h \]

A picture of an ideal basic square patch antenna is shown below.

Fig. 1: Ideal square patch antenna.
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<table>
<thead>
<tr>
<th>Design Frequency</th>
<th>Substrate Height</th>
<th>Dielectric Constant</th>
<th>Length Of The Patch</th>
<th>Width Of The Patch</th>
<th>Length Of Ground Plane</th>
<th>Width Of The Ground Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4GHz</td>
<td>1.56mm</td>
<td>4.4</td>
<td>28mm</td>
<td>40mm</td>
<td>40mm</td>
<td>50mm</td>
</tr>
</tbody>
</table>

Table 1: Designed Parameters

III. GEOMETRY INITIALIZATION AND CUTTING
First a simple patch antenna is designed in mgrid and simulated in ZEELAND IE3D software. Again the simple patch is cut in a gradual manner to form a regular hexagon. And the simulated results are observed. The following geometries will clear the geometry formation.

![Fig. 2: Initialization of Geometry](image)

IV. SIMULATION OF PROPOSED ANTENNA IN ZEELAND IE3D
The designed patch antenna is constructed in ZEELAND IE3D software. The mid length of patch is 28mm and the midwidth of patch is 40mm. The peripheries of simple patch are cut to form a hexagonal structured patch antenna and different iterations [4] are done changing the feed locations. The inset feeding method is used here. A Quarter wave transformer [1] is utilised at the input to match the line impedance of input feed with antenna input impedance. At last the geometry with the maximum output response is chosen.

![Fig. 3: Square Patch](image)

![Fig. 3: A Hexagonal Patch and Return Loss](image)

![Fig. 4: Elevation Pattern Gain Display of Hexagonal Patch. AtE Theta, Phi=90 Degrees](image)

![Fig. 5: Elevation Pattern Directivity Display at E Theta, Phi=90 Degrees](image)

V. OPTIMIZATION AND TUNING OF GEOMETRY FOR AUTOMATIC ADJUSTMENT
The proposed geometry is optimised in ZEELAND IE3D software taking a Powel optimiser and the geometry is tuned to arrive at the minimum return loss[16], resulting in the maximum power transfer to antenna thus minimising the reflected waves towards the antenna and hence maximum gain, directivity and bandwidth. Maximum problems of antenna are connected with termination of feed network. Impedance matching accuracy is generally tested in a laboratory room in an absorber box [3]. The tuned geometry is saved and simulated in the ZEELAND IE3D software.

VI. DIFFERENT ITERATIVE STAGES AND DISCUSSION
A novel way of constructing any type of patch antenna is to start constructing it with a simple patch of computed dimension then iteratively cutting the structure to arrive at the desired geometry and satisfactory results.
The structure of a hexagonal geometry of patch is as shown in the fig.3. The fractals are introduced in the hexagonal patch [9] at each level and the output is checked. Finally we arrived at the geometry with maximum outputs.

The structure given in iteration 3 is again modified; a $\frac{\lambda}{4}$ transformer is inserted for impedance matching. The characteristic resistance of the transformer is just the geometric average between the original line impedance and also the load seen by the transformer. We remove the metal from antenna each time when we insert a level of fractals, because of this reason the Radiating metal area reduces and there will be relatively less gain for this type of antennas. But it increases the frequency range of the antenna, and also shows frequency results at multiple points. As a result of removal of metal there will be a large impedance mismatch in case of fractal antennae.

The simulation results of all the iteration is discussed below. At every stage a new ring of fractals is inserted [4], simulates and the geometry is optimised [18] for automatic adjustment of dimensions to arrive at best results.

The first iteration is done by itching the triangular self-similar fractals called a Sierpinski gasket fractal [1,15] the return loss plot showing the multi-frequency operation [14] with -27 db return loss at WLAN range.

A. Iteration I

B. Iteration II
C. Iteration III

fractal antennae exhibits frequency response at different multiple places, as frequency of operation will vary the length of a quarter wave transformer will no more remains as 1/4 the of wavelength and so it is necessary to overcome for this large mismatch we can use a quarter wave transformers. But as adjust the length of a quarter wave transformer to the actual operating frequency of antenna. one way to do this is electromagnetic tuning of antenna for automatic adjustment of dimensions. With quarter wave transformer there will be impedance match up to some extent but not perfectly. Because with quarter wave transformer the Real resistive impedance will be matched but not conjugate impedances. In this paper we have tried to match the antenna impedance with line impedance for maximum power transfer by using 1/4 quarter wave transformer and electromagnetic tuning. And we arrived at the final geometry with optimised bandwidth [5, 10].

Fig. 9: (a) Geometry and (b) Return Loss of Iteration III

Table 2: Iterative Structures and Their Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Iteration 1</th>
<th>Iteration 2</th>
<th>Iteration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2D Gain Pattern</td>
<td>4.30699</td>
<td>3.1942</td>
<td>4.0035</td>
</tr>
<tr>
<td>2D Directivy Pattern</td>
<td>4.31821</td>
<td>3.19606</td>
<td>4.0603</td>
</tr>
<tr>
<td>Return Loss</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half Power Bandwidth</td>
<td>3.21</td>
<td>5.52</td>
<td>37.5</td>
</tr>
<tr>
<td>Bandwidth</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VII. FABRICATION OF PROPOSED STRUCTURE AND TESTING

The fabrication of proposed structure is done on a substrate of dielectric constant 4.4. A substrate height is chosen according to the design that is 1.56mm. The fabricated structure looks like as shown below.

Fig. 6: Photo of a Proposed Fractal Antenna

50Ω SMA connector is chosen to input as an inset feed [13]. And the structure is tested using an antenna measurement system. The transmitter and receiver are kept at 1 meter distance apart. And the far field radiation pattern is as shown below.

There are many environmental factors that will affect the antenna performance like interferences occurring
due to cellular phone signals, reflected waves, refracted waves, diffracted waves, and other radiating materials causes the antenna to behave slightly different compare to the simulated results. For this purpose the testing should be carried out in an anechoic chamber but if the antenna is to be operated in real time environment slight interferences from surrounding atmosphere is unavoidable so we tested the antenna using an antenna measurement system which works with existing interferences to give the resulting radiation pattern the results are shown in the following diagram.

VIII. TEST RESULTS

![Fig. 7: radiation pattern of proposed antenna](image)

The output values obtained after testing the antenna are listed in the following table:

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Parameters</th>
<th>Testing Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gain</td>
<td>3.03446</td>
</tr>
<tr>
<td>2</td>
<td>Directivity</td>
<td>3.90313</td>
</tr>
<tr>
<td>3</td>
<td>HPBW</td>
<td>97.2</td>
</tr>
</tbody>
</table>

Table 4: Test Results

A. Comparison between Hardware and Software Results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Simulation Results</th>
<th>Tested Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>4.0035</td>
<td>3.03446</td>
</tr>
<tr>
<td>Directivity</td>
<td>4.0603</td>
<td>3.90313</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>37.5</td>
<td>97.2</td>
</tr>
</tbody>
</table>

Table 3: comparison of simulated and test results

IX. CONCLUSIONS

The drawback of low band width of patch antennas is eliminated in this paper by inserting the triangular fractals. Such any types of fractals can be used. If we compare the bandwidth of a simple hexagonal patch and a hexagonal patch with fractals we can observe remarkable increase in the bandwidth. Thus giving wideband response.

In the first iteration we have introduced fractals we found a little bit increase in bandwidth in the second and third iterations we found the remarkable improvement in the bandwidth. But there is slight decrease in the gain because of the removal of metal areas of iterations.

Further improvement can be done by extending the iterations of inserting the fractals; we can also achieve the multi-frequency operation [11-12] with improved bandwidth [8]. The same antenna can be designed in mobile frequency range (1.88 GHz) and increased bandwidth can be utilised for mobile harvesting applications.

REFERENCES


