**ABSTRACT**

In this paper, Minkowski fractal antenna for Bluetooth application has been designed. Apart from this, it can be used for various other applications as well because of its multiband feature. The antenna is fed by Microstrip feeding technique. Its advantage is that it can be easily fabricated as it is a just conducting strip connecting to the patch and therefore, can be considered as an extension of the patch. The proposed patch antenna is designed and simulated on IE3D simulation software and it is designed to operate in 2.45GHz band. Dielectric substrate with the permittivity $\varepsilon=2.2$ (RT/Duroid 5880) with width of 1.588mm is used to make a resonant patch antenna of linear polarization. In this analysis, we have compared the antenna parameters such as gain, impedance, antenna efficiency, radiation efficiency, radiation pattern, polar plots, VSWR and Q-factor. Reduction in patch antenna size is achieved when performing fractalization of the main patch.

**General Terms:** Microstrip patch antenna, Minkowski Fractal Antenna, Microstrip feed

**Keywords:** Radiation pattern, VSWR, Directivity, 2D Polar Plot, Return loss, Fractal Antenna,

1. **INTRODUCTION**

The concept of microstrip radiators, introduced by Deschamps in 1953, remained dormant until the late 1970s when low-profile antennas were required for an emerging generation of missiles [1], [2]. However, first practical antennas were developed by Munson [3] and Howell in the 1970s. Since then, extensive research and development of microstrip antennas and arrays, aimed at exploiting their numerous advantages such as low profile, light weight, conformable to planer & non-planer surfaces, compatibility with integrated circuits, mechanically robust, have an ease of fabrication and so on, which led to diversified applications and to the establishment of the topic as a separate entity within the broad field of microwave antennas [4]. In last 40 years, the microstrip antennas have been developed for various communication systems such as radars, sensors, wireless, satellite, broadcasting, ultra-wideband, radio frequency identification (RFIDs), reader devices etc. But a low bandwidth can be achieved with simple microstrip antennas and advanced communication systems require antennas with more bandwidth and smaller dimensions as compared to conventional antennas. Various desirable features like smaller size, multi-band and broad-band properties can be easily achieved by using fractal geometry-based antennas. Fractals have self-similar shapes and can be subdivided into parts such that each part is a reduced size copy of the whole.

2. **MICROSTRIP PATCH ANTENNA**

2.1 **INTRODUCTION**

A microstrip antenna mainly consists of a single ground plane and an open strip conductor separated by dielectric substrate as shown in the fig. 1. It is constructed by the photographic processed used for integrated circuits [13]. The most commonly used microstrip element consists of a rectangular element that is photoetched from one side of a printed-circuit board. However, other shapes, such as the square, circular, triangular, semicircular, sectoral and annular ring shapes can also be possible [5]. Microstrip antennas shown as in fig. 1, consists of a very thin [11] ($t<<\lambda_o$ where $\lambda_o$ is a free-space wavelength) metallic strip (patch) placed at a small fraction of a wavelength ($h<<\lambda_o$ usually $0.003\lambda_o \leq h \leq 0.05\lambda_o$) above a ground plane. This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. For a rectangular patch, the length $L$ of the element is usually $\lambda_o/3 < L < \lambda_o/2$. The strip and ground plane are separated by a dielectric sheet usually referred to as the substrate. The dielectric constants are usually in the range of $2.2 \leq \varepsilon \leq 12$. 

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2.2 EFFECT OF DIMENSIONS AND OTHER FACTORS ON ANTENNA PARAMETERS ARE AS FOLLOWS:

- The width, W of the patch can be taken smaller or larger than the value obtained using equation (4.1). If W is smaller, then the bandwidth and gain both will degrade. If W is larger, BW increases due to increase in the radiated fields. The directivity increases due to increase in the aperture area. However, if W is too large, then the higher order modes could be excited [5], [7], [11].
- As the W increases, it not only affects gain and bandwidth, but also affects the resonant frequency as well. Resonant frequency decreases due to decrease in $\Delta L$ and $\epsilon_{eff}$ [5].
- Input impedance also decreases as W increases because the radiation from the radiating edge increases, which decreases the radiation resistance [5].
- The aperture area of the antenna increases as W increases; resulting in the increase in the directivity, efficiency and hence, gain. The HPBW in the H-plane decreases, whereas it remains almost same in the E-plane, because the increase in the width is in the H-plane [5].
- As the ‘h’ or substrate height increases, the fringing fields from the edges increase, which increases the extension in the length $\Delta L$ and hence, the effective length, thereby decreasing the resonant frequency. On the other hand, as ‘h’ increases, the W/h ratio reduces, which decreases $\epsilon_{eff}$ and hence increases the resonant frequency. However, the effect of the increase in $\Delta L$ is dominant over the decrease in $\epsilon_{eff}$. Therefore, the net effect is to decrease the resonant frequency [5].
- The BW of the antenna increases as ‘h’ increases [5], [7].
- The efficiency also increases with an increase in the substrate thickness or ‘h’ [5], [7].

3. FRACTAL ANTENNAS

3.1 INTRODUCTION

Fractals (term coined by Benoit Mandelbrot in 1975, derived from Latin word fractus, meaning “broken” or “fractured”) are highly convoluted and jagged shapes that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. These are nature inspired antennas. The discontinuities in these antennas causes increase in bandwidth and effective radiation.

3.2 MAJOR VARIATIONS OF FRACTALS

Fractals come into two major variations:

- **Deterministic (chaotic) fractal:** It consists of those fractals that are composed of several scaled down and rotated copies of itself, such as Koch curve (fig. 2.a). They are also called geometric fractals. They exhibit the property of self symmetry.
- **Random fractal:** It includes those fractals which have an additional element of randomness allowing for simulation of natural phenomenon, so they exhibit property of statistical self similarity. They look like random walks (Brownian motion), dendrites or lightning bolts.

3.3 MINKOWSKI FRACTAL ANTENNA

Fractal antennas can take on various shapes and forms. There are many mathematical structures that are fractals; e.g. Sierpinski’s Carpet, Sierpinski’s gasket, Cantor’s comb, von Koch’s snowflake, the Mandelbrot set, Minkowski square loop and hexagonal etc.
Minkowski gasket is one of the earliest structures of fractal geometry. A miniaturization of loop antenna using the fractal technique is known as Minkowski square loop antenna.

![Figure 2](image.jpg)  
**Figure 2** Construction of the Minkowski-like fractal structure [17]  
a.) The generator  
b.) First Iteration  
c.) Square patch antenna (Initiator)

### 3.4 SPECIAL PROPERTIES OF FRACTALS

Fractal antennas have some very special properties that make them attractive for the design of small antennas. These properties are [17], [20]:

- **Broad band operation**: The fractals antennas radiate and detect efficiently within a wide range of frequencies. The frequency range is specified by the smallest and largest size present in the antenna. The radiation pattern and hence, the detection efficiency do not vary much as a function of frequency.

- **Gain**: the fractal antennas can display a gain which depends slowly on frequency over a large frequency range.

- **Spatial structure**: The fractal antennas can display a spatial structure which is also related to the antenna gain, as the antenna concentrates certain power in certain positions and not in others.

- **Space filling and multiple scale properties**: Fractal antennas can place long electrical length into small volume only because of this property.

- **Self-similar pattern**: Because one should expect a self-similar (at least approximately or stochastically) antenna (which contains many copies of itself at several scales) to operate in a similar way at several wavelengths. That is, the antenna should keep similar radiation parameters through several bands.

- **Mechanical simplicity and robustness**: The characteristic of fractal antenna are obtained due to its geometry and not by the addition of discrete components.

### 4. DESIGN METHODOLOGY

**a. DESIGN PROCEDURE**

a.) The width of the microstrip antenna can be calculated as

\[ W = \frac{c}{2\varepsilon_0 \sqrt{\frac{(S_2+1)}{2}}} \]  
\[ = 48.4\text{mm} \]  

b.) For low frequencies, the effective dielectric constant is essentially constant; but at intermediate frequencies, its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate. It is given by the expression as follows:

\[ \varepsilon_{\text{eff}} = \frac{S_2 + 1}{2} + \frac{S_2 - 2}{2} \left[ 1 + 12 \frac{S_1}{W} \right]^{-\frac{1}{2}} \]  
\[ = 2.1082 \]

c.) Due to the fringing effect, electrically the patch of the microstrip antenna looks greater than its physical dimensions. So, first we will calculate the extra length which is extended on each side of the patch along its
The final rectangular patch antenna will look as follows:

\[
\Delta L = 0.412h \left( \frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.3} \right) \left( \frac{W}{h} + 0.264 \right) \\
= 0.84\text{mm}
\]

d.) After that, we will calculate the effective length of the patch, which is given by:

\[
L_{eff} = \frac{c}{2f_r \sqrt{\varepsilon_{eff}}} \\
= 41.27754\text{mm}
\]

e.) So, the actual length of the rectangular patch can be determined as follows:

\[
L = L_{eff} - 2(\Delta L) \\
= 40.49\text{mm}
\]

f.) Input impedance of the patch can be given as:

\[
Z_0 = \frac{90\Omega}{\varepsilon_r - 1} \left( \frac{L}{W} \right)^2 \\
= 254.04\Omega
\]

g.) Characteristic impedance of the transition section should be:

\[
Z_0 = \sqrt{\frac{50 \times 254.04}{\varepsilon_r}} \\
= 122.69\Omega
\]

h.) Transition line width can be calculated by using the formula:

\[
Z_c = \frac{50 \Omega}{\ln \left[ \frac{\varepsilon_r + 1}{\varepsilon_r - 1} \left[ 1 + 1.2 \frac{\varepsilon_r}{W_T} \right]^{-1/2} \right]} \\
W_T = 0.615\text{mm}
\]

i.) Transition line length can be calculated as:

\[
\lambda_0 = \frac{2\pi}{\delta} = \frac{2\pi}{\sqrt{\varepsilon_r}} \\
= 1.706
\]

Hence, the length of the transition should be:

\[
\frac{\lambda_0}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_r}} \\
= 23.437\text{mm}
\]

j.) Width of 50 Ω microstrip line feed can be calculated as:

\[
Z_c = \frac{120\pi}{\sqrt{\varepsilon_r \left[ \frac{W_{m}}{2(\delta)} + 1.393 + 0.667\ln \left( \frac{W_{m}}{2(\delta)} + 1.444 \right) \right]}} \\
50 = \frac{120\pi}{\sqrt{\varepsilon_r \left[ \frac{W_{m}}{2(\delta)} + 1.393 + 0.667\ln \left( \frac{W_{m}}{2(\delta)} + 1.444 \right) \right]}}
\]

So, \(W_m = 4.367\text{mm}\)

The final rectangular patch antenna will look as follows:

![Figure 3](image-url) A reference patch antenna for 2.45GHz with 0 iteration
Initially, simulation of the actual patch (with 0 iteration) has been done. First of all, width \( W_2 \) is varied for fixed value of \( W_1 \) (say 1mm). As per our simulation results, best results have come on \( W_2 = 8 \text{ mm} \). After that \( W_1 \) is varied for fixed value of \( W_2 (= 8 \text{ mm}) \).

5. SIMULATION RESULTS AND DISCUSSION

The iterations of the microstrip patch antenna were examined by using the IE3D simulation software tool. The frequency lies between (1GHz-5GHz) upto 1000 number of frequencies. The simulation of this antenna structure provides good results and makes this antenna suitable to work in 4 different frequency bands.

5.1 WHEN \( W_2 \) IS VARIED AND \( W_1 \) IS KEPT CONSTANT

Simulation results for \( W_1 = 1 \text{ mm} \) and \( W_2 = 1 \text{ mm}, 2 \text{ mm}, 4 \text{ mm}, 8 \text{ mm}, 10 \text{ mm}, 12 \text{ mm}, 19.475 \text{ mm} \) and \( 23.7 \text{ mm} \) (beyond that is not possible) are as follows (for \( W_1 \) and \( W_2 \), see fig.2).

![Minkowski Fractal Antenna with same value of \( W_1 \) and different values of \( W_2 \).](image)

**Figure 4** Minkowski Fractal Antenna with same value of \( W_1 \) and different values of \( W_2 \).
Here, ‘unequal cuts’ (last antenna of fig.4) refers to the case when the cuts along the L and W are not same, i.e. here it is 23.7 along the W and 19.745 along the L. In last, a comparison table (Table 1) is made for better understanding. For more clarity, simulation results for only few values of W₂ are shown in the below figures.

Figure 5 $S_{11}$ Display (dB)

Figure 6 VSWR Display

Figure 7 Antenna Efficiency

Figure 8 Radiation Efficiency
5.2 WHEN $W_1$ IS VARIED AND $W_2$ IS KEPT CONSTANT
Similarly, if we vary the $W_1$, we will get the different results. Simulation results for $W_2$ = 8mm and $W_1$ = 1mm, 2mm, 4mm, 8mm, 12mm (for $W_1$ and $W_2$, see fig.2) are as follows. Comparison table (Table 2) for the same is also given after the simulation results.

Figure 9 Total Gain (dBi)  
Figure 10 Directivity (dBi)

Figure 11 Minkowski Fractal Antenna with same value of $W_1$ and different values of $W_2$. 
Figure 12 Antenna Efficiency

Figure 13 Radiation Efficiency

Figure 14 Total Gain (dBi)

Figure 15 Directivity (dBi)
Figure 16 S_{11} Display (dB)

Figure 17 VSWR Display

Table 1: Comparison table when W_1 is constant & W_2 is varied.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>f_c (GHz)</th>
<th>S_{11} (dB)</th>
<th>VSWR</th>
<th>G (dBi)</th>
<th>A.E and R.E (%)</th>
<th>D (dBi)</th>
<th>B.W. (MHz)</th>
<th>No. of bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>0^{th} Iteration</td>
<td>2.39493</td>
<td>-10.9726</td>
<td>1.7882</td>
<td>5.125</td>
<td>60.7, 89.47</td>
<td>7.38677</td>
<td>11.4566</td>
<td>4</td>
</tr>
<tr>
<td>1mm 1mm</td>
<td>2.38511</td>
<td>-11.3887</td>
<td>1.73787</td>
<td>5.524</td>
<td>65.25, 89.4</td>
<td>7.38106</td>
<td>13.42</td>
<td>4</td>
</tr>
<tr>
<td>1mm 2mm</td>
<td>2.37349</td>
<td>-11.7348</td>
<td>1.69899</td>
<td>5.151</td>
<td>60.1, 89.37</td>
<td>7.37007</td>
<td>14.40</td>
<td>4</td>
</tr>
<tr>
<td>1mm 4mm</td>
<td>2.3374</td>
<td>-13.2189</td>
<td>1.55859</td>
<td>5.733</td>
<td>75.4, 89.10</td>
<td>7.33425</td>
<td>17.15</td>
<td>4</td>
</tr>
<tr>
<td>1mm 8mm</td>
<td>2.19319</td>
<td>-24.9774</td>
<td>1.11945</td>
<td>5.161</td>
<td>69.7, 86.45</td>
<td>7.21526</td>
<td>18.90</td>
<td>4</td>
</tr>
<tr>
<td>1mm 10mm</td>
<td>2.09709</td>
<td>-20.3512</td>
<td>1.21216</td>
<td>1.929</td>
<td>37.65, 84.7</td>
<td>7.13674</td>
<td>16.366</td>
<td>4</td>
</tr>
<tr>
<td>1mm 12mm</td>
<td>1.997</td>
<td>-15.0852</td>
<td>1.42</td>
<td>3.362</td>
<td>72.3, 81.16</td>
<td>7.07755</td>
<td>11.17</td>
<td>4</td>
</tr>
<tr>
<td>1mm 19.745mm</td>
<td>4.10704</td>
<td>-24.5723</td>
<td>1.12556</td>
<td>8.603</td>
<td>81.1, 81.95</td>
<td>9.51054</td>
<td>59.57</td>
<td>2</td>
</tr>
<tr>
<td>1mm 23.7mm (Unequal Cuts)</td>
<td>4.14707</td>
<td>-13.9132</td>
<td>1.5048</td>
<td>7.084</td>
<td>71.42, 81.7</td>
<td>8.58537</td>
<td>58.66</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2: Comparison table when W₂ is constant & W₁ is varied.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>f₀ (GHz)</th>
<th>S₁₁ (dB)</th>
<th>VSWR</th>
<th>G (dBi)</th>
<th>A.E and R.E. (%)</th>
<th>D (dBi)</th>
<th>B.W. (MHz)</th>
<th>No. of bands</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mm 8mm</td>
<td>2.19319</td>
<td>-24.9774</td>
<td>1.11945</td>
<td>5.161</td>
<td>69.70,69.7</td>
<td>7.21526</td>
<td>18.90</td>
<td>4</td>
</tr>
<tr>
<td>2mm 8mm</td>
<td>2.17316</td>
<td>-24.4130</td>
<td>1.12778</td>
<td>5.930</td>
<td>78.9,86.49</td>
<td>7.18957</td>
<td>18.71</td>
<td>4</td>
</tr>
<tr>
<td>4mm 8mm</td>
<td>2.14115</td>
<td>-21.9151</td>
<td>1.17442</td>
<td>1.064</td>
<td>30.83,85.1</td>
<td>7.16057</td>
<td>17.8981</td>
<td>4</td>
</tr>
<tr>
<td>8mm 8mm</td>
<td>2.10907</td>
<td>-15.6177</td>
<td>1.39692</td>
<td>4.957</td>
<td>68.3,84.35</td>
<td>7.10668</td>
<td>15.0245</td>
<td>2</td>
</tr>
<tr>
<td>12mm 8mm</td>
<td>2.10917</td>
<td>-12.6528</td>
<td>1.60789</td>
<td>4.187</td>
<td>58.9,83.16</td>
<td>7.07843</td>
<td>11.228</td>
<td>1</td>
</tr>
</tbody>
</table>

**G=Gain, D=Directivity, B.W= bandwidth, A.E=Antenna Efficiency, R.E=Radiation Efficiency**

6. CONCLUSION

Minkowski fractal antenna upto 1st iteration with microstrip feed has been designed and simulated using IE3D ver.14.0. As W₂ starts increasing (keeping W₁=1mm), the results were fine upto W₂=8mm; but starts deteriorating beyond that. So we are getting best results at W₁=1mm & W₂=8mm and hence this patch has been taken as the reference patch for our next simulation where W₁ starts changing and keeping W₂ constant. Before making the main patch fractal, the bandwidth was 11.45MHz. However after making it fractal, the bandwidth has been enhanced to 18.9MHz for the same resonant frequency. Along with bandwidth, return loss (S₁₁) parameter also gets reduced to -24.9774dB from -10.9726dB, gain increases to 5.16dBi from 5.12dBi and antenna efficiency to 69.7% from 60.7%, which clearly indicates the advantages of making the patch fractal. We can further enhance the performance of the antenna by performing 2nd iteration over it. Since the number of frequency bands are 4 i.e. 1.8689GHz, 2.19319GHz, 4.043GHz and 4.599GHz; so the proposed Minkowski antenna can be used in various other applications as well apart from the Bluetooth like UMTS, GSM and other industrial, medical and scientific applications. So in future, Minkowski fractal antenna upto 2nd iteration with EBG will be designed and simulated for the same resonant frequency in order to achieve better gain, bandwidth etc which will make it suitable for other applications as well.

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AUTHOR

Munish Kumar received the B-Tech degree in Electronics and Communication Engineering from Bharati Vidyapeeth’s College of Engineering, New Delhi in 2011 and published one of his papers ‘Analysis of Sierpinski’s gasket multiband fractal antenna’ in National Conference on Electronics and Communication held in MITS in 2010, Gwalior, MTTS IEEE Council. Now, he is receiving M-Tech degree from USICT, Guru Govind Singh Indraprastha University, New Delhi in Electronics and Communication. During 2011-2013, he worked with HCL Technologies Limited as a software engineer. His research interest is in the area of Electromagnetic theory, Mobile and Wireless Communication, Microstrip Antennas & propagation, Fiber optics and Optics, and Fractals antennas.