# Design and Simulation of Pythagorean Tree Monopole Fractal Antenna

Suresh Sahni, Vishal Gupta, Sakshi Negi

**Abstract**— This paper describes the design and simulation of a unique type of fractal patch antenna, known as Pythagorean tree monopole fractal antenna with a microstrip line feed. The antenna uses a truncated ground plane and was simulated using Ansoft HFSS electromagnetic simulation software. The proposed antenna has been designed for single frequency broad-bandwidth operations and operates over the frequency band between 5.34 and 5.75 GHz for VSWR < 2. The simulated results give significant improvement in terms of directive gain and bandwidth. In this paper, the improvement process of the impedance bandwidth has been presented and discussed.

**Index Terms**— Pythagorean tree, fractal, antenna, microstrip, patch, self-similarity, HFSS

## 1 Introduction

In recent years, modern telecommunication systems require antennas with wider bandwidth and smaller dimension rather than conventional ones. Most importantly, the antennas should be well impedance-matched over the operating frequency range. Narrowband operation of antennas has become a necessity for many applications too. In recent wireless communication systems, dual band as well as single band behaviour with good gain is the need for many applications, such as GPS, GSM services operates at two different frequency bands. WLAN, Wi-Fi systems require single band operation. In this wireless world, integration of many applications is also required. So, it requires same antenna to work for all of the integrated applications.

Design of conventional microstrip patch with bandwidths as low as a few percents, wideband applications are very limited. Other disadvantages include low gain, low power handling capability, high Q value and poor polarization purity. For over two decades, researchers have proposed several methods to achieve miniaturization, improvement in bandwidth in case of wideband behaviour and realizing narrowband characteristics using planar microstrip antenna. Due to unique advantages such as small volume, low manufacturing cost and easy integration into planar circuits, planar microstrip antennas are ideal candidates.

Another method to have compact and small volume antenna is by using fractals in the planar microstrip antenna geometry. The concept of fractal was initially exposed by the French mathematician B.B.Mandelbrot during 1975 while conducting research on several naturally occurring irregular and fragmented geometries [1]. Euclidean geometry based conventional antennas are defined by some formula, whereas fractal antennas are defined by iterative rule. Fractal antenna engineering is an emerging field that employs fractal concepts for developing new types of antennas with notable characteristics [2]. Puente et al. [3] and Cohen [4] were the pioneers in the study of antennas using fractals elements [5].

Fractalisation of planar antenna will help to make an antenna more efficient. Fractal geometries have two main features in common, space-filling and self-similarity properties, which will expand the bandwidth and reduce the dimensions of the antenna [6]. These unique properties of fractals have been exploited in order to develop a new class of antenna-element designs. They are believed to possess several highly desirable properties, including multi-band performance at non-harmonic frequencies, low or negligible wastage of power in side lobes, size reduction. They also find applications in reconfigurable systems [7].

In this paper, the proposed Pythagoras tree monopole fractal antenna is presented for single frequency broad-bandwidth operations. The use of fractals provides us with a bigger set of parameters to control the antenna characteristics. The proposed antenna operates over the frequency band between 5.35 and 5.74 GHz for VSWR < 2, and finds its applications in Wi-Fi/WLAN, WiMAX and satellite mobile communication.

## 2 Sructure Of The Proposed Antenna

The basic antenna geometry considered for the design is of Pythagorean tree type, which is a plane fractal constructed from squares. The antenna geometry is named after Greek mathematician Pythagoras, because sides of each triple of touching squares together forms a Pythagorean triplet which in turn encloses a right triangle, this is a traditional method which is used to depict the Pythagorean Theorem [7]. The same procedure is then applied recursively for the next two iterations.

## 3 Antenna Configuration

First three iterations with a basic patch designed manually as microstrip patches are shown in Fig.1.

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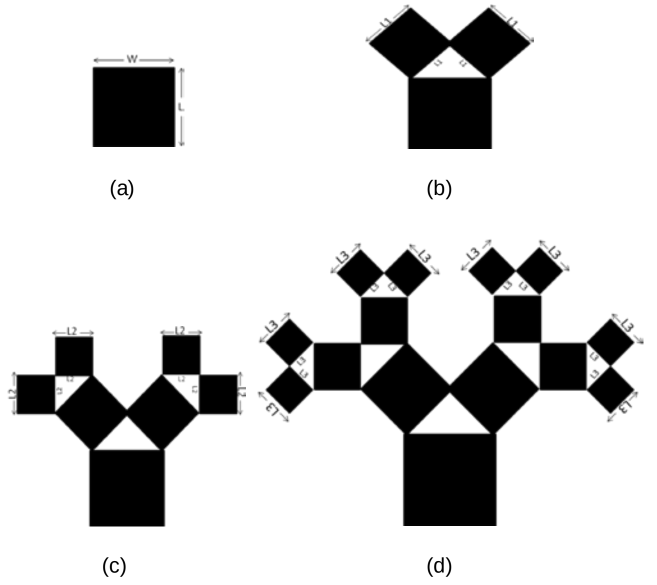

Figure 1. Pythagorean tree structures (a) Basic structure (b) First iteration (c) Second iteration (d) Third iteration

In terms of dimension of the basic structure, L is the length and W is the width. Since the basic structure is of square shape, therefore the facet of length and width remains the same i.e. L=W. So the total length of the basic patch is 2L mm.

The first iteration is obtained by creating a fractal structure from its basic structure after applying Pythagoras theorem to compute the two sides of a right angled triangle which in turn will form the facet of each of the two corresponding scaled down squares touching the vertices of the basic square patch structure. Here, in this design we have used an isosceles right angled triangle that's each flare angle is of 45 degrees. In this design the value of L is 42mm. So for computing the length of the sides of an isosceles right angled triangle i.e. $L_1$, we will apply Pythagoras theorem i.e.$\sqrt{(L_1^2 + L_1^2)} = L$ to it. The same principle is repeated in second and third iterations to calculate the dimensions of $L_2$ and $L_3$ respectively.

We can calculate the number of squares, scaling factor of square patch, dimensions of the structure after 'n' number of iterations as,

Let iteration factor be 'n', then,

Number of new square patch structures in each iteration = $2^n$

Total number of square patch structures after 'n' number of iterations = $(2^{n+1} - 1)$

Scaling factor of a square patch structure after 'n' number of iterations = $[1/\sqrt{2}]^n$

Dimensions of the structure after 'n' number of iterations = $[(L+1)*(L/2+1)]$

Using above relations in our proposed Pythagorean tree fractal antenna we found out that, the basic patch is having the dimensions of L*L $mm^2$ and the squares are further iterated onto the base patch and each iteration is scaling down the size of the square by a factor of $(1/\sqrt{2})$ and after the third iteration the structure was having the dimensions of 4L*3L $mm^2$ and the size of the square patch structure was scaled down by the factor of $(1/2\sqrt{2})$.

The proposed antenna consists of a patch element mounted on a dielectric isotropic layer over a truncated ground plane of length 9mm and having the same width as that of a dielectric isotropic layer. The proposed antenna was designed using Rogers RT/duroid 5880 PCB substrate whose dielectric constant ($\varepsilon_r$) is 2.2 which is moderate enough with a loss tangent of 0.0009. This substrate is preferred because it is readily available, low cost and provides ease of fabrication for prototype designs. The thickness of the substrate layer is 1.57 mm and the antenna is fed with a microstrip line feed as shown in Fig. 2 and the size of the board is 188X146 $mm^2$.

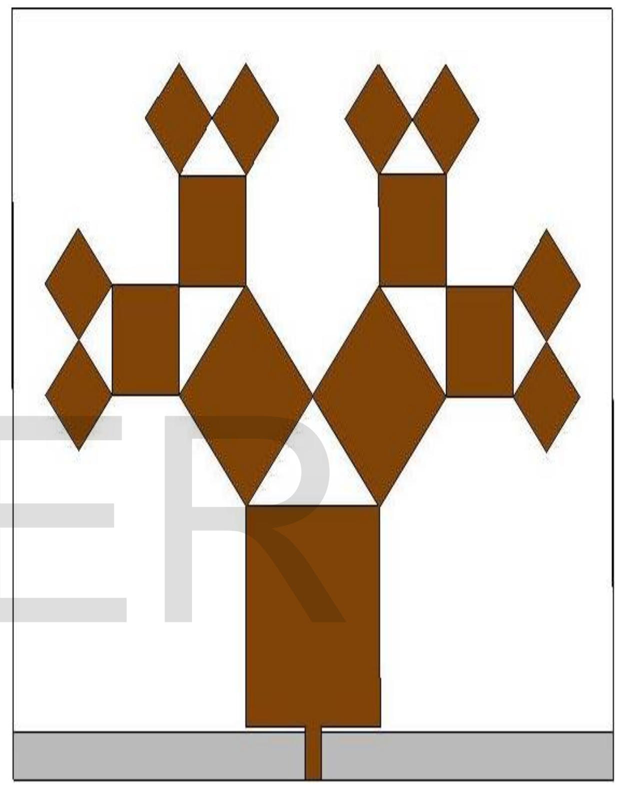
Figure 2. Simulated Pythagorean tree monopole fractal antenna with a microstrip line feed

## 4 SIMULATIONS

An important issue associated with the evaluation and comparison of how the different design parameters play a role on the antenna performance involves the appropriate application of computational tools capable of accurately predicting antenna performance. Accurate simulation results provide insight into the impedance behaviour and radiation characteristics of the antenna. In addition, these results may be used to develop design methodologies, and optimize antenna designs [8].

There are number of software's that are available for the simulation of the RF component designs such as IE3D, CST, Feko, EMPro etc. In this paper, the structure has been designed and simulated using full wave analysis tool of Ansoft Designer™.

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## 5 Results & Discussion

The antenna is simulated and fabricated for the above configuration. The results shown in Fig. 3 to Fig. 6 reveal that the newly designed fractal antenna resonates at a frequency of 5.51 GHz. The simulated antenna with an impedance bandwidth of 410 MHz (for VSWR < 2) shows broad-bandwidth operation for different wireless applications, such as Wi-Fi/WLAN, WiMax and satellite mobile communication.

The Table I describes the performance characteristics of the designed antenna.

Table I. Performance characteristics of Pythagorean tree monopole fractal antenna

| Parameters | Practical design |
|---|---|
| Resonant Frequency ($f_r$) | 5.51 GHz |
| Return Loss | -38.11 dB |
| VSWR | 1.03 |
| Gain | 5.73 dB |
| Directivity | 6.09 dB |
| Bandwidth (for VSWR < 2) | 410 MHz |
| Port Impedance | 58.31 Ω |

Fig. 3 represents the variation of Return Loss with Frequency. Plot shows that the antenna is resonating at 5.51 GHz with a minimum return loss of -38.11 dB.

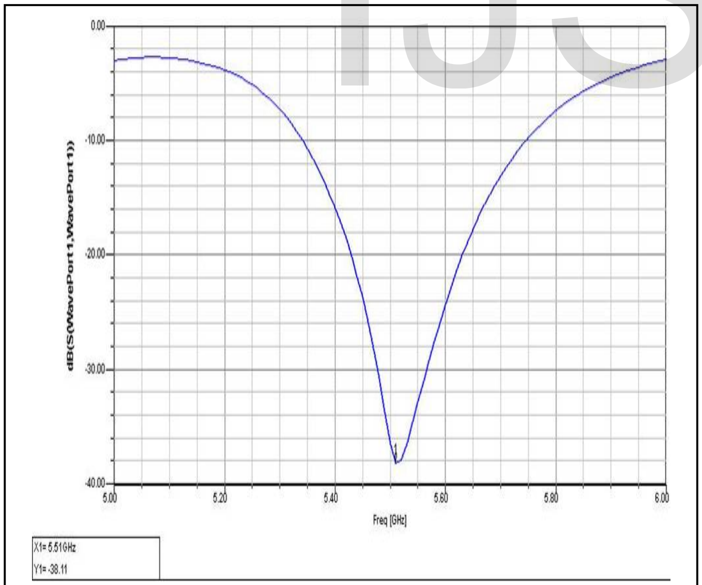


Figure 3. Return Loss vs Frequency

The VSWR of the simulated Pythagorean tree monopole fractal antenna was plotted in Fig. 4. According to the plot the reflection coefficient of the simulated antenna at resonating frequency is 1.03. Ideally the reflection coefficient must be equal to one, which is practically unachievable. So every antenna is designed with an idea to keep reflection coefficient closer to one.

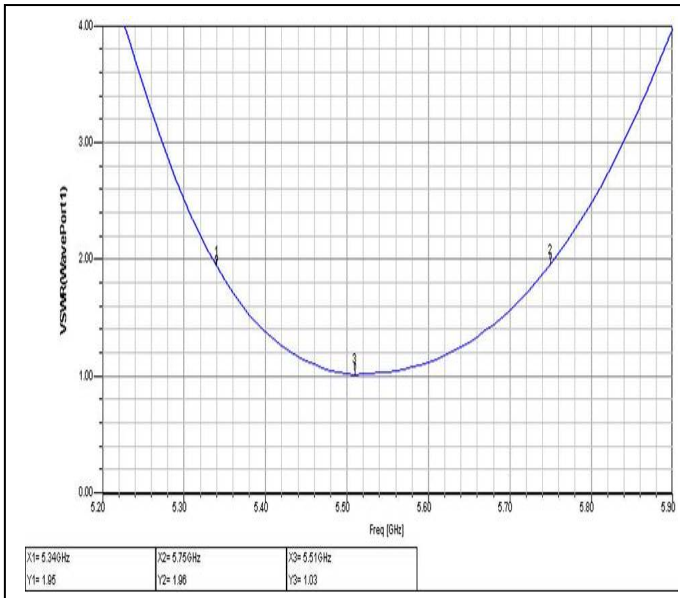


Figure 4. VSWR vs Frequency

In Fig. 4, three points were indicated, among which Point 1 and Point 2 are representing the lower cut-off frequency (i.e. 5.34 GHz) and higher cut-off frequency (i.e. 5.75 GHz) and giving an impedance bandwidth of 410 MHz for the simulated antenna.

The Directive Gain and Port Impedance of the simulated antenna were plotted in Fig. 5 and Fig. 6. The Port Impedance of the simulated antenna at resonating frequency is 58.31Ω, it shows that the impedance of the simulated antenna is almost perfectly matched with that of the waveport of 50Ω. The value of the reflection coefficient at resonating frequency also justifies the previous statement.

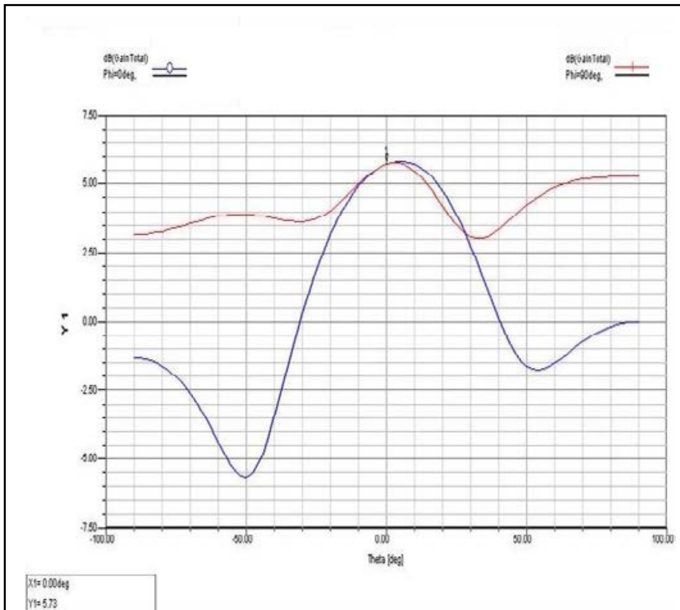


Figure 5. Directive Gain of the Pythagorean tree monopole fractal antenna

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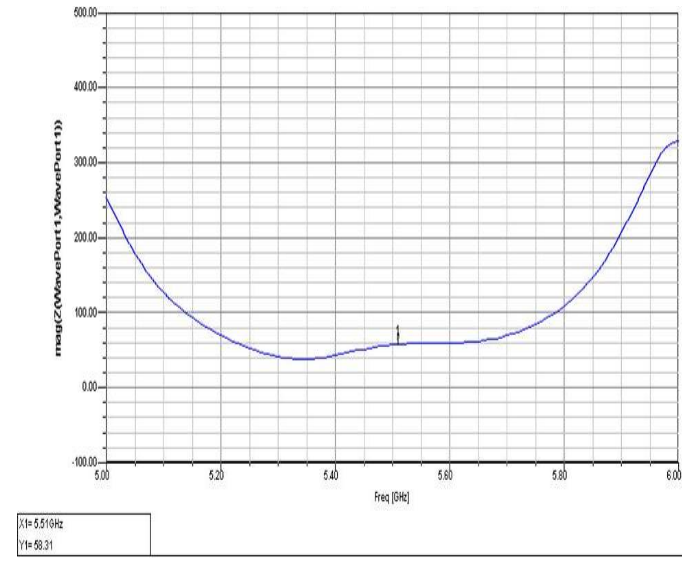


Figure 6. Port Impedance of the Pythagorean tree monopole fractal antenna

## 6 Conclusion & Outlook

The Pythagorean tree monopole fractal antenna design has been proposed and successfully implemented. The use of fractal geometry (i.e. Pythagoras tree) shows tremendous potential for broad-bandwidth applications without employing any further modification, such as incorporation of U or L slots and stacking techniques which offer an added advantage. However, a supplementary use of such modifications will certainly help in antenna size reduction with a further improved performance. The resonance effect changes with the position of the feed and the length of the ground plane. Hence an optimized feed width, its position and ground length are to be chosen so that the VSWR and impedance are within the accepted levels. Further work in this paper is to optimize, fabricate and then measure the performance for accuracy of operation.



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