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# Design and Optimization of C Structured Microstrip Multiband Antenna for Wireless Communication Using Fractal Geometry

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## Abstract

**Objectives**: To develop a microstrip antenna with a C structure utilizing fractal geometry to minimize the antenna's size and for more multiband frequency components which are useful in wireless applications. **Method:** This paper presents multiband C shaped microstrip multiband patch antenna. There are two iterations have been applied one by one on square patch which results in fractal patch antenna The IE3D software application has been used to simulate every designed microstrip antenna which resonates at 4.7 GHz, 6.5 GHz at corresponding frequencies.. With the use of this antenna design simulation tool, parametric analyses were done to establish the antenna's geometries. A maximum of two iterations were made to the developed antenna in order to run it in multiband and make it appropriate for wireless applications including WIFI, ISM, and satellite C band. Proposed antenna is designed using IE3D and results are analyzed in terms of gain, return loss, directivity, bandwidth and VSWR. **Findings:** This design makes constructing a microstrip patch C-shaped fractal antenna for ISM and WIFI applications possible at a reasonable cost using a basic FR4 substrate which is cheaper as compared to RT Duroid and other substrates. It features a new shape for its patch and does not just cover a favorable bandwidth. Future assessments may find the antenna to be a good contender due to its compact size, needed bandwidth, more number of multiband and acceptable gain in contrast to antennas that have already been built or manufactured. **Novelty and Applications:** TheIE3D software has been used to run every simulation. The C-shaped antenna's small size (28.83X37.26

mm$^2$), seven multiband and desired bandwidth with acceptable gain compared to design or fabricated antennas reported earlier. The comparison between the simulated and the measured results is incorporated in the manuscript. A comparison of the presented design with other articles is included to check the novelty of the design. The proposed method helps to target applications such as WiFi, Earth observation and microwave links.

**Keywords:** Return Loss; Microstrip Patch; IE3D; VSWR; Patch Antenna; Fractal; Multiband

## 1 Introduction

The Micro strip C Structured Multiband Patch Antenna is the second-generation antennas. It is a metallic patch, printed on thin grounded dielectric substrate using a process similar to lithograpy in which patterns are printedon the substrate while fabricating printed circuit boards or integrated circuit. The main advantages are its low weight and low cost. Narrow bandwidth and low efficiency are its main disadvantages. Fractal antennas are still in their early stages of development. In 1988, the first fractal antenna later on patent and published was built by Dr Nathan Cohen. As we know antenna size and operating wavelength are related such that, when the size of an antenna is made much smaller than the operating wavelength or less than one fourth of the operating wavelength ($\lambda/4$), it becomes highly inefficient. A curve or geometrical figure, each part of whish has the same statistical character as a whole. They are used in which similar pattern recur at a progressively smaller scale, and in describing partly random chaotic phenomena such as a crystal growth and galaxy formation. The c structured microstrip patch antenna can connect directly to a microstrip line transmission line. At the edge of path, impedance is generally much greater than 50Ω(e.g200 Ω). To avoid the impedance mismatch, section of quarter-wavelength long impedance transformer can be used to transform a large input impedance to a 50Ω line. With this feed approach an array of patch elements and their microstrip power division lines can all be designed and chemically etched on the same substrate.

The Sierpinski gaskets fractal shape microstrip patch antenna operates in many resonant frequencies. Due to the self-similar nature of fractals, resonance frequencies can be seen at multiband frequencies [1,2]. The L-Shaped Fractal antenna for wireless communication was studied [3], and the designed patch antenna resonated at 5GHz single Frequency. The L-shaped study describes the two types of feeding techniques: Microstrip line feed and inset cut line feed..An F-shaped microstrip fractal patch antenna fabricated using roger RT/duroid material and FR4 g substrate materials. The microstrip line feeding method is employed in this F shape antenna. This antenna is studied up the third iteration using An soft HFSS antenna design tool and obtained 5 resonant frequencies [4]. In another work, a novel compact stair-shaped fractal microstrip patch antenna and maximum 3 resonant frequencies are attained and simulated up to third iteration. [5]. For high-speed and multi-frequency operation, a customized fractal antenna in the form of a wheel was examined [6]. Applications in WBAN and satellite telecommunications can be found for a dual-band comparatively tiny, low-profile antenna that uses Minkowski and Sierpinski carpet fractals [7].

The examination of the Moore and Hilbert patch antenna, which can operate at multiband frequencies and pick up the PD signal, was also conducted [8]. To get a frequency bandwidth ratio of 8.4:1 [9], for the uses of wideband frequencies, a hexagonal-triangular slotted design creation was also recently performed, and in one more research design, Hilbert and Minkowski fractal geometry patch antennas were compared in relation to antenna properties, and it was demonstrated that the blended Hilbert and Minkowski antenna has a significant number of resonant frequency components in comparison to the individual antennas [10].

The related work [11,12] and [13] focuses on both fractal patches with self-similarity. However, still there is a need for compacted and more numbers of multiband frequencies of operation by different fractal structures having different shapes. Hence this work focuses on a compact C structure type microstrip antenna with the application of fractal geometry. In this research, the designed antenna operates at 7 different frequencies between 1.722 GHz and 6.0 GHz which also covers the S and C, band applications. The proposed construction consists of C-shaped patch on the top surface and ground at the bottom side. For all resonant frequencies, the designed antenna attained a return loss of less than -10dB. The gain and directivity are fairly good, and the VSWR lies less than 2. This fractal c shaped antenna design yielded multiband behavior and size lessening and attained better gain in the L- band, S-band, and C- band frequencies wireless communication uses.

This literature review work provided an insight in determining the performance of C structured microstrip patch antenna, from the literature survey, Fractal geometry enhanced the bandwidth of the antennas up to great extant. Fractal antennas have different properties which results in small size, high gain, and high efficiency antenna. With increasing the number of iterations of fractal geometry, resonant frequency increases that realized in lower return losses. The performance parameters of antennae for instance radiation pattern, return loss, bandwidth, VSWR, and many resonant frequencies have been explored thoroughly. The microstrip antenna design considerations and their optimization were carried out through the IE3D simulation tool to obtain optimum results. Fractal antennas have various applications in radar, telecommunications, satellite communications, medical imaging, weather forecasting etc. Fractal plays vital role to reduce the size of conventional antenna which is prime requirement for the modern wireless system.

## 2 Methodology

The proposed microstrip antenna is based on fractal techniques and designed for wireless applications. The radiating element is a C-structured triangle on which fractal concept is applied. Fractal concept is applied on the proposed C-Structured Fractal Microstrip Antenna (CSFM-Antenna), similar to English alphabet letter C. Further the analysis and verification of result is achieved by testing the fabricated antenna and also comparison of simulated and experimental results.

The microstrip C-shaped fractal antenna geometries are designed from the fundamental square patch and then iterations are introduced. The antenna geometry is optimized using the IE3D simulation tool. All the antennas are designed using low-cost glass epoxy FR4, with a 1.6 mm height and dielectric materials constant of 4.4.

### 2.1 Antenna Design

**A. Microstrip Antenna 1, Iteration 0**

The size of a microstrip patch antenna and the adopted probe feed have a relationship with the center frequency fr. The width ”W” and length ”L” of the microstrip patch antenna play a significant role in setting the resonant frequency of the operating microstrip antenna in the suggested design of the antenna. The proposed radiating patch antenna of size 28.83X37.26 mm2 for rectangular antenna size is calculated by referring to the microstrip antenna design equations 1 to 7 as provided below [1,2,14], to operate at 2.44GHz.

Calculation of width: The width of the microstrip patch antenna is given by the equation

$$Wo = \left(\frac{c}{2fr}\right)\left(\frac{\sqrt{2}}{\sqrt{\varepsilon r + 1)}}\right) \tag{1}$$

Calculation of effective dielectric constant

$$\varepsilon r_{eff} = \frac{\varepsilon \mathrm{r}+1}{2} + \frac{\varepsilon \mathrm{r}-1}{2}\sqrt{1+12\,\mathrm{h/w}} \tag{2}$$

Calculation of effective patch length

$$Leff = \frac{c}{2fr\sqrt{\varepsilon r_{ef} f}} \tag{3}$$

Calculation of patch length extension

$$\Delta L = 0.412h\frac{\left(\varepsilon r_{eff}+0.3\right)\left(\frac{w}{h}+0.264\right)}{\left(\varepsilon r_{eff}-0.258\right)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

Calculation patch actual length

$$Lo = Leff - 2\Delta L \tag{5}$$

Calculation of patch ground plane parameters (Lg and Wg)

$$Lg = L + 6h \tag{6}$$

$$Wg = W + 6 \tag{7}$$

The ground plane's overall dimensions are 39.7 mm by 47 mm.

Where, $\varepsilon_{reff}$ = Effective material dielectric constant.

$\varepsilon_r$ = Dielectric constant of the material.

h = Height of dielectric substratum.

c is the speed of light

Utilizing IE3D antenna simulation tool Ver. 15, the patch antenna is simulated. The dielectric substrate for Antenna 1 is FR-4, with a material thickness of 1.6 mm, a dielectric constant of 4.4, and a loss tangent of 0.02. The IE3D antenna modeling software program is used to optimize the antenna-designed parameters. For the optimal gain, impedance bandwidth, and multiband operation, the optimization was carried out across a number of rounds. The suggested antenna-1's geometry is depicted in Figure 1. The various dimensions of antenna 1 are shown in Table 1.

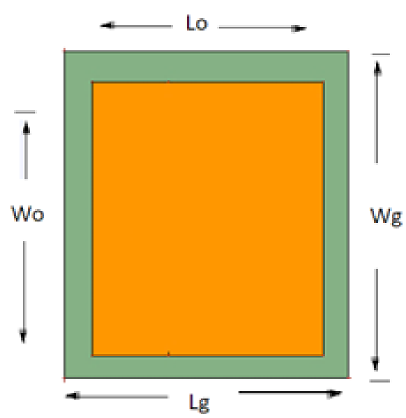


**Fig 1.** Basic antenna-1's geometry

**Table 1.** List of parameters of antenna -1 configuration

| Antenna Parameters | Antenna Dimension (mm) |
|---|---|
| $L_0$ x $W_0$ | 28.83x37.26 |
| $L_g$x $W_g$ | 39.7x47 |

**B. Microstrip Antenna 2, Iteration-1**

The Figure 2 demonstrates the configurations of the proposed C shape patch microstrip antenna with the first iteration. This proposed antenna is designed by the application of fractal geometry to the basic patch antenna-1. Antenna 2 is constructed by dividing the antenna-1 into 9 equal rectangular structures each of size 9.61mmx 12.42mm and E shape structure of size 9.61mmx 12.42mmx 2mm is constructed at the center of the patch. The various dimensions of antenna 2 are shown in Table 2. The proposed microstrip antenna is designed and simulated using IE3D design tool Ver 15 and is constructed using FR-4 material with $\varepsilon$r = 4.4 as the dielectric substrate constant, having a thickness of 1.6 mm, and tangent($\delta$) = 0.02. The designed microstrip antenna parameters are optimized with the IE3D antenna modeling simulation tool. The optimization was accomplished with much iteration for the better antenna gains, impedance frequency bandwidth, and multiband functioning. The probe feeding technique is being used.

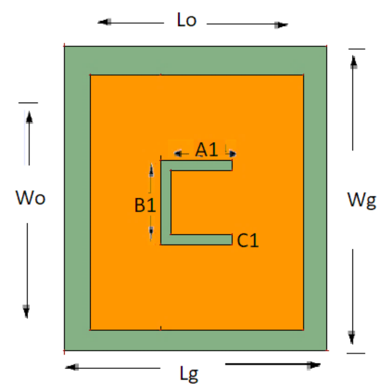


**Fig 2.** C shape Microstrip Antenna-2 Iteration-1

### C. Microstrip Antenna 3, Iteration-2

Figure 3 depicts the configuration of the proposed C-shape microstrip antenna-3 with fractal geometry with iteration-2. Antenna 3 structures are made by dividing the antenna-2 into 9 equal rectangular structures each of size 9.61mm x 12.42mm.

**Table 2.** List of Microstrip antenna geometry-2 parameters

| Parameters | Dimension (mm) |
|---|---|
| A1 | 9.61 |
| B1 | 12.42 |
| C1 | 2 |

The C shape structure of size 9.61mmx 12.42mmx 2mm is constructed at the center of the patch In the remaining 8 rectangular parts of each size 9.61mmx 12.42mm, all the 8 rectangular structures have been divided again 9 equal rectangular parts of size 3.203 mm x 4.140mm. At the center of 3.203 mm x 4.140mm, C shape structure of 1mm width is constructed. The various dimensions of antenna 3 are shown in Table 3. IE3D simulation software Ver 15 is used to simulate the antenna 3 and the parameters of the antenna are optimized through a number of repetitions.

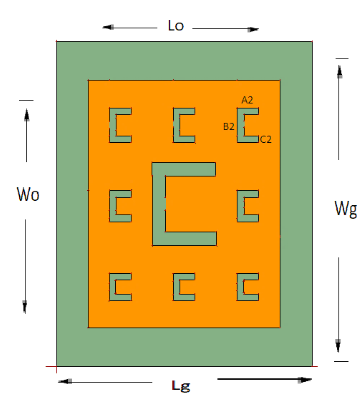


**Fig 3.** C shape Microstrip Antenna-3 Iteration-2

**Table 3.** List of Microstrip antenna geometry-3 configurations

| Antenna Parameters | Antenna Dimension (mm) |
|---|---|
| A2 | 3.203 |
| B2 | 4.140 |
| C2 | 1.000 |

## 3

## Results and Discussion

The twofold iterations of the self-similar fractal microstrip patch antenna with the probe feeding technique were studied using the IE3D antenna simulation tool. The C-shaped fractal patch antennas 2 and 3 are created using inexpensive FR-4 material with a refractive index of 4.4 and simulation results with parameters as displayed in Table 4. This Table 4 clearly shows that these antennae have several multiband resonance components with excellent bandwidth, low return loss, and high antenna peak gain values. Simulated and constructed at 2.44 GHz is the fundamental Antennas-1. By altering the feeding point locations, the findings have been optimized to produce trustworthy antenna-performing characteristics.

The recommended microstrip antenna-1 resonated strongly at three different multiband frequencies and has a peak gain of 1.74 dB with a bandwidth of 170.99 MHz, a return loss of -21.84 dB, and a VSWR of 1.39 at the 2.44 GHz frequency. These specifications are appropriate for wireless applications like WiFi and Bluetooth. Figure 4 s illustration of a 3D radiation pattern exhibits excellent omni-directional radiation properties. Cross polarizations on the 3D radiation patterns at 2.44 GHz are less than 20 dB, and rear radiations are also minimal. Antenna-1 has a peak field directivity of 6.24dbi, a 35.29% antenna efficiency, and a 44.63% antenna radiation efficiency. Incorporating the first iterated fractal geometry to antenna-1 has been used as a strategy to obtain multiband and reduce the volume of the antenna. To acquire better values of radiating parameters, many more optimizations were carried out by altering the C shape structure, as shown in Table 4. According to the results of the simulation, antenna-2 generated five multi-band resonance frequencies that are appropriate for use in 5G, Wi-fi connectivity, and WIMAX applications.

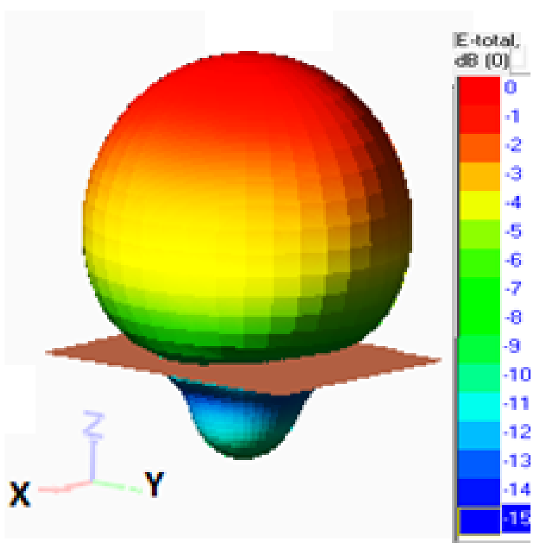


**Fig 4.** Simulated Basic microstrip antenna-1,3D Radiation plot at 2.44GHz

A maximum antenna gain of 3.27 dB has been attained at 6.488 GHz with a wider bandwidth of 158.84 MHz having an antenna return loss of -17.59dB and 1.20 VSWR which is suitable for radar and satellite applications. The suggested antennas' 2D radiation patterns are shown in Figure 5, which also illustrates their good omni-directional properties with fewer minor lobes and maximal radiation at an angle of 0 degrees. At 3.686GHz, the antenna efficiency was 27.37% and the peak radiation efficiency was 35.39%. At 5 GHz, the antenna efficiency was measured to be 28.85 dB, the radiation efficiency to be 30.43%, and the highest aggregate electromagnetic field directivity to be acquired to be 7.8 dB. The shape antenna-2 reduces its size by 5% as compared to antenna-1.

As can be seen from the results, the C-shape type second-iterated fractal antenna-3 has 7 multiband resonance frequency components that are compatible with ISM, Bluetooth, WIFI, and WIMAX uses. These frequencies have good bandwidth, better returns loss, and VSWR, as depicted in Table 4. The second iterated C-shape structured fractal antenna has a maximum gain of 3.61dB at 5. 362GHz after multiple iterations for optimizing antenna parameters for feed point positions. The antenna efficiency of this proposed antenna-3 is 35.29%, the total field directivity attained is 9.7dBi, and the maximum efficiency of antenna radiation obtained is 44.63%. Additionally, a size decrease of 24% overall is accomplished. Figure 6 depicts a simulated suggested antenna-1,2 and 3 optimized comparative study of return loss(S11), which exhibits a satisfactory return loss. The simulated polar radiation graphs at ø=900 and ø=00 =900 and =00 are displayed in Figure 7 and shows omni-directional characteristic at 6GHz.The return loss characteristics obtained are all above -10dB and indicate good return loss at the resonant frequencies. The VSWR results as shown in Table 4 shows good matching of antenna and feed point and indicate less reflected power. The diagram portrays that the microstrip antenna is much further directive and has greater frequency bandwidth as compared to antenna 2. The designed microstrip antenna three has led to a total size decrease of 24%.

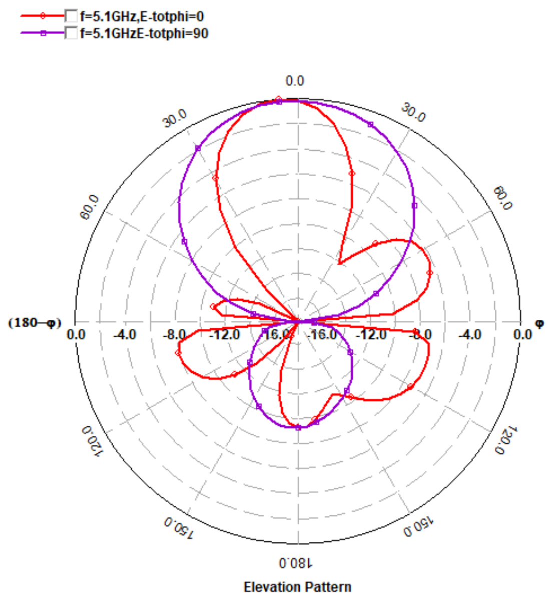


**Fig 5.** Simulated microstrip antenna-2,2D Radiation Pattern

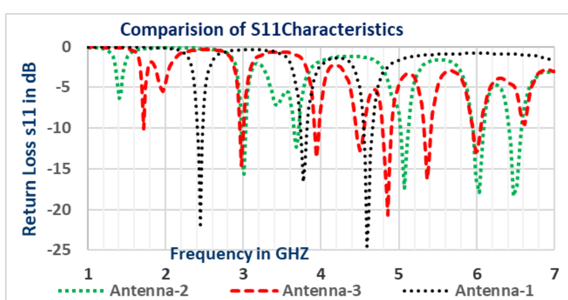


**Fig 6.** C shape microstrip antenna one, two and three comparison of return loss S11 characteristics

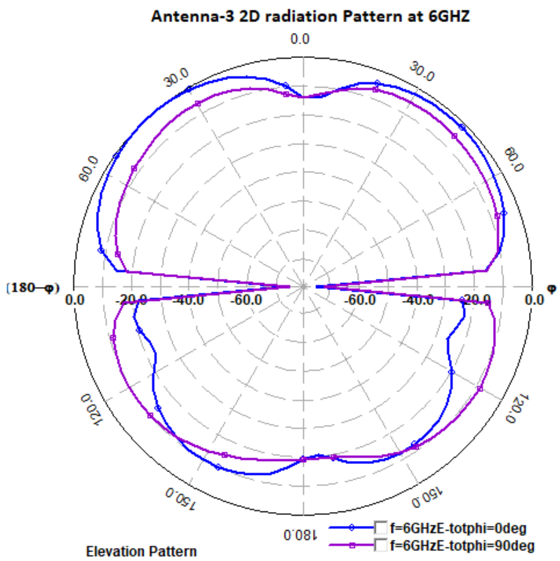


**Fig 7.** Simulated microstrip antenna-3,2D Radiation Pattern

**Table 4.** Designed Antenna1,2 and 3 parametrs Results

| Type of Antenna | Resonant Frequency (GHz) | Return Loss($S_{11}$ )(dB) | Bandwidth(MHz) | VSWR | Gain(dB) |
|---|---|---|---|---|---|
| | 2.44 | -21.84 | 170.99 | 1.39 | 1.74 |
| Antenna-1 | 3.79 | -13.45 | 183.20 | 1.52 | 0.18 |
| | 4.60 | -24.20 | 111.47 | 1.14 | -1.40 |
| | 3.012 | -15.60 | 58.59 | 1.39 | -1.01 |
| | 3.686 | -12.24 | 60.79 | 1.64 | 1.21 |
| Antenna-2 | 5.088 | -17.617 | 104 | 1.32 | 1.16 |
| | 6.034 | -17.83 | 138.68 | 1.30 | -2,25 |
| | 6.488 | -17.59 | 158.84 | 1.20 | 3.27 |
| | 1.722 | -10.034 | 09 | 1.91 | -2.45 |
| | 2.975 | -14.486 | 50.27 | 1.52 | -2.48 |
| | 3.941 | -13.527 | 62.03 | 1.55 | -0.85 |
| Antenna-3 | 4.490 | -12.705 | 97.56 | 1.6 | -1.5 |
| | 4.855 | -20.650 | 110.33 | 1.25 | -0.56 |
| | 5.362 | -16.198 | 98.40 | 1.40 | 3.61 |
| | 6.000 | -12.911 | 110.43 | 1.58 | -0.85 |

## 4 Conclusion

A fractal-geometry-based c-structure type microstrip patch antenna has been introduced. Comparing the investigated geometry to the standard basic microstrip antenna, the results are overall optimal. The C-shape-sized microstrip patch antenna resulted in 7 resonant multiband frequencies, where multiband frequencies in the literature found minimum number. According to the presented antenna work design and analysis performed here, the second iteration's overall size was reduced by 24.23 percent (antenna-3). The performance is analyzed regarding the reflection coefficient response, gain, directivity, E-field and radiation pattern. The operating frequencies that produced the best results were 2.44 GHz with a BW of 170.99 MHz and a maximum gain of 1.74 dB for the basic microstrip antenna 1, 6.488 GHz with a frequency bandwidth of 158.84 MHz and the highest gain of 3.27 dB for antenna-2, and 5.362 GHz with a wider bandwidth of 98.40 MHz and a peak gain of 3.61 dB for antenna-3, respectively. The design highlights are compared with other published articles to identify the improvement. The multiband response over the 4 GHz to 12 GHz helps to attain multiple wireless communication applications such as WiFi and Microwave links. Applications in these fields can benefit from these operating frequencies in the S-band (unlicensed applications) like Wi-MAX, Wi-Fi, LTE ISM, and blue tooth modules.

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