# Design and Comparison of LTCC Based Fractal Antennas

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## Abstract

The paper presents design of three different fractal antennas in Low Temperature Co-fired Ceramic (LTCC) substrate. An aperture coupled feeding technique has been used in all the three designs which is highly suitable for multi-layer system on package (SoP) concept. The three fractal designs demonstrated are Sierpinski carpet fractal antenna, Sierpinski gasket fractal antenna and Koch snowflake fractal antenna. Bandwidths of 1.8 GHz (7.5%), 1.75 GHz (7.5%) and 1.6 GHz (6.7%) have been achieved from these designs at a centre frequency of 24 GHz in comparison to the typical aperture coupled patch antenna bandwidth of 2%. In addition to their large bandwidths the designs have demonstrated a size reduction of greater than 20%. A detailed comparison among the three designs has been presented in the paper to highlight various performance parameters and related tradeoffs.

## 1. Introduction

Recently the design of miniaturized yet high performance antennas has been one of the key topics under research due to large interest in portable and wearable wireless devices. The desired parameters of these designs are the large band width and small size of the antenna. Large bandwidth is one of the key requirements in high data rate applications such as Wireless Personal Area Network (WPAN) [1] where as miniaturization is an emerging trend in all the wireless applications. Small bandwidth of the planar antennas devoid their use in the above mentioned applications. Several papers have been published which demonstrate the methods to improve the bandwidth of these antennas [2]. These techniques have proved to be useful but they add design complexities in the antenna structure. Such complications in the design can be avoided by the use of fractal antennas [3].

Fractal is a new class of geometry that was proposed by 'Madelbrote' [4]. The fractal structures are designed by stacking of numerous small units together in such a way that the final geometry has the same shape as that of the unit structure. This gives the fractal a unique property of non integer dimension. However, in antenna design fractals have gained a lot of attention due to their compact size and large bandwidth due to multiple resonances [5, 6]. In addition to their larger bandwidths, fractal antennas are compact in size relative to the conventional antennas because of their efficient volume filling nature. Fractal antennas have been implemented previously but in PCB based substrates [7]. In [8] for the first time we presented a fractal antenna design in an LTCC medium to exploit the multilayer nature of this technology. This design technique allows the vertical integration of RF circuits and antenna and thus isolates RF circuits from antenna radiations.

## 2. Concept and Design

The vertical stacking of LTCC is ideal for aperture coupled technique. The design concept is illustrated in Fig. 1. An eight layer thick LTCC module (CT707) has been used in the designs. A cavity in the first four layers can accommodate the microwave and millimeter wave integrated circuit (MMIC). This chip can be then connected to the microstrip feed line using bond wires, which is designed on the fourth layer. The feed line excites the slot in the ground plane which is designed on the fifth layer. The ground plane also acts as a shield between the RF circuits and the antenna element places on the top layer. In this work three fractal designs have been investigated for the 24 GHz ISM band. Each one of them will be discussed in the following sections.

### 2.1 Sierpinski Fractal Antennas

Sierpinski fractal structures are designed by carrying out multiple iterations on a basic geometrical shape such as triangle, rectangle, circle or square [4]. Sierpinski Carpet fractal antenna is realized by successive iterations

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applied on a simple square patch as shown in figure 2(a), which can be termed as the zeroth order iteration. A square of dimension equal to one third of the main patch is subtracted from the centre of the patch to retrieve first order iteration, as shown in Fig. 2(b). The next step is to etch squares which are nine times and twenty seven times smaller than the main patch as demonstrated in Fig. 2(c) and 2(d) respectively. The second and third order iterations are carried out eight times and sixty four times respectively on the main patch. This fractal can be termed as third order fractal as it is designed by carrying out three iterations. The pattern can be defined in such a way that each consequent etched square is one-third in dimension as compared to the previous one sharing the same centre point. This procedure of design carried out on a square shaped patch can be implemented on any of the four geometries named above.

Sierpinski Carpet fractal antenna implemented in this design is a third order fractal with a dimension of 1.8 mm x 1.8 mm. At 24 GHz this fractal antenna is 53 % smaller as compared to a conventional patch antenna. The dimensions of its iterations are 0.6 mm, 0.2 mm and 0.067 mm respectively. The dimension of the slot for the carpet design is 1.8 mm x 0.1 mm. The dimensions of the slot shall be critically optimized as they determine the input impedance of the design and also help to reduce the backward radiation from the slot.

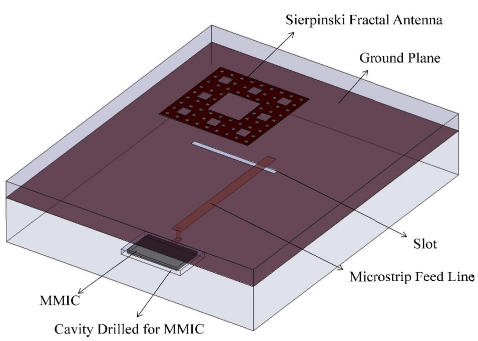


Figure 1: SoP Concept

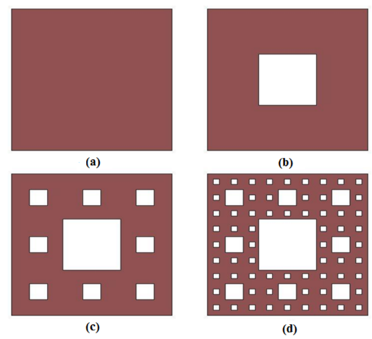


Figure 2: Sierpinski Carpet Fractal Antenna
(a) First Order Iteration, (b) Second Order Iteration,
(c) Third Order Iteration, (d) Fourth Order Iteration

The execution of iterations for a Sierpinski gasket fractal antenna is identical to its carpet counterpart. The design implemented in this work is again a third order fractal just as in the case of carpet design. An equilateral triangle of 2 mm length is used in this model for the implementation of gasket design. The dimensions of its iterations are 0.667 mm, 0.223 mm and 0.074 mm respectively. In this case the slot has a dimension of 1 mm x 0.1 mm. The gasket design exhibits a 35 % reduction in its size as compared to conventional design which shows that carpet design is superior to gasket design in terms of size reduction.

## 2.2 Koch Snowflake Fractal Antenna

Koch snowflake is the type of fractal design that uses space overlapping properties of multiple structures of similar shape [19]. It is usually designed with the help of a simple triangular structure. The structures starts with an equilateral triangle which can be regarded as the zeroth order iteration just as in the case of Sierpinski gasket design. Unlike Sierpinski gasket which is designed by removing smaller triangles, Koch snowflake is designed by adding smaller triangles to the main triangle. After designing the main triangle, another triangle of same size is placed on it but in inverted position to give the design a star like shape as shown in figure 4(b) and can be termed as the first order iteration. The star like shape has six small triangles in it. The same procedure will be repeated on all these triangles i.e. six inverted triangles will be placed on these six triangles. This can be regarded as the second order iteration. For the third order iteration, same procedure of placing the inverted triangles is carried out on the second order iteration. The last two iterations are shown in figure 4(c) and 4(d) respectively.

Koch snowflake antenna starts with an equilateral triangle of 2 mm in this design. Due to non geometrical structure, it is difficult to exactly calculate the area of Koch snowflake design but it shows similar kind of miniaturization as Sierpinski gasket fractal design. The area of Koch snowflake is greater than the gasket design because it is implemented by addition of triangles instead of subtraction as in the case of gasket design. From this deduction it can be concluded that gasket design is more compact than the snowflake design.

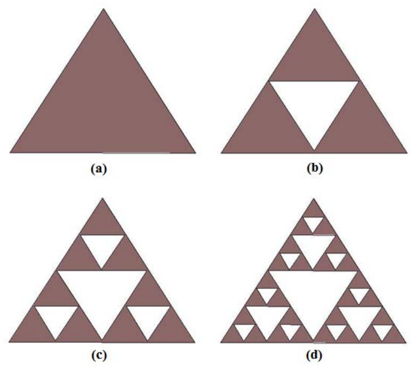

Figure 3: Sierpinski Gasket Fractal Antenna
(a) First Order Iteration, (b) Second Order Iteration,
(c) Third Order Iteration, (d) Fourth Order Iteration

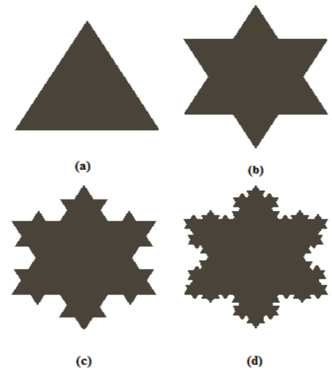

Figure 4: Koch Snowflake Fractal Antenna
(a) First Order Iteration, (b) Second Order Iteration,
(c) Third Order Iteration, (d) Fourth Order Iteration

## 3. Simulation Results and Design Comparison

### 3.1 Simulation Results

The designs are simulated in Ansoft HFSS. The simulated bandwidth of the Sierpinski carpet fractal antenna achieved is 1.8 GHz which is 7.5 % of the centre frequency as shown in Fig. 5. This bandwidth is almost 4 times greater than the bandwidth of a conventional patch antenna. The design depicts a gain of 5.0 dB with beam widths of 85° and 120° in H plane and E plane respectively. The 3D radiation pattern of the fractal antenna is shown in Fig. 6. These results exhibit that Sierpinski carpet fractal antenna has a similar performance of gain but a wide bandwidth as compared to conventional patch antenna as shown in Fig. 5.

A bandwidth of 1.75 GHz has been obtained from the Sierpinski gasket fractal design which is again 7.3 % of the centre frequency. A simulated gain of 4.9 dB has been achieved from the gasket design with beam widths of 82° and 124° in H plane and E plane respectively. The return loss and the radiation pattern of the design are shown in Fig. 5 and Fig. 6 respectively. The simulation results of gasket design show that the gain and bandwidth of the gasket design are quite comparable to that of the carpet design. However, the size of the gasket design is not as compact as the carpet design.

The Koch snowflake design exhibits a bandwidth of 1.6 GHz which is 6.7 % of the centre frequency as shown in Fig. 5. A gain of 4.9 dB has been achieved from this fractal design as shown in Fig. 6. The simulated radiation pattern of Koch snowflake design exhibits beam widths of 87° and 125° in the H plane and E plane respectively. A performance comparison among the three fractal designs is summarized in Table 1.

### 3.2 Comparison among Three Designs

The simulated results of the three fractal designs implemented in LTCC medium show that they have more or less similar radiation patterns as shown in Fig. 6. A gain of 5 dB has been achieved from the three antennas while they demonstrate a HPBW of around 85° and 120° in the H plane and E plane respectively. The bandwidths achieved in these designs are consistent with the previously published work [5, 6, 8]. In this work, it has been observed that Koch snowflake has a relatively lower bandwidth as compared to the other two designs and is complicated than the Sierpinski designs. In addition to this the Sierpinski antennas exhibit greater reduction in size as compared to Koch snowflake. On the basis of complexity, size reduction and small bandwidth of snowflake design it can be concluded that Sierpinski designs are better than the Koch design. On comparing the two Sierpinski fractal designs it is observed that they have similar performance of gain, radiation pattern and even the bandwidth. Despite the similarity in their performance there are two advantages of Sierpinski carpet design over Sierpinski gasket design. One is the smaller size and the other is easy fabrication as it is easy to etch rectangles rather than triangles. Similarly the size reduction of carpet design is better than the gasket design as can be observed from table 1. Therefore it can be deduced that among all the three fractals Sierpinski carpet holds the advantage over the other two designs.

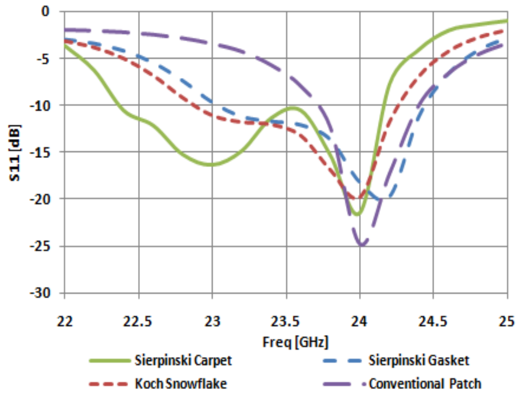


Figure 5: Return Loss of Three Fractal Designs and Conventional Patch

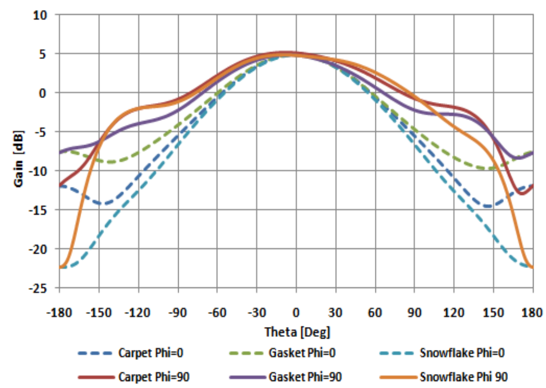


Figure 6: Radiation Pattern of Three Fractal Antennas

Table 1: Comparison among the fractal designs

| Antenna | Gain (dB) | HPBW in H and E Planes (Degrees) | Bandwidth (GHz) | Size Reduction Compared to Conventional Designs (%) |
|---|---|---|---|---|
| Sierpinski Carpet | 5.0 | 85 and 120 | 1.75 (7.5% of 24GHz) | 53 |
| Sierpinski Gasket | 4.9 | 84 and 124 | 1.8 (7.5% of 24 GHz) | 35 |
| Koch Snowflake | 4.9 | 87 and 125 | 1.6 (6.7% of 24 GHz) | 25 |

## 4. Conclusion

The paper presents design of Sierpinski carpet, Sierpinski gasket and Koch snowflake fractal antennas in LTCC medium. The designs exhibit large bandwidth as compared to the conventional antennas. A comparison among the three designs has been presented which shows that the Sierpinski carpet fractal antenna is better than the other two fractal designs. The carpet design exhibits a bandwidth of 1.8 GHz which is comparable to the other designs where as it has demonstrated a size of reduction of 53 % which is greater than the two fractal designs. These results show that the carpet design is extremely suitable for high data rate applications such as automotive radars and satellite communication.

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