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Design of Sierpinski Carpet Fractal Antenna for Wireless Applications

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ABSTRACT

In wireless applications the antenna plays a vital role. It acts as an electromagnetic wave transmitter and receiver. When wireless antennas emit electromagnetic waves, they will reflect when they come into contact with objects. The research work suggests an antenna producing multiple frequencies operating in the 1 GHz–8 GHz range including both C-band and S-band applications operating range. The antenna is designed for VSWR< 2 and return loss S_{11} < 10 dB. A rectangular microstrip patch with a fractal Sierpinski carpet approach is used in the antenna's design. The actual antenna is made of Epoxy FR-4 substrate, which has a thickness of 0.06 mm and a relative permittivity of $\varepsilon_r = 4.4$. According to the test results, there are three operational frequencies: 2.72 GHz, 3.5 GHz, and 5.04 GHz for first iteration of Fractal carpet antenna and there are 4 operational frequencies: 2.76 GHz, 3.4 GHz, 4.92 GHz and 7 GHz for Second iteration of Fractal carpet antenna. Based on the findings, the developed antenna satisfies the required criteria to be used in many wireless applications.

KEYWORDS
Microstrip antenna, S-band, Sierpinski Carpet fractal, C-band, return loss, VSWR.

1. INTRODUCTION

In an electromagnetic wave's transmission and reception, the antennas are considered as one of the important elements and in the modern times these waves are used effectively for various wireless technologies and at different frequency bands, but the need for new ranges in communication is never stopped. In order to satisfy the demands of the increasing telecommunication technologies, radio detection and ranging, or radar, was developed. Antennas are one radar component that is crucial to the communications process. Many methods were created during its development to enable antennas to function well in a wide range of required frequencies. For WLAN applications, a microstrip antenna that operates between 3.31 GHz and 13.1 GHz has been created, as shown in reference. The idea of microstrip fractal antenna using Hilbert technique for both S-band and C-band radar application has been proposed in [1], [2].

Reactively loaded dual frequency approach is a regularly used method for producing multiple frequencies. The way this method operates is by loading the patch. One solution to solve issues with antenna size is a microstrip. The Microstrip Antenna makes use of basic material, the antenna's dimensions and form are smaller, the cost of production is lower, and it can perform well. Microstrip antennas have drawbacks in addition to their many benefits. Narrow bandwidth, poor efficiency, and little increase are a few drawbacks.

The shortcomings of this microstrip antenna can be addressed in a variety of ways, for as by altering the substrate or patch design. Using fractal patches is one method of altering the field's design.

The benefit of using a fractal antenna is that it can function at multiple frequencies and has compact dimensions. In accordance to the existence of various fields in science and technology, the concept of breaking a component into fragments known as fractal was first brought into light by Mandelbrot. Fractal is a self-sustaining pattern that maximizes the length of the antenna or the perimeter of the material for the radio waves to transmit and receive.

Recently, various designs of fractal antennas have been introduced for various wireless communication appliances and even for satellites to a smaller extent [3]. A wide range of work has been done on Ultra-wide band, Wireless communications and 5G cellular applications by modifying the shapes of the ground plane to C and Square shaped, triangular modules with proper angle at the edges has been discussed in [4][8]. Performance analysis with proper explanation of all fractal techniques been developed till the latest along with some optimization techniques have been covered in [9]-[14].

A hybrid structure of fractal using FR4 substrate has been designed to work at a frequency of 3.5 GHz and it is able to produce a result for multiple frequency bands [15].

In [16], the fractal antenna has been designed for 2 iterations and substrate used is FR4, where as in [17], [22], a modified version of Sierpinski carpet fractal antenna has been proposed to investigate till 10 GHz with a lower antenna height and the substrate used is same FR4 at 3rd iteration of fractal.

In [18]-[19], 3rd iteration of fractal on a patch is implemented with significant size reduction and with respect to 5G wireless communications.

A new approach of Sierpinski triangle having triangular slots is designed on patch with FR4 substrate and the results provide a comparable return loss as well as gain in [20].

The fractal structure usage can be found out at various designs in literature [23-28], where different types of structures such as Maple shaped useful in RADAR and satellite communications, circularly polarized fractals designed to work at ISM band, Rogers substrate are used with U-Slot to provide increased bandwidth, hexagonal patches of fractals can also be used for short range wireless communications. A textile application also has an approach of fractal antenna.

This research proposes a Sierpinski carpet fractal antenna at first iteration designed to operate on three frequencies that are close to C-band displaying a frequency span of 4 – 8 GHz and for S-band radars the frequency span is in the range of 2 - 4 GHz. Similarly, the experiment is carried out for second iteration of Sierpinski carpet fractal antenna and there appear four frequencies for the corresponding C-band and S-band. The tool used for simulation is MATLAB 2021 version.

2. ANTENNA DESIGN

The proposed fractal Sierpinski carpet antenna is intended to operate on three frequencies for C-band, which works in the frequency range of 4 – 8 GHz and for S-band radars they work in the frequency range of 2 - 4 GHz for both the first and second iteration of the fractal design.

The Sierpinski Carpet Planar Monopole Antenna is the first element in the design. A basic rectangle patch is designed initially. The basic square patch is split in the first iteration by taking 1/3 of the scale factor and deleting the middle square from it. Segments on the remaining eight squares are completed for the second iteration using a 1/3 scale factor. For subsequent iterations with the same scale factor, the same process is followed.

As seen in Figure 1 and Figure 2, two iterations have been created utilizing this methodology and the formulas from [3] and are displayed below:

(i) Frequency (f) Calculation:

This frequency is the one that is desired, or resonance frequency, at which the antenna will vibrate and will be responsible for electromagnetic wave generation.

$$\lambda = v/f \text{ or } c/f \quad (1)$$

λ: Wavelength of the antenna; v or c (velocity of light in free space): 3×10^8 m/s.

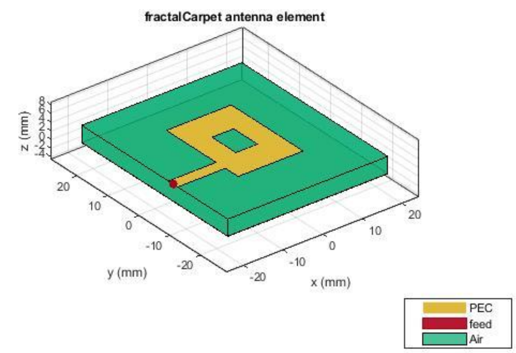

Fig. 1. Fractal carpet Antenna for 1st iteration.

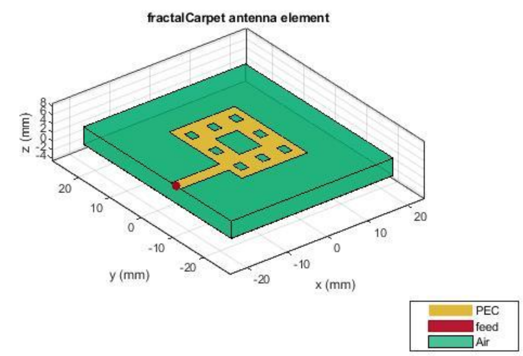

Fig. 2. Fractal carpet Antenna for 2nd iteration.

(ii) Dimensions of the antenna L, W:

Design of a patch comprises of the center-fed length, width, and location, where W denotes the patch's width and 'f' denotes its frequency.

$$W = \frac{c}{2f}\left(\sqrt{\frac{2}{\varepsilon_r+1}}\right) \quad (2)$$

The effective length Leff, effective dielectric constant ε_{reff}, height of the substrate h, and *and* ΔL must all be calculated in order to determine the length L. The thickness or height of the substrate must be carefully determined, as this will have a significant impact on the resonant frequency.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}(1+12(\frac{h}{W}))^{-1/2} \quad (3)$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \quad (4)$$

$$L = L_{eff} - 2\Delta L \quad (5)$$

(iii) Dimensions of ground Lg , Wg

$$W_g = W + 6h \quad (6)$$

$$L_g = L + 6h \quad (7)$$

The Table 1 below shows the critical values that have been used for the sketch and simulations of the proposed antenna using MATLAB.

Table. 1. DIMENSION OF ANTENNA

Material	Epoxy FR4
Thickness (mm)	0.06
ð	0.026
ε_r	4.4
L(mm)	17.80
W(mm)	24
h(mm)	2.80
L_G(mm)	34.60
W_G(mm)	40.80

Table. 2. FREQUENCY BANDS AND VSWR OF ANTENNA

Antenna Height (mm)	Iteration	Center Frequency (GHz)	VSWR
h = 2.8	n = 1	2.72	1.946
		3.5	1.402
		5.04	1.114
h = 2.8	n = 2	2.76	1.833
		3.4	1.808
		4.92	1.036
		7	1.623

It is observed from Table 2 that there are three frequency bands in the first iteration which appear at 2.72 GHz, 3.5 GHz and 5.04 GHz, and four frequency bands emerge in the second iteration at 2.76 GHz, 3.4 GHz, 4.92 GHz and 7 GHz.

3. RESULT AND ANALYSIS

A FR4 substrate with a 0.06 mm thickness and a dielectric permittivity of 4.4 is used to create the antenna with a height of 2.8 mm. Antenna performance in this work is determined by a number of factors including bandwidth, VSWR and the return loss S_{11}. A graph of the S_{11} parameter findings is presented in Figure 3 and Figure 4 for the case when the fractal antenna is evaluated for first and second iteration respectively. As compared to [15], where using the same substrate, the antenna resonates at 3.5 GHz only.

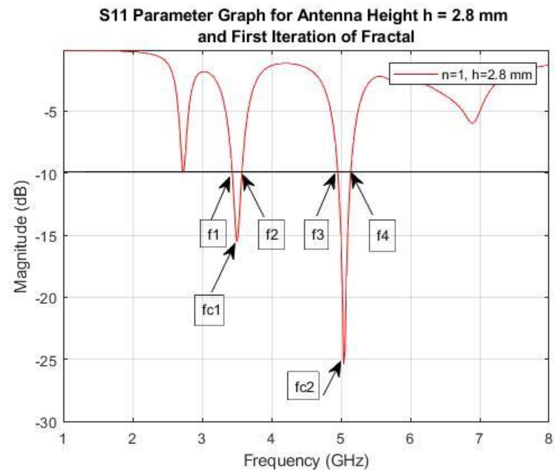

Fig. 3. A S11 graph for 1st iteration of Fractal at antenna height of 2.8 mm.

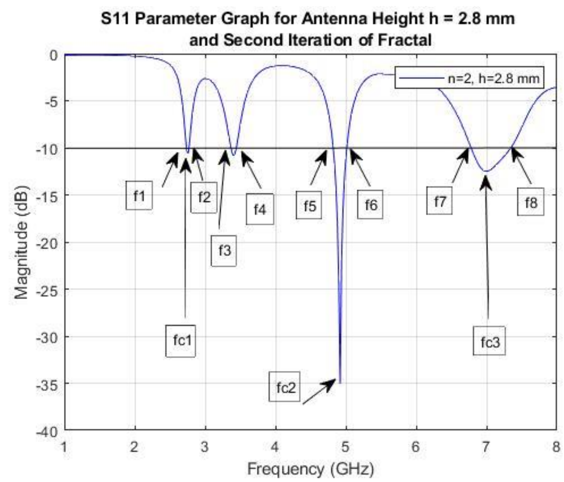

Fig. 4. A S11 graph for 2nd iteration of Fractal at antenna height of 2.8 mm

Based on Figure 3, the obtained output demonstrates that it has a return loss S_{11} of -9.86 dB at a frequency of 2.72 GHz, S_{11} at 3.5 GHz and 5.04 GHz frequencies, respectively, are -15.52 dB and -25.30 dB.

From Figure 4, the obtained output demonstrates that it has a return loss S_{11} of -10.62 dB at a frequency of 2.76 GHz, S_{11} at 3.4 GHz, 4.92 GHz and 7 GHz frequencies, respectively, are -10.81 dB, -35.04 dB and -12.49 dB.

As compared to [16], where it is evaluated only for 2nd iteration of fractal with different height, in this work the antenna is designed and compared for 1st and 2nd iteration respectively as discussed further below.

In Figure 5, the first and second iteration of fractal antenna is used for comparing the voltage standing wave ratios of the obtained output. The VSWR is less than 2 at the resonant frequencies as discussed above and respective values are listed in Table II.

It can be inferred from the VSWR graph that for fractal antenna at first iteration at frequency band of 3.5 GHz the value of VSWR is 1.402 and at frequency band of 5.04 GHz the value of VSWR is 1.114.

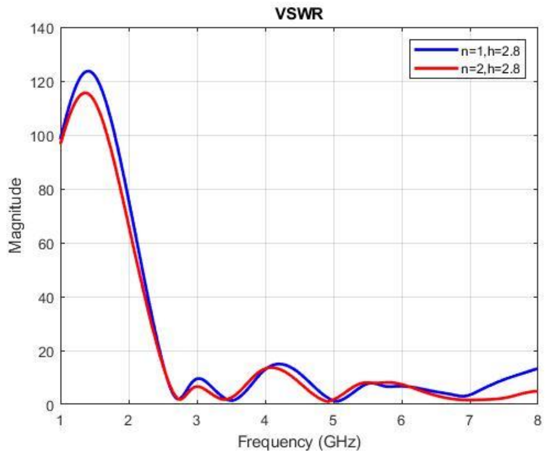

Fig. 5. VSWR graph for 1st and 2nd iteration of Fractal at antenna height of 2.8 mm

As can be seen from Figure3, for the fractal antenna at first iteration there are two frequency bands, the start frequencies are designated by (f1, f3) and stop frequencies are designated by (f2, f4). From Table 3 below, the bandwidth at center frequency of 3.5 GHz turns out to be 140 MHz and at center frequency of 5.04 GHz, the bandwidth is 200 MHz.

Table. 3. ANTENNA BANDWIDTH

Antenna Height (mm)	Iteration	Band (GHz)	Bandwidth
h = 2.8	n = 1	3.5	(3.58 - 3.44) GHz = 140 MHz
		5.04	(5.15 - 4.95) GHz = 200 MHz
h = 2.8	n = 2	2.76	(2.77 – 2.74) GHz = 30 MHz
		3.4	(3.44 – 3.37) GHz = 70 MHz
		4.92	(5.02 – 4.82) GHz = 200 MHz
		7	(7.35 – 6.755) GHz = 600 MHz

The bandwidth can also be computed by referring to the S_{11} chart. The bandwidth is calculated by drawing a line at -10 dB on the plot, the frequencies that intersect at the drawn line indicate the start and stop frequencies and the difference of these gives the bandwidth.

Referring to Figure 4, for the fractal antenna at second iteration there are four frequency bands, the start frequencies are designated by (f1, f3, f5, f7) and stop frequencies are designated by (f2, f4, f6, f8). From Table III the bandwidth at center frequency of 2.76 GHz turns out to be 30 MHz and at center frequency of 3.4 GHz, 4.92 GHz and 7 GHz, the bandwidth is 70 MHz, 200 MHz and 600 MHz respectively.

4. CONCLUSION

The operating frequencies of the proposed fractal antenna design for both the 1st and 2nd iterations fall within a range of 1-8 GHz, satisfying the need for the wireless, WLAN and 5G commercial applications which include the C- and S-band ranges as shown in the simulations. It is observed that fractal antenna at first iteration provides 2 frequency bands where the VSWR is also maintained below 2. At the second iteration of the fractal, 4 frequency bands are observed which satisfy the VSWR condition as well. It has been demonstrated that the fractal approach may produce multiple frequency bands on the antenna and result in compact antennas and improve the overall performance of the antenna and can be used for wireless applications effectively such as WLAN, 5G commercial applications to name a few.

Future scope: The work discussed above can further be extended to 3rd iteration of fractal and check the frequency bands it offers with such a fractal design. The work can also be redirected towards the usage of different substrates taking into consideration of the work done in [22] for various wireless applications while maintaining the same antenna height and check for different resonant frequencies the antenna can offer.

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