Design of Multiband Fractal Antenna Array for Wireless Communication

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Abstract. This work proposes a modified circular fractal antenna array for multiband applications, including WLAN (5.15–5.85 GHz), C-band applications (3.8–4.4 GHz), and X-band for satellite communication (7.1–7.76 GHz). High Frequency Structure Simulator (HFSS) is used to simulate the antenna. The substrate material is FR4 epoxy, which has a 4.4 relative permittivity and 1.6 mm of thickness. It is discovered that the antenna only covers a portion of the bandwidth of the aforementioned applications.

1 Introduction

With the multiplication and miniaturization of telecommunication systems, many research efforts are focused on the integration of antennas into small environments [1], such as smartphones, tablets, automobiles, airplanes, and other embedded systems, and the design of multiband, the design of multi-band and wide-band antennas becomes a necessity [2].

To achieve this, several techniques are adopted. These techniques include designing multiband antennas that operate in multiple frequency bands by inserting slots in the radiating elements or using fractal geometries [3].

The term fractal, is coined by Mandelbrot from the Latin adjective fractus which means broken or irregular fragments [4]. Fractal geometry is based on a shape that repeats itself at different scales. Clearly, when we "zoom in" a fractal shape, we always see the same fractal shape repeated till infinity [5].

Fractal antenna is used to provide better characteristics as compared to the simple microstrip antenna [6]. Fractal antennas have several advantages, one can note the reduction in size at a given frequency, but also concomitantly, a better gain with improved directivity [7], or multiple bandwidths suitable for multiband applications. Fractal Optimizes the shape of the antennas in order to increase their electrical length [8].

Also, fractal geometry improves input resistance and enhances electrical area of antenna [9]. Thus, to miniaturize the antenna size with high radiation efficiency, fractal antennas are most suitable [10].

The Sierpinski fractal is one of the fractal types found in literature. This structure was made by the Polish mathematician SIERPINSKI. The Sierpinski Triangle, Sierpinski Carpet, and Sirpinski Circle are only a few examples of this geometry's various permutations.

This paper presents an antenna array with Sierpinski fractal geometry, it is a multiband antenna that resonates on ten resonance frequencies. In the following sections the geometry

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of the proposed antenna is presented, as well as the results of the reflexion coefficient, surface current distribution, gain, and finally the conclusion.

2 Antenna design

2.1 Antenna structure

The proposed circular fractal antenna consists of a substrate material of FR4 epoxy with dielectric constant $\epsilon_r = 4.4$ and thickness $h = 1.6mm$. The fractal antenna is designed based on development of a circular microstrip antenna with a 50 Ω microstrip feedline, the resonant frequency is taken at 4 GHz.

The design of the proposed fractal antenna starts from the geometry of the circular patch antenna (shown in "Fig. 2").The circular patch's radius was determined using the following the following equations as given in [11], and its value is 10 mm.

$$a = F\left[1 + \frac{2h}{\pi F \epsilon_r}\left[Ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right]^{-1/2} \tag{1}$$

F is calculated by using

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \tag{2}$$

- a : Radius of the circular patch.
- f_r : Resonant frequency.
- h : Height of the substrate.
- ϵ_r : Dielectric constant of the substrate.

This fractal antenna is designed by using the Ansoft High-Frequency Structure Simulator (HFSS) simulation software, and by following 3 steps :

1. The first design step is a basic circular patch antenna, of radius $R_1 = 10mm$, its shown in "Fig. 1".

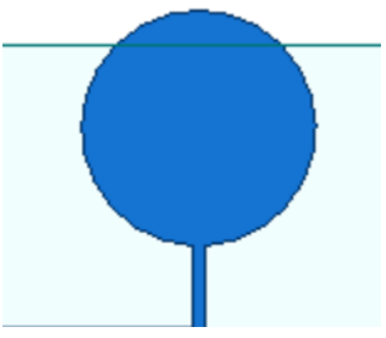

Figure 1. Antenna design of step 1

2. The second design step is obtained by cutting a circular slot of radius $R_2 = R_1/3$ (3.333mm) from the center of the circular patch antenna. The antenna is shown in figure 2.

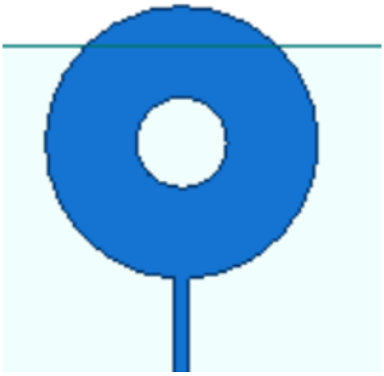

Figure 2. Antenna design of step 2

3. The third design step is obtained by cutting eight more circular slot of radius $R_3 = R_2/3$ (1.111mm) around the circular slot in step 2. The antenna is shown in figure 3.

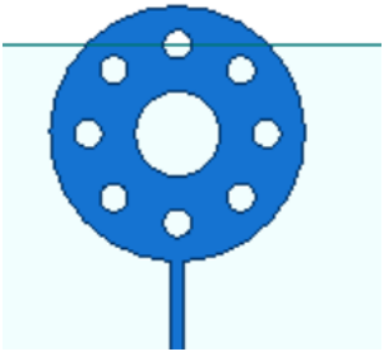

Figure 3. Antenna design of step 3

2.2 Antenna array structure

Since we need a multi-band antenna, we employ an antenna array based on circular fractal antennas because a single circular patch antenna only offers one resonant frequency.

The proposed antenna consists of 8 Array elements which are separated from each other by $\lambda/2$ (37.5mm)[12]. The antenna is matched to a 50 Ω input impedance using a microstrip feedline.

The HFSS design model of the fractal antenna Array is described in figure 4.

Table 1. Parameters of the proposed antenna array

Parameters	Dimensions (mm)
L_S	100
W_S	300
L_G	53
W_G	300
h	1.6
R_1	10
D_1	36.5
D_2	73.5
D_3	38.5
D_4	148
D_5	76.5
D_6	152
D_7	37.5
D_8	3
$K_1 = K_2$	8
$K_3 = K_4$	10

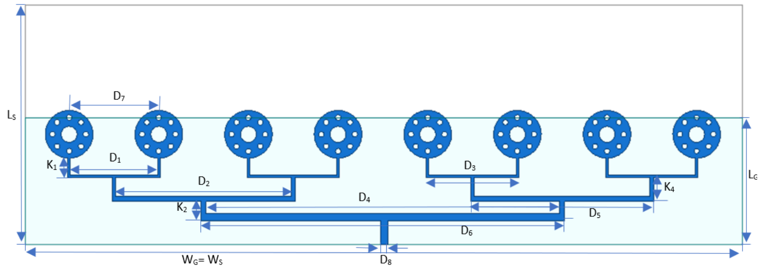

Figure 4. The design of the fractal antenna Array

3 Results and discussion

From the simulation results of the designed antenna, reflexion coefficient , gain, directivity are represented in this paper as following.

3.1 Reflexion coefficient

Figure5 shows the reflexion coefficient plot of the fractal antenna array. The resonance frequencies are 2.99 GHz (-11.84), 3.47 GHz (-17.91 dB), 3.83 GHz (-13.79 dB), 4.20 GHz (-14.80 dB), 4.62 GHz (-15.24 dB), 5.10 GHz (-12.40 dB), 5.46 GHz (-15.89 dB), 6.13 GHz (-19.20 dB), 6.55 GHz (-15.52 dB), and 7.28 GHz (-17.37 dB).

The values of all the resonance frequencies (F_r) with their reflexion coefficient (S_{11}) is shown in table 2. The reflexion coefficient value, of the proposed antenna array, is less than -10dB at all the resonance frequencies, which is a suitable value.

Table 2. Simulated frequency of the proposed antenna array

$F_r(GHz)$	$S_{11}(dB)$
2.99	-11.84
3.47	-17.91
3.83	-13.79
4.20	-14.80
4.62	-15.24
5.10	-12.40
5.46	-15.89
6.13	-19.20
6,55	-15.52
7.28	-17.37

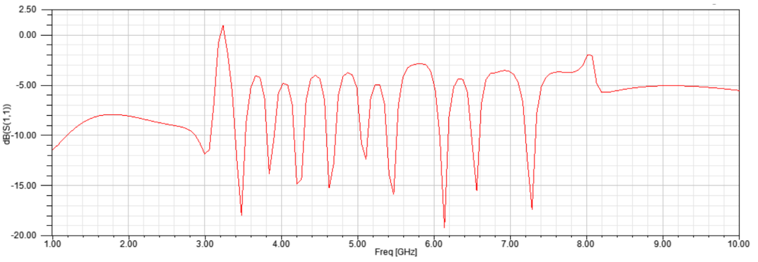

Figure 5. Reflexion coefficient of proposed antenna array

3.2 Surface current distribution

Figure 6, figure 7, and figure 8 illustrate the surface current distribution of the proposed antenna structure at three different frequencies 4.20 GHz, 5.46 GHz, and 7.28 GHz. The radiating patch's surface current is shown to be evenly distributed throughout. It is confirmed that higher-order modes are excited with increasing frequency by the way the surface current distribution is shown at various frequencies.

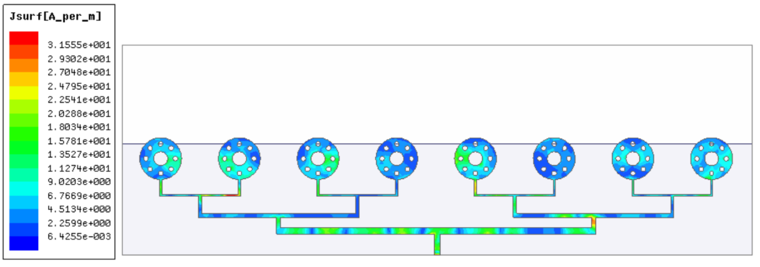

Figure 6. Surface current distribution of the proposed antenna array at 4.20 GHz

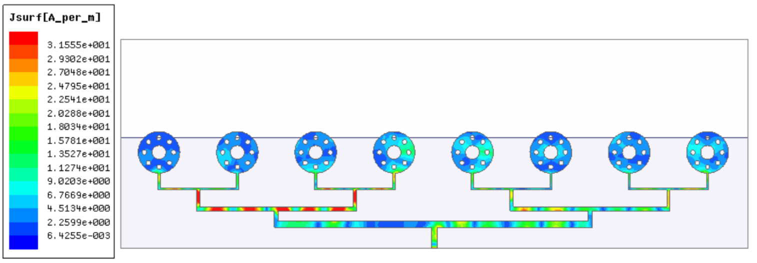

Figure 7. Surface current distribution of the proposed antenna array at 5.46 GHz

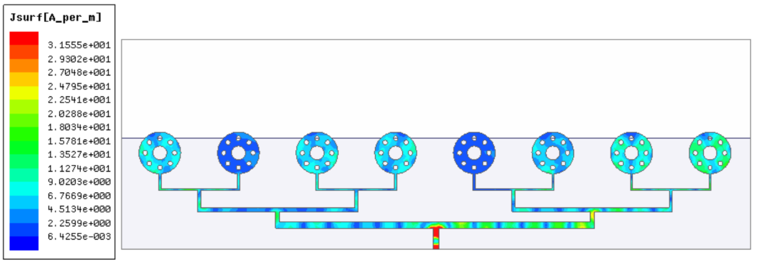

Figure 8. Surface current distribution of the proposed antenna array at 7.28 GHz

3.3 Gain

The gain of an antenna defines the area of coverage and the directional characterises of the designed antenna. Figure9 shows the gain of the proposed antenna array in polar plot at 4 GHz in E plane ($\phi = 0deg$) and H plane ($\phi = 90deg$) with an important gain equal to 8.62 dB.

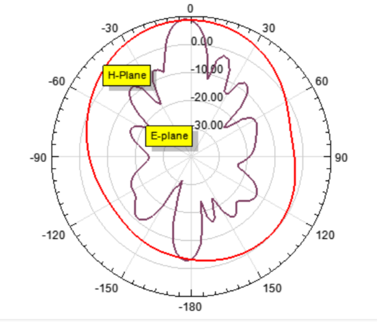

Figure 9. 2D ain of the proposed antenna array at 4 GHz

Additionally, figure 10 displayed the 3D gain plot of the suggested antenna at each resonant frequency.

It is observed from "Fig. 10" that the proposed antenna array shows significant gain in some resonant frequencies and a passable gain in others, as stated in table 3.

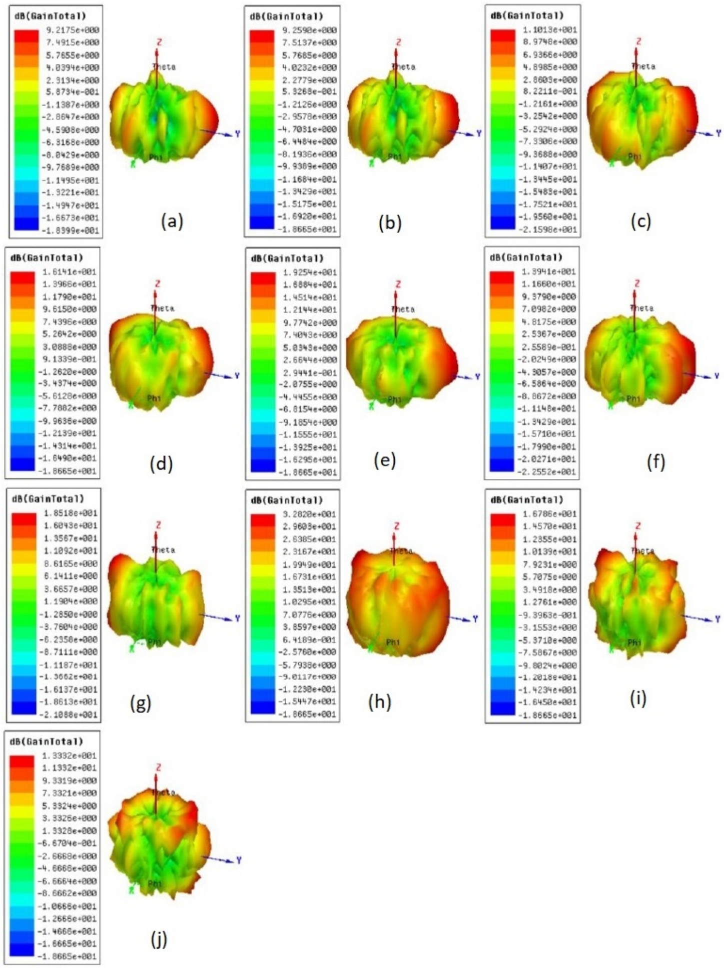

Figure 10. 3D gain plot of the proposed antenna array at (a) 2.99 GHz, (b) 3.47 GHz, (c) 3.83 GHz, (d) 4.20 GHz, (e) 4.62 GHz, (f) 5.1 GHz, (g) 5.46 GHz, (h) 6.13 GHz, (i) 6.55 GHz and (j) 7.28 GHz frequency bands

3.4 Comparaison of the propsed antenna with other antenna

The results of the proposed fractal antenna array are compared with published research results, as shown in the table 4. Table 4 shows that the proposed antenna has more resonant frequencies and shows high gain at some resonant frequencies compared with the antennas of published works.

Table 3. Simulated gain of the proposed antenna array

$F_r(GHz)$	$Gain(dB)$
2.99	9.21
3.47	9.25
3.83	1.10
4.20	1.64
4.62	1.92
5.10	1.39
5.46	1.85
6.13	3.28
6,55	1.67
7.28	1.33

Table 4. Comparaison of the propsed antenna with other antenna

References	$F_r(GHz)$	$Gain(dB)$
[7]	2.48/3.6/5.8/	2.2/1.8/1.6
[1]	1.8/2.1/2.4/2.6	5.3/6.3/6/6.25
Proposed antenna	2.99/3.47/3.83/ 4.20/4.62/5.10/ 5.46/6.13/6.55/7.28	9.21/9.25/1.10/ 1.64/1.92/1.39/ 1.85/3.28/1.67/1.33

4 Conclusion

This study looked at a multiband fractal antenna array for wireless applications, including WLAN (5.15–5.85 GHz), C-band applications (3.8–4.4 GHz), and X-band for satellite communication (7.1–7.76 GHz). After examining the simulated results, we discovered that the proposed design covers a portion of the bandwidth of the aforementioned applications. The results also show that the suggested antenna has an important gain in some resonant frequencies and a passable gain in others.

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