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Design of A Novel Reconfigurable Fractal Antenna for Multi-Band Application

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Abstract

With advancement in communication technology over the past decade, there is an increasing demand for miniaturization, cost effective, multiband and wideband antennas. Fractal antenna designs can support in meeting these requirements. Though these antennas provide several advantages but at the same time miniaturization and performance of the fractal antennas can be further enhanced using reconfiguration concept. This paper proposes a novel hybrid reconfigurable fractal antenna that combines the advantage of both the categories. A reconfigurable fractal antenna is designed, simulated and optimized using Ansoft-High Frequency Structure Simulator (HFSS). The optimized antenna is fabricated and tested using Vector Network Analyzer. The fabricated antenna results are in good agreement with simulated results. The proposed antenna can be used for satellite communication, medical imaging and microwave imaging application, Vehicular radar applications and wireless industry application.

Keywords: *Fractal antenna, planar antenna, reconfigurable*

1. Introduction

The rapid expansion of wireless technology during the last years has led to increase in demand for small size, low-cost and multiband antennas for use in commercial communications systems. Fractal antenna [1] is one such category that provides miniaturization and have multi-band characteristic. These are composed of multiple iterations of a single elementary shape and are used to describe a family of complex shapes that possess an inherent self-similarity and self-affinity in their geometrical structure. Various researchers [2-8] have proposed fractal antennas of different shapes such as Sierpinski fractal antenna [2-4], tree-shaped fractal antenna [5-6], and some other types including snowflake fractal antenna [7] and Koch fractal antenna [8]. Though these antennas reduce the size and cost, but in case of communication system many applications are used that works at different frequency band hence a single fractal antenna cannot be used to serve the purpose of the whole communication system.

To resolve this issue researchers have proposed reconfigurable antennas [9-13]. These antennas resonate at different frequencies at different time by using switches therefore reduces the cost and overall size of the system. In comparison to fractal antennas the reconfigurable antennas have the following advantages [12] as follows:

- Compact size

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- Effective use of electromagnetic spectrum
- Similar radiation pattern and gain at all desired frequency bands

We are of the opinion that reconfiguration concept when applied to fractal can be a great asset for future wireless communication industries since it provides enhanced miniaturization in size of the overall communication system as well as provides frequency selectivity. Therefore this paper presents a hybrid reconfigurable fractal antenna that tries to incorporate the merits of both the antennas.

The rest of the paper has been organized into following sections. Section 2 provides the design and simulation results of reference antenna. Section 3 provides the design of the proposed novel hybrid reconfigurable rectangular fractal antenna. Section 4 provides the simulation and measured results of the proposed antennas in all optimized reconfigurable modes and section 5 provide the conclusion followed by references.

2. Design & Simulation Results of Reference Antenna

Reference Antenna is a rectangular patch antenna designed on FR4 epoxy substrate having dielectric constant $\mathcal{E}r$ = 4.4, loss tangent δ=.0025 and thickness h = 1.6 mm as shown in Figure 1. This antenna is fed using coaxial cable.

Antenna design parameter for f =5.6 GHz resonant frequency is calculated using transmission line model equations[14] given below.For an efficient radiator, practical width W that leads to good radiation efficiencies is calculated by

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon r+1}{2}}}$$

The effective dielectric constant is obtained by referring to equation:

$$\mathcal{E}_{\text{reff}} = \frac{\mathcal{E}r+1}{2} + \frac{\mathcal{E}r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}}$$

The effective length is calculated using equation

$$\boldsymbol{L_{eff}} = \frac{\boldsymbol{c}}{\boldsymbol{2f\sqrt{\varepsilon reff}}}$$

The value of ΔL can be obtained by using equation

$$\Delta L = 0.412h\left(\frac{(\varepsilon reff+0.3)\left(\frac{W}{h}+0.264\right)}{((\varepsilon reff-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

The actual length of radiating patch is obtained by: $L_{eff} = L + 2\Delta L$

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as: $L_g = 6h$+W , $W_g = 6h+ W$

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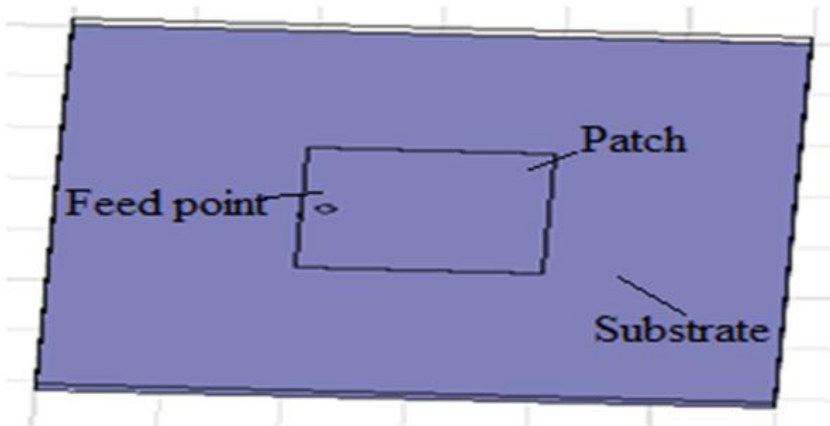

Figure 1. Top view of Reference antenna

After calculating the antenna design parameters it is modeled and optimized using HFSS software. After optimization it resonates at 5.61 GHz and 8.6 GHz as shown in Figure 2.

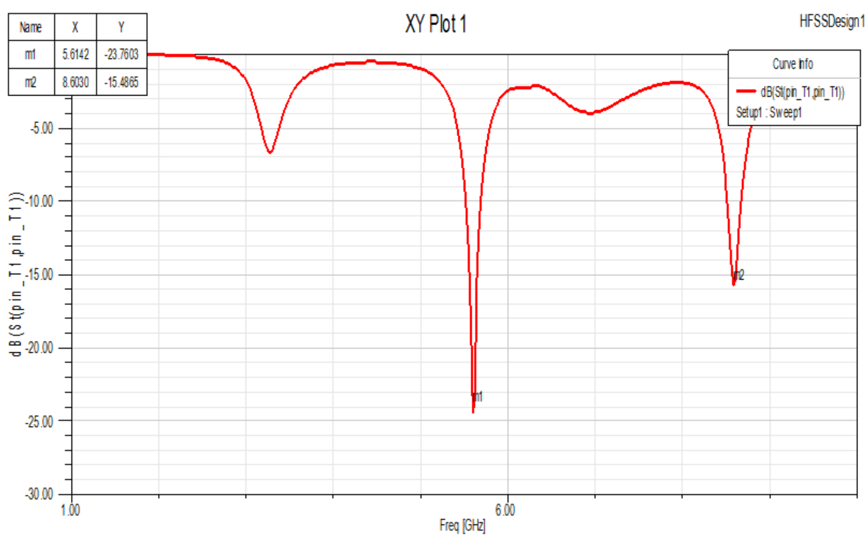

Figure 2. Return loss of Reference antenna

3. Design of Proposed Reconfigurable Fractal Antenna

The proposed reconfigurable fractal geometry is shown in Figure 3 and its design parameter is given in Table 1. For the purpose of reconfiguration, four RF switches D1-D4 are used. Antenna is fed with a 50Ω coaxial cable. Figure 4 shows the side view of the proposed antenna. The prototype of antenna is fabricated using lithography process. The top and bottom view of fabricated antenna is shown in Figure 5 and Figure 6.

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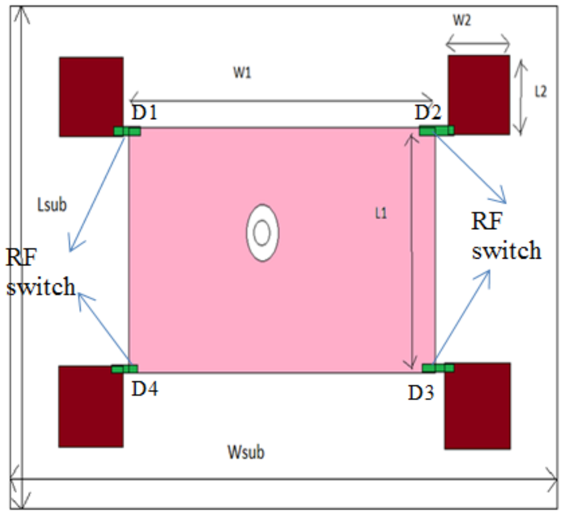

Figure 3. Geometry of proposed reconfigurable fractal antenna

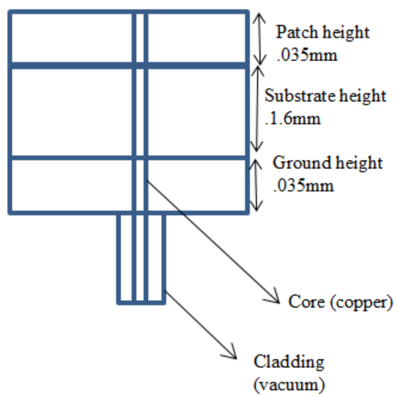

Figure 4. Side view of proposed re-configurable fractal antenna

Figure 5. Top view of fabricated reconfigurable fractal antenna

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Figure 6. Bottom view of fabricated re-configurable fractal antenna

Table 1. Critical antenna dimension of proposed reconfigurable fractal antenna

Antenna parameter	Dimension(mm)	Antenna parameter	Dimension(mm)
W1	23.7	ε_r	4.4
L1	20.02	H	1.6
W2	11.85	L2	9.87
Wsub	71.7	Lsub	60.02

4. Simulated and Measured Results of Proposed Reconfigurable Fractal Antenna

Simulated results presented here are obtained using HFSS software. This antenna is optimized for four modes using different switch position. Relationship between the operation modes and the states of switches for the 1^{nd} iteration of antenna are shown in Table 2.

Table 2. Relationship between various modes and switch positions

S.NO.	MODES	Switch Position
1	Mode 1	D1=OFF,D2=OFF D3=OFF,D4=OFF
2	Mode 2	D1=ON,D2=ON, D3=ON, D4=ON
3	Mode 3	D1=ON,D2=OFF D3=ON,D4=OFF
4	Mode 4	D1=OFF,D2=OFF, D3=OFF,D4=ON

For modeling of RF switch, a common way is that when switch is on, it is represented by copper strip ($1\times1mm^2$) and when switch is off, no copper strip is used. In simulation and measurement this modeling is used to get the results. The results of fabricated antenna are measured using Agilent Technologies VNA N5230A: A.07.50.13

and compared with the simulated ones. This section presents details of the various reconfigurable modes of proposed antenna.

Modes of Proposed Antenna

4.1. Mode 1

In this mode, all switches are off. Figure 7 shows the simulated and measured return loss of optimized reconfigurable antenna. Following points can be concluded for above mode.

- The antenna resonates nearly at same frequency of 5.74GHz & 8.82GHz as that of reference antenna since all the switches are in the off position.

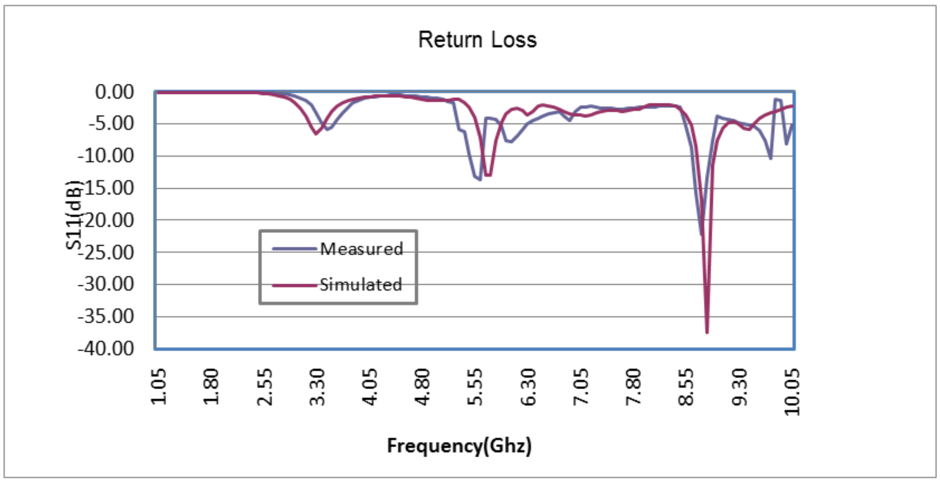

Figure 7. Return loss of proposed reconfigurable antenna in mode 1

- The maximum gain of antenna is 2.488dB & 4.93 dB for the above mentioned frequencies.
- The radiation efficiency of antenna at two resonant frequencies is 36% and 38% respectively.
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4.2. Mode 2

Figure 8 shows the return loss of the antenna in mode 2 when all the diodes are in the on position. Following points can be concluded for this mode.

- The resonant frequencies for the antenna in this mode are 5.76GHz, 6.35GHz, 7.54GHz and 9.80GHz.
- The gain of antenna above mentioned resonant frequencies are 4.8 dB, 4.6dB, 2.20dB and 5.46dB respectively.
- Radiation efficiency of antenna at above frequencies is 87%, 43%, 45% and 62%.

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- For non-reconfigurable fractal antenna only this mode will exist for 1st iteration.

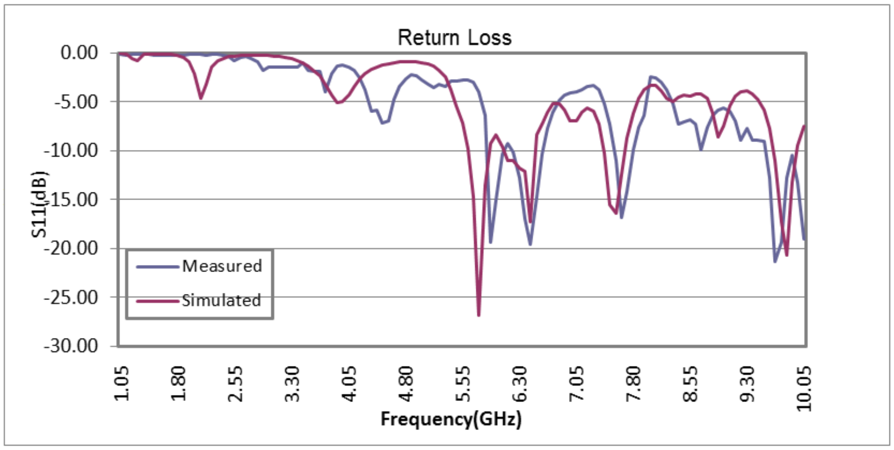

Figure 8. Return loss of proposed reconfigurable antenna in mode 2

4.3. Mode 3

The switches D1 and D3 are turned on while D2 and D4 are turned off in this mode. Following point can concluded for above mode

- Figure 9 shows that the antenna resonates at 5.70 GHz, 7.23GHz and 9.52GHz with a good return loss of -25.43, -28.05 and -21.74 dB respectively.
- Antenna has a gain of 3.62,5 and 5.02dB at above mentioned resonant frequencies respectively.

4.3. Mode 3

The switches D1 and D3 are turned on, while D2 and D4 are turned off in this mode. Following point can concluded for above mode

- Figure 9 shows that the antenna resonates at 5.70 GHz, 7.23GHz and 9.52GHz with a good return loss of -25.43dB, -28.05dB and -21.74 dB respectively.

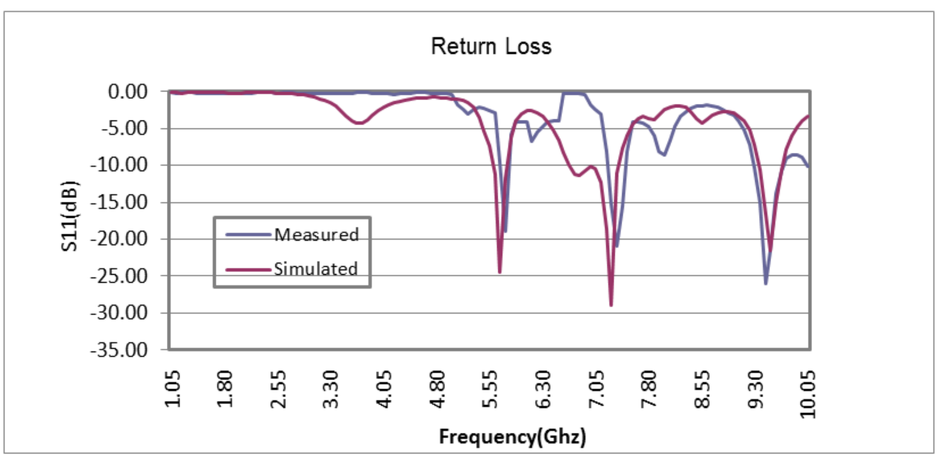

Figure 9. Return loss of proposed reconfigurable antenna in mode 3

- Antenna has a gain of 3.62dB, 5dB and 5.02dB at above mentioned resonant frequencies respectively.
- Radiation efficiency of antenna at resonant frequencies is 56%, 47% and 52% respectively.
- Measured results are in good agreement with simulated results.

4.4. Mode 4

In this mode switch position D1, D2 and D3 are turned off and D4 is on. Following points can be concluded for above mode.

- Figure 10 show that antenna resonates at 3.436GHz, 5.811GHz, 6.51GHz, 7.363GHz and 8.915GHz.

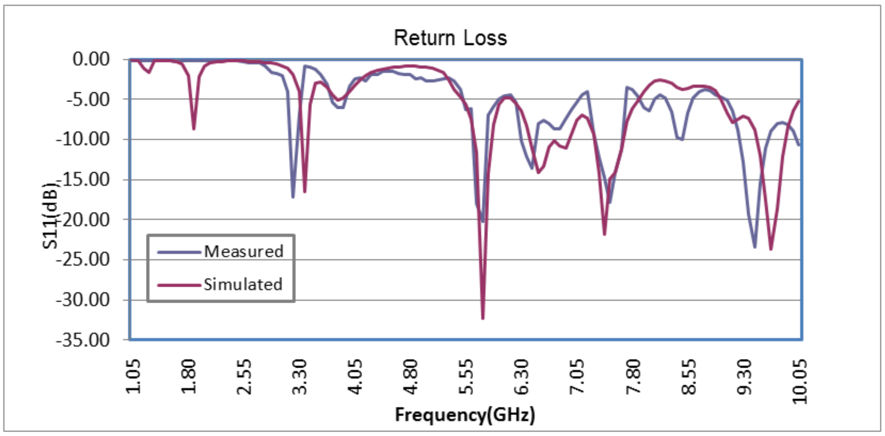

Figure 10. Return loss of proposed reconfigurable antenna in mode 4

- Simulated resonant frequencies 3.436GHz and 8.915 GHz shifted slightly to lower side in measurement results due to fabrication errors.
- At 3.436GHz antenna has very good radiation efficiency of 80%.

The antenna parameters for various reconfigurable modes for the 1nd iteration of reconfigurable fractal antenna are shown in Table 3.

Table 3. Various modes of reconfigurable antenna and its parameters

	Resonant Frequency(GHz)	Return - loss(dB)	Gain (dB)	Radiation Efficiency (magnitude)
Mode 1	5.74 8.822	-14.97 -37.69	2.488 4.93	.36 .38
Mode 2	5.76 6.35 7.54 9.800	-26.59 -12.35 -17.42 -22.35	4.8 4.6 2.20 5.46	.87 .43 .45 .62

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Mode 3	5.70 7.23 9.52	-25.43 -28.05 -21.74	3.62 5 5.02	.56 .47 .52
Mode 4	3.436 5.811 6.51 7.363 8.91	-16.03 -22.84 -27.00 -12.36 -14.60	5 3.60 3.03 2.24 3.02	.80 .60 .55 .39 .54

5. Conclusion

The proposed hybrid reconfigurable fractal antenna is novel compact, simple, multiband and reconfigurable. The presented antenna is multiband in each reconfigurable mode due to self-similarity of fractal structure. The antenna presents only three resonant frequencies if non-reconfigurable fractal configuration is used in which central patch is permanently connected to all small patches (MODE 2), but by using reconfiguration concept this antenna can resonates at approximately ten different resonant frequencies in all the modes. Also by using reconfiguration concept power interference issues can be avoided by switching between different modes. The proposed multi-band reconfigurable antenna can be used for satellite communication, medical imaging and microwave imaging application, Vehicular radar applications and wireless industry application.

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