Numerical Analysis of the size effect on a Printed 2D-irregular fractal-jet Antenna

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Abstract—**Printed antenna based on 2D-images of a fractal liquid jet has been designed and analyzed numerically. In this work, the effect of the structure's size on the antenna behavior was presented. The return loss, radiation patterns and surface current densities were simulated over the frequency band 1-20 GHz for 3 different sizes of the structure. It is found the size of the fractal antenna affects the antenna radiation properties.**

Index Terms—***Miniaturization; Printed and Multiband; Irregular Fractal Antennas;***

I. Introduction

The rapid development of telecommunications requires new smaller design efficient antennas that permit broadening frequency bandwidth and sharing multi-frequency bands for various and practical modern communication systems. In last decades, fractal printed antennas were widely studied and performed especially on deterministic structures to enhance the antenna performances; Sierpinski monopole for multi-frequency operation [1], Koch monopole for miniaturization [2], Koch Island patch for high directivity [3]...

Therefore, random/natural fractal antennas, which require more complex mathematical laws to be represented, still unknown and few studies were performed to explorer their exotic properties [4-7].

Recently, a numerical study of an irregular fractal-jet printed antenna was presented for better understanding the fractal boundary effect on its radiation behavior [8].

In this work, we continue our analysis of this type of structures by exploring the effect of the fractal patch size on the antenna performances in terms of impedance matching, gain and radiation behavior. A scaling low was applied to the basic structure presented in [8] in order to obtain two other antennas similar geometrically to the first one but their sizes are different. All the three antennas were considered and were investigated over the frequency range 1-20 GHz. This type of antennas is characterized by many resonating bands allowing their use in different multiband communication systems.

II. Antennas design

In order to understand the effect of the fractal patch size on the antenna performances, we have studied numerically (ansoft-HFSS) the scaling effect of the fractal image (Fig. 1) on the antenna properties by comparing the simulated results for 3 antennas (Fig. 2) obtained from the same fractal image with different sizes.

The reference antenna (denoted A1) was designed from a complex fractal-jet image [8]. A fractal patch of length L_p =42 mm and width W_p=12 mm was printed on a Duroïd substrate of dimensions L_s = 51 mm and W_s =15 mm with thickness 0.8 mm and permittivity 2.17 (Fig. 1), where a micro-strip of length L_f=8 mm, width W_f = 2.45 mm and impedance Z_0 = 50 Ω was used as a feed feedline. The length L_p and width W_p of the radiating patch of rectangular antenna are defined as the dimensions of the smallest rectangle containing the fractal image. The feed-line is situated at the distance X = 2.5 mm from the lower edge of the rectangle $L_p \times W_p$ (Fig.3). The bottom face of the substrate is metalized and acts as a ground plane.

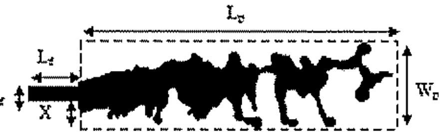

Fig. 1. Antenna FA designed by HFSS.

By applying a scaling law to the reference antenna A1, we have obtained antennas A2 and A3 by considering scaling factors equal to 145% and 220%, respectively (Fig. 2). The design parameters of the three antennas A1, A2 and A3 are given in Table I.

TABLE. I. Design Parameters of Antennas A1, A2 and A3.

	Patch			Substrate		Feed line		
	Scaling factor	Lp, mm	Wp, mm	Ls, mm	Ws, mm	W_f, mm	L_f, mm	X, mm
A1	100 %	42	11.6	51	15	2.48	8	3.36
A2	145 %	92	25.73	102	30	2.48	8	8.71
A3	220 %	192	53.38	205	60	2.48	8	19.6

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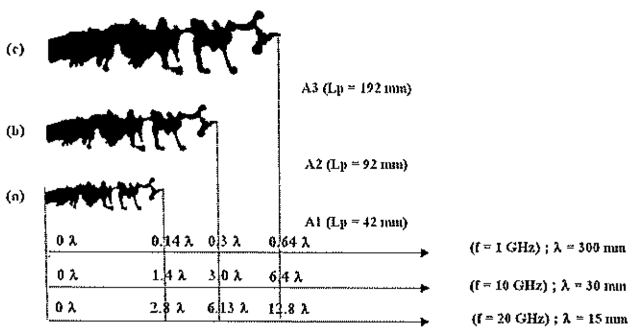

Fig. 2. Schemas of studied fractal patches: (a) initial image for antenna A1; (b) image with scaling factors of 145 % for antenna A2; (c) image with scaling factor of 220 % for antenna A3.

III. Results

The size effect of the fractal image was studied by comparing the obtained performances of 3 antennas.

Fig.3 shows the simulated return loss of antennas A1, A2 and A3 over the frequency band 1-20 GHz. The main deduced results from this Figure are illustrated in Table II. It can be noted from the obtained values (Table II) that the peak gain and peak directivity are affected by the size of the fractal patch.

TABLE. II. Simulates Data of Three Fractal Antennas

	Fr, f_n(GHz)	Return loss, dB	Ratio, f_{n+1}/f_n	Peak gain	Peak directivity
A1	9.25	-23.20	1.14	4.99	5.17
	10.55	-12.35	1.12	2.64	2.8
	11.75	-21.47	1.57	2.27	2.44
	18.55	-13.42	-	5.52	5.65
A2	5.2	-10.96	1.40	2.51	2.98
	7.25	-32.94	1.39	6.55	6.84
	10.10	-12.13	1.23	9.16	9.88
	12.40	-14.90	1.19	4.66	4.91
	14.75	-27.18	1.33	7.85	7.81
	19.55	-21.63	-	7.20	7.25
A3	6.10	-23.82	1.71	2.59	2.85
	10.45	-23.15	1.18	6.10	6.72
	12.35	-25.74	1.19	2.12	2.22
	14.65	-23.18	1.13	1.50	1.59
	16.55	-18.77	1.21	3.97	4.11
	19.95	-19.48	-	4.99	5.13

From Fig.3, we can notice also a multiple numbers of resonating peaks, which confirms the multi-frequency property of the 2D-fractal jet antenna, and its dependence on the antenna size.

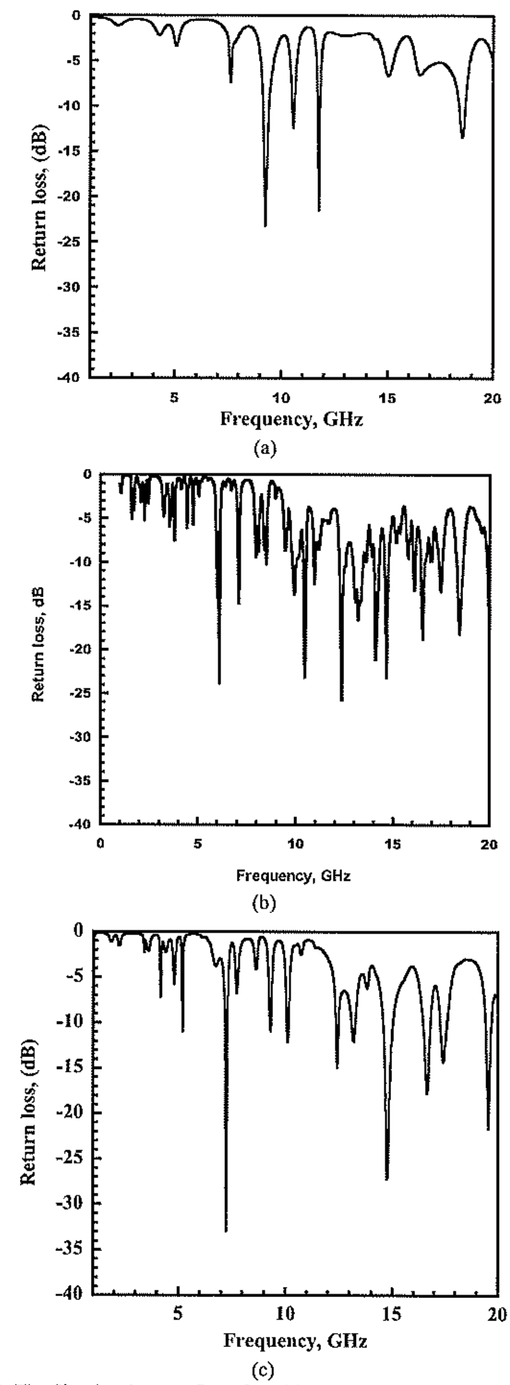

Fig. 3. The Simulated return Loss for : (a) antenna A1, (b) antenna A2 and (c) antenna A3.

From Fig. 4, we can notice that the gain of the fractal structure is greater for large antennas, but more stable over the frequency band for antenna with smallest size (A1).

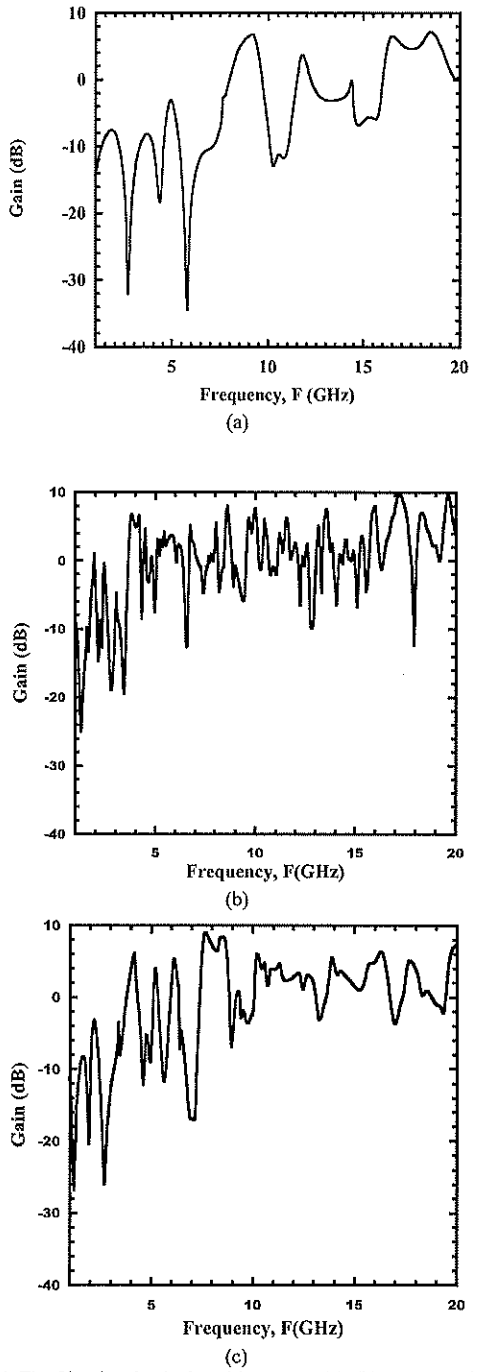

Fig. 4. The Simulated gain for : (a) antenna A1, (b) antenna A2 and (c) antenna A3.

The gain is not highly affected by the size reduction of the antenna because it is compensated by the increase due to the electromagnetic coupling, between resonating fractions of the irregular contour where high-gain modes are localized.

The simulated 3D-radiation patterns and the surface current of antennas A1, A2 and A3, are illustrated in Figs. 5 and 6, respectively.

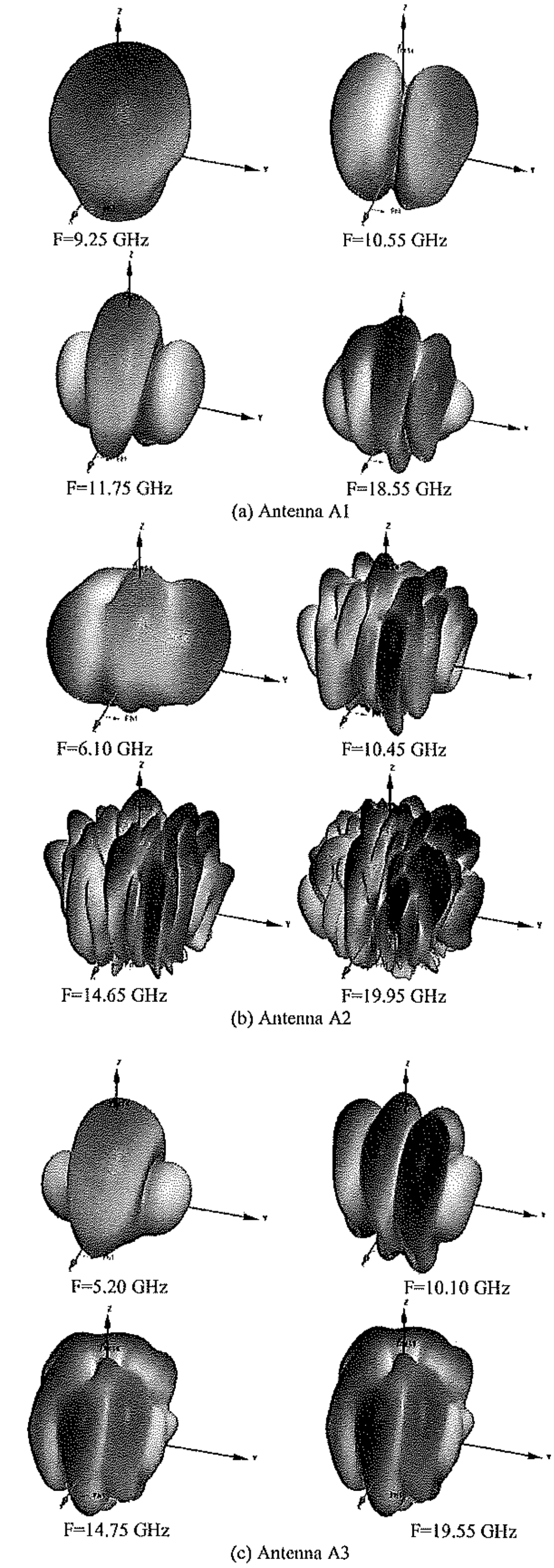

Fig. 5. Simulated radiation patterns for antennas A1 (a), A2 (b) and A3 (c).

From Fig 5, we remark that all the radiation patterns are symmetric around the z-axis. This symmetry is improved as the size of the fractal antenna decrease, especially at low resonance frequencies. We can remark also that the values of the gains peaks are better at high resonant frequencies. This symmetry although the irregular and asymmetric geometry of the patch.

Although the irregularity of the fractal image is independent on its size, the radiation patterns are highly affected by the size of the antenna. For example, the lobes and ripples of 3D-patterns, which usually increase with the frequency, decrease by reducing the size of the antenna, giving then more stable and smooth 3D radiation patterns.

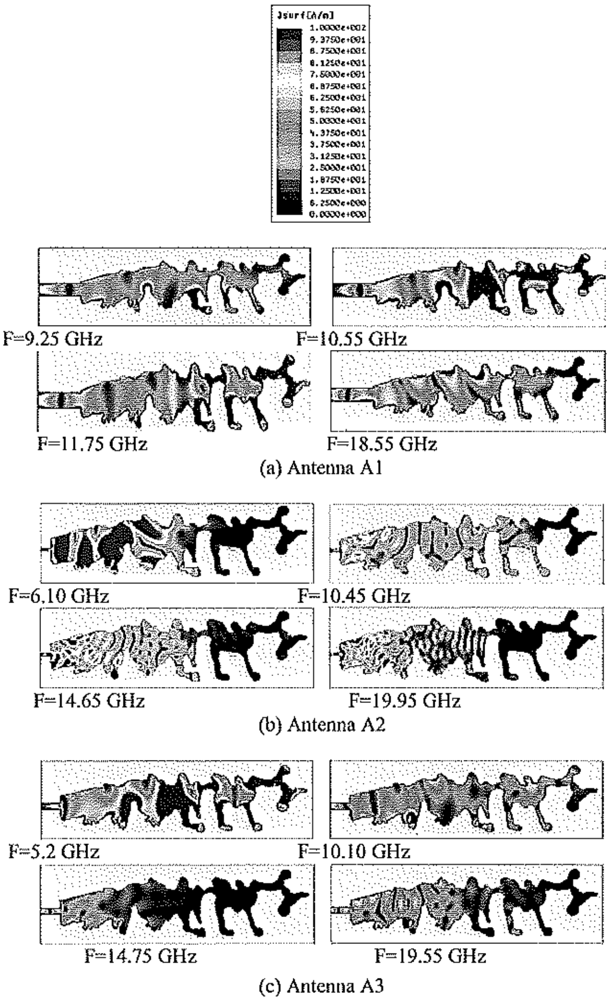

Fig.6. Distribution of surface current density for (a) A1, (b) A2 and (c) A3.

The analysis of the surface currents distribution on the radiating patches of antennas presented in Fig.6, for some resonance frequencies, explain better the dependence of the radiation patterns on the antenna size: when the frequency increase, the associated wavelength decrease and the excitation of fractional parts from the fractal boundary becomes more frequent since the fractions with small dimensions are more frequent in the morphology of the 2D irregular contour, which explain the increase of localized modes with the frequency for a considered antenna, also by reducing the antenna size. These localized currents density are more important in small details of the contour than large ones.

III. Conclusion

The size effect of an irregular fractal patch on the electromagnetic performances of a printed antenna was studied. Three antennas with same geometry and different sizes were simulated and the obtained results were presented and discussed. It was found that the structure exhibit a multi frequency behavior allowing its application in multi-band wireless systems.

Analysis of both radiation patterns and surface currents at some resonating frequencies shows that they are highly affected by the size of the antenna, although the irregularity of the fractal image is independent on its size. Therefore, it seems that the gain of the structure is not highly affected by the size reduction of the antenna. This phenomenon may be explained by the compensation of the gain drop by electromagnetic coupling between resonating fractions of the irregular contour where high-gain modes are localized.

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