Analysis of the Behavior of Sierpinski Carpet Monopole Antenna

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Abstract **–** Three fractal monopole antennas using the Sierpinski carpet geometry is described in this paper. The idea for these designs is gotten from semi-log-periodic behavior of fractal antenna. In this paper, we noted input impedance matching of antennas throughout the passband of them. In this point of view, we will apply the wideband, broadband and multiband for these antennas. Our first wide-band design is named antenna-1. This has a good input impedance match throughout the passband 2-20GHz. Second antenna is named antenna-2. This antenna has an interesting behavior while has a multi-band behavior from 1-7GHz and has broad-band behavior from 7-20 GHz. However, because of two slots in ground plane of this antenna, the 6-7GHz band is eliminated. Third of antennas is named antenna-3. It has a multi-band behavior from 0.5-17GHz. On average, we could match input impedance of proposed antennas, for three desired behavior. The dimension of main- square for antenna-1, antenna-2 and antenna-3 is 45, 60 and 132 mm respectively. These antennas are suitable for the operating bands of GSM, ICMS, UMTS, Bluetooth, WLAN and HIPERLAN systems.

Keyword: Fractal antenna, sierpinski-carpet, semi-log-periodic behavior.

I. INTRODUCTION

Modern telecommunication systems require antennas with wider bandwidths and smaller dimension rather than conventional ones. In recent years several fractal geometries have been introduced for antenna applications with different level of success in antenna characteristics improvement. Some of these geometries are reported recently [1, 2]. These are low profile antennas with moderate gain, and are able to be operative at multiple frequencies [3]. Generated monopolar mode polarization is interested especially for applications in ICMS, UMTS, Bluetooth, WLAN and HIPERLAN systems [4, 5].

Several fractal shapes have been introduced in recent years too. Certain fractal designs have been shown to be self-similar, small, space filling and have log periodic performances when used as antennas [6, 7]. In [8] capability of two new fractal geometries for application in antenna design is described. In [9] dual-band monopole antenna using the concept of Sierpinski carpet shape and semi-circular geometry is introduced and has interesting property.

In this paper, the behavior of Sierpinski carpet monopole antenna is described by means of experimental and computational results and we could match input impedance of antenna, for three desired behavior.

II. THE PROPOSED ANTENNA CONFIGURATION

The square patch was selected for initial design. Figure 1 shows the Sierpinski carpet iteration up to third repetitions.

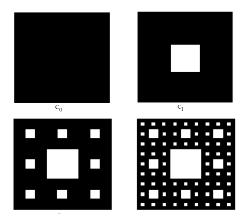


Fig. 1. Sierpinski carpet antenna up to third iteration.

Figure 2 and table 1 show the geometrical parameters of the Sierpinski carpet antenna for three desired designs.

Table 1. The geometrical parameters of the three Sierpinski carpet antennas.

	W_1 (mm)	W_2 (mm)	W_3 (mm)	W_4 (mm)
Antenna-1	45	15	5	1.67
Antenna-2	60	20	6.67	2.22
Antenna-3	132	44	14.67	4.9

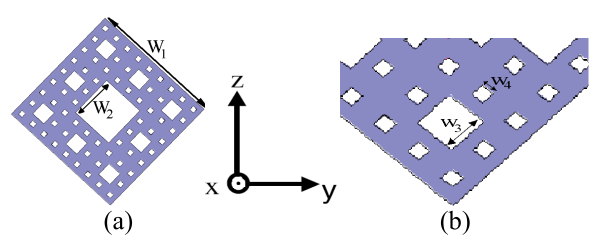


Fig. 2. Geometrical parameters of Sierpinski carpet antenna in proposed design.

The ground plane of this antenna is very interesting and is the same as ground plane in [8, 9]. The size of ground-plane is approximately 110 mm for all antennas [8].

The radiation elements of antenna-1 and antenna-2 are printed on Rogers RO4003 with thickness of 60mil. For antenna-3, radiation element is printed on FR4-epoxy with thickness of 63mil. These elements are fed at apexes. Figure 3 shows the final design and the pictures of three antennas.

(a) (b) (c)

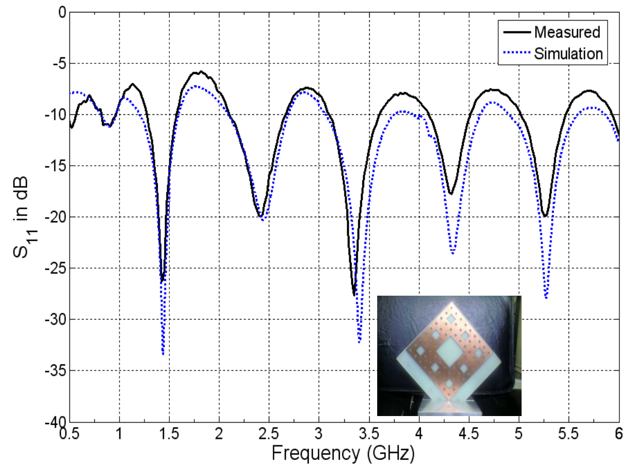
Fig. 3. The pictures of proposed antennas (a) Antenna-1, (b) Antenna-2, and (c) Antenna-3.

III. INPUT RETURN LOSS OF ANTENNAE

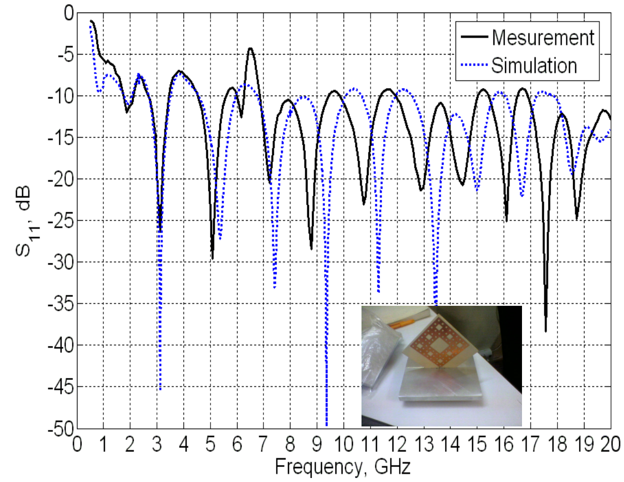
These antennas were simulated on Ansoft HFSS V10 using a FEM algorithm. The return loss of proposed antennas was also measured with hp8720 network analyzer from 0.5-20GHz. Figure 4 (a), (b), and (c) show the reflection coefficient relative to 50Ω of three-monopole together. The plots corresponding to the antenna-3 antenna-2 and antenna-1 appear at the top row, middle row and bottom row respectively. Figure 5 shows all measured proposed antennas in one plot from 0.5 GHz - 20 GHz.

Antenna-1 achieved a good match with return loss about -9dB throughout the pass-band from 2 to 20 GHz. But, antenna-2 has the multiband behavior from 1-7 GHz and has broadband behavior from 7-20 GHz. However, 6-7GHz eliminated for this antenna. Because, two slots is made in ground plane of this antenna. These slots aren't simulated in HFSS and it can be seen for this band simulation and measurement results and they don't resemble together. Multi-band behavior for antenna-3 is very obvious. The obtained results for this antenna shows this antenna can operate in most commercial bands, such as: GSM900, ICMS, DECT, WLAN and HIPERLAN.

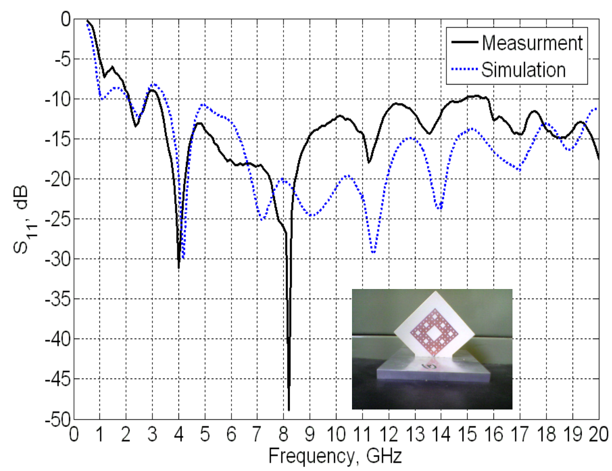
Of course, we used tiny absorber in back of antenna-1 which is shown in Fig. 6. This absorber has imaginary part of permittivity and permeability, and we couldn't simulate effect of this in our design. Because of this, there is noticeable difference between simulation and measurement results in higher frequencies.



(a)



(b)



(c)

Fig. 4. Input reflection coefficient of three monopole Sierpinski carpet antenna (a) Antenna-3, (b) Antenna-2, and (c) Antenna-1.

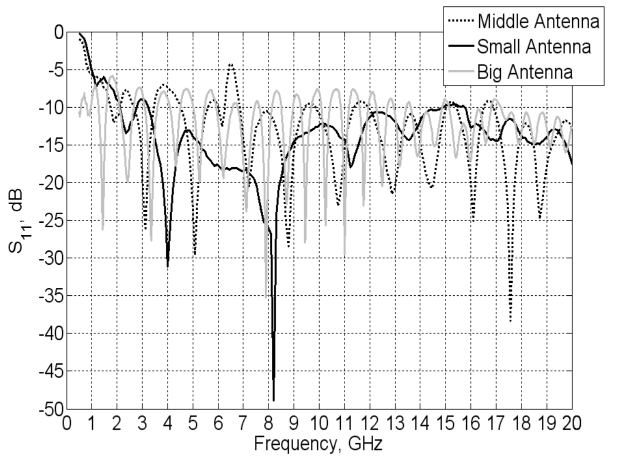
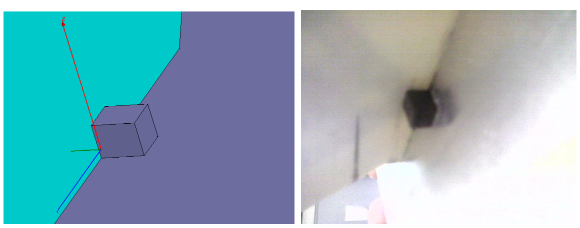


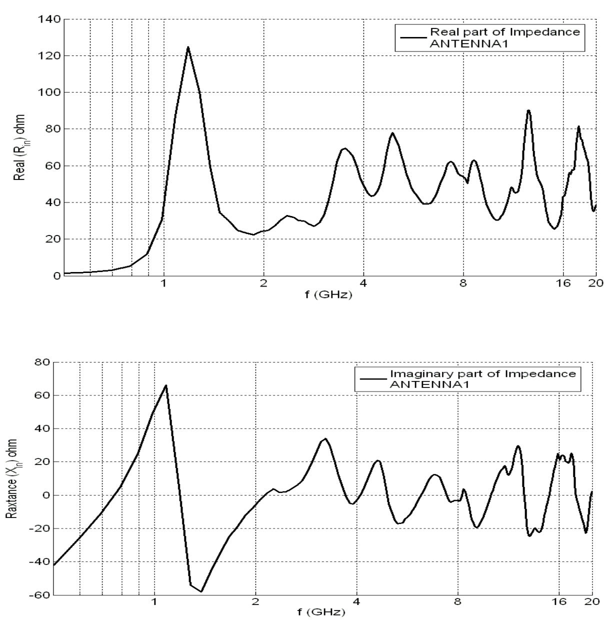
Fig. 5. Compare the measured reflection coefficient of the proposed antennas.



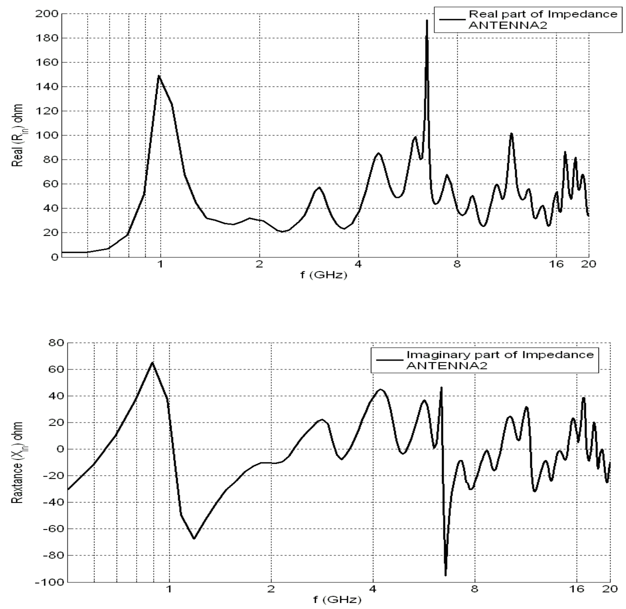
(a) (b)

Fig. 6. Absorber is used in antenna-1 (a) simulation, (b) implementation.

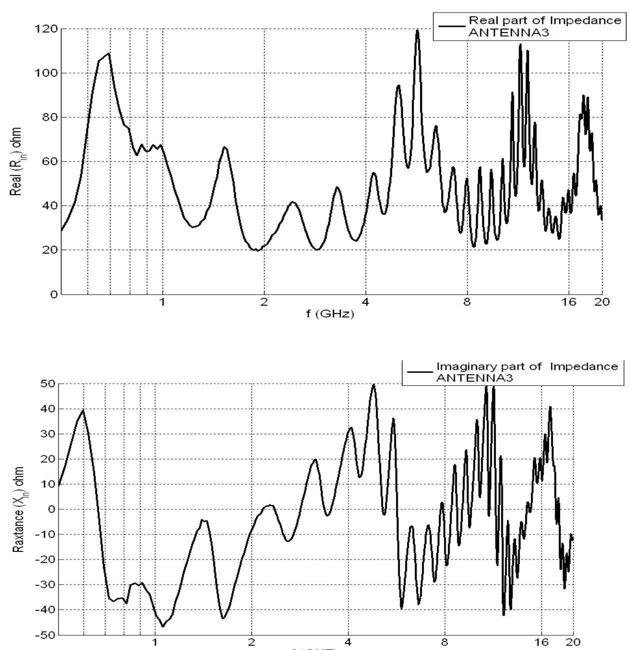
To get better insight on the log-periodic behavior of these antennas, in Fig. 7 the measured input impedance frequency is shown in logarithmic scale to emphasize the semi-log-periodic behavior of the proposed antennas.



(a) Antenna-1



(b) Antenna-2

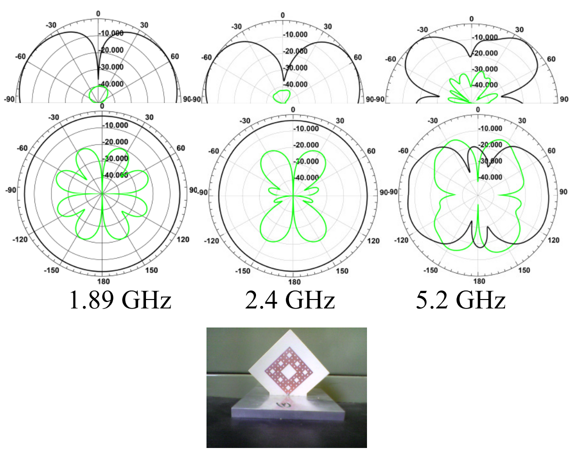


(c) Antenna-3

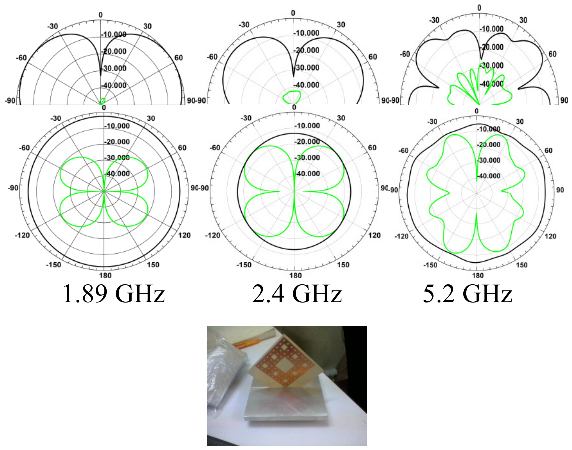
Fig. 7. Measured input resistance (top) and input reactance (bottom) of three monopole antennas.

IV. RADIATION PATTERNS

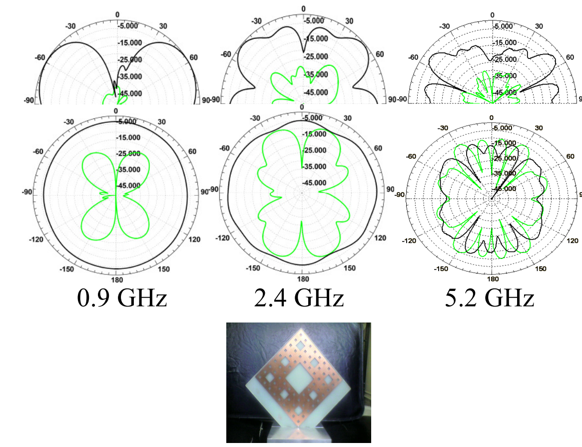
Figure 8 (a) and (b) show radiation patterns of antenna-1 and antenna-2 correspond to operating bands of 1.89, 2.4 and 5.2 GHz representing DECT, WLAN and HIPERLAN bands respectively. Figure 8 (c) shows radiation patterns of antenna-3, correspond to operating bands of 0.9, 2.4 and 5.2 GHz representing GSM900, WLAN and HIPERLAN bands. In all plots, the black-line is Co-polarization pattern and the gray-line shows Cross-polarization pattern. The top row of each plot shows the E-plane radiations while the bottom row shows the H-plane radiations. Because of symmetry and flatness, good radiation patterns are obtained for these bands. However, it should be noticed that the effect of the finite size of the ground-plane must be taken into account when analyzing the patterns on these figures [10]. For instance, those at upper bands show characteristic ripple, which is due to diffraction at the edges of the plane. The variations on the ripple are faster when frequency is increased since the squared plane is not self-scalable and edges are spaced a longer distance in terms of corresponding wavelength. Also, the expected null in the z-axis direction is hidden by the contribution of the anti-symmetrical mode of the ground plane overall radiated power [10].



(a) Antenna-1



(b) Antenna-2



(c) Antenna-3

Co-polarization
Cross polarization

Fig. 8. Radiation pattern of proposed antennas (Top row of each plot is E-plane, Bottom row is H-plane).

V. MEASURED GAIN

The peak gain of the proposed antennas was measured (in dB) for some of frequencies in operating bands of each one. These are shown in Table 2. Minimum gain is 3.23 dB in measurement frequencies. In results, these antennas have moderate gain. Increase in peak antenna gain is expected when operating frequency is increased. But the minimum gain is in higher frequencies. The reason of this event is back-scattering from edge of ground plan. It forms ripples and nulls in radiation pattern of antennas. That cause reduction in gain of proposed antennas and the gain doesn't depend on frequency and geometry of antenna, exactly.

Table 2. Gain of proposed antenna, measured at various frequencies in operating bands.

	Antennas Gain (dB)		
Frequency (GHz)	Antenna-1	Antenna-2	Antenna-3
0.9			4.43
1	3.69	3.23	
1.89			5.96
2.4	4.03	5.46	4.97
5.2	6.6	6.3	9
8	5.47	7.62	
11	6.05	9.74	
14	5.48	9.4	
17	4.91	8.57	
20	6.98	9.64	

VI. THE PHISICAL INSIGHT FOR THESE DESIGNS

The idea for these designs is gotten from semi-log-periodic behavior of fractal antenna. In each conventional fractal structure and each repetition, many resonance edges are made. The edges of the each square are subtracted from the original square contribute to make resonance behavior with other edges of fractal shape. However, the resonance behavior of each edge in relation with other edges in Sierpinski carpet is very complicated and requires further study about the resonance behavior of this shape. For the antenna-1, the resonance edges of each repetition have balanced resonance frequency and with small increase in frequency in smaller wavelength, cause the majority of edges contributes to produce resonance behavior. However, we observed small mismatch in lower operating frequencies (between 2 GHz - 3.5 GHz) obviously, because of unbalancing resonance frequency of each iteration edges from other iteration edges. In antenna-2, the same phenomenon occurs. But mismatches cause multi-band behavior from 1 GHz - 7 GHz. Because of balanced resonance frequencies of iteration edges, broad-band behavior is observed from 7-20 GHz. In antenna-3, this reason (unbalancing resonance frequencies edges) cause multi-band behavior in all operating frequencies.

VII. CONCLUSION

The three fractal monopole antennas are designed using Sierpinski carpet geometry. For antenna-1 designs achieved an approximate 10:1 match for 50 Ω feeding port. Antenna-2 has multi-band behavior from 1-7 GHz and has broadband behavior for 7 GHz - 20 GHz. For this antenna, band from 6-7 GHz is eliminated. Antenna-3 has multi-band behavior and can apply for most of commercial bands. On average, the radiation patterns are suitable for current application in the GSM900, ICMS, UMTS, Bluetooth, WLAN and HIPERLAN bands. The results obtained for the antennas show capabilities of fractal geometry for wireless communications considering multi-band and wideband operations.

Furthermore, with such an antenna design, a wide range of wireless communication systems, considering frequency selective channel characteristics with multi-media transmission would become possible [8, 9].

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