Design and Testing of a Multifrequency Antenna With a Reconfigurable Feed

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***Abstract*—The implementation of a frequency-reconfigurable antenna with the use of a moving feeding technique is described in this letter. A flexible coaxial feed is attached to the main microstripline feed of a perturbed Sierpinski monopole gasket, and it slides with the help of computer-controlled motor mechanism. Single and multiple operational frequencies are observed during the movement of the feed. The antenna and the reconfigurable system were designed, implemented, and experimentally verified to show the feasibility of the proposed concept. The experimentally verified response of the antenna is also compared to full-wave simulation results.**

***Index Terms*—Fractal antenna, reconfigurable antenna.**

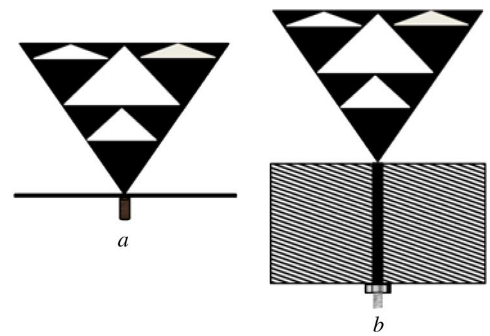

Fig. 1. Feeding to Sierpinski gasket: (a) classical and (b) modified feeds.

I. Introduction

RECONFIGURABLE antennas have been gaining much attention recently because of the number of unconventional demands by wireless communication engineers. Depending on the parameter that is modified, these antennas can be categorized as frequency-, pattern-, or polarization-reconfigurable antennas. Over the years, several of these antennas have been reported in the literature. A general review of these reconfigurable antennas can be found in [1]–[3]. Due to their multiple-functionality nature, these antennas find their applications in space, communication, cognitive radio, multiple-input–multiple-output (MIMO) systems, etc. A frequency-reconfigurable antenna is one in which the radiating structure changes its operating frequency by hopping different frequency bands. Literature review reveals that the frequency change usually occurs by changing the antenna physical structure. Basically, a change in the antenna physical structure changes the antenna surface current distribution, and hence its working frequency.

In this letter, we propose a fractal-based multifrequency-reconfigurable antenna. The reconfigurability is obtained not by changing the antennas physical structure, but by using a variable feed instead of the standard static feed. A two-iterated Sierpinski gasket was taken as the candidate antenna to show the feasibility of the proposed approach. The microcontroller-controlled coaxial feed can slide over the main microstripline feed of the antenna. For different positions of the moving coaxial feed on the main microstripline feed, the Sierpinski gasket structure resonates either at a single frequency or at multiple frequencies. The reconfigurable antenna was fabricated and experimentally measured to validate the results obtained by full-wave simulation.

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II. Theoretical Background of the Antenna

The Sierpinski gasket is one of the antenna structures that has received a lot of attention within the fractal antenna category. The monopole antenna based on the Sierpinski gasket has been studied extensively as an excellent candidate for multiband applications [4]–[6]. The classical way of feeding this monopole is by a coaxial cable through a large ground plane placed perpendicular to the antenna surface as shown in Fig. 1(a). In order to improve the input matching characteristics, authors of [6] have suggested a modified feed for these antennas, as shown in Fig. 1(b). In this feeding approach, the 50-Ω SMA connector is attached to one end of the ground plane with its feed attached to the 50-Ω microstrip line. Corresponding to the input impedance at one of the resonant frequencies, the length of the microstrip line can be chosen accordingly to improve the matching. This not only improves the matching at the desired frequency, but also improves the performance at the adjacent operating frequencies [6]. The modified feed is mainly helpful for perturbed structures because changing the Sierpinski gasket shape from its classical structure (scale factor 0.5) to perturbed structure (scale factor other than 0.5) changes the input impedance behavior drastically.

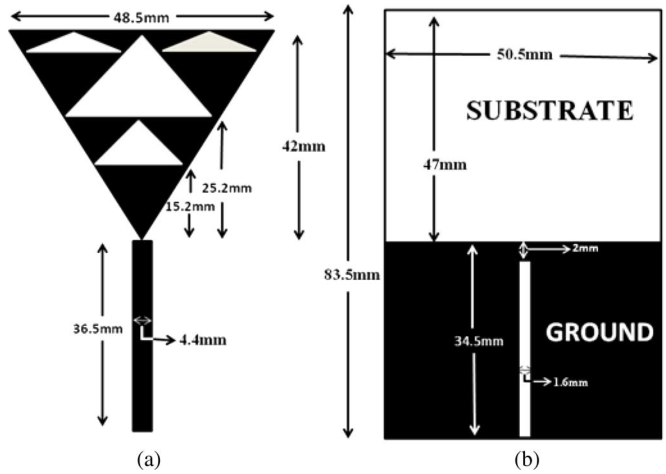

Fig. 2. Design dimensions on the (a) front and (b) back view of the antenna.

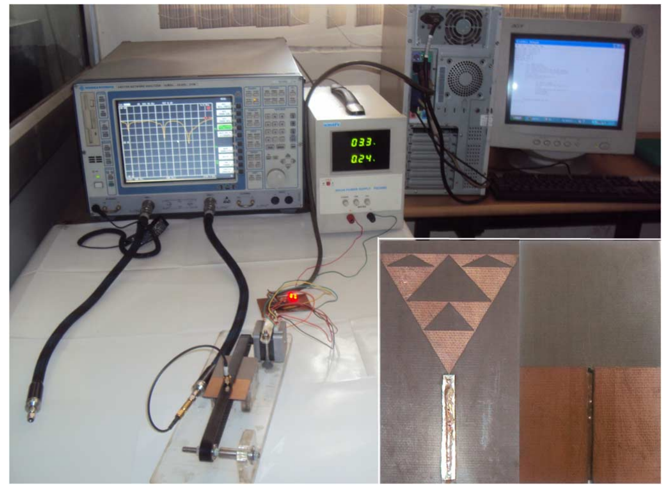

Fig. 3. Photograph of the reconfigurable feeding and measurement setup with the front and back views of the antenna in the inset.

The limited use of fractal antennas in practical applications is mostly due to the following reasons: 1) in its classical shape, all the resonant frequencies of antenna are not user-defined frequencies; and 2) during application, all the working frequencies may or may not be used at the same time, leaving the other resonant frequencies unused. This fact and the characteristics of the modified feeding discussed above prompted us to use a variable-position feeding system to a perturbed Sierpinski gasket for the system to work as a frequency-reconfigurable antenna.

III. Design and Operation of the Reconfigurable System

A. Design of the Antenna

The Sierpinski gasket monopole was designed for operation at frequencies 3.4 and 5.8 GHz to work at WiMAX and ISM band applications. For a two-iterated fractal (three operating frequencies), these frequencies were chosen as second and third resonant frequencies to make the antenna size a bit larger, for ease of making the laboratory prototype. A scale factor of 0.6 with the use of Arlon substrate ($\varepsilon_{\rm r} = 3.2$ and $h = 1.524$ mm) for designing the antenna resonates at 1.2, 3.4, and 5.8 GHz. The initial design dimensions of the Sierpinski structure were decided according to [5] and then optimized using the CST Microwave Studio simulator [7]. The values of all these design dimensions on the front and back sides of the antenna are shown in Fig. 2.

B. Design of the Feed System

The reconfigurable feeding system for the perturbed Sierpinski gasket is basically a transition from coaxial to microstripline feed. Provisions were made for the movement of the inner conductor of a flexible coaxial cable on the lower side of the microstripline. As shown in Fig. 2(b), a slot was made in the ground at the microstripline position by removing the dielectric and the metal for the movement of the flexible coaxial cable. The microstripline feed was implemented by soldering a thicker copper strip of the same size as that of the original feedline for smooth sliding of the coaxial feed inner conductor over it. Fig. 2(b) shows the size of the slot and other dimensions for implementation of the reconfigurable feed on the antenna.

C. Design of Feed Moving System

For an automatic controlled movement of the coaxial feed, a feed moving system was designed on Perpex material. The entire system consists of a stepper motor, a driver circuit for the stepper motor, a conveyor belt, a pulley, and a personal computer (PC) for giving input to the stepper motor. The coaxial connector was attached to the belt that is connected between the pulley and the motor. With the rotation of the motor, the coaxial connector slides over the microstrip line. The stepper motor helps in very fine and accurate movement of steps without the use of feedback sensors. The entire feeding and measurement setup is shown in Fig. 3, with the photograph of the antenna in the inset.

The Minebeas unipolar stepper motor was used in the implementation of the reconfigurable system as it gives better holding torque for our application [8]. A C-program was written to give data in the form of bit streams to the parallel port of the computer connected to the motor. Before feeding the data to the stepper motor, it passes through a driver IC for current amplification. In our work, we have used the ULN2803 driver IC [9]. The stepper motor takes 144 steps to travel the entire slot distance of 34.5 mm. The fabricated system can take feed positions with an accuracy of 0.24 mm.

IV. Results and Discussion

A Rohde & Schwarz 1127.8500 ZVM vector network analyzer was used for measuring the antenna's return loss at all the 144 positions of the feed point. Both single and multiple frequencies were observed in the measurement. Few of the typical S_{11} plots corresponding to single and multiple resonances are shown in Fig. 4. Simulations were made to cross-check the measured results at the corresponding feed points, and the responses are shown in Fig. 4.

The characteristics of the reconfigurable feed and the antenna behavior for these six typical cases are shown in Table I. The main idea of getting varying frequency behavior for different

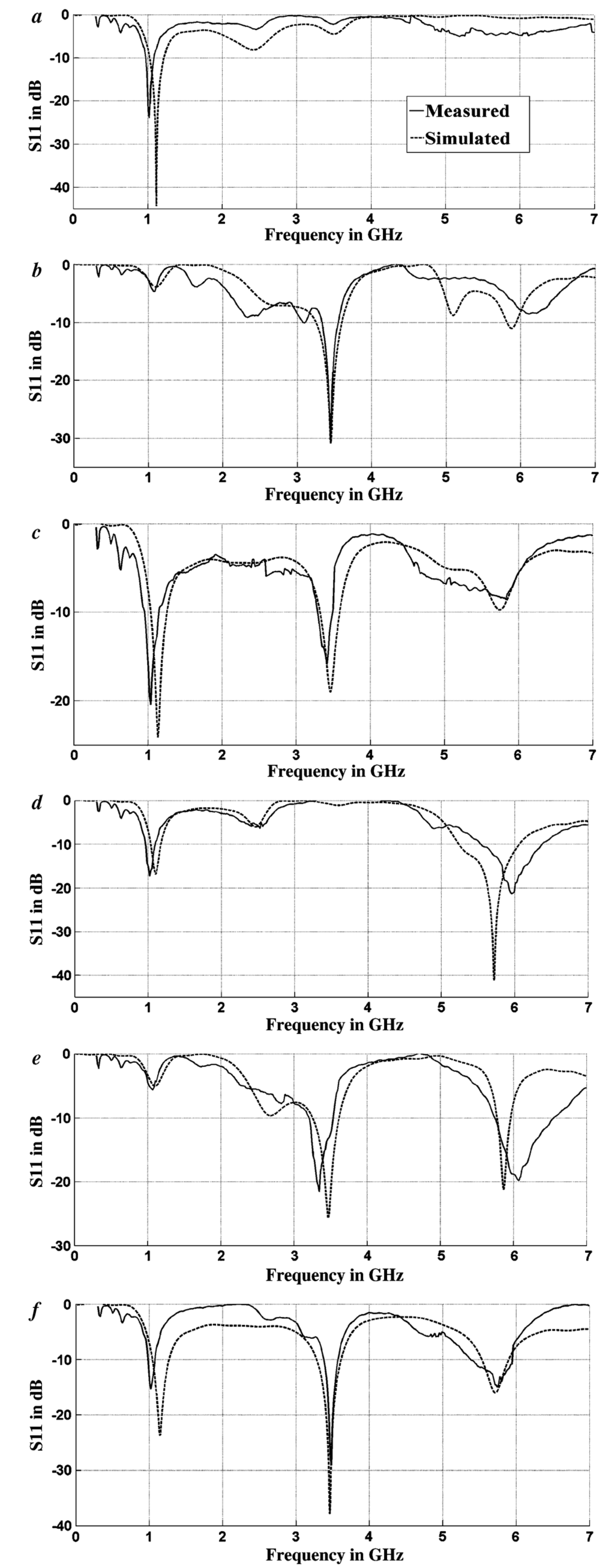

Fig. 4. S_{11} plots of some typical single- and multiple-resonance behavior of the reconfigurable antenna.

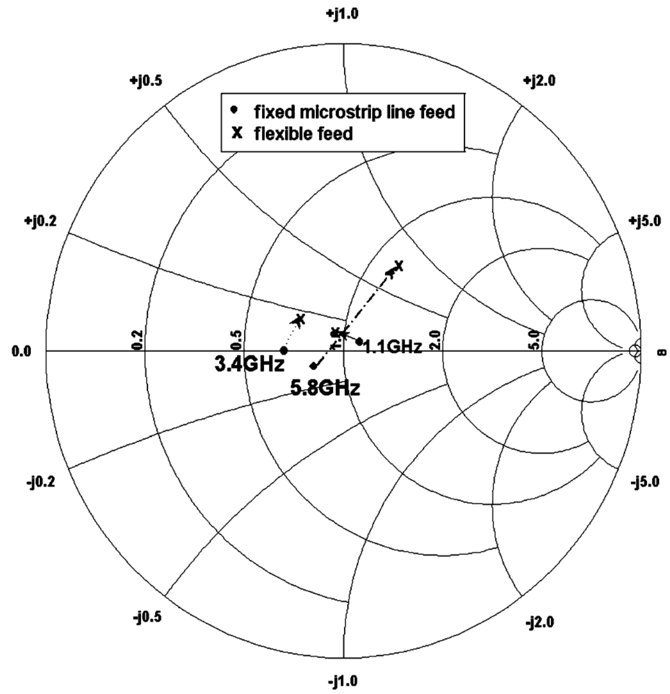

Fig. 5. Smith chart showing shift of the impedances for the three frequencies for a typical case (c) of the flexible feed with respect to the fixed microstripline feed.

TABLE I
CHARACTERISTICS OF THE RECONFIGURABLE FEED AND THE ANTENNA FOR THE TYPICAL CASES

Case	Measured feed position from beginning of slot (mm.)	Frequency response	No. of steps taken by the motor	Simulated (Measured) gain (dBi)
a	24.48	Single (1.1 GHz)	102	1.928 (1.78)
b	2.64	Single (3.4 GHz)	11	6.630 (6.41)
c	30	Dual (1.1 and 3.4 GHz)	125	2.015 (1.81), 6.368 (6.14)
d	18	Dual (1.1 and 5.8 GHz)	75	1.915 (1.72), 4.792 (4.57)
e	5.52	Dual (3.4 and 5.8 GHz)	23	6.627 (6.23), 6.495 (5.96)
f	34.08	Triple (1.1, 3.4 and 5.8 GHz)	142	2.091 (1.74), 6.306 (5.98), 4.325 (4.22)

feed positions lies in the fact that the input impedance of the antenna for three operational frequencies changes. The self-similar behavior of the input impedance property is destroyed for the three working frequencies because of peturbation. The feeding impedance at the transition point of coax-to-microstripline consists of impedance of the main connecting line and that of the other portion of the line beyond the feed point. The portion of the microstrip line beyond the feed point acts as an open stub attached to the main connecting line and plays a major role in establishing the matching [10]. Therefore, in contrast to the fixed

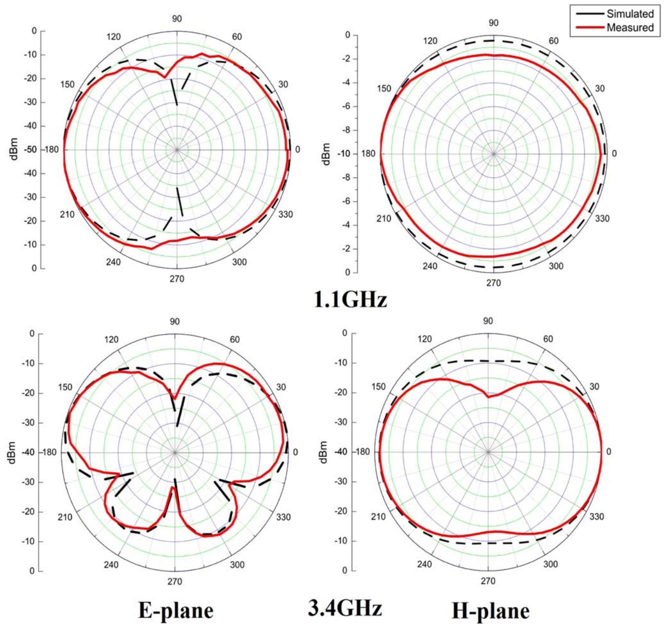

Fig. 6. Radiation patterns at the two working frequencies corresponding to typical case (c).

feed, the impedance changes when the feed slides from one end to the other. In order to show this changing impedance behavior, in Fig. 5 we have plotted its values corresponding to the typical case (c) in comparison to its values for fixed microstripline feed. From the Smith chart plot, it can be seen that for the feeding position corresponding to case (c), the impedance for 5.8 GHz moves far away from the center, producing a weak resonance at that frequency, whereas for the other two frequencies, the resonance is more pronounced. Similarly for other positions of the feed, the occurrence of a working frequency depends on how close the antenna impedance at that frequency is to the total feed impedance.

The patterns at the two working frequencies corresponding to case (c) are shown in Fig. 6. As expected, the pattern changes to that of a dipole because of the modified feed, and furthermore the ground plane size contributes to the alteration of the patterns below the zenith [6]. Here, it may be emphasized that, for the same operating frequency, it is possible to get different gains for different positions of the feed because of the varying nature of current distribution on the antenna. This can be marked clearly from Table I by comparing the gains for typical cases (e) and (f) corresponding to 5.8-GHz frequency.

V. Conclusion and Future Scope of Work

In this letter, we have demonstrated the feasibility of a variable feed for the implementation of a frequency-reconfigurable antenna. A flexible coaxial feed slides over the main microstripline feed of a perturbed Sierpinski gasket monopole antenna to give varying resonance patterns for different positions of the feed. A microcontroller-based motor slides the coaxial cable. Here, not only does the characteristic impedance of the microstrip line play a role, but at the same time, the portion of the line beyond the contact point acts as a stub and plays a major role for impedance matching at different frequencies. As a part of the future work, mechanisms should be developed to fix the probe position automatically for user-defined single or multiple frequencies.

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