Research Article

Dual Band and Beam-Steering Antennas Using Reconfigurable Feed on Sierpinski Structure

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Fractal patch antennas based on the Sierpinski structure are studied in this paper. The antennas operate at dual bands (around 2 and 5 GHz) and are designed to steer the beam directions at around 5 GHz band (the first harmonic). The antennas use reconfigurable triple feeds on the same antenna plane to have three beam directions. The same scale factor defines the geometrical self-similarity of the Sierpinski fractal. The proposed antennas are fabricated through three iterations from 1st order to 3rd order and utilize FR-4 ($\epsilon_r = 4.4$) for the microwave substrate. The performances of the antennas, such as reflection coefficients and radiation patterns are verified by simulation and measurement. The results show that the properties of the proposed antennas in three orders are similar.

1. Introduction

Fractal-shaped antennas have already been proved to have some unique characteristics that are linked to the geometrical properties of fractals [1, 2]. Additionally, reconfigurable antennas are leading the current antenna research for wireless communication applications [3, 4]. The reconfigurable capability enables that single antenna performs equal function with multiple antennas. As thoroughly discussed in [5–13], the self-similarity property of fractals makes them suitable for the design of multifrequency antennas. Sierpinski gasket structures have been credited for their log-periodic behavior in a single antenna element [6]. Because these structures are made by a repeated process, they can produce a wide surface area in a limited space [14]. In this type of iterative procedure of the Sierpinski structure, an initial structure, the so-called generator, is replicated many times at different scales, positions, and directions to grow the final fractal structure. The current distribution on the Sierpinski structure shows that most of the current density concentrates on the joints and edges of the different triangle clusters that make up the structure [15]. Because the Sierpinski structure is widely studied as a standard fractal structure, it is easy to utilize in applications.

The idea of this paper is to use simple symmetrical structures to offer the possibility of multifrequency band and beam tilt by using three feeding points. The beam-steering capability of the proposed antennas is achieved by changing location of the feeding points without using particular RF switches. Therefore, this paper focuses on a Sierpinski shaped patch antenna, offering the possibility to adjust its main beam in three directions by using three different feed points in one structure [16]. A Sierpinski fractal is used for the design of a dual band beam-steering antenna. In order to compare differences, the Sierpinski structures from 1st order to 3rd order are designed. The proposed antennas operate at around 2 GHz and 5 GHz bands and use the geometrical symmetry of the Sierpinski structure to redirect the beam. In communication systems, these antennas are utilized in various MIMO applications and adaptive beam-steering with high directivity and low correlation by using beam-steering characteristics [17, 18].

2. Antenna Design

2.1. Antenna Geometry. The fractal antenna with Sierpinski structure is chosen for its simple configuration and

FIGURE 1: Configuration of the proposed antenna.

advantage in multifrequency. The Sierpinski structure has been generated through three iterations using the subtraction. Firstly, draw an equilateral triangle (0th iteration). Secondly, generate an inner triangle (1st iteration) by connecting the midpoints of the three sides of a triangle. Thirdly, subtract the inner triangle from the equilateral triangle. Then, the 1st-order structure is obtained. By repeating the same process with each of the remaining smaller triangles, 2nd-order and 3rd-order structures are obtained. The configuration of the proposed antenna is shown in Figure 1. With this shape, a multiband feature can be obtained. The goal of this study is to design a dual band and beam-steering antenna. This antenna was fabricated on a FR-4 substrate with relative permittivity of 4.4 and loss tangent of 0.02. The triangle Sierpinski structure part and ground were manufactured with copper. The ground was located in the bottom plane. The size of the substrate was 100 mm (SL) $\times$ 100 mm (SW), and its thickness was 1.6 mm (H). The distance from the feed to a vertex was 3.75 mm (FD). The antennas were fed through three feeding points (F_1 , F_2 , and F_3) with coaxial cables. In practical applications, a 50- Ω coaxial cable can be used as a feeder. The diameter of the inner coaxial cable was 1 mm (G_1) and that of outer one was 3.8 mm (G_2), respectively. One of the coaxial cables was used to excite the antenna. At the first resonance of the antenna, the antenna radiation pattern is similar to that of a normal patch antenna. However, at the second resonance (the first harmonic), the antenna radiation pattern has two different directions which are tilted and depended on the feeding location. The detailed dimensions of the proposed antenna are summarized in Table 1.

2.2. Antenna Simulation. The proposed antennas are simulated using HFSS simulation software. The simulated

TABLE 1: Detailed dimensions of the proposed antenna (unit: mm).

Parameter	SL	SW	FD	H	L_1	L_2	L_3	L_4	G_1	G_2
Value	100	100	3.75	1.6	71	35.4	17.6	8.75	1	3.8

FIGURE 2: Simulated reflection coefficients (S_{11}) of the proposed antennas.

reflection coefficients of the proposed antennas are shown in Figure 2. As can be seen, the simulated reflection coefficients were under -6 dB (VSWR < 3) at an operation frequency band. The simulated operation bandwidths of the 1st order are 2.89–3.09 GHz and 4.79–5.09 GHz, those of the 2nd order are 2.44–2.52 GHz and 4.97–5.16 GHz, and those of the 3rd order are 2.39–2.47 GHz and 4.84–5.42 GHz. This figure shows that antennas in three orders (1st, 2nd, and 3rd) have similar resonant frequencies to a dual band. Figure 3 shows the three-dimensional radiation patterns of the proposed antennas. The simulated radiation patterns at the first resonant frequencies, specified at 3 GHz, 2.48 GHz, and 2.43 GHz for three orders, respectively, do not tilt and radiate toward z -axis as a normal patch antenna. In contrast, the beam-steering characteristics of these proposed antennas are clearly seen at the second resonant frequencies, namely, 5.03 GHz, 5.06 GHz, and 5.3 GHz in three orders, respectively. Because the antennas have symmetrical feed structures, the maximum beam directions of the radiation patterns clearly change according to three feeding points (F_1 , F_2 , and F_3). The detailed performances of the simulated antennas are summarized in Table 2.

3. Measurement Results of the Antenna

Figure 4 shows the fabricated antennas at three orders. Figure 5 shows measurement process of radiation patterns in

FIGURE 3: Continued.

FIGURE 3: Simulated 3D radiation patterns of the proposed antennas: (a) 1st order, (b) 2nd order, and (c) 3rd order.

TABLE 2: Summary of the simulated antennas' performances.

Order	Resonant frequency	Maximum beam direction (°)		HPBW (°)	Peak gain (dBi)
		θ	ϕ		
1st order	3 GHz	—	—	71	4.78
	5.03 GHz	-41, 55	274	(L) 44, (R) 48	7.16
2nd order	2.48 GHz	—	—	69	1.07
	5.06 GHz	-38, 30	51	(L) 50, (R) 33	3.2
3rd order	2.43 GHz	—	—	75	3.41
	5.3 GHz	-34, 44	89	(L) 50, (R) 39	5.19

an anechoic chamber. The measured reflection coefficients of the proposed antenna at three orders are shown in Figure 6. All the reflection coefficients were under -6 dB ($VSWR < 3$) at an operation frequency band. The measured operation bandwidths of the 1st order are 2.89–3.1 GHz and 4.64–5.3 GHz, those of the 2nd order are 2.4–2.5 GHz and 5.09–5.3 GHz, and those of the 3rd order are 2.36–2.47 GHz and 4.88–5.44 GHz. Figure 7 shows the measured two-dimensional radiation patterns of the three cases at

three orders, namely, radiation pattern at the first resonant frequency with half power beam width (HPBW) at $\theta = 90^\circ$, radiation pattern at the second resonant frequency with left half power beam width (LHPBW), right half power beam width (RHPBW), with maximum beam directions at $\theta = 90^\circ$, and radiation pattern at the second resonant frequency with maximum beam directions at $\theta = 90^\circ$. The maximum beam directions of the radiation patterns were changed by three orders (1st, 2nd, and 3rd). The maximum beam directions

FIGURE 4: The fabricated antennas at three orders: (a) 1st order, (b) 2nd order, and (c) 3rd order.

FIGURE 5: Measurement process of radiation patterns in an anechoic chamber.

FIGURE 6: Measured reflection coefficients (S_{11}) of the proposed antennas.

of the 1st order were -35° and 35° , those of the 2nd order were -30° and 30° , and those of the 3rd order were -40° and 40° symmetrically at the second resonance on yz plane ($\theta = 90^\circ$). The radiation patterns of the proposed antennas at the first resonant frequencies (3 GHz, 2.44 GHz, and 2.44 GHz) in the three orders are similar to those of standard patch antenna. However, at the second resonant frequencies (5 GHz, 5.2 GHz, and 5.34 GHz), the radiation patterns are tilted about average 35° against each feeding point. This characteristic was employed intentionally to tilt the beam according to the change in location of the feeding points. Furthermore, the proposed antennas are easy to fabricate using the Sierpinski triangle. The measured maximum beam direction, peak gain, and HPBW of the proposed antennas are summarized in Table 3. The measurement result for the antennas is in good agreement with the simulated result. Minor differences between the simulated and measured values can be caused by fabrication tolerance and the effect of the feeding cable, which the simulation tool does not take into account for calculating results of S -parameter and radiation patterns.

4. Conclusions

Dual band and beam-steering antennas using reconfigurable feed on Sierpinski structure have been designed and measured. The proposed fractal antennas are configured with three orders (1st, 2nd, and 3rd). Table 4 shows the comparison of the proposed antenna with other dual band reconfigurable antennas. The proposed antennas are manufactured with well-known fractal structure and are able to have a dual band by using the structure itself without additional components. By changing location of the feeding points without using particular RF switches, the antennas have beam-steering capability. The applicability area of the antenna is communication devices which operate in ISM band and IEEE 802.11a/b/g/n band. Therefore, it is possible to use it for applications which require enhancing communication

FIGURE 7: Measured 2D radiation patterns of the proposed antennas: (a) 1st order, (b) 2nd order, and (c) 3rd order.

TABLE 3: Summary of the measured antennas' performances.

Order	Resonant frequency	Maximum beam direction (°)		HPBW (°)	Peak gain (dBi)
		θ	$\emptyset$		
1st order	3 GHz	—	—	78	5.06
	5 GHz	−35, 35	275	(L) 43, (R) 49	5.93
2nd order	2.44 GHz	—	—	67	2.38
	5.2 GHz	−30, 30	55	(L) 52, (R) 32	3.06
3rd order	2.44 GHz	—	—	69	2.14
	5.34 GHz	−40, 40	95	(L) 47, (R) 43	4.07

TABLE 4: Comparison of the proposed antenna with other dual band reconfigurable antennas.

Reference	Dimensions (mm × mm × mm)	Bandwidth (GHz)	Peak gain (dBi)	Characteristics
[19]	80 × 80 × 3.04 (19,456 mm ³)	3.72–3.84 4.64–4.76	9.2 9.3	4-feed/2 square-loop
[20]	70 × 30 × 0.8 (1,680 mm ³)	1.56–1.58 2.39–2.5	2.1 2.7	Using a folded slot with a branch edge
[21]	160 × 170 (27,200 mm ²) The height was not mentioned.	2.41–2.59 5.56–5.98	0.1 0.2	4-element array/8 PIN diodes
[22]	60 × 60 × 40.8 (146,880 mm ³)	2.31–2.76 4.92–5.22	3.54 7.77	Frequency-selective reflector
This work	100 × 100 × 1.6 (16,000 mm ³)	2.44–3.13 4.67–5.44	5.06 5.93	3-feed/fractal structure

efficiency, such as healthcare systems, industrial fields, and military services.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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