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Abstract — This paper presents the design of a compact dual-band slot antenna for use in the recently available wireless communication applications. The slot structure of the proposed antenna is based on an annular slot-ring with Koch snowflake fractal geometry of the third iteration. The antenna slot structure has been etched on the ground plane of a substrate with relative permittivity of 4.5 and 1.524 mm thickness. On the other side of the substrate, a 50-Ohm microstrip line has been etched as the antenna feed structure. The proposed antenna has a compact size of (40 × 40 × 1.524) mm³. Simulation results show that the proposed antenna could excite two resonant bands. The lower resonant band extends from (2.38–3.03) GHz while the upper resonant band extends from (4.45–5.06) GHz. This makes the antenna suitable for a wide range of currently available communication services.

1. INTRODUCTION

The dramatic evolution of modern communication systems and the relevant applications have made the antenna designers encounter many challenges. The antennas designed for these applications should be with compact size and have the capability of achieving multiband applications, high performance concerning the radiation efficiency and the optimum gain [1]. In this context, the annular slot-ring antenna with a CPW-feed could achieve a dual-band response after the addition of a circular back-patch on the other side of the substrate [2]. It is possible to use the annular ring slot structure for the purpose of miniaturization besides to its ability to generate the dual response [3]. On the other hand, the application of fractal geometries of various types has been proved as an attractive approach to design compact dual-band and multiband printed antennas with slot structures as reported in the literature. In this respect, Peano [4–6], Cantor [7, 8], Sierpinski [9, 10], Koch [11–13] and their variants have successfully applied to the slot structures dual-band and multiband printed slot antennas. Furthermore, other space-filling fractal curves such as Hilbert, Moore, and Minkowski have also been reported [14–18].

In this paper, a new fractal-based printed slot antenna is presented as a candidate for use in dual-band communication applications. The proposed antenna slot structure results from applying the third iteration Koch snowflake fractal geometry in such a way to produce a fractal shaped annular slot. Simulation results show that the resulting antenna offers compact size with dual-band resonant response and reasonable radiation characteristics.

2. KOCH SNOWFLAKE FRACTAL GEOMETRY AND THE PROPOSED ANTENNA STRUCTURE

Koch snowflake fractal geometry can be constructed with an equilateral triangle as shown in Figure 1; the middle third of each side in this triangle can be replaced by two sides connected in the form of an equilateral triangle but with a length of about third the length of the original side in the previous iteration. This process can be repeated, for higher iteration, to form the structure of Koch snowflake fractal with higher order.
Let $N_n$ be the number of sides, $L_n$ be the length of a single side, and $l_n$ be the length of the perimeter, after the $n$th iteration. Then

\begin{align*}
N_n &= (3) \cdot (4)^n \\
L_n &= \left(\frac{1}{3}\right)^n L_0 \\
l_n &= N_n L_n = 3 \left(\frac{4}{3}\right)^n L_0
\end{align*}

The first step is to investigate the performance of a snowflake slot antenna structure as shown in Figure 2. Figure 2(a) depicts the perspective view of the modeled slot antenna structure. The front view is illustrated in Figure 2(b), where a square ground plane with dimensions of $(W_{gp} \times L_{gp})$ has been trenched by a Koch snowflake of the 3rd iteration. A 50 Ω microstrip feed line of $(W_{fl}\times L_{fl})$ dimensions is constructed on the opposite side of the substrate as shown in Figure 2(c). It is assumed that the antenna is to be etched on a substrate of 4.5 relative dielectric constant and 1.524 mm thickness.

3. PERFORMANCE EVALUATION AND PARAMETRIC STUDY

The first stage has been suggested to model slot antenna, depicted in Figure 2, with the slot structure in the form Koch snowflake fractal geometry with different iteration levels. Modeling of the antennas in all stages along with their performance evaluations have been carried out using computer software technique CST Microwave Studio [20]. Choosing antenna with $L_o$ of 27 mm and ground plane dimensions of $(40 \times 40 \times 1.6)$ mm$^3$, the resulting input reflection coefficient responses are shown in Figure 3. As the results in Figure 3 imply, the modeled antennas possessed dual-band resonant responses but with two resonant bands located close to each other and coupled to form a single broadband. The results of Figure 3 confirm the finding reported in [21] for the slot antenna based on the 2nd iteration Koch snowflake structure. However, the slight difference in the results is attributed to the coupling structure loaded to the feed line of the antenna in [21].

The second step is to investigate the performance of the annular slot ring antenna with the annular slot structures based on the 3rd iteration Koch snowflake fractal geometry. The modeled antenna structure is shown in Figure 4. Figure 5 shows the simulated input reflection coefficient responses of the modeled antennas with Koch snowflake slot structure, depicted in Figure 2, and with Koch snowflake annular slot structure, illustrated in Figure 4. The antenna with the annular slot structure offers two distinct resonant bands; a lower band extending from 2.38 to 3.03 GHz and an upper band extending from 4.45 to 5.06 GHz. The results of Figure 5 can be discussed better...
Figure 3. The input reflection coefficient responses of the snowflake slot antenna for different fractal iteration levels.

Figure 4. The proposed slot antenna with 3rd iteration Koch Snowflake annular slot structure.

with the aid of the current distribution on the surfaces of the two modeled antennas at 2.45 GHz as demonstrated in Figure 6. The existence of the inner part of the annular slot structure, shown in Figure 6(b), provides a considerable coupling with the outer structure enabling larger current path as compared with that created in the antenna with slot structure. Consequently, the larger radiating path will excite lower resonant band. The inner conducting part inside the slot structure will provide an additional coupling which helps produce an antenna response with the lower resonant band. The inner conducting part in the slot structure is reclaiming the electric field by directing the electric current to the regions that generate another resonating band. Furthermore, the positions of the two resonant bands can be tuned if a defected ground structures with suitable shape embedded in the ground plane.

Figure 5. The input reflection coefficient responses of the fractal-based slot and annular slot antennas.

Figure 6. The simulated current distributions at 2.45 GHz on the surfaces of (a) Koch snowflake slot antenna, and (b) Koch snowflake annular slot antenna.
The characteristics of the far-field radiation patterns for the total electric field in Figure 7 of the proposed dual-band antenna have also been studied. Figure 7(a) shows the simulated far-field radiation patterns for the total electric field in the x-y plane, the x-z plane, and the y-z plane at 2.61 GHz; the center frequency of the obtained lower band. Figure 7(b) depicts the radiation patterns at 5.18 GHz; the center frequency of the acquired upper band from the proposed antenna.

The 3D radiation patterns for the total electric field of the proposed dual-band antenna are depicted in Figure 8. Figure 8(a) assigned to the center frequency of the lower resonating band 2.61 GHz and Figure 8(b) allocated to the center frequency of the upper resonating band 4.75 GHz. Furthermore, the simulated results reveal that the antenna offers peak gains of about 2.64 dBi and 2.25 dBi at the lower and the upper bands respectively.

Figure 7. The simulated total electric field radiation patterns of the proposed dual-band antenna at (a) 2.61 GHz, and (b) 4.75 GHz.

Figure 8. The 3D total electric field of the proposed dual-band antenna at (a) 2.61 GHz, and (b) 4.75 GHz.

4. CONCLUSIONS

A compact fractal-based annular slot-ring antenna has been introduced in this paper as a candidate to serve dual-band communication applications. The annular slot structure of the proposed antenna is modified to be in the form of Koch Snowflake fractal of the third iteration. Results show that the proposed antenna with the annular slot structure offers two distinct resonant bands; a lower band extending from 2.38 to 3.03 GHz, and an upper band extending from 4.45 to 5.06 GHz. Furthermore, the proposed antenna has achieved a reasonable response and radiation characteristics that make it a suitable candidate for the dual-band communication applications.

REFERENCES


