CPW-fed Circular Fractal Slot Antenna for 2.38/5.35 GHz Dual-bands

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1. Introduction

Multiband/broadband antennas have received the increasing interest in wireless communications. Compared to typical microstrip antennas \cite{1}, coplanar waveguide (CPW) structures have several useful properties including wider bandwidth, better impedance matching, lower radiation loss and easy application with AI\textsuperscript{A} (active integration antenna). Therefore, various techniques of broadband and dual-band \cite{2}-\cite{3} \cite{9}-\cite{10} responses were explored in this investigation. Fig. 1 depicts an innovative configuration of circular-shaped aperture with an appropriate inner conductor, which can be applied to broadband response and high gain antennas.

Using a self-similar iteration design, a practical fractal antenna could be developed for multiband and broadband applications \cite{3}-\cite{4}\cite{11}. The typical Sierpinski gasket configuration was slotted in the triangle patch to form the multi-band antenna, broadband and ultra-wideband antennas \cite{11}. Dependent on the Descartes circle theorem in the CPW-fed circular aperture has been proposed to present alternative broadband antennas \cite{5}-\cite{7}.

By configuration synthesis and design map for accurate design and better performance, the CPW-fed circular fractal slot antennas are proposed for dual-band applications in this paper. The practical quarter-wavelength designs with wide-band response and available radiation gain are described herein. Simulations are verified by measurements with $S_{11}$ spectrum, two-cut patterns, contour distribution patterns and current distributions.

2. Antenna Configuration and Design

The proposed antenna has a circular inner conductor, circular aperture, feed-line, and ground plane on one side of the PCB, while the other side is completely etched. As illustrated in Fig. 1, the dimension of the circular aperture is $D$ with enough ground of areas $W_1 \times W_2$. For feeding, the width of CPW feed-line is given by $w$, the spacing is given by $s$, and the impedance matching of the circular aperture can be improved by adjusting $w$ and $s$.

For normalization, the circular aperture is expressed as a unit. Pointing with an outward normal is given by $-1$. The circular inner conductor is constructed with the circular fractal patterns using Descartes circle theorem. The Descartes circle theorem states that if four circles are mutually tangential in the plane, with disjoint interiors, their curvatures satisfy the relationship \cite{5}-\cite{8}.

At the start of the iteration, resonances represent the multi-band responses in the operating range. Notably, the resonances shift downward and increase as the iteration progress. And space-filling configuration is achieved with iteration. Finally, the antennas possess the characteristics of multi-band/broad-band frequency operations in the spectrum. However, the three original circles generated at first iteration dominate the resonances in spectrum as to it is the largest inner conductor. Especially, the first two resonances are closely related to the dimension of the circles. Therefore a motivation of dual-band design is proposed herein.

For deterministic design and better performance, a design map in company with a procedure for dual-band application is presented in this paper. For an analytical approach, the
design map is plotted. It proposes $d_1$ represents the higher resonant frequency of desired band and $d_2$ depicts the lower resonated frequency graphically. Then, the design procedure is stated [13].

3. Quarter-wavelength Design

For CPW-fed circular fractal slot antenna in Fig. 1 and Fig. 2, the dimensions are with $W_1 = 44$ mm, $W_2 = 44$ mm, $D = 34$ mm, $s = 0.5$ mm, $w = 2.5$ mm and $r_a = 7.8$ mm. The identical FR4 substrate is used. Similarly, the measured and simulated results of S11 spectrum with the original and three stage iterations are presented in Fig. 3.

Using the design map and the 3.53 GHz resonance which is higher about the desired 2.70 GHz resonated frequency with a 20-25% empirical value is preset to determine the $d_1 = 21.4$ mm with quarter-wavelength characteristics for a typical monopole. Meantime, the half-wavelength resonance is 7.02 GHz in the original. Then, $D = 34$ mm and $d_0 = 15.6$ mm are achieved by steps. Finally, the desired quarter-wavelength (2.38 GHz) resonated frequency is obtained with $d_2 = 27.3$ mm. The half-wavelength resonance 5.35 GHz is presented.

As the iteration progresses, the resonance is downward shifted and distinct multi-band responses are observed using the space-filling technique. In the Stage-3, the resonance (2.38 GHz) is greatly lowered by 32.5% compared to the original. In addition, two available broadbands with –10dB bandwidth 75.9% (1.88 to 4.18 GHz) and 16.1% (4.96 to 5.83 GHz) are obtained for IEEE 802.11a/b/g systems. The directional patterns are observed in the X-Z cut and the non-directional patterns are presented in the Y-Z cut in Fig. 4. At resonance 2.38 and 5.35 GHz, the directivity with 3.16 and 6.62 dBi are obtained. Axial ratio (AR) responses with various ground size (46×46 mm², 48×48 mm², and 50×50 mm²) are depicted in Fig. 5 (a) and (b). The minimum AR with 0.34 at $\varphi = 60^\circ$, $\theta = 150^\circ$ and 0.27 dB at $\varphi = 50^\circ$, $\theta = 80^\circ$ are presented respectively. It is evident that the ground size affects the AR profile. The contour distributions for the omni-directional patterns are presented with the blue color for both 2.38 and 5.35 GHz in Fig. 6. The central area consists of the null and two side-lobes of the patterns with three spots in blue color for 2.38 GHz. $\lambda/4$ designs are illustrated with photography in Fig. 7.

We have simulated the current distribution generated in the antenna at 2.38 GHz and 5.35 GHz, shown in Fig. 8 respectively [14]. A larger surface current distribution is observed to flow along the bottom edges of the inner conductor. It indicates that the larger moon-shaped current distribution related to $d_2$ in design map does effectively provide the electrical current path for the 2.38 GHz resonance. The surface current distribution flows along not only the bottom edges but also the upper edges of the inner conductor. Thus, two small moon-shaped current distributions are located among the inner conductor. These are related to $d_1$ of design map for the 5.35 GHz resonance. These obtained results seem to agree with the design map.

4. Conclusion

This study proposes an alternative dual-band approach to obtain a CPW-fed slot antenna with circular fractal patterns. For accurate design and better performance, a synthesis with the design map is presented here. Two available broadband responses with –10dB bandwidth 75.9% (2.38 GHz) and 16.1% (5.35 GHz) are obtained for IEEE 802.11a/b/g systems applications. At resonance 2.38 and 5.35 GHz, the directivity with 3.16 and 6.62 dBi and the axial ratio with 0.34 and 0.27 dB are obtained. The minimum AR with 0.34 and 0.27 dB are achieved respectively, thus the proposed antenna can be applied to circular polarization applications. The contour distribution patterns are applied to figure out the omni-directional patterns. The current distribution is simulated to clarify the EM characteristics of the antenna.
Figure 1: CPW-fed Slot Antenna

Figure 2: CPW-fed Circular Fractal Slot Antenna

Figure 3: Iterative $S_{11}$ Spectrums for $\lambda/4$ Design

Figure 4: Radiation patterns for $\lambda/4$ design

Figure 5: AR Profiles for $\lambda/4$ Design

Figure 6: Contour Distribution Patterns for $\lambda/4$ Design
Figure 7: Photography of $\lambda/4$ Designs

Figure 8: Current Distributions

References