CPW-fed Circular Fractal Slot Antenna for Dual-band Applications

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Abstract

By configuration synthesis and design map, the CPW-fed circular fractal slot antenna is proposed for dual-band applications. The practical design with wide-band (47.4% BW at 0.98 GHz and 13.5% BW at 1.8 GHz) and available radiation gain (peak gain 3.58 dBi at 0.98 GHz and 7.28 dBi at 1.8 GHz) are described herein.

1. INTRODUCTION

Multi-band/wide-band antenna designs are rapid growth in wireless communications. Compared to typical microstrip antennas, coplanar waveguide (CPW) structures have useful properties including wider bandwidth, lower radiation loss, better impedance matching, and easy application with active integration antenna [1]. Therefore, various wide-band [2-6] and dual-band [7-8] techniques were explored in this investigation. Conventionally, CPW-fed antennas have impedance bandwidth of 15–20%. Thus, designing wider bandwidth and dual-band CPW-fed antenna has become an interesting topic. However, the trial and error method to obtain the configurations and achieve the applications was needed for design.

Generally, CPW-fed slot antennas have co-planar configuration, which the main structure includes the slot, inner conductor and feed-line couplings. They can broaden the bandwidth by using an inner conductor in the slot. Geometrically, hybrid slot [2] and widened tuning stub [3] belong to the square pattern, cusp [4] and circular patch [5] have circular structure. In addition, practical four fractal antennas with mathematic synthesis in the circular slot have been proposed for multiband/wideband applications [6].

By configuration synthesis and design map, the CPW-fed circular fractal slot antenna is proposed for dual-band applications in this paper. First, a circular aperture is slotted inside the ground plane for CPW structure, then using four mutually tangent configurations to construct the circular fractal pattern. Based on the iterative processes according to the Descartes circle theorem, the circular fractal configurations are synthesized. Second, a design map in company with a procedure is proposed for dual-band applications. The practical design with wide-band and available radiation gain are described herein. Simulations are verified by measurements with S_{11} spectrum and two-cut patterns.

2. ANTENNA CONFIGURATION SYNTHESIS

A. Antenna Configuration

Based on the co-planar configuration, the proposed antenna has the circular inner conductor, circular aperture and ground plane on one side of the PCB, while the other side is completely etched. As illustrated in Fig. 1, the dimension of circular aperture is $\boldsymbol{D}$ with enough ground of areas $\boldsymbol{W}^2$. For excitation, the width of CPW feed-line is given by $\boldsymbol{t}$, the spacing is given by $\boldsymbol{s}$, and the impedance matching of circular aperture can be improved by adjusting $\boldsymbol{t}$ and $\boldsymbol{s}$.

B. Iterative Design

For normalization, circular aperture is expressed as unit. The circular inner conductor is constructed with the circular fractal patterns by Descartes circle theorem. The Descartes circle theorem states that if four circles are mutually tangent in the plane, with disjoint interiors, their curvatures satisfy the relationship [8]:

$$(a_i+b_i+c_i+d_i)^2 = 2(a_i^2+b_i^2+c_i^2+d_i^2),\ \mathrm{i}=1, 2, \ldots \tag{1}$$

where $a_i = \frac{1}{r_{ai}},\ b_i = \frac{1}{r_{bi}},\ c_i = \frac{1}{r_{ci}},\ d_i = \frac{1}{r_{di}}$, and the radii of circles are $r_{ai}, r_{bi}, r_{ci}, r_{di}$.

Thus, at the first stage, $i = 1$, $r_{a1} = -1$, the radii of each of the three identical inner circles are $r_{b1} = r_{c1} = r_{d1} = \frac{3}{3+2\sqrt{3}}$, and the curvature about the initial four circles is:

$$\left(-1,\ \frac{3+2\sqrt{3}}{3},\ \frac{3+2\sqrt{3}}{3},\ \frac{3+2\sqrt{3}}{3}\right) \tag{2}$$

Once the first stage configuration of the four circles is obtained, the Descartes circle equation can be applied in the next stage to specify the size of smaller circle from any set of three original circles. By the step processes with stage to stage, this is designated as the self-similar iteration design. Hence, at the second stage, a set of three circles is selected from the initial four circles obtained in the first stage to determine the fifth circles. As shown in Fig. 2 :

$$e^{I}_{2-1} = e^{II}_{2-1} = e^{III}_{2-1} = \frac{1}{r_{e2-1}}, \tag{3}$$

$$e^{I}_{2-2} = \frac{1}{r_{e2-2}} \tag{4}$$

where r_{e2-1}, r_{e2-2} denote the radii of the obtained circles.

Similarly, in the third stage, a set of two circles is selected from the initial four circles obtained in the first stage and the fifth circles obtained in the second stage to determine the ninth circles. The radii of obtained circles are r_{f3-1}, r_{f3-2}. The iterative results of circular fractal patterns are shown in Fig. 2. The related radii of four variety circles are followings:

$$r_0 = 1,\ r_1 = \frac{3}{3+2\sqrt{3}},\ r_2 = \frac{1}{1+2\sqrt{3}} \text{ and } r_3 = \frac{1}{7+4\sqrt{3}}.$$

C. *Design Map*

For deterministic design and better performance, a design map in company with a procedure for dual-band application is presented in this paper. For analytical approach, the design map is plotted in Fig. 3, proposed d_1 represents the higher resonated frequency of desired band and d_2 depicts the lower resonated frequency graphically. Then, the design procedure is stated as:

a. The guided half-wavelength of higher resonated frequency determines d_1.
b. d_0 is obtained by the relation of $d_0 : d_1 = 2 : (1+\sqrt{3})$.
c. D is decided by the relation of $D : d_0 = 1 : \frac{3}{3+2\sqrt{3}}$.
d. The guided half-wavelength of lower resonated relates d_2.
e. d_2 is obtained by the relation of $d_0 : d_2 = 1 : 2\sqrt{3}$.
f. The tuning for certain lower resonated frequency can be achieved by space-filling the pattern with iteration.

3. SIMULATED AND EXPERIMENTAL RESULTS

The measured and simulated results of S_{11} spectrum with the original and three iterations are presented in Fig. 4. Firstly, the resonance is 2.22 GHz in the original. While the iteration progressed, the resonance is downward shifted and distinct multi-band responses are observed. In the Stage-3, the resonance (0.98 GHz) is greatly lowered by 55.9% compared to the original. This lowering in the resonance can correspond to an antenna size reduction of 80.5%. In addition, two available bands with -10dB BW 47.4% (0.82 to 1.33 GHz) and 13.5% (1.73 to 1.98 GHz) are obtained for ISM-band. The Both measurements and simulations agree well with the frequency responses. Fig. 5 illustrates the measured and simulated results of normalized two-cut pattern. Clearly, the bidirectional patterns are observed in the X-Z cut, the omnidirectional patterns are presented in the Y-Z cut. Furthermore, at resonance 0.98 and 1.8 GHz, the directivity is 3.58, 7.28 dBi and axial ratio is 5.79, 1.18 dB, it can applied to circular poralization applications.

4. CONCLUSION

This study proposes an alternative multi-band approach to obtain a CPW-fed slot antenna with circular fractal patterns. Circular fractal patterns with three iterations have been measured and analyzed herein. Significantly, the resonance is lowered by 55.9% with size reduction of 80.5%, and two available bands with -10dB BW 47.4% (0.98 GHz) and 13.5% (1.8 GHz) are obtained for ISM-band applications. It is a compact and available microstrip antenna for ISM applications.

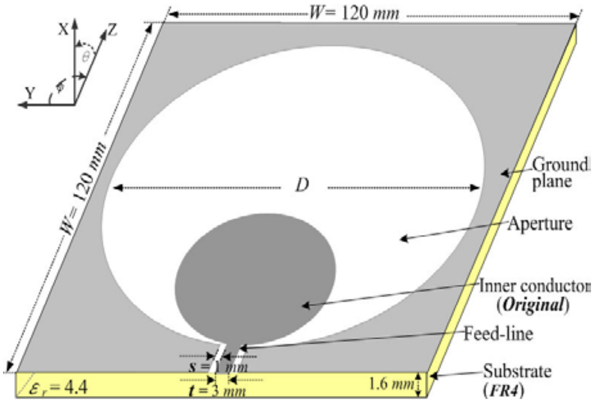


Fig. 1: CPW-fed Slot Antenna

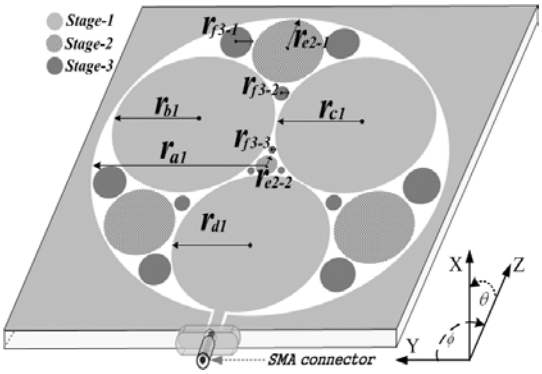


Fig. 2: CPW-fed Circular Fractal Slot Antenna

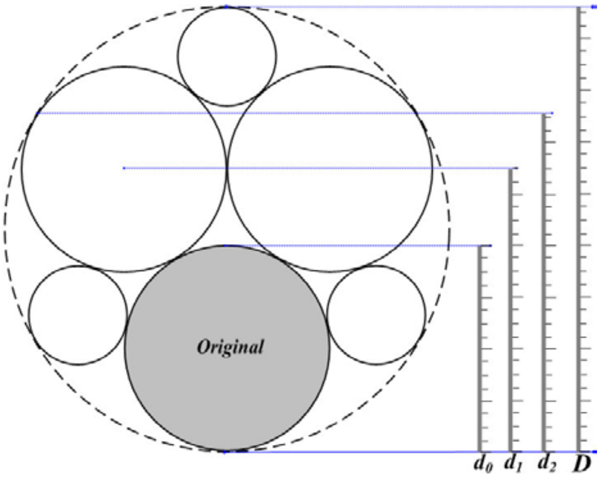


Fig. 3: Design Map

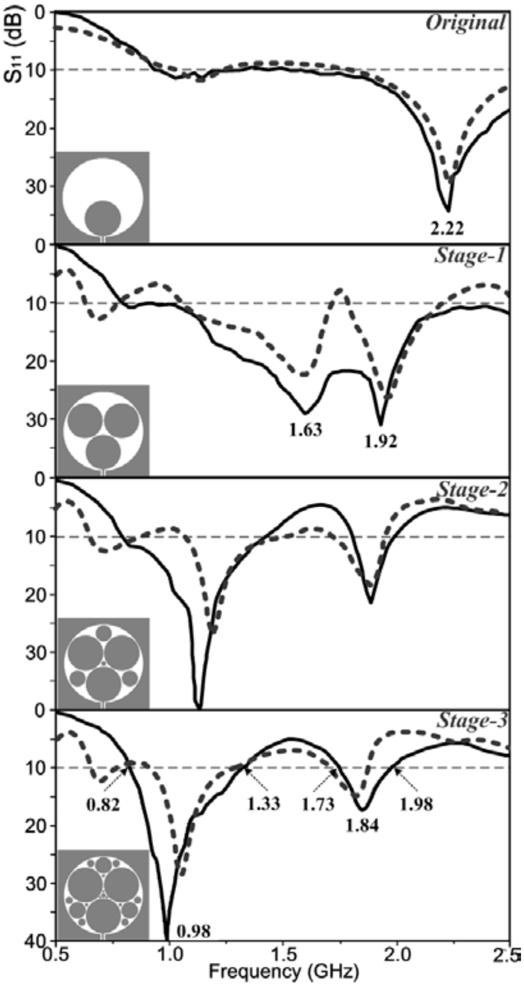
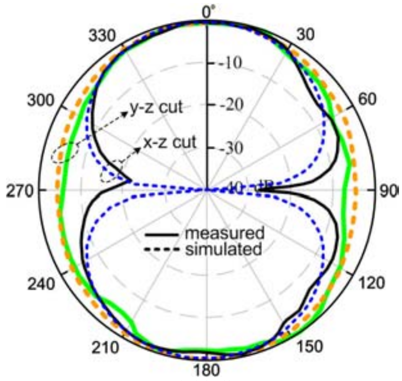
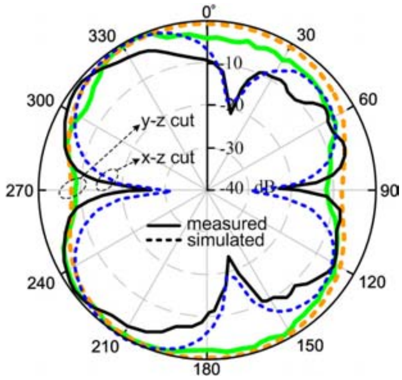


Fig. 4: Iterative S_{11} Spectrums



(a) 0.98 GHz



(b) 1.8 GHz

Fig. 5: Radiation Patterns

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