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A New Miniaturized Fractal Bandpass Filter Based on Dual-Mode Microstrip Square Ring Resonator

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Abstract—A novel fractal dual-mode microstrip bandpass filter design has been introduced in an attempt to produce filters with highly miniaturized size for modern wireless applications. The filter structure has been generated based on the 3rd iteration Minkowski-like pre-fractal geometry, using the conventional dual-mode square ring resonator as the initiator in the fractal generation process. The space-filling property, self-similarity and the diagonal symmetry of the structures corresponding to the successive iteration levels of this fractal geometry have found to produce reduced size filter structures with accepted performance. The bandpass filter structure produced by the 3rd iteration of this fractal geometry can be considered as a novel design with adequate performance. This design structure possesses a size reduction of about 72% compared with the conventional dual-mode square ring resonator operating at the same frequency and using the same substrate material. In addition, the new design technique seems reliable, since it provides the filter designers with more degree of freedom and further size reduction as compared with those reported in the literatures.

Index Terms—Microstrip bandpass filter, filter miniaturization, fractal bandpass filter, dual-mode resonator, square ring resonator.

I. INTRODUCTION

Recent developments in wireless communication systems have presented new challenges to design and produce high-quality miniaturized components. These challenges stimulate microwave circuits designers and antennas designers to seek out for solutions by investigating different fractal geometries [1-5].

Most of the research efforts has been devoted to the antenna applications. In passive microwave design, the research is still limited to few works and is slowly growing. Among the earliest predictions of the use of fractals in the design and fabrication of filters is that of Yordanov et.al. [6]. Their predictions are based on their investigation of Cantor fractal geometry.

Different from Euclidean geometries, fractal geometries have two common properties, space-filling and self-similarity. It has been shown that the self-similarity property of fractal shapes can be successfully applied to the design of multi-band fractal antennas, such as the Sierpinski gasket antenna, while the space-filling property of fractals can be utilized to reduce antenna size. Fractal curves are well known for their unique space-filling properties. Research results showed that, due to the increase of the overall length of the microstrip line on a given substrate area as well as to the specific line geometry, using fractal curves reduces resonant frequency of microstrip resonators, and gives narrow resonant peaks.

Hilbert fractal curve has been used as a defected ground structure in the design of a microstrip lowpass filter operating at the L-band microwave frequency [1].

Sierpinski fractal geometry has been used in the implementation of a complementary split ring resonator [2]. Split ring geometry using square Sierpinski fractal curves has been proposed to reduce resonant frequency of the structure and achieve improved frequency selectivity in the resonator performance.

Koch fractal shape is applied to mm-wave microstrip band pass filters integrated on a high-resistivity Si substrate. Results showed that the 2nd harmonic of fractal shape filters can be suppressed as the fractal factor increases, while maintaining the physical size of the resulting filter design [3].

In this paper, a new fractal microstrip dual-mode bandpass filter is presented. A miniaturized filter structure is fractally generated based on Minkowski-like pre-fractal geometry, and using the conventional dual-mode square ring resonator as a starting step in the fractal generation process. The resulting filter structures are supposed to have miniaturized sizes with adequate reflection and transmission responses.

II. THE MINKOWSKI-LIKE PRE-FRACTAL GEOMETRY

The starting pattern for the proposed bandpass filter as a fractal is a square ring with a side length \( L_o \), Fig. 1b. From this starting pattern, each of its four sides is replaced by what is called the generator structure shown in Fig. 1a. To demonstrate the fractal generation process, the first three iterations are shown. The first iteration of replacing a segment with the generator is shown in Fig. 1c. The starting pattern is Euclidean and, therefore, the process of replacing the segment with the generator constitutes the first iteration. The generator is scaled after such that the endpoints of the generator are exactly the same as the starting line segment. In the generation of the true fractal, the process of replacing every segment with the generator has been carried out an infinite number of times.

In the traditional Minkowski island fractal, the generator is composed of five segments with equal length of one-third. However in the present work, generator is composed of five unequal length segments. According to this, the term
Minkowski-like pre-fractal has been used to describe the resulting pre-fractal geometry. The middle segment, \( w_1 \), is chosen such that it is less than the two end segments. The other two vertical segments are tuned to adjust the overall perimeter of the fractal length. This tuning length is called the indentation width, \( w_2 \) [8].

The basic idea, to propose this fractal technique to generate a miniaturized microstrip bandpass filter structures, has been borrowed from the successful application of such a technique in the microstrip antenna design, where compact size and multi-band behavior have been produced due to the space-filling and self-similarity properties of the resulting microstrip fractal antenna design [9],[10]. It has been concluded in antenna design, that the number of generating iterations required to make use of the benefits of miniaturization is only few before the additional complexities become indistinguishable [8],[9]. This is right in this field, since the antenna aperture, when much reduced, leads to less gain though the radiation performance is still attractive. However, this cannot be as serious in the filter design unless practical limitations obscure its implementation due to fabrication tolerances.

Practically, shape modification of the resulting structures in Fig. 1c and d is a way to increase the surface current path length compared with that of the conventional square ring resonator, Fig. 1b; resulting in a reduced resonant frequency or a reduced resonator size, if the design frequency is to be maintained. The space filling geometry and the self similarity that the 1\(^{st}\) iteration structure in Fig. 1c possesses, make it analogous to the modified square microstrip antenna reported in the literature [11],[12]. It is expected then, that the 2\(^{nd}\) iteration, shown in Fig. 1d will exhibit further miniaturization ability owing to its extra space filling property. Theoretically the size reduction process goes on further as the iteration steps increase.

An additional property that, the presented fractal scheme possesses, is the symmetry of the whole structure, in each of the iteration levels, about its diagonal. This property is of special importance in the design of dual-mode loop resonators [13],[14].

The resulting pre-fractal structure has the characteristic that the perimeter increases to infinity while maintaining the volume occupied. This increase in length decreases the required volume occupied for the pre-fractal bandpass filter at resonance. It has been found that:

\[
P_n = (1 + 2\alpha_2)P_{n-1} \tag{1}
\]

where \( P_n \) is the perimeter of the \( n^{th} \) iteration pre-fractal and \( \alpha_2 \) is equal to the ratio \( w_2/L_o \). Theoretically as \( n \) goes to infinity the perimeter goes to infinity. The ability of the resulting structure to increase its perimeter at every iteration was found very triggering for examining its size reduction capability as a microstrip bandpass filter.

The length, \( L_o \) of the conventional microstrip dual-mode square ring resonator has been determined using the classical design equations reported in the literatures [13-15], for a specified value of the operating frequency and given substrate properties. This length represents a slightly less than quarter the guided wavelength at its fundamental resonant frequency in the resonator.

\[
L_o = (0.6)^{n/2}L_o \tag{2}
\]

while the enclosing area, \( A_n \), has been found to be:

\[
A_n = (0.6)^nA_o \tag{3}
\]

where \( A_o \) is the area occupied by the conventional square ring resonator.

III. FILTER DESIGN

As shown in Fig. 1, applying geometric transformation of the generating structure (Fig. 1a) on the square ring resonator (Fig. 1b), results in the 1\(^{st}\) iteration filter structure depicted in (Fig. 1c). Similarly successive bandpass filter shapes, corresponding to the following iterations can be produced as successive transformations have been applied. Fig. 1e shows an enlarged copy of the 3\(^{rd}\) iteration fractal structure, on which the proposed bandpass filter design is based. At the \( n^{th}\) iteration, the corresponding filter side length, \( L_n \) has been found to be:

\[
L_n = (0.6)^{n/2}L_o \tag{4}
\]

where \( \lambda_{go} \) is the guided wavelength. Then the side length, \( L_n \), for the successive iterations can be calculated, based on the value of \( L_o \), using (2).

The small perturbations applied to each dual-mode resonator, at locations that are assumed at a 45\(^{\circ}\) offset from its
two orthogonal modes. These perturbations are in the form of a small patch added to the square ring, and the other subsequent iterations loop resonators. It should be mentioned that, for coupling of the orthogonal modes, the perturbations could also take forms other than this shape. But, since the proposed resonating structures are characterized by their diagonal symmetry, this shape of perturbation is the most convenient to satisfy the required coupling. The effect of the perturbation size on the dual-mode ring resonator performance is beyond the scope of this paper. The dimensions of the perturbations of each filter must be tuned for the required filter performance, since the nature and the strength of the coupling between the two degenerate modes of the dual-mode resonator are mainly determined by the perturbation’s size and shape. However, extensive details about this subject can be found in [18],[19].

It is worth to mention that, the filter structures based on the 1st and 2nd iterations depicted in Fig. 3 and 4, have similar structures with those reported in [20] and [21]. The reported structures represent two separate attempts to produce compact size microstrip bandpass filters; each consists of a single design step and does not go on further. However, the corresponding structures, introduced in this paper, represent intermediate steps in a more general fractal generation process. These filter structures have been found to possess size reductions of 40% and 64% respectively, as compared with the conventional dual-mode microstrip square ring resonator, with accepted filter performances [22].

Accordingly, the filter structure, based on the 3rd iteration, depicted in Fig. 5 can be considered, up to the author’s knowledge, a novel design. This filter offers further size reduction of about 72% as compared with the conventional dual-mode square ring resonator.

IV. Performance Evaluation

Filter structures, depicted in Fig. 2-5, have been modeled and analyzed at an operating frequency, in the ISM band, of 2.4 GHz using the IE3D electromagnetic simulator, from Zeland Software Inc. This simulator performs electromagnetic analysis using the method of moments (MoM). Simulation results of return loss and transmission responses of these filters, together with their corresponding structures, are shown in Fig. 2-5 respectively.

Results show that, the resulting bandpass filters possess good performance responses. Using a substrate, with prescribed parameters, the simulated 3rd iteration bandpass filter structure has been found to possess a compact structure. The overall side length of this structure is of 7.6 mm, with a trace width of about 0.18 mm, while an accepted coupling has been satisfied with coupling spacing of about 0.15 mm. As can be seen, all of the filter responses show a two transmission zeros symmetrically located around the design frequency. Fig. 6 shows the current density pattern, using the IE3D EM simulator for 3rd iteration dual-mode microstrip bandpass filter at the design frequency. It is clear from this figure that, at the design frequency the two degenerate modes are excited and coupled to each other leading to the required filter performance.

V. Conclusion

In this paper, a novel miniaturized fractal bandpass filter structure has been presented as a result of a new technique for dual-mode microstrip bandpass filter design. In this technique, the dual-mode bandpass filter structure has been generated based on the 3rd iteration Minkowski-like pre-fractal geometry and using the conventional dual-mode square ring resonator as an initiator. Up to the 3rd iteration, microstrip bandpass filter structures have been designed, according to this technique, and analyzed using the method of moments (MoM), at the ISM frequency band. Results showed that, these filters possess a progressive size reduction with reasonable return loss and transmission responses.
Fig. 4. Performance responses of the bandpass filter based on the 2nd iteration.

Fig. 5. Performance responses of the bandpass filter based on the 3rd iteration.

It has been found that the presented filter design offers a size reduction of about 72% as compared with the conventional dual-mode microstrip square ring resonator under the same design specifications.

Consequently, the proposed technique can be generalized as a flexible design tool for compact microstrip bandpass filters for a wide variety of wireless communication systems. It is expected that, more size reduction of about 78% can be gained for the filter structure corresponding to the 4th iteration of the prescribed fractal generation process, if there are no practical limitations.

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REFERENCES


