A New Tunable Dual-mode Bandpass Filter Design Based on Fractally Slotted Microstrip Patch Resonator

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Abstract — A dual-mode slotted microstrip patch resonator is introduced in this paper for use in wireless communication applications. The slot structure, etched inside the patch resonator, is in the form of the 2nd iteration Koch fractal curve; using the conventional square microstrip patch resonator as the initiator. Modeling and performance evaluation of the proposed filter design have been carried out using a method of moment based EM simulator, IE3D. Simulation results show that the resulting resonator filter has good transmission and return loss responses. The modeled resonator has been found to possess a side length of about 0.22 the guided wavelength, which represents a size reduction of about 81% as compared with that based on the conventional square microstrip patch without slot. In addition, slits have been symmetrically etched in the external edges of the patch structure, in an attempt to provide the resonator with tuning facility. Besides the tuning possibility, these slits have been found to offer further size reduction without worsening the resulting filter performance; providing the designer with more degrees of freedom.

1. INTRODUCTION

Among the earliest predictions of the use of fractals in the design and fabrication of filters is that of Yordanov et al. [1]. Their predictions are based on their investigation of Cantor fractal geometry. Since then, dramatic developments in wireless communication systems have presented new challenges to design and produce high-quality miniaturized components. These challenges stimulate microwave circuits and antennas designers to seek out for solutions by investigating different fractal geometries [2–6]. 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 [2]. Sierpinski fractal geometry has been used in the implementation of a complementary split ring resonator [3]. Split ring geometry using square Sierpinski fractal curves has been proposed to reduce the resonant frequency of the structure and achieve improved frequency selectivity in the resonator performance. Koch fractal shape is applied to mm-wave microstrip bandpass 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 [4]. Based on Peano fractal geometry, a miniaturized multi-resonator bandpass filter with 2nd harmonic reduction has been reported in [7]. Minkowski type fractal geometry has been successfully used in producing high performance miniaturized dual-mode microstrip bandpass filters [8, 9].

In this paper, a new dual mode slot microstrip square patch resonator bandpass filter is presented. The slot has a square structure with its four edges have been modified by applying Koch pre-fractal curve to each of them. This produces successive miniaturized design structures for the dual-mode microstrip bandpass filters as compared with those based on the conventional square patch microstrip resonator. The resulting bandpass filters are supposed to have noticeably miniaturized sizes with adequate reflection and transmission responses. In addition, the proposed bandpass filter can be further miniaturized by inserting slits in the resonator outer structure. These slits have the role of tuning besides miniaturization.

2. THE PROPOSED FILTER CONFIGURATION

The proposed microstrip dual mode bandpass filter configuration consists of a square microstrip patch resonator. A square slot structure has been etched in the patch such that the patch and the slot are co-centered. The edges of the slot have been modified to be in the shape of Koch fractal geometry with different iteration levels. To demonstrate the fractal generation process of the slot structure, the first two iterations are shown in Figure 1. The starting pattern, Figure 1(a), is Euclidean since the slot has the initial square shape. The process of replacing the slot edges with the first and second iteration Koch pre-fractal geometries are shown in Figures 1(b) and 1(c) respectively. 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:

\[ P_n = \left(\frac{4}{3}\right)^n P_{n-1} \]  

where \( P_n \) is the perimeter of the \( n \)th iteration pre-fractal structure. Theoretically, as \( n \) goes to infinity the perimeter goes to infinity. The ability of the resulting structure to increase its perimeter in the successive iterations was found very triggering for examining its size reduction capability as a microstrip bandpass filter.

In practice, shape modification of the resulting structures in Figures 1(b) and 1(c) is a way to increase the surface current path length compared with that of the conventional square patch resonator; resulting in a reduced resonant frequency or a reduced resonator size, if the design frequency is to be maintained. It is expected then, that higher iterations 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 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 resonators [10, 11]. The length of the conventional microstrip dual-mode square microstrip patch resonator has been determined using the classical design equations reported in the literature [10] for a specified operating frequency and given substrate properties. This length is slightly less than half the quarter guided wavelength at its fundamental resonant frequency in the resonator.

3. THE PROPOSED FILTER DESIGN

A dual-mode microstrip patch bandpass filter with the patch has the slot structure corresponding to the 2nd iteration Koch pre-fractal geometry, Figure 1(c), has been designed for the ISM band applications at 2.4 GHz. The modeled filter is shown in Figure 2(a). The filter structure has been supposed to be etched using a substrate with a relative dielectric constant of 10.8 and thickness of 1.27 mm. The input/output ports have a 50 Ω characteristic impedance.

A small perturbation has been applied to each dual-mode resonator at a location that is assumed at a 45° offset from its two orthogonal modes. The dimensions of the perturbation of the modeled
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 [12, 13]. A second filter, similar to that depicted in Figure 1(a), has been also modeled with slits inserted in the outer edges of the resonator as shown in Figure 2(b).

4. PERFORMANCE EVALUATION
Filter structures, depicted in Figures 2(a) and 2(b), have been modeled and analyzed at the design frequency, using the commercially available EM simulator, IE3D [14]. This simulator performs electromagnetic analysis using the method of moments (MoM). The resonator side length is equal to 10.18 mm, which represents about 0.22 the guided wavelength. On another word, this represents a size reduction of about 81% as compared with the conventional square patch resonator. The corresponding simulation results of return loss and transmission responses of these filters are shown in Figure 3. It is implied that the resulting pre-fractal based resonator bandpass filters offer adequate performance curves. As can be seen, the filter responses show two transmission zeros symmetrically located around the design frequency. However, these responses and their consequent poles and zeros could be, to a certain extent, controlled through the variation of the perturbation dimensions and/or the input/output coupling used. As shown in Figure 3(b), the inserted slits can be used to gain further miniaturization or to provide provides the designer with a practically useful means to tune the resulting filter response to the specified design frequency.

5. CONCLUSION
A Koch fractal based slotted patch resonator filter design has been presented in this paper, as a new technique for miniaturization of microstrip bandpass filter based on the dual-mode square patch resonator. The presented filter patch resonator has a square slot, with its edges in the form of 2nd iteration Koch pre-fractal geometry, is designed and its performance has been analyzed using the method of moments (MoM) at the ISM band. Simulation results show that this filter possesses reasonable return loss and transmission performance responses and offers size reduction of about 81% as compared with the conventional microstrip square patch bandpass filter. The filter with slits provides a tuning feature or can be used for further miniaturization. As the practical fabrication tolerances may permit, it is expected that the higher iterations based filter structures will offer further size reductions. The proposed technique can be generalized, as a flexible design tool, for compact microstrip bandpass filters for a wide variety of wireless communication systems.

REFERENCES


