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An Extra Reduced Size Dual-mode Bandpass Filter for Wireless Communication Systems

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Abstract—A new miniaturized dual-mode microstrip bandpass filter is presented. The filter structure has been fractally generated based on the 4th iteration Minkowski-like pre-fractal geometry, using the conventional dual-mode square ring resonator as the initiator in the fractal generation process. It has been found that the presented filter possesses a size reduction of about 88% as compared with the dual-mode bandpass filter based on the conventional square ring resonator. In addition; simulation results show that the filter has acceptable return loss and transmission responses besides the miniaturized size gained.

1. INTRODUCTION
Dual-mode resonators have been characterized by many advantages such as small size, light weight, and low loss, making them widely used in realization of microwave filters for wireless communication systems, such as satellite and mobile communication systems. Each dual-mode resonator can be used as a doubly tuned resonant circuit, and therefore the number of resonators required for an N-order filter is reduced by half, resulting in a compact filter configuration. Microstrip dual-mode resonator filters have been first introduced in 1972 [1]. Since then, different configurations for the dual-mode resonators have been reported [2–9]. Numerous techniques have been proposed in order to reduce the size of the dual-mode resonator bandpass filters. These involve the use of meander resonators [2, 3], slotted patch [4, 5], stepped impedance resonators [6, 7], and many others [8, 9].

Fractal curves are characterized by a unique property that, after an infinite number of iterations, their length becomes infinite although the entire curve fits into the finite area. This space-filling property can be exploited for the miniaturization of microstrip resonators. Due to the technology limitations fractal curves are not physically realizable. Pre-fractals, fractal curves with finite order, are used instead [10]. Various fractal geometries have been applied to realize compact size bandpass filters [10–16]. Most of the published works concentrates on the application of different fractal geometries to construct single-mode resonator filters [10–15]. Furthermore, it has been reported that microstrip bandpass filters with fractal shaped dual-mode resonators can be realized [16]. Results show that these filters possess considerable size reductions as compared with the one based on the conventional dual-mode square ring resonator.

In this paper, a new dual-mode microstrip bandpass filter based on the 4th iteration Minkowski-like pre-fractal geometry has been presented. The filter is supposed to be suitable for microwave applications as a low cost mass-producible, high performance and compact component.

2. THE FILTER STRUCTURE
The dual-mode filter structure presented in this paper is composed of a single fractally generated microstrip dual-mode ring resonator. The resonator structure is the result of the 4th iteration Minkowski-like pre-fractal geometry. Details of the generation process have been outlined in Figure 1. As in the case of most of the deterministic pre-fractals, the resulting structures, corresponding to the different iteration levels are self-similar and are space-filling. These structures possess an additional property in each of the iteration levels; the symmetry of the whole structure about its diagonal. This property is of special importance in the design of dual-mode loop resonators [8].

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:

\[ P_n = (1 + 2a_2)P_{n-1} \]  \hspace{1cm} (1)

where \( P_n \) is the perimeter of the nth iteration pre-fractal and \( a_2 \) 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 all iterations, 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 literature [8, 9], 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 of the resonator.

As shown in Figure 1, applying geometric transformation of the generating structure (Figure 1(a)) on the square ring resonator (Figure 1(b)), results in the 1st iteration filter structure depicted in (Figure 1(c)). Similarly successive bandpass filter shapes, corresponding to the following iterations can be produced as successive transformations have been applied. Figure 1(f) shows an enlarged copy of the 4th 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 [16]

$$L_n = (0.6)^{n/2}L_0$$

(2)

A large variety of prefractal structures can be produced corresponding to different values of $a_1$ and $a_2$. It is expected, then, that the resulting structures will resonate at different frequencies when $L_o$ is maintained constant. In this paper, the values of $a_1$ and $a_2$ have been chosen to fit with the filter structures reported in [2, 16, 17]; making direct comparison of their performances with that of the presented filter easy.

3. FILTER DESIGN

A bandpass filter structure, based on dual-mode microstrip fractal-shaped resonator, has been designed for the ISM band applications at a design frequency of 2.4 GHz. At first, the side length of the square ring resonator $L_o$, that matches the passband frequency, has to be calculated. It has been found that this length is of about a quarter the guided wavelength. Then the side length, $L_4$, for the 4th iteration fractal-shaped resonator can be calculated based on the value of $L_o$, using (2). Then a small discontinuity (perturbation) is placed in the symmetry axis of the ring. Figure 2 shows the layout of the 4th iteration fractal-shaped dual-mode resonator with the perturbation applied at a location that is assumed at a 45° offset from its two orthogonal modes. The perturbation is in the form of a small patch added to the square ring, and the other subsequent iterations ring resonators. Low passband loss requires strong input/output coupling to the resonator. This is achieved by a narrow gap and a large coupling area that can be provided by the capacitive coupling. The spacing (gap) is very critical parameter: If it is too narrow, matching is insufficient, and fitting the poles to the desired stopband is not possible. On the other hand, if the gap is too wide, the two modes separate from each other so that the filter becomes broadband and the insertion loss in the passband increases dramatically.
It is worth to mention that, the filter structures based on the 1st and 2nd iterations depicted in Figures 1(c) and 1(d), have similar structures with those reported in [2] and [17] respectively. 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. 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. In addition, dual-mode bandpass filter structure, based on a fractal-shaped resonator in the form depicted in Figure 1(e), offers a size reduction of about 79% as reported in [16]. Accordingly, the filter structure, based on the 4th iteration can be considered, up to the author’s knowledge, a novel design. This filter offers further size reduction of about 88% as compared with the conventional dual-mode square ring resonator.

4. PERFORMANCE EVALUATION
A dual-mode microstrip bandpass filter, based on the fractal shape shown in Figure 1(f), has been modeled and analyzed at an operating frequency of 2.4 GHz using a full-wave electromagnetic EM simulator, from Sonnet Software Inc. [18], with a substrate having a thickness of 1.27 mm and a relative dielectric constant of 10.8. The resonator side length that matches the specified frequency has been found to be of about 4.55 mm with a trace width of 0.18 mm. For the present case, it has been found that the modeled filter performs well with a square perturbation patch having a length of about 0.33 mm. The input/output coupling structure is capacitive with an optimum gap of about 0.15 mm. Simulation results show that the resulting bandpass filter exhibits a quasi-elliptic response with two transmission zeros at finite frequencies near the passband as depicted in Figure 3. The filter shows a very good response with a return loss of about $-10$ dB and a fractional bandwidth of about 5% at a frequency of 2.38 GHz.

Figure 4 shows the current density pattern at the surface of the 4th iteration dual-mode microstrip bandpass filter at the design frequency. This figure implies that, at the design frequency the two degenerate modes are excited and coupled to each other leading to the required filter performance. The filter presented in this paper offers a size reduction of about 88% as compared with the conventional dual-mode microstrip square ring resonator, while those filters reported in [2, 16, 17, 19].

5. CONCLUSIONS
An extra reduced size microstrip bandpass filter structure has been presented in this paper, as a result of a new design technique for dual-mode microstrip bandpass filters. A dual-mode bandpass filter structure has been produced based on the 4th iteration Minkowski-like prefractal geometry, using the conventional dual-mode square ring resonator as an initiator. The proposed microstrip bandpass filter design has been modeled and analyzed using a full-wave EM simulator, at the ISM band. This dual-mode filter has been found to possess a size reduction which is better than that
reported in the literatures. It has been found that the presented filter design offers a size reduction of about 88% as compared with the conventional dual-mode microstrip square ring resonator under the same design specifications. The proposed filter can be generalized as a flexible design tool for compact microstrip bandpass filters for a wide variety of wireless communication systems.

REFERENCES