Compact Dual-Band Bandpass Filter Based on Fractal Stub-Loaded Resonator

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Available at: https://works.bepress.com/jawad_ali/83/
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Abstract—Fractal geometries have shown to be a suitable choice for the antenna and microwave circuit designers to produce compact size microwave devices and components. Moreover, the multimode resonators are found advantageous in the design of reduced size multiband bandpass filters. In this paper, a stub loaded resonator (SLR) based on modified Minkowski fractal geometry, is suggested to produce a compact microstrip bandpass filter with dual-band response for wireless communication applications. Based on the second iteration Minkowski fractal geometry, dual-band compact microstrip BPF has been presented. The proposed filter structure is composed of two fractal based symmetrical SLRs. The filter structure has been etched using a substrate with dielectric constant of 3.02 and thickness of 1.425 mm. Simulation results show that the proposed fractal based SLR can be used to construct compact microstrip BPFs with dual-band responses. The lower resonant band is centered at about 1.875 GHz, and the upper resonant band is positioned at 5.575 GHz. The corresponding bandwidths of the two bands extend from 1.841–1.918 GHz and 5.438–5.650 GHz respectively. Besides the compact size, the suggested filter offers reasonable performance responses.

1. INTRODUCTION

The dramatic evolution in modern multi-service communication systems has imposed additional challenges on these systems to be compact and with multiband responses. In this respect, Multiband filters can be implemented by cascading many pairs of microstrip resonators [1, 2]. However, the resulting BPF will be of a relatively large circuit size. A dual-plane microstrip/defect ground structure (DGS) was used to design dual-band and triple-band filters [3, 4]. Many techniques are adopted to design compact multiband BPFs based on the dual-mode and multimode resonators. Dual-mode resonators are planar microstrip structures having two-dimensional symmetry, and a perturbation has been added to couple the two degenerative modes they support. These modes have the same resonant frequency but orthogonal field distributions [5]. Dual-mode dual-band microstrip BPFs have been successfully designed as reported in [6, 7].

On the other hand, various fractal geometries are characterized by two unique properties which are the space-filling and self-similarity. These properties have opened new and essential approaches for antennas and electronic solutions in the last three decades. Additionally, fractals give another era of optimized design tools, initially utilized effectively in antennas but applicable in a general manner [8]. Furthermore, fractal geometries have been applied to the conventional microstrip resonators which are successfully adopted to design compact microwave microstrip filters and planar circuits. Sierpinski carpet and its variants have been suggested to propose a miniaturized dual-mode bandpass filter derived from the conventional square patch [9, 10]. Besides, fractal geometries such as Hilbert, Moore, and Koch are also suggested to produce compact size bandpass filters [11–16]. Moreover, Peano fractal curve has been effectively applied to the typical resonators to construct high performance miniaturized single-mode and dual-mode bandpass filters [16–19].

Minkowski fractal based microstrip resonators have more attracted microwave filter designers to be successfully applied to produce compact dual-mode microstrip ring resonator BPFs, owing to its high space-filling property [20–24].

In this paper, the design compact multiband microstrip BPFs with fractal based SLR resonators is presented as a candidate for use in GSM and WLAN applications. A modified variant of the Minkowski fractal curve has been applied to produce microstrip SLR resonators of the proposed BPFs. Besides the miniaturized size, the resulting BPFs have been shown to offer reasonable dual-band and multiband responses with high insertion loss in the out of the passbands.

2. THE PROPOSED FILTER CONFIGURATION

The basic idea of the proposed filter design is based on that presented in [25], where a uniform impedance resonator is centrally loaded with an open stub to produce a dual-band BPF. The resulting filter size has been dominantly determined by the length of the uniform impedance resonator.
To achieve filter miniaturization, the length segment of the uniform impedance resonator has been modified to take the shape of 2nd iteration Minkowski fractal geometry depicted in Figure 1(d).

![Figure 1. The first two iteration levels of the Minkowski fractal geometry [24].](image)

Figure 1 displays the formation process of the Minkowski fractal geometry when it is applied to the sides of a square ring structure. The shape modification of the structure depicted in Figures 1(c) and 4(d) is an approach to enhance the surface current path length in comparison with ring resonator having a square shape. For the $n$th iteration, the perimeters of the Minkowski fractal structures shown in Figures 1(c) and (d) can be calculated as [24]:

$$L_n = \left(1 + \frac{2w_2}{L_o}\right) L_{n-1}$$  \hspace{1cm} (1)

where $L_n$ is the length of the $n$th iteration pre-fractal structure, $w_2$ and $L_o$ are as shown in Figure 1. Equation (1) and Figure 1 imply that at particular iteration level, a wide variety of structures with different perimeters can be obtained by varying $w_1$, $w_2$, or both. As a result, more size reduction can be achieved when applying fractal geometries to the typical SLR.

3. THE FILTER DESIGN

The proposed dual-band BPF is composed of a pair of fractal-based stub-loaded resonators. The use of two similar resonators is a way to enhance the coupling of the resonant bands. The open stub is shunted at the midpoint of the fractal based microstrip line. Figure 2 demonstrates the layout of the modeled dual-band filter with two symmetrical SLRs in the form of the 2nd iteration Minkowski fractal geometry. A substrate with dielectric constant of 3.02 and thickness of 1.425 mm is used to model the filter. The input/output ports have a characteristic impedance of 50 Ω; this corresponds to a transmission line width, $w_f$, of about 2.75 mm. The proposed filter is modeled, and its performance has to be evaluated using the commercially available EM simulator, IE3D, which performs electromagnetic analysis using the method of moments (MoM).

Since the proposed filter is symmetrical in structure, odd and even-mode analyses can be applied to characterize it. The fractal based resonator is shown in Figure 3(a). The odd-mode and the even-mode equivalent circuits of the proposed filter structure are shown in Figures 3(b) and (c).

![Figure 2. The modeled structure of the proposed dual-band fractal-based SLR BPF.](image)

![Figure 3. The proposed fractal-based SLR structure: (a) a schematic view, (b) odd-mode equivalent circuit and (c) even-mode equivalent circuit.](image)

At resonance, $Y_{\text{in-odd}} = 0$ and $Y_{\text{in-even}} = 0$; then the odd-mode and even-mode resonant frequen-
cies are given by (2) and (3) respectively [25]:

\[ f_{\text{odd}} = \frac{(2n - 1)c}{L_2 \sqrt{\varepsilon_{re}}} \]  

(2)

\[ f_{\text{even}} = \frac{nc}{(L_2/2 + 2L_s) \sqrt{\varepsilon_{re}}} \]  

(3)

where \( n = 1, 2, 3, \ldots \), \( c \) is the speed of light in free space, and \( \varepsilon_{re} \) is the relative dielectric constant of the substrate. The length \( L_2 \) is half the perimeter of the 2nd iteration Minkowski fractal as calculated by (1) in terms of the resonator side length \( L_{rs} \).

At the design frequency of 1.85 GHz, it has been found that the modeled BPF has the dimensions summarized in Table 1 with the parameters as labeled in Figure 3. Since the resonator is with uniform impedance, then (2) and (3) are valid for the determination of the odd-mode and the even-mode frequencies. At first, it is planned to design a dual-band BPF taking into consideration the effect of the open stub length as applied in (2) and (3) Providentially; it has been found that the modeled filter possesses a dual-band performance even with small values of \( L_s \). According to (3), the small dip at about 3.55 GHz is attributed by \( L_s \). For larger values of \( L_s \), the evolution of third resonant band has taken place. Higher resonator harmonics, a nightmare for single mode resonator design, are a useful tool in multiband component design [26].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( L_{rs} )</th>
<th>( w_r )</th>
<th>( L_s )</th>
<th>( w_s )</th>
<th>( w_f )</th>
<th>( s_g )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (mm)</td>
<td>16.18</td>
<td>0.81</td>
<td>1.34</td>
<td>2.70</td>
<td>2.75</td>
<td>0.22</td>
</tr>
</tbody>
</table>

4. THE FILTER PERFORMANCE EVALUATION

The filter performance has been evaluated through a frequency swept range from 1–6 GHz. Figure 4 demonstrates the input reflection coefficient and the transmission responses of the modeled filter. The results of Figure 4 imply that the filter possesses a dual-band response. The first resonant band is centered at about 1.875 GHz, and the upper resonant band is positioned at 5.575 GHz. The corresponding bandwidths of the two bands extend from 1.841–1.918 GHz and 5.438–5.650 GHz respectively. These bands are suitable for GSM and WLAN applications.

![Figure 4](image-url)

Figure 4. The simulated scattering coefficients of the modeled dual-band filter structure depicted in Figure 3.

![Figure 5](image-url)

Figure 5. The simulated current distributions on the surface of the modeled dual-band BPF structure illustrated in Figure 3; (a) and (c) at the centers of the passbands and (b) at the out of the passbands.
On the other hand, the current distributions at the surface of the modeled filter are shown in Figure 5 at the center of the passbands and outside the passbands. The results imply that there is no signal to pass through the filter at 3.550 GHz. At the passbands, 1.875 GHz and 5.575 GHz, it is clear that the effective length exiting the second resonant band is larger than that excited the lower resonant band.

5. CONCLUSIONS

A modified Minkowski fractal based SLR loaded with an open stub resonator presented in this paper has proved its validity to design compact dual-band microstrip BPF. In addition to the reasonable performance of the proposed filter, the application of Minkowski fractal based SLRs results in filter structures with more size reduction as compared with those reported in the literature. The proposed filter offers two resonant bands with bandwidths suitable for GSM and WLAN applications extending from 1.841 to 1.918 GHz and from 5.438 to 5.650 GHz respectively. Based on the proposed filter structure, further investigation is to be carried out to explore the possibility to excite a third resonant band created by the open stub resonator. It is hopeful to fabricate the presented BPF model in this paper to justify the validity of the proposed design. It is planned to apply higher fractal iteration levels to design SLR based microstrip BPFs with further miniaturization.

REFERENCES


