Design of a Triple-band Fractal-based BPF with Asymmetrical SLR Structures

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Abstract- The use of asymmetrical structures has been verified in the design BPF dual-band and multiband responses. On the other hand, fractal geometry has been successfully applied to design compact BPFs. Based on these concepts, a triple-band Minkowski fractal based BPF is presented in this paper. The structure of the proposed filter is composed of two different stub-loaded fractal-based resonators that are capacitively coupled to a microstrip transmission line. The two resonators are with the same fractal iteration order, but one of the resonators is a closed variant of the other resonator. The open fractal SLR resonator will excite the dual-band response while the close SLR resonator will produce its own resonant band. Each resonator can perform individually, and the resulting filter response is the combination of their responses. The current distribution analyses at the surface of the filter, at different frequencies, are used to justify the resulting performance. The dimensions of the proposed filter are found lower than those produced using other techniques in terms of the design guided wavelengths.

1. INTRODUCTION
Dual-band and multiband bandpass filters have found newly increased application to address the requirements of the ever developing communication and wireless services. The designers have to conduct much work to meet the challenges. For this, different design approaches have been suggested. Among the proposed design techniques to produce compact dualband and multiband bandpass filters, is the use of the stepped-impedance resonators. These filter configurations provide dual-mode and triple-mode resonant behavior. Such resonators were first introduced to design BPFs in (Zhu et al., 2000). Many SLR based BPF structures with comparable performance have been presented in (Mondal and Mondal, 2008; Virdee et al., 2011; Babu et al., 2011; He et al., 2008). These structures consist of ring-shaped SLRs, but they adopt different schemes to provide transmission zeros. To improve the selectivity of the resonant bands, BPFs with asymmetric SIR resonators have been proposed (Zhang et al., 2009; Yin et al., 2010; Chen et al., 2012; Chu et al., 2013; Lan et al., 2015).

On the other hand, the size miniaturization of the BPFs can be further improved through the application of various fractal geometries. In this sequence, based on fractal geometries, such as Sierpinski, Hilbert, Moore, and Koch have also been adopted to design miniaturized bandpass filters (Weng et al., 2009; Mezaal et al., 2014; Mezaal et al., 2015; Li et al., 2012). Peano fractal geometries have been successfully applied to the conventional resonators to produce high performance miniaturized single mode and dual-mode microstrip bandpass filters (Ali and Miz’el, 2009; Ali et al., 2012; Mezaal et al., 2013). The large space-filling property of this fractal geometry makes it an attractive choice to design bandpass filters with high size reduction levels. Minkowski fractal based microstrip resonators have more attracted microwave filter designers to be successfully applied to produce compact dual-mode microstrip ring resonator BPFs, because of the relatively high space-filling property it possesses (Ali, 2008; Ali and Hussain, 2011; Ali et al., 2012; Ali et al., 2016; Ahmed et al., 2015).
In this paper, a triple-band BPF design based on fractal asymmetric SIR has been proposed to construct a compact and selective filter for the use in multi-service wireless applications.

2. THE PROPOSED FILTER STRUCTURE

The triple-band Minkowski fractal based bandpass filter presented in this paper relies originally on the resonator reported in (Ziboon and Ali, 2017). The structure of the proposed filter is shown in Figure 1, where it is composed of two different resonators. It has been verified that the use of asymmetrical structures in the BPF design is a way to make it capable of producing dual-band and multiband (Zhang et al., 2009). The lower resonator structure is the same as that used in the filter in (Ziboon and Ali, 2017). The second resonator structure is a closed variant of the same resonator. The idea of the excitation of the triple resonant band response is as follows; the open fractal SLR resonator will excite the dual-band response while the close SLR resonator will produce its own resonant band. Each resonator can perform individually, and the resulting filter response is the combination of their responses.

Figure 1: The structure of the proposed triple-band fractal-based BPF with asymmetrical SLR structures.

3. DESIGN AND PERFORMANCE ASSESSMENT OF THE PROPOSED FILTER

A substrate with dielectric constant of 3.02 and thickness of 1.425 mm is used to model the filter depicted in Figure 1. The input/output ports have a characteristic impedance of 50 Ω; this corresponds to a transmission line width, $w_t$, 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). The first resonant frequency, $f_1$, is centered at about 1.890 GHz and, the upper resonant frequency, $f_2$, is positioned at 5.389 GHz. At the design frequency of 1.85 GHz, it has been found that the modeled BPF has the dimensions summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$L_{rs}$</th>
<th>$w_1$</th>
<th>$L_s$</th>
<th>$w_s$</th>
<th>$w_f$</th>
<th>$s_b$</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>

To provide better justification for the proposed design idea of the BPF with asymmetrical SLR structures, each of the resonators has been modeled alone, and the individual performance responses are evaluated. Figure 2 illustrates the performance responses of lower SLR of the modeled triple-band BPF. It is apparent that the
resonator offers a dual-band response as reported in (Ziboon and Ali, 2017).

![Figure 2](image2.png)

Figure 2: The simulated scattering coefficients of the modeled lower resonator of the triple-band BPF structure.

On the other hand, Figure 3 shows the performance responses the proposed BPF when the upper resonator exists alone. The simulated scattering coefficients imply that the upper resonator offers a single resonant frequency, $f_1$, located at 3.30 GHz. It is clear that the resulting response has low selectivity.

![Figure 3](image3.png)

Figure 3: The simulated scattering coefficients of the modeled upper resonator of the triple-band BPF structure.

The resulting triple-band BPF performance responses are shown in Figure 4. The results reveal that the filter possesses three resonant bands located at 1.890 GHz, 3.300 GHz, and 5.382 GHz. It is clear that the positions of the three resonant bands are very slightly deviated as compared with those presented in Figures 2 and 3. Furthermore, the corresponding bandwidths become more selective than those excited by the individual resonators, if each one performs alone.
The justification of the difference between $f_0$ and $f_1$, despite the two resonators have the same side length and width, can be interpreted as follows. The generation techniques of the two bands are different. In this context, the resonance at $f_0$ is excited according to the stepped impedance resonator technique which results in filter structure with a compact structure, or with the lower resonant band, if the resonator size is maintained unchanged. In this case, the lower resonant frequency is determined by the resonator impedance ratio and its dimensions as implied by Figure 5 which shows the odd-mode and even-mode equivalent circuits when the lower resonator performs alone. Furthermore, more insight is demonstrated in Figure 6.

On the other hand, the resonance at $f_1$ is attributed to the conventional ring resonator, and consequently, its resonant frequency can be determined by the perimeter of the whole ring.
The results of Figures 2-4 can be justified with the aid of the current distribution on the surface of the modeled triple-band shown in Figure 6. The simulated current distributions on the surface of the modeled fractal based triple-band BPF structure are demonstrated in Figure 6. The surface current distributions shown in Figures 6(a) and (c) confirm again that 1st and the 3rd resonant frequencies, $f_1$ and $f_2$ located at 1.890 GHz and 5.382 GHz respectively, are attributed to the lower SLR alone. Similarly, the surface current distributions, shown in Figure 6(b), verify that the excitation of the 2nd resonant frequency, $f_1$, positioned at 3.300 GHz, is attributed to the upper SLR. On the other hand, it is clear that there is no signal passes through each of the SLRs at the selected frequencies in the rejection band as shown in Figures 6(d), (e), and (f).

![Current Distributions](image)

Figure 6. The simulated current distributions on the surface of the proposed BPF structure at; (a) the centers of the passbands and (b) the out of the passbands

4. CONCLUSION
A New compact microstrip BPF with triple-band responses is suggested in this paper. The design methodology adopted to design the proposed filter is to apply both the SIR approach together with the fractal geometry on the conventional open ring resonator. Inspection of the resulting responses of the modeled filters leads to interesting findings. Besides the achieved size miniaturization and the triple-band response, it is possible to tune the resonant bands independently. The current distribution analyses at the surface of the filter, at different frequencies, are used to justify the resulting performance. The dimensions of the proposed filter are found lower than those produced using other techniques in terms of the design guided wavelengths.
REFERENCES


