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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 study. 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.

Key words: Asymmetrical, design, fractal geometry, capacitively, wavelengths, dimensions

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 research to meet the challenges. For this, different design approaches have been suggested. Among the proposed design techniques to produce compact dualband band 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 by Zhu *et al.* (2000). Many SLR based BPF structures with comparable performance have been presented by Mondal and Mandal (2008), Virdee *et al.* (2011), Babu *et al.* (2011) and 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 and Li, 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.*, 2012a, b; 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.*, 2012a, b; Ali and Ziboon., 2010; Hayder *et al.*, 2015).

In this study, 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.

MATERIALS AND METHODS

The proposed filter structure: The triple-band Minkowski fractal based bandpass filter presented in this study relies originally on the resonator reported by Ziboon and Ali (2017). The structure of the proposed filter is shown in Fig. 1 where it is composed of two different resonators.

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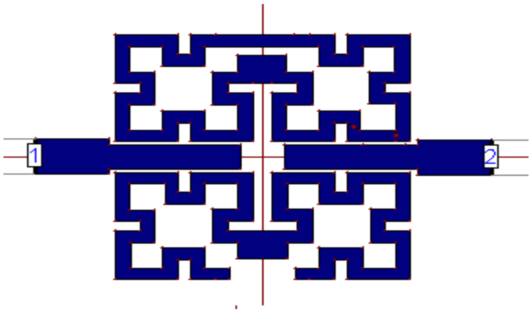

Fig. 1: The structure of the proposed triple-band fractal-based BPF with asymmetrical SLR structures

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 by 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.

RESULTS AND DISCUSSION

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 Fig. 1. 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). The first resonant frequency, f_0 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.

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 by Ziboon and Ali (2017).

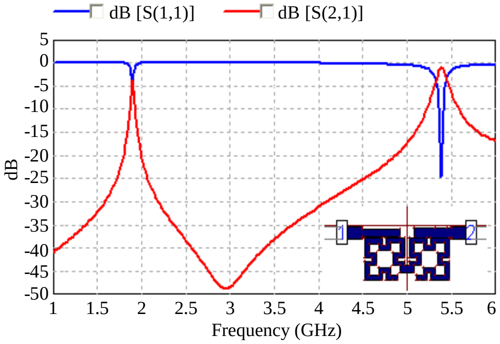

Fig. 2: The simulated scattering coefficients of the modeled lower resonator of the triple-band BPF structure

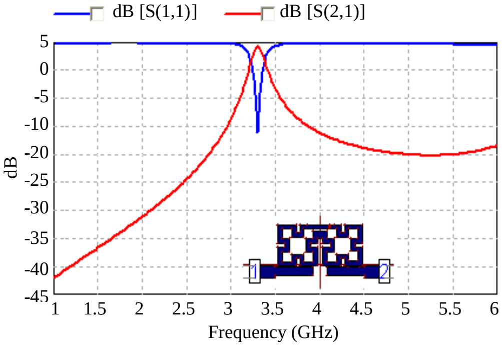

Fig. 3: The simulated scattering coefficients of the modeled upper resonator of the triple-band BPF structure

Table 1: Summary of the dimensions of the modeled filters in mm

Parameters	Dimensions (mm)
L_{rs}	16.18
w_r	0.81
L_s	1.34
w_s	2.70
w_f	2.75
s_g	0.22

On the other hand, Fig. 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.

The resulting triple-band BPF performance responses are shown in Fig. 4. The results reveal that the filter possesses three resonant bands located at 1.890, 3.300 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 Fig. 2 and 3. Furthermore, the corresponding bandwidths become more selective than those excited by the individual resonators, if each one performs alone.

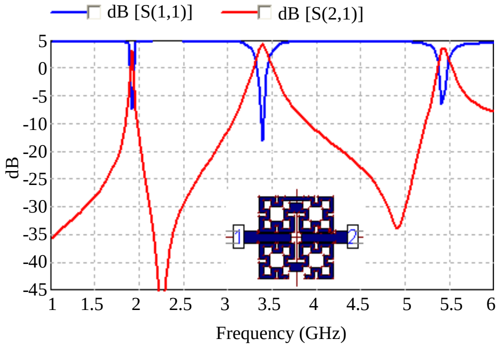

Fig. 4: The simulated scattering coefficients of the modeled triple-band BPF structure

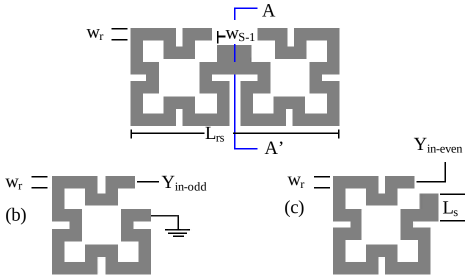

Fig. 5: The modeled BPF when the lower resonator alone: a) A schematic view; b) Odd-mode equivalent circuit and c) Even-mode equivalent circuit

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 Fig. 5 which shows the odd-mode and even-mode equivalent circuits when the lower resonator performs alone. Furthermore, more insight is demonstrated in Fig. 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 Fig. 2-4 can be justified with the aid of the current distribution on the surface of the modeled triple-band shown in Fig. 6. The simulated current distributions on the surface of the modeled fractal based triple-band BPF structure are demonstrated in Fig. 6. The surface current distributions shown in Fig. 6a and confirm again that 1st and the 3rd resonant frequencies, f_0 and f_2 located at 1.890 and 5.382 GHz, respectively are attributed to the lower SLR alone. Similarly, the surface current distributions, shown in Fig. 6b, 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 Fig. 6d-f.

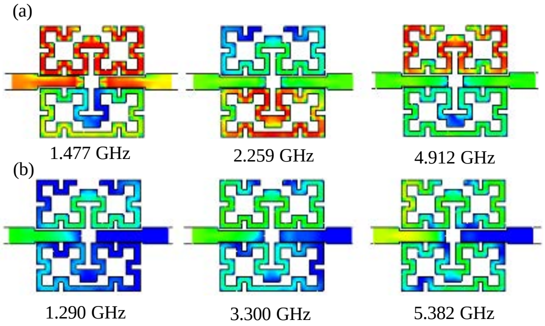

Fig. 6: The simulated current distributions on the surface of the proposed BPF structure at: a) the centers of passbands and b) the out of the passbands

CONCLUSION

A new compact microstrip BPF with triple-band responses is suggested in this study. 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.

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