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Design of Compact Multiband Microstrip BPF Based on Fractal Open-Ring Configuration

Abstract- *Multiband bandpass filters (BPFs) are one of the core elements in the multi-services wireless communication systems. For this purpose, this paper presents a design of a compact multiband microstrip BPF design based on fractal open loop configuration. The proposed filter structure is composed of an array of equal side length open-loop resonators; each with different fractal iteration level. More specifically, the modified Minkowski fractal geometry has been adopted to be applied to the conventional open-loop rectangular resonator. The resulting filter configuration has an array of different open-loop structures corresponding to various iteration levels. The simulation of the presented filter is performed using the EM Sonnet software package environment. The proposed filter is printed on a substrate of dielectric constant is 10.8 with thickness 1.27 mm. A filter structure with three resonators having different fractal iteration levels offers a triple band frequency response around 3.05 GHz, 2.05 GHz, and 1.68 GHz. Each of the three resonant bands is attributed by a distinct resonator according to the iteration levels. Additional resonant bands can be realized using extra loops with higher iteration levels.*

Keywords- *BPF- Multiband - Open Ring- Fractal*

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1. Introduction

In the last century, different development scenarios in communication technologies have been taken place rapidly. However, keeping up the urgent design requirements for multi-applications devices are still not satisfied yet; therefore, several research societies started to concentrate their work in the field of designing multi-band pass filters, multi band stop filters and multi band antennas [1-9]. For example in [1-3], different stepped impedance resonators were used to design triple band pass filters at various frequency bands. Another triple band pass filter was developed by structuring half wave lines coupled in anti-parallel directions [4]. In [5], a fractal geometry was applied to overcome the traditional challenges including enhancing the bandwidth and size reduction [5]. Other types of fractal geometries, Minkowski-Like and Peano, with different iterations and lengths applied to open loops resonators were proposed to design multiband stop filters in [6-8]. Lately, in [9], a triple band antenna by using three Minkowski-like fractal geometry patches of different iterations was developed to attribute three-frequency bands.In this paper, a new triple-band bandpass filter, as a candidate for use in wireless communication systems, is presented by adopting fractal geometry on open-loop resonators.

2. Filter Design and Geometrical Details

The suggested filter design based on the 0^{th} iteration, shown in Figure 1, is derived from a conventional Band Pass Filter (BPF) based on a rectangular resonator that was reported in [10]. Where w is feed line width, l is side length of the resonator, while s is middle gap's length. Minkowski-Like fractal geometry is shown in Figure 2 was reported in [11], is applied to obtain open-loop resonators of different levels. The proposed BPF consists of three resonators with different Minkowski-Like fractal levels; each resonator produces one band since due to the different perimeter that provides an increase in the current path to result in a size reduction. The perimeter L_n and center frequency f_n of each open loop resonator before and after applying fractal geometry with w_1 = 1/3 l can be determined by using the following equations [7]:

$$\mathcal{L}_n = (4 \times l - s)\left(\frac{27.4058+n}{18.35}\right)^n for\ (0 \leq n < 3) \ldots (1)$$

$$\therefore f_n = \frac{c}{1.578\left(\frac{7.2276}{6.6+n}\right)^n \mathcal{L}_n \sqrt{\varepsilon_{re}}}\ for\ (0 \leq n < 3) \ldots (2)$$

where n is the level of iteration, ε_{re} is the effective dielectric constant of the substrate. The format of BPF with applying 1^{st} Minkowski-Like fractal geometry on the open loop resonator is shown in Figure 3.

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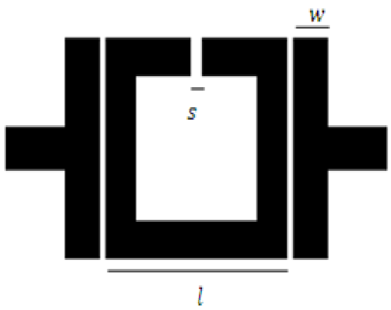

Figure 1: The Configuration of the first stage of suggested BPF

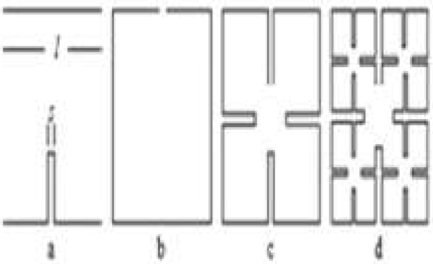

Figure 2: The steps of growth of Minkowski-Like fractal geometry: (a) the generator, (b) the square ring, (c) the 1st iteration, and (d) the 2nd iteration[11].

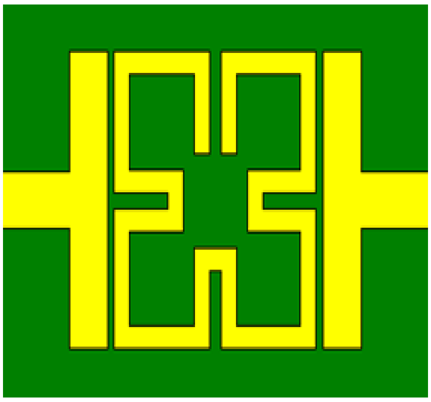

Figure 3: The open loop coupled BPF configuration after applying 1stMinkowski-Like fractal geometry.

3. The Triple-Band Bandpass Filter Response

The proposed triple band band-pass filter passing through seven steps to reach to the final configuration, in all these steps the same substrate with the dielectric constant 10.8 and thickness equal to 1.27 mm have been used. To get more matches with input/output port 50 ohms, the feeding transmission line with width w = 1.15 mm has been used. The other parameters l, s, and w_1 are chosen to be 6mm, 0.4mm, and 2 mm respectively. To evaluate the filter, the commercial EM sonnet simulator that is depending on MOM (Moment of Method) is used. All the resonators have same dimensions 6×6 mm^2, to show the effect of applying pre-fractal geometry. The first three steps designed three single band-pass filters by using single resonator with applying Minkowski-Like fractal geometry with different iteration levels starting from 0th, 1st, and 2nd iteration in each filter. The S-parameter response of the three single band BPFs is shown in Figure 4. From S_{11} response, it is clear that the center centers frequencies were at 3.04 GHz, 2.04 GHz, and 1.62 GHz for single band BPF with square open-loop resonator, SB-BPF with 1st iteration fractal resonator, and SB-BPF with 2nd iteration fractal resonator, respectively. To inquire the multi-band principle, three dual bands BPFs consisting of two resonators by applying fractal geometry with different iterations is designed. Figure 5 shows the S-Parameter (S_{11} and S_{21}) of DB-BPFs. From Figure 5 (a), the band at lower center frequency produced by high iteration level resonators while lower iteration level resonators resulted in the band at the upper center frequency in the same structure. The primary and expected form of triple band BPF combine from three resonators by applying Minkowski-Like fractal geometry with different iteration only, but this configuration didn't have appropriate frequency response; therefore the open stub as shown in Figure 6 is used. Four symmetry open stubs with dimensions d = 3 mm, and t = 0.2 mm are to be added between the adjacent resonators to increase the coupling [12, and 13], where d and t are the dimensions of open stub as depicted in Figure 6. The final structure and S-Parameter response of triple band BPF is shown in Figures 7 and 8, respectively. The bands of triple band BPF centered at 1.6 GHz, 2.04 GHz, and 3.14 GHz, there are slightly change in the center frequency of the upper band of TB-BPF from SB-BPF with a square open-loop resonator that results in from the coupling between the resonators. The surface current distribution had been calculated at the different frequencies to explain the work of BPF. At the center frequencies 1.6 GHz, 2.04 GHz, and 3.14 GHz, the current is found to be maximum at 0th, 1st, 2nd iteration resonators, respectively; that means the signal passes from one port to another at these frequencies and consequently each resonator is responsible for one band only. While the BPF works as a band-stop filter at center frequencies of 1 GHz, 1.8 GHz, and 2.5 GHz since the current is found minimum around the resonator structure. Figure 9 shows the current distributions.

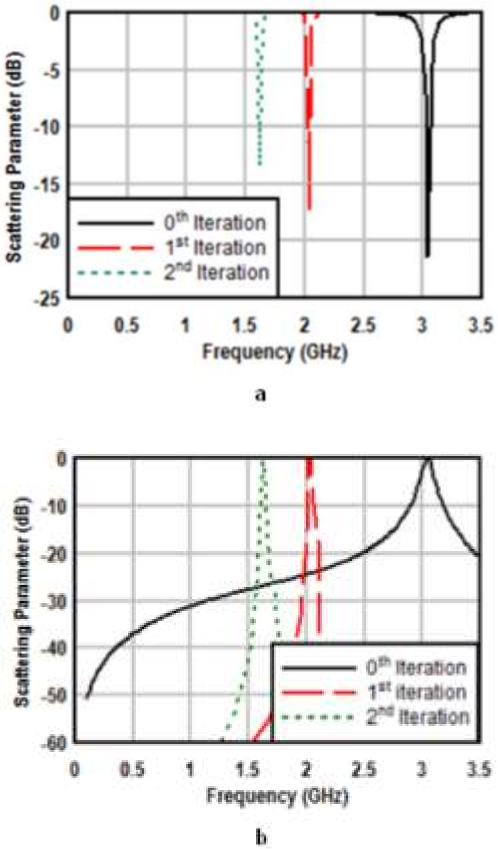

Figure 4: The S-Parameter of single band bandpass Filter; (a) S_{11} and (b) S_{21}.

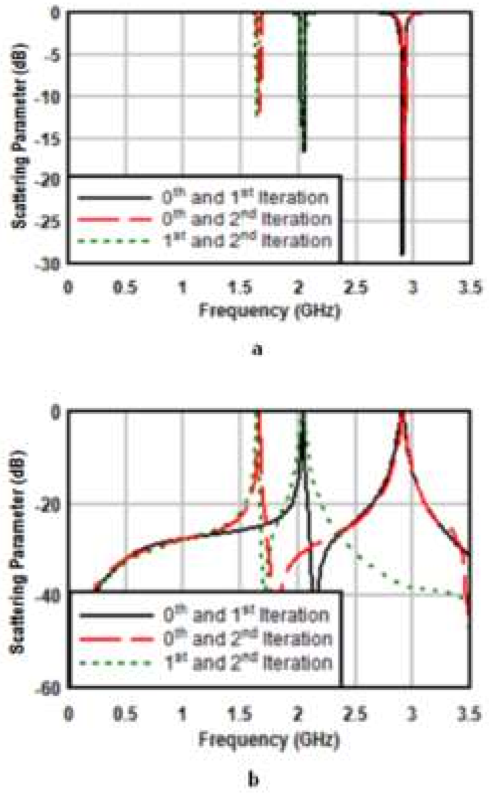

Figure 5: The S-Parameter of dual band band-pass filter, (a) S_{11}, (b) S_{21}.

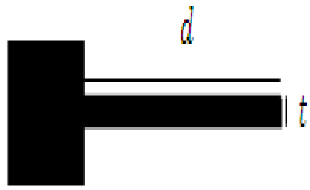

Figure 6: The open stub configuration

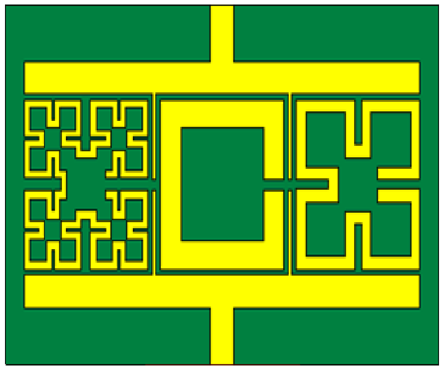

Figure 7: The final format of triple band BPF.

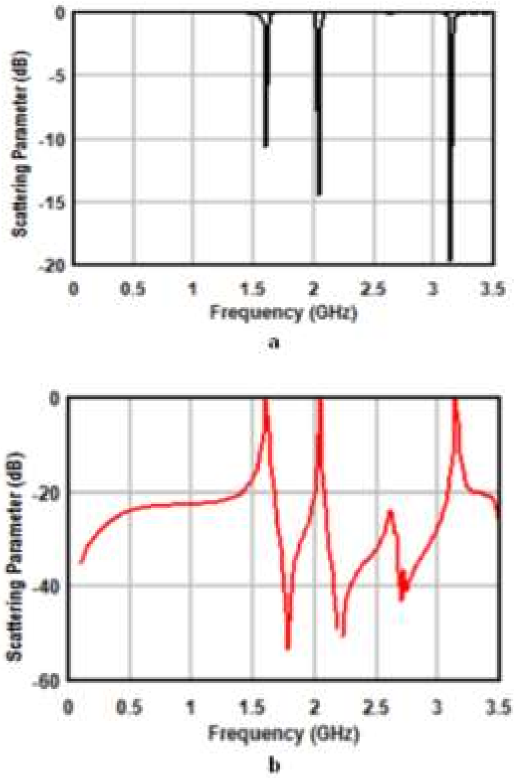

Figure 8: Simulated S-Parameter of triple band band-pass filter, (a) S_{11}, (b) S_{21}.

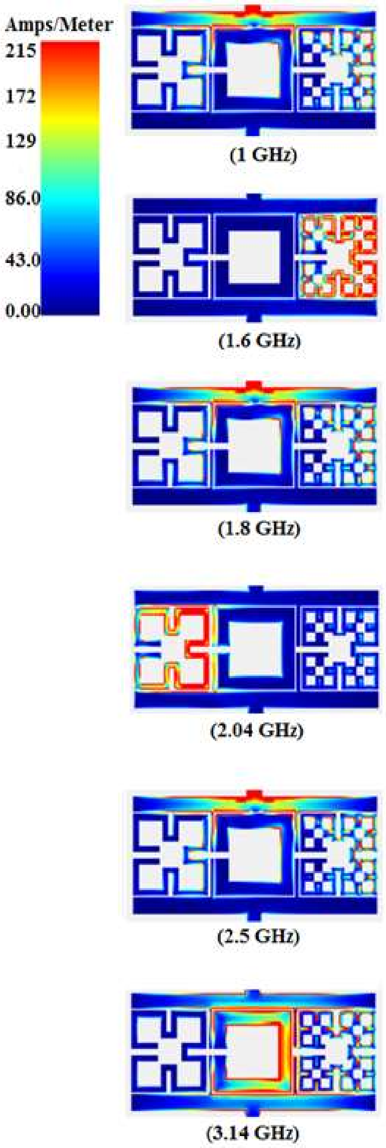

Figure 9: Surface current distribution at different frequencies; the red color means that the current is distributed maximally while the blue color indicated the minimum variation of the current.

4. Conclusion

A triple band band-pass filter is investigated in this paper. The filter configuration consists of three open-loop resonators with applying different iteration levels of Minkowski-Like fractal geometry started from 0^{th} to 2^{nd} iteration, and four symmetrical open stubs between each are implemented adjacently to increase the coupling. The substrate with a dielectric constant 10.8 and thickness 1.27 mm is used to design the proposed filter. The lower band is produced by the higher iteration level resonator while the lower iteration level resonator administrates the upper band. All the evaluated results are performed using commercial EM sonnet simulator.

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