Design of Compact Dual-Mode BPFs Based on Cantor Fractal Geometry with U-Shaped Capacitive Coupling

Abstract- This study displays two microstrip bandpass filters using dual mode loop and patch resonators in form of Cantor geometry. The proposed filters exhibit one and two bands frequency responses for each of them respectively. The microstrip filter using Cantor loop has been tested by AWR 12 software package at resonances of 4.55 and 4.58 GHz, whereas for Cantor dual band patch filter has been simulated at band frequencies of 3.6 and 6.84 GHz respectively. RT/ Duroid 6010 substrate has been adopted for filter designs with thickness and relative permittivity of 1.27 mm and 10.8, respectively. The simulated filters have notable miniaturization and frequency performances that stand for looked-for facets of the contemporary wireless uses.

Keywords- Microstrip filter, Cantor fractal resonator, dual-mode bandpass filter, single and dual band filter responses.

1. Introduction

The wireless access communications system is a speedily growing market. Like these systems, they generally use filters in microwave and mm-wave transceivers as channel dividers. There are rising requests for cheap, low weight and compacted filter devices. To meet these requirements, the progress to get efficient materials and fabrication technologies led to the fast expansion to employ microstrip filters [1,2]. According to the microstrip filter electrical specifications, frequency response for these devices is mainly categorized into Quasi-elliptic, Chebyshev, and Cauer. The first type has dual transmission zeros that explain the rejection band levels, while Chebyshev type filters include ripples in the passband and comprise a steep band levels, while Chebyshev type filters include ripples in the passband and comprise a steep frequency response using microstrip technology. A compacted microstrip BPF based on hexagonal open-loop resonators and an E-shaped stub loading has been reported in [11]. An E-shaped stub loading decreases the high-order mode frequency of the single-mode hexagonal open-loop resonator. The resultant filter has a small size with proper frequency responses. A new BPF using dual-mode hexagonal loop resonator and a step impedance open-end stub perturbation is presented in [12]. The interior angles of the hexagonal geometry of this filter are large in relation to square and rectangle counterparts that leads to superior
smallness in the microstrip circuits. This filter is miniature and straightforward to be fabricated and useful for many wireless systems. Compact BPFs that are based on dual-mode ring resonator have been designed as stated in [13]. The smallness has been achieved by deforming the ring trace to a spiral arrangement. The output frequency results have wide passband with dual degenerate modes. This wide passband feature has been carried out by robust I/O coupling based on an impedance transformer for external quality factor matching with the filter bandwidth. On the other hand, fractal geometries such as Moore, Minkowski, and Peano have been successfully used in the design of compact single band and dual-band microstrip BPFs for various communication applications [14-18]. It is worth to reveal that the Cantor fractal geometry presented in [19] has been successfully utilized in the design of dual-band printed monopole antenna for microwave communication applications. In this paper, condensed microstrip BPFs based on dual-mode resonator have been designed as single and dual-band devices. It uses Cantor fractal resonator as loop and patch EM elements with U shaped I/O feeders. The input reflection coefficient, S11, and the transmission coefficient, S21, for resultant band responses of the proposed devices are sensible. Furthermore, they have narrow band responses that can be functional in wireless systems.

2. The Proposed Filter Design

Theoretically, there is a necessity for microstrip BPF topology to be 2D in design as in Figure 1. The height of the substrate is symbolized as h, the width of microstrip conductor is W, the thickness of the metallic strip is t and L is the microstrip line length. This 2D arrangement involves the above dimensions in a single plane as in the setting of microstrip line width to organize its impedance [2].

Presently, microwave BPFs design typically employs dual-mode resonators. On the other hand, the higher modes have not adequate realistic applications. Currently, loop and patch microstrip resonators [14, 20] have paid attention microwave circuit engineers for manufacturing new filter devices with significant frequency responses. All of them have planar symmetry with different topologies. Figure 2 exemplifies general microstrip dual mode resonators, where D on top of all resonators represents its usual dimension, while \( \lambda_{go} \) is the guided-wavelength at its specified design frequency. A small patch or cut as inducing element is positioned to each resonator at 45° angle from its dual orthogonal I/O ports as illustrated in Figure 2. In this study, Cantor fractal filters based on loop and patch resonators are designed using a dielectric constant of 10.8 and thickness of 1.27 mm and conductor thickness of 35 \( \mu \)m. The guided wavelength (\( \lambda_{go} \)) is evaluated by [14,20]:

\[
\lambda_{go} = \frac{c}{f_0 \sqrt{\varepsilon_{\text{eff}}}}
\]  

(1)

Where c stands for light speed, \( f_0 \) is the fundamental frequency, and \( \varepsilon_{\text{eff}} \) is the effective dielectric constant of the substrate that can be determined from [14,20]:

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \sqrt{1 + \frac{12H}{W}}
\]  

(2)

Where \( \varepsilon_r \) stands for the relative substrate constant, W is the conductor width and H represents the substrate thickness. All the same, \( \varepsilon_{\text{eff}} \) can be roughed to \((\varepsilon_r + 1)/2\) [15]. The designed fractal filters are depicted in Figure 3 and Figure 4 based on loop and patch fractal resonators respectively. The fractal topology is based on 1\textsuperscript{st} iteration of the Cantor fractal geometry [21]. The length of r that can be straightforwardly used to generate Cantor fractal resonator is 1 mm. Therefore, the perimeter of Cantor resonator is (28r). Accordingly, the external length of the Cantor fractal resonators as loop and patch topologies is 9 mm. The side length of the perturbation square patch, (t), is of about 0.3 mm whereas the width (w) of input/output U shaped feeders is 0.7 mm. The spacing between U shaped feeders and Cantor square loop resonator is 0.1 mm. These feeders and perturbation element are used to provide the required electromagnetic coupling for the filter frequency response.

**Figure 1: The microstrip configuration**
The fractal curve of the resonator represents dynamic perturbation outcome to the electromagnetic steadiness of the resonator formation. As a result, the electromagnetic scatterings of the degenerated modes will be no longer orthogonal and joint to each other.

3. Simulation Results

The intended microstrip filters using 1st iteration of Cantor fractal loop resonator have been simulated by the AWR 12 simulator. The first filter structure is depicted in Figure 3. The consequential S11 and S21 responses of the BPF have been illustrated in Figure 5. It is perceptible from this graph that there are dual transmission zeros that correspond to rejection band levels at 4.315 and 5.33 GHz respectively with S21 magnitudes of -66.82 and -104.9 dB. The input reflection coefficient and insertion loss values at center frequency are -19.33 and -0.05 dB respectively. Dual transmission poles at 4.55 and 4.58 GHz in the -3dB passband region are feasibly identified remarkably. Regarding the transmission response, S12, it has the same response as that of S21, since the filter structure is reciprocal. This filter has very small bandwidth response of about 100 MHz that is characteristically a huge objective in wireless systems to cause the filter capable of avoiding the interfering signals working in the neighboring bands. Besides, it has an acceptable return loss and insertion loss magnitudes to be applied in C band wireless systems.

Figure 2: Some microstrip dual-mode resonators

Figure 3: The modeled Cantor fractal loop BPF

Figure 4: The modeled Cantor fractal patch BPF

The simulated current distributions are shown in Figures 9-10 for Cantor square loop BPF at transmission pole resonances of 4.55 and 4.58 GHz, while another current distribution patterns are simulated for dual band frequencies in Figures 11-12 regarding dual band Cantor patch filter. All these results are performed using Sonnet simulator. The uppermost coupling effect is denoted by red color, whereas the least one is apparent by blue color. From Figures 9-12, the current intensity patterns for both designed filters
are symmetrically distributed. The physically powerful current values are concentrated within 45 degree offset from I/O coupling feeders with magnetic intensities of 48 and 27 Amp/meter for Cantor square loop BPF at its pole resonance and 30 and 17 Amp/Meter for Cantor dual band BPF at its band frequencies. Besides, it is identifiable that Cantor square loop BPF exhibits higher magnetic intensities than Cantor dual band BPF.

Figure 5: In-band frequency responses for the projected microstrip filter

Figure 6: The frequency response of the Cantor fractal patch filter

Figure 7: Output S21 and S11 phase responses of Cantor fractal loop BPF

Figure 8: Output S21 and S11 phase responses of the Cantor fractal patch BPF

Figure 9: Current intensity distribution of Cantor square loop BPF at 4.55 GHz pole resonance

Figure 10: Current intensity distribution of Cantor square loop BPF at 4.58 GHz pole resonance

Figure 11: Current intensity distribution of dual band Cantor square patch BPF at 3.6 GHz frequency band
To validate the designed bandpass filters, filter responses have been simulated using Sonnet EM simulator as shown Figures 13-14. These responses are in good agreement with filter responses using AWR 12 EM software package. The side length of Cantor loop and patch resonators are 0.33 λg0 and 0.26 λg0 that represent effective compactness at their fundamental frequencies.

4. Conclusions

In this paper, doubly-tuned compact filters based on the loop and patch fractal geometries are presented as compact devices for mobile communication systems. These filters are constructed using the first iteration of the Cantor fractal loop resonator. The design and simulation results of the proposed filter have been examined using AWR 12 EM software package with RT/Duroid substrate constant of 10.8 and substrate height of 1.27 mm. The proposed Cantor loop filter has an acceptable S11 and S21 responses at pole resonant frequencies 4.55 and 4.58 GHz, while patch Cantor filter is designed as dual-band device at band frequencies of 3.6 and 6.84 GHz respectively. These characteristics can be adopted in C band wireless schemes, and they can be integrated into many wireless devices. The simulated results are validated with Sonnet EM simulator.

References

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Seevan F. Abdulkareem received her B.Sc. degree in Electronics and Communications from the University of Baghdad, Iraq in 2007 and M.Sc. degree in Microwave Engineering from the Department of Electrical Engineering, University of Technology, Iraq in 2013. From 2008–2011, she was a Lab Assistant, and from 2013 till now she is Asst. Lecturer at Al-Mansur University College. Her fields of interests are microwave antenna miniaturization, and design and she has published many papers in international conferences and journals in this field.