IJE TRANSACTIONS A: Basics, Vol. 29, No. 1, (January 2016) 49-52

International Journal of Engineering

Journal Homepage: www.ije.ir

RESEARCH NOTE

Fractal Bandpass Filter Using Y-shaped Dual-Mode Resonator for C-Band Receiver

G. Karimi* [a], F. Sabaghi [b]

[a] *Department of Electrical Engineering, Faculty of Engineering, Razi University, Kermanshah, Iran*
[b] *Department of Electrical Engineering, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran*

PAPER INFO

Paper history:
Received 26 December 2015
Received in revised form 17 January 2016
Accepted in 28 January 2016

Keywords:
Bandpass Filter
Y-shaped Resonator
Fractal Shaped
Dual Mode

ABSTRACT

In this study, a fractal, Y-shaped dual-mode resonator bandpass filter (BPF) with input-output cross-coupling is introduced. A parallel-coupling feed structure with a cross coupling has been used to generate two transmission zeroes (TZs) near the lower and upper cutoff frequency that can effectively improve the passband edge selectivity. Also, a fractal shaped based on conventional diamond and square is located. Current density and equivalent model is also given depending on the odd/even excitation resonance condition. The demonstrated filter with a compact size of 0.5*18.3mm^2 exhibits a fractal bandwidth of 67% centred as 6GHz (f_0) within the 4 to 8GHz bandwidth and minimum insertion loss of 0.3 dB, maximum return loss of 13,15.7dB and flat group delay around 0.3ns that is candidate for use in commercial communications satellites (C-Band).

***doi**: 10.5829/idosi.ije.2016.29.01a.07*

1. INTRODUCTION

The mathematical roots of the fractal idea have been traced throughout 19th century which is driven by Latin word “fractus”. In classic mathematics, fractus means ″broken″ or ″fractured″. A fractal is a complex pattern that displays self-similarity in the same technical sense, on all scales [1-3].

Fractals are not limited to geometric structures, but can also describe process in many scientific research domain, certainly in microwave engineering research for planography of new microwave circuits and betterment of performance as well as miniaturization. Nevertheless, usage prevailingly intensive on filters.

For all narrowband and wideband bandpass filters the dual-mode is mainly applied in the planar microwave bandpass filters on account of low cost, compact size, and easy fabrication. Consequently, dual-mode bandpass filters are very popular to apply in wireless communication system and measurement instruments [4, 5].

In RF/microwave systems [6] Wideband bandpass filters (BPFs) with low insertion loss within the passband and large attenuation in the stopband and low insertion loss in the passband are most desirable. To achieve this, a number of filter structures have been introduced for example to extend the upper stopband bandwidth and improve the selectivity of the passband [7]. Various methods such as electromagnetic (EM) loaded bandgap, I/O cross coupling, the cascaded low/high pass filters and T-shaped resonators were used.

Authors in reference [8] proposed another wideband bandpass filter with transversal resonator and asymmetrical interdigital coupled lines that has a good stopband resonance.

In addition, high selectivity bandpass filters have been designed in two references [9, 10] , using T-shaped structures and open coupled lines.

In modern wireless communication systems fractal wideband dual-mode filters with low insertion loss in passband and large attenuation in out of band with compact size are becoming most desirable. A new configuration of the wideband dual-mode bandpass filter using Y-shaped resonator combined a fractal shaped resonator to meet these requirements is presented in this paper.

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*Corresponding Author’s Email: *ghkarimi@razi.ac.ir* (G. Karimi)

Please cite this article as: G. Karimi and F. Sabaghi, Fractal Bandpass Filter Using Y-shaped Dual-Mode Resonator for C-Band Receiver, International Journal of Engineering (IJE), TRANSACTIONS A: Basics..Vol. 29, No. 1, (January 2016) 49-52

2. MAIN RESONATORS

2. 1. Modified Fractal-shaped Resonator

The structure of modified fractal shaped resonator is shown in Figure 1. The original configuration of proposed fractal is named the formal diamond (FD). At first stage, FD pattern design, then square fractal shape (SF) is introduced. At the end, in order to have a reduce size, fractal shaped pattern (RSF) is designed by realigning the fractal parts [11].

2. 2. Y-Shaped Dual-mode Microstrip Resonator

Figure 2 exhibits Y-shaped microstrip dual-mode resonator is configured by three microstrip-line arms that joint together with 135^o rotation angels. Both microstrip arms, left and right, is the same [12]. Y-shaped resonator becomes a T-shaped resonator when the angle between the left and the right arms becomes 180^o.

To analyze even and odd mode frequencies, Figure 2 is split into two symmetric sections (see Figure 3 (c) and (d)). In odd mode resonance, there is a virtual short at center of pattern; because of odd mode excitation, both microstrip branches have the opposite voltage potentials; therefore, the symmetric plane is an electric wall. In addition, odd mode frequency controlled by l_1 is shown in Figure 3 (c). In the same way, in even mode resonance, both microstrip branches have the same voltage potentials that is magnetic wall at the symmetry plane is shown a virtual open at center of pattern (see Figure 3 (d)). The typical microstrip current distributions of two modes are shown in Figure 3. In addition, the simulation is carried out by ADS software.

Figure 3 (a) depicts the sign charges which are carried from port 1 to port 2. This is odd mode excitation because of left and right microstrip branches carry the same sign charges. The input admittance for odd-mode can be derived as follows:

$$Y_{in.odd} = -jY_1 \cot(\theta_1) \tag{1}$$

Where $\theta_1 = \beta l_1$ is the electric length and β is the propagation constant. From the resonance condition of $Y_{in,odd}=0$ the odd-mode resonant frequency f_{odd} can be expressed as follows:

$$f_{odd} = \frac{(2n-1)C}{2l_1\sqrt{\varepsilon_{eff}}} \tag{2}$$

where n=1, 2,… and C is the speed of light in free space ($3*10^8$) and ε_{eff} denotes the effective dielectric constant. Apparently, the sign charges in port 1 is out of phase to that on the port 2 (see Figure 3 (b)). Furthermore, the currents on the middle stub is also at the same phase to each other against middle stub. Figure 3(a) is out of phase to each other. Therefore, the mode thus behaves as an even mode. The input admittance for even-mode can be approximately obtained as follows:

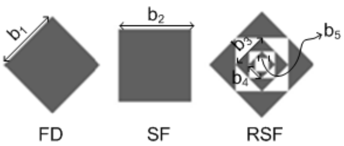

Figure 1. structure of modified fractal-shaped resonator

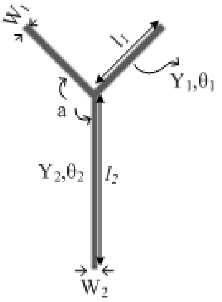

Figure 2. Topology of the Y-shaped dual-mode resonator

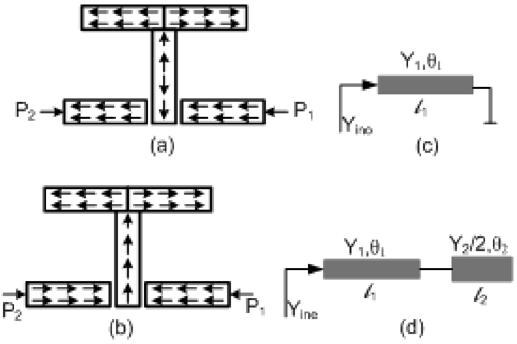

Figure 3. (a) Surface current pattern at the resonance frequency of odd mode, (b) surface current pattern at the resonance frequency of even mode, (c) equivalent circuit of odd-mode resonance, (d) equivalent circuit of even-mode resonance

$$Y_{in} = jY_1 \frac{Y_1 \tan(\theta_1) + Y_2 \tan(\frac{\theta_2}{2})}{Y_1 - Y_2 \tan(\theta_1)\tan(\frac{\theta_2}{2})} \tag{3}$$

The resonance condition is $Y_{in,even}=0$. Thus, at the even-mode resonant frequencies, it can be deduced as follows:

$$Y_1 \tan(\theta_1) + Y_2 \tan(\theta_2/2) = 0 \tag{4}$$

Similarly, the even-mode resonant frequency f_{even} can be calculated as follows:

$$f_{even} = \frac{nc}{(2l_1 + l_2)\sqrt{\varepsilon_{eff}}} \tag{5}$$

3. STRUCTURE AND DESIGN OF THE FRACTAL AND Y-SHAPED DUAL-MODE BPF

Figure 4 exhibits the configuration of proposed filter. It includes a fractal shaped combine Y-shaped dual-mode resonator with a cross coupling between port 1 and port 2. To improve the passband edge selectivity and out of band performances, two transmission zeroes near the lower and upper cut off frequency are generated and controlled by l_2; it is obtained from Equation (2) and (5).

4. SIMULATION RESULTS

The proposed filter was designed on substrate RT/Duroid 5880 with $\varepsilon_r = 2.2$, h=31ml and loss tangent of 0.0009. Finally physical size of proposed filter are b_1=6mm, b_2=4.4mm, b_3=3mm, b_4=1.5mm, b_5=1mm, l_1=6mm, w_1=0.5mm, l_2=11.2mm, w_2=0.35mm, a=135^o, S_1=S_2=0.1mm, l_3=9.1mm, w_3=0.2mm, w_p=2.42mm. The simulation is accomplished using ADS software. Figure 5 shows the simulated results.

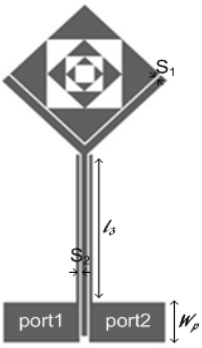

Figure 4. Layout of the proposed filter

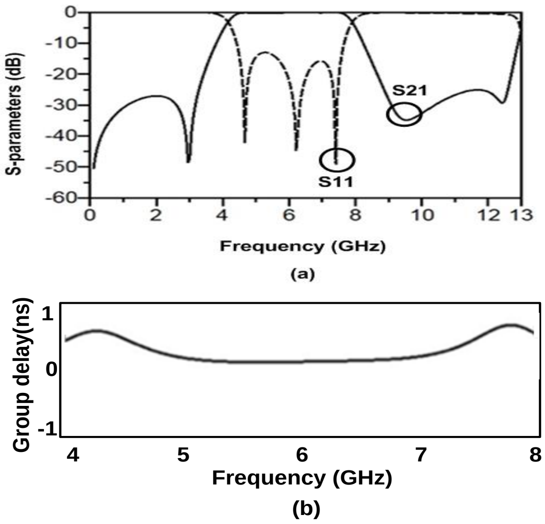

Figure 5. (a) Frequency response of proposed filter, (b) Group delay.

From 4 to 8GHz, the simulated return loss is greater than 13, 15.7 dB and the insertion loss is less than 0.3 dB. In the simulated upper-stopband responses, a 20dB rejection in the frequency range of 8 to 13GHz was also obtained. The proposed BPF provides a relatively wide 3dB fractional band width of 67% frequency response, that can be determined as follows:

$$FBW = \frac{f_u - f_l}{\sqrt{f_u \cdot f_l}} \tag{6}$$

In addition, the group delay within the WB passband is between 0.3-0.5 ns, showing a good linearity. Also, the total size of this filter is 0.5×18.3 mm^2.

5. CONCLUSION

In this work, fractal, Y-shaped dual-mode resonator bandpass filter with cross-coupling was proposed and designed. Also, compact size, low insertion loss, sharp rejection are features of this filter. With passband around 4 to 8GHz, the proposed filter is attractive for the use in C-band. The C-band includes wavelengths of microwaves that are applied for long-distance radio telecommunications. The IEEE C-band (4 to 8GHz) and its slight variations contain frequency ranges that are used for many satellite communications, Wi-Fi devices, cordless telephones, and weather radar systems.

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G. Karimi [a], F. Sabaghi [b]

[a] *Department of Electrical Engineering, Faculty of Engineering, Razi University, Kermanshah, Iran*
[b] *Department of Electrical Engineering, Kermanshah Branch, Islamic Azad University,Kermanshah,Iran*

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چکیده

در این مقاله، یک فیلتر میان گذر با رزوناتور دو مدی Y و فرکتال شکل به همراه کوپل ورودی- خروجی متقاطع معرفی شده است. به منظور تولید دو صفر انتقال نزدیک فرکانس قطع پایین و بالا از ساختار تغذیه ای کوپل موازی به همراه کوپل متقاطع استفاده شده است که انتخاب پذیری لبه باند عبور را نیز بهبود می بخشد. همچنین در ساختار این فیلتر فرکتالی بر پایه اشکال لوزی و مربع ایجاد شده است. چگالی جریان و مدل معادل وابسته به شرایط رزونانس تحریک مد زوج و فرد جهت آنالیز این فیلتر به کار برده شده است. فیلتر مطرح شده دارای سایزی کوچک به اندازه 18.3 × 0.5 میلیمتر مربع بوده است. پهنای باند کسری حدود 67 درصد در فرکانس مرکزی 6 گیگاهرتز در باند عبور 4 تا 8 گیگاهرتز به همراه تلفات عبوری کمتر از 0.3 دسی بل و تلفات بازگشتی حدود 13 و 15.7 دسی بل و همچنین پاسخ صاف تاخیر گروهی حدود 0.3 نانو ثانیه از مزایای این فیلتر به شمار می آید که آن را برای استفاده در ماهواره های مخابراتی تجاری باند C به عنوان یک کاندید مناسب معرفی می کند.

***doi**: 10.5829/idosi.ije.2016.29.01a.07*