Design of Microstrip Band Pass Fractal Filter for Suppression of Spurious Band

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Abstract. *In this paper, the design and subsequent fabrication of a hairpin-line band pass filter has been proposed. This filter exhibits periodic frequency response. By proper design, the spurious bands are being suppressed significantly through the implementation of Koch fractal on the microstrip coupled line.*

Keywords

Hairpin-line, Koch fractal, band pass filter, spurious band.

1. Introduction

Microstrip filters are essential parts of the microwave system and play important role in many communication applications especially wireless and mobile communications. These are getting popular due their compact size, light weight, low cost and ease of fabrication [1]. Coupled line microstrip filters like pseudo combline, hairpin-line, etc. possess narrow fractional bandwidths due to their relatively weak coupling. However, due to commensurate nature (equal electrical length of transmission-line elements), such networks have additional spurious responses at the even-order frequencies due to the absence of homogeneous substrate [2]. Such spurious bands degrade the performance of system components like generating asymmetric pass-band and reduce out-of-band rejection [3]. To overcome this problem, Koch fractal geometry has been applied to the coupled sections of a hairpin-line filter, in this paper.

Recently, the use of fractals in the design of filters have attracted a lot of attention to achieve objectives like reduced resonant frequencies and wide bandwidth. Fractals were first defined by Benoit Mandelbrot in 1975 as a way of classifying structures whose dimensions were not whole numbers [4]. Fractal means broken or irregular fragments that possess an inherent self-similarity in their geometrical structure. Looking at geometries whose dimensions are not limited to integers lead to the discovery of filters with compact size and improved characteristics. Till date several fractal geometries such as Hilbert curve, Sierpinski carpet, Koch curve etc. have been used to develop various microwave devices [5].

One of the best methods to suppress spurious bands involve making optimum line structures by inserting periodic shapes, such as grooved, wiggly and inter-digitized lines into conventional coupled lines [6]. These periodic structures are used to create Bragg reflections to suppress the harmonics. In this work, a conventional hairpin-line is designed and simulated through moments method IE3D software [7]. Subsequently, Koch fractal is applied to the conventional filter and spurious band is being suppressed successfully. Finally, the proposed filters are physically implemented on FR-4 'Glass/Epoxy' PCB and the simulated and measured results discussed.

2. Koch Fractal and Its Property

Basically, Koch fractal geometry, named after mathematician Helge Von Koch, is very popular in designing miniature antennas [8]. Fig. 1 shows the configuration of a Koch island, which consists of a Koch curve up to 2^{nd} iteration order.

More elaborately, in case of Koch Island fractal as the number of iterations increases bandwidth of this filter decreases. Also, it is observed that the imaginary part of input impedance at the resonant frequency changes from capacitive to an inductive component.

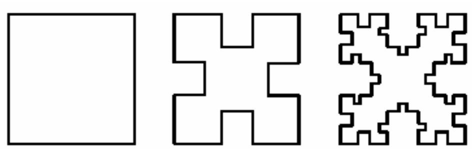

Fig. 1. Koch fractal island shapes.

Investigating the Koch fractal-shaped filter property, from electromagnetic simulation of a Koch fractal shape resonator it observed that the first transmission null point becomes lower in magnitude with increase in iterations and for zero iteration, the null point is found away from the second harmonic. Whereas in Koch fractal resonator, the null point which is near to the 2^{nd} harmonic decreases as iteration number increases [6]. This is due to the space-filling property of fractal geometry. Controlling the null point at the harmonics creating stop band, can be used to suppress spurious bands generated by conventional filters.

3. Design of Hairpin-Line Band Pass Fractal Filter

Hairpin-line band pass filters are simple and compact in structures. They are obtained by folding parallel-coupled resonators of half-wavelength, in to a 'U' shape. Such resonators are the so-called Hairpin-line resonators. In order to fold the resonators, it is necessary to take into account the reduction of the coupled-line lengths, which reduces the coupling between resonators [1], [9]. If the two arms of each resonator are closely spaced, they function as a pair of coupled lines themselves, which has an effect on the coupling as well.

For the 3rd order conventional Hairpin-line filter, the following are the design parameters: Fractional Band width, B_f = 20% or 0.2 at mid band frequency 1 GHz, dielectric constant, ε_r = 4.4, substrate thickness, h = 1.6 mm, Loss tangent, $\tan\delta$ = 0.02, Passband ripple 0.1 dB.

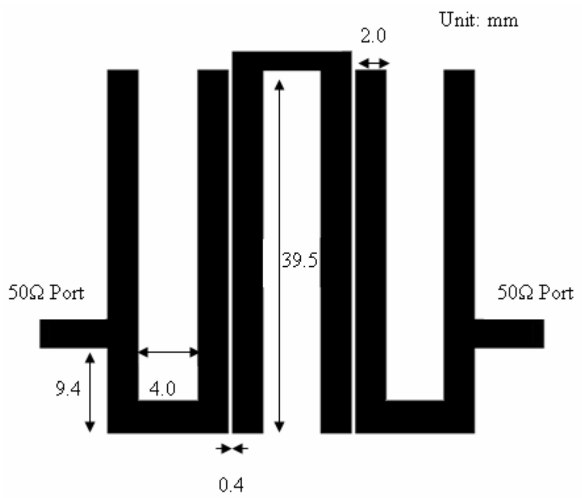

Fig. 2 (a). Layout of hairpin-line band pass filter.

The lowpass prototype parameters, are $g_0 = g_4 = 1$; $g_1 = g_3 = 1.0316$; $g_2 = 1.1474$. Having obtained the low pass parameters [1], the band pass design parameters are calculated using the following equations [2]

$$Q_{en} = (g_n g_{n+1})/FBW, \tag{1}$$

$$M_{i,i+1} = FBW/\sqrt{(g_i g_{i+1})}, \text{ for } i = 1 \text{ to } (n-1). \tag{2}$$

Here, Q_{en} is the external quality factor of the resonators and $M_{i,i+1}$ are the coupling coefficients between the adjacent resonators. For this design, Q_e = 5.158, $M_{1,2} = M_{2,3}$ = 0.184. The designed filter is shown in Fig. 2 (a). Using IE3D simulation tool [7], the band pass filter is simulated and the corresponding plot is shown in Fig. 2 (b).

The conventional filter as shown in Fig. 2(a), termed as Koch zero iteration, was designed using traditional Chebyshev filter design theory. Its center frequency is located at 1 GHz and fractional bandwidth is 20%. The zero iteration Koch filter has a large second harmonic of 5.0 dB at 1.9 GHz. After Koch fractal of iteration factor ¼ implemented on the conventional design, Figs 3(a) and 4(a) show the fractal Hairpin-line band pass filter for the 1st and 2nd iteration order respectively. And for the 3-pole filter, the spurious band is considerably suppressed to -18.42 dB for the 1st iteration, and -29.81 dB for the 2nd iteration. The simulated transmission coefficient and reflection coefficient for the 1st and 2nd iteration order are shown in Fig. 3(b) and Fig. 4(b), respectively.

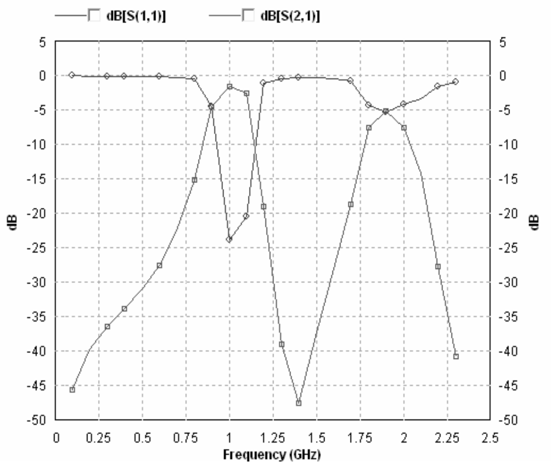

Fig. 2 (b). Frequency response of hairpin-line band pass filter.

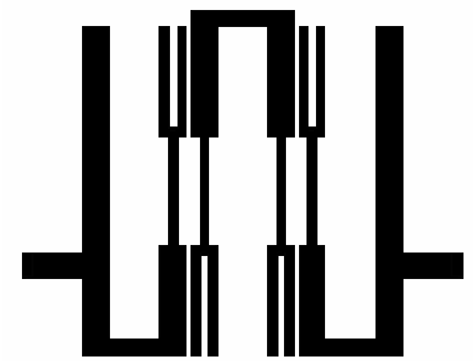

Fig. 3 (a). Layout of the 1st iteration fractal band pass filter.

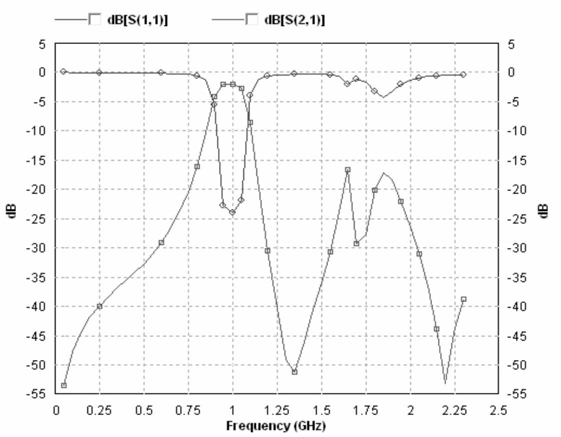

Fig. 3 (b). Frequency response of the 1st iteration band pass filter.

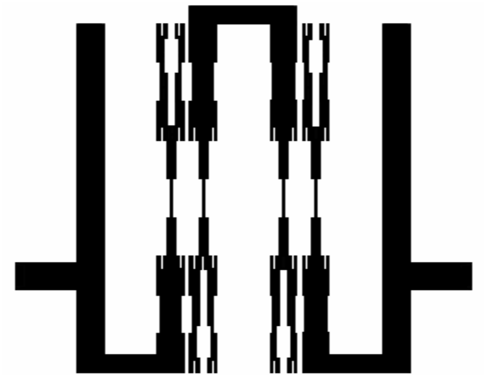

Fig. 4 (a). Layout of the 2nd iteration fractal band pass filter.

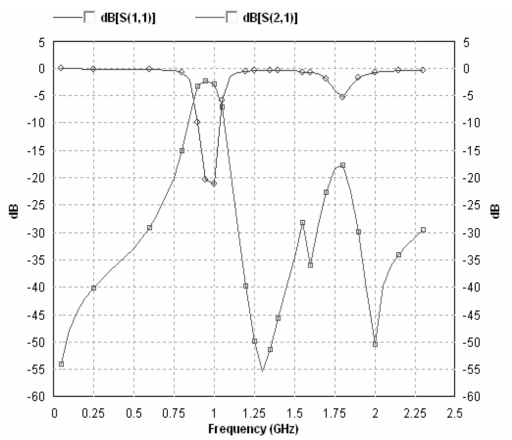

Fig. 4 (b). Frequency response of 2nd iteration band pass filter.

Finally, all the filters have been physically implemented on FR-4 'Glass/Epoxy' substrate, using conventional fabrication processes. The comparison plots for transmission coefficient and reflection coefficient, of both simulated and measured results are shown in Fig. 5 (a,b), 6(a,b), and 7 (a,b). Since Zeland IE3D software is based on moments method, and the current distribution on filter elements is one of the primary quantities concerned, we use this program to analyze current distributions. The photograph of all the filters along with their respective current distribution functions are shown in Fig. 8(a,b), 9(a,b), and 10(a,b). From the current distribution plots it is observed that the current concentration is uniform for the conventional filters, whereas in the fractal designs it is non-uniform and more concentrated at the input port.

4. Conclusion

In the present work, Hairpin-line filters with Koch fractal implementation have been proposed and investigated using numerical and experimental methods. It was found that the unwanted harmonics can be suppressed using the property of fractal geometry. The suppression can be up to even 29 dB, for the 2nd iteration fractal order. The proposed method can be applied to other coupled microstrip structures facing harmonic problems. And it could be the solution for RF systems requiring reduced harmonic components.

Acknowledgements

The authors thankfully acknowledge the financial support provided by M.P. Council of Science & Technology, Bhopal, India.

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R. N. BARAL (*1976) received his Bachelors degree from the Institution of Electronics and Telecommunication Engineers in 1998 and his Masters degree from MITS, Gwalior in 2002. Currently he is pursuing his PhD degree from RGPV, Bhopal, India, on "Design and Analysis of Microstrip Filters". Till date, he has twelve papers at national and international level. He is a life member of Institute of Electronics and Telecommunication Engineers (I.E.T.E.), New Delhi, India.

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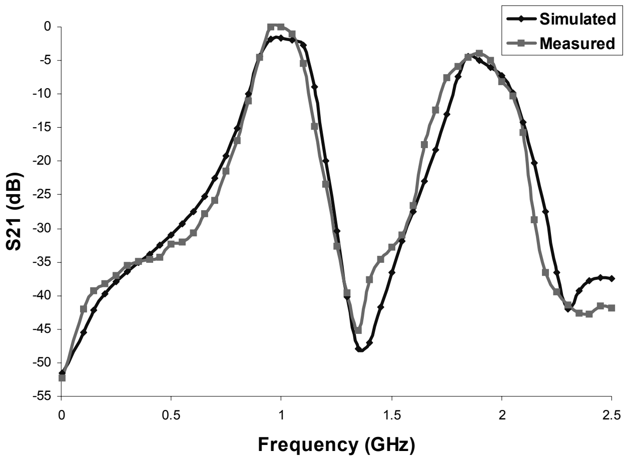

Fig. 5 (a). Transmission co-efficient for zero iteration.

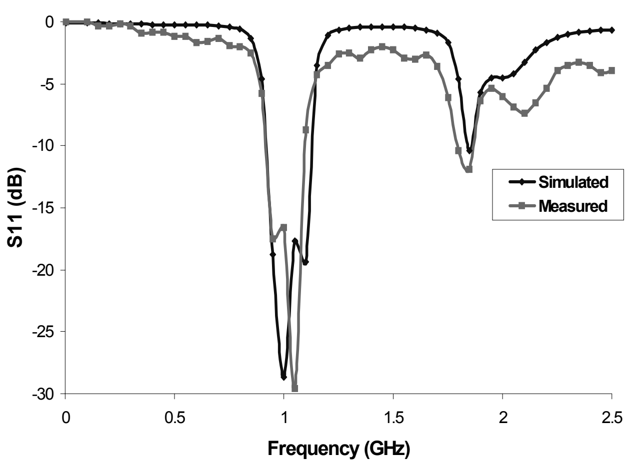

Fig. 5 (b). Reflection co-efficient for zero iteration.

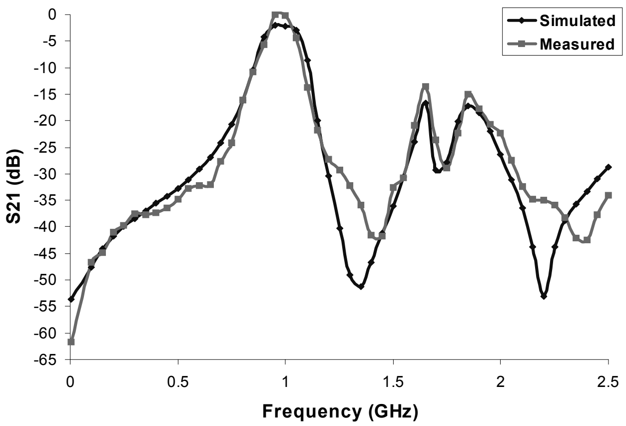

Fig. 6 (a). Transmission co-efficient for 1st iteration.

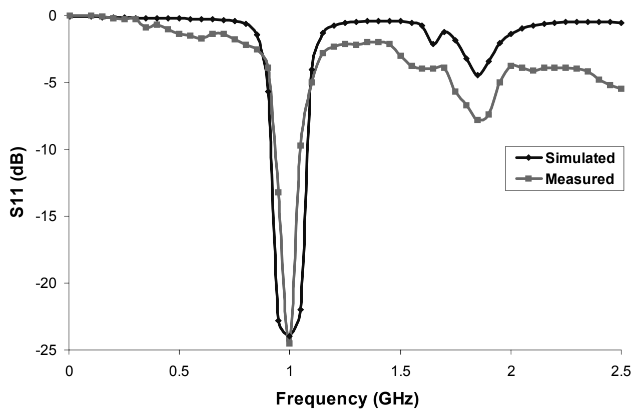

Fig. 6 (b). Reflection co-efficient for 1st iteration.

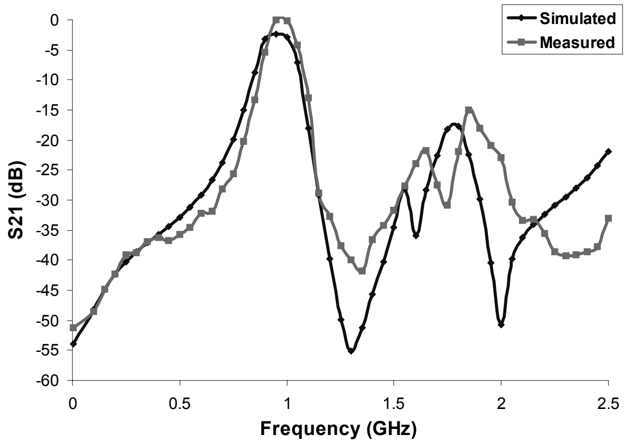

Fig. 7 (a). Transmission co-efficient for 2nd iteration.

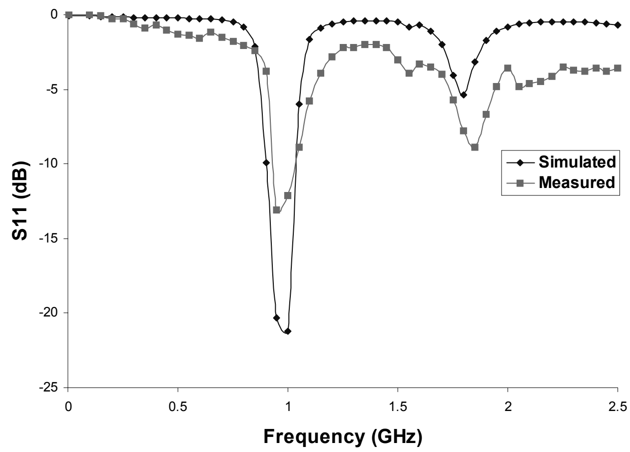

Fig. 7 (b). Reflection co-efficient for 2nd iteration.

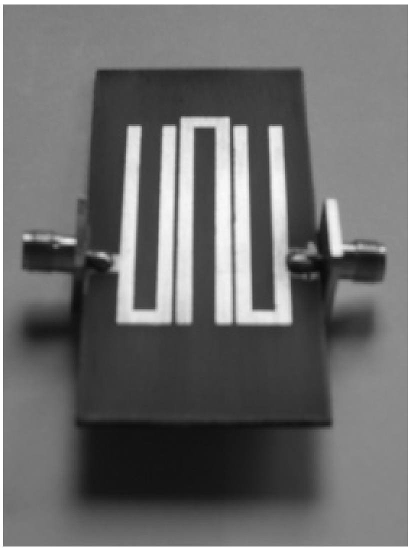

Fig. 8 (a). Photograph of hairpin-line filter for zero iteration.

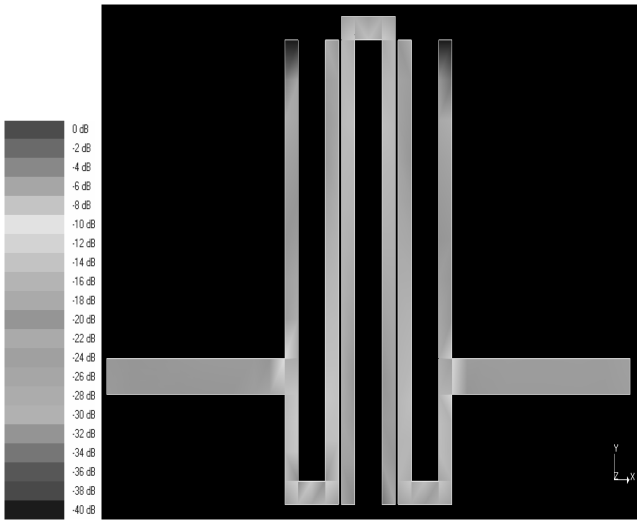

Fig. 8 (b). Distribution of the magnitude of the current density on $f_c = 1$ GHz.

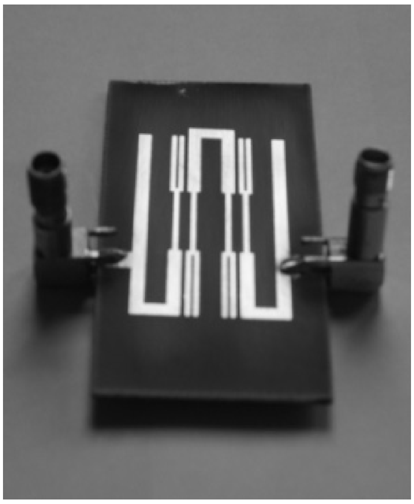

Fig. 9 (a). Photograph of hairpin-line filter for 1st iteration.

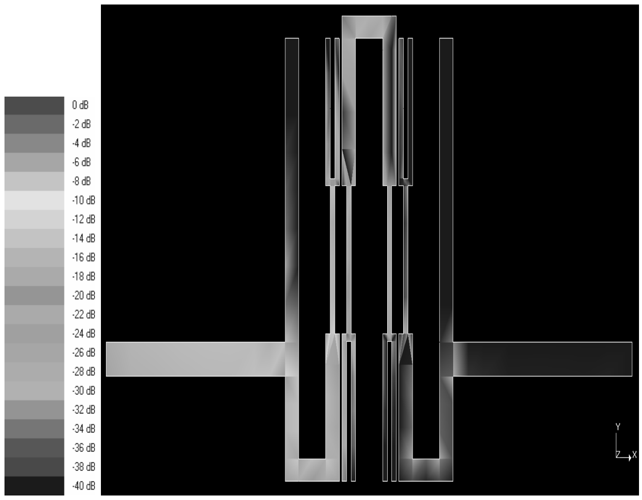

Fig. 9 (b). Distribution of the magnitude of the current density on $f_c = 1$ GHz.

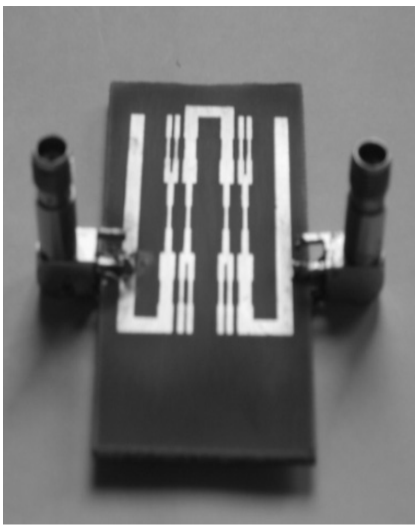

Fig. 10 (a). Photograph of hairpin-line filter for 2nd iteration.

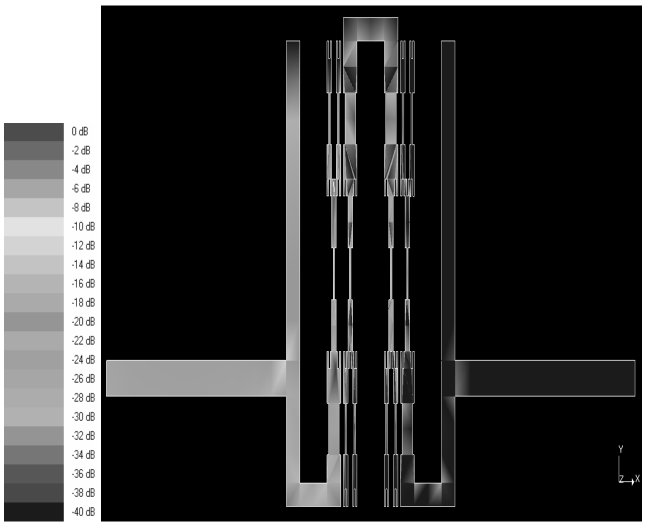

Fig. 10 (b). Distribution of the magnitude of the current density on $f_c = 1$ GHz.