Novel Design of UWB Band-Stop Filter (BSF) Based on Koch Fractal Structures

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Abstract **─** In this paper, a novel design of compact microstrip Ultra-Wideband (UWB) Band-Stop Filter (BSF) for wireless applications is proposed. The proposed BSF structure is based on Koch fractal geometry where its third iteration operates over a very wide bandwidth and improves the impedance matching. The microstrip filter configuration consists of a transmission line with pairs of Koch fractal Radial Stubs Loaded Resonators (RSLRs), and a modified ground plane with triple modified Defected Ground Structures (DGSs). Operation frequencies of the filter can be easily controlled by changing the iteration of embedded fractal structure. The DGS slots evolved from Photonic Band Gap (PBG) is embedded to achieve a good impedance matching and the required filter's characteristics. The proposed BSF has a flat rejected-band characteristic around of 3.1-10.6 GHz with an insertion loss which is larger than 45 dB and a return loss less than 0.5 dB at the centre of the band-stop frequency range. An excellent agreement between measured and simulated was obtained. The proposed microstrip filter is fabricated on a *Rogers RT/Duroid* 5880 substrate with a relative dielectric constant of 2.2 and has a small size of $10\times15\times0.635$ mm^3. The proposed filter configuration is and can be integrated into any UWB system.

Index Terms **─** Band-stop filter, DGS, Koch fractal, UWB application.

I. INTRODUCTION

In modern communications, one of the important parameters is isolation between channels in a given bandwidth. Filters with different configurations are essential components in communication systems and these are generally used as signal rejection for unwanted signals and simultaneously allow the wanted signals in required bands. In recent times, the design of filters has become an active research area as filtering is important when used in close proximity to other circuit components, like power amplifiers in the transmitter part and low noise amplifiers in receiver part, for various RF applications [1].

Conventionally the microwave filter is implemented either by all shunt stubs or by series connected high-low stepped-impedance microstrip line sections. However, generally these are not easily available in microwave band due to the high impedance microstrip line and the spurious pass-bands. To remove these disadvantages, defected ground structures for microstrip lines have been presented in recent years. They have been presented in a number of different shapes for filter applications [2-3]. The DGS applied to a microstrip line causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slot. This technique is suitable for periodic structures, and for both band-stop and low-pass filters, e.g., [4].

Recently, the use of fractals in the design of

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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. 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]. Subsequently, Koch fractal is applied to the conventional filter and spurious band is being suppressed successfully. Finally, the proposed filters are physically implemented and the simulated and measured results discussed.

More elaborately, in case of Koch fractal, as the number of iterations increases, stopped bandwidth of this filter increases. Also, it is observed that the imaginary part of input impedance at the resonant frequency changes from capacitive to an inductive component. This paper work deals with design and development of a microstrip band-stop filter for UWB applications. In this structure, the resonant behaviors of the RSLRs which are used here, introduces transmission zeroes to the filter response and consequently improves its band-stop performance. Also, the reason for the choice of modified DGS is that it can provide an almost constant tight coupling, which is important to generate a good frequency response. The designed filter has a small dimension of 10×15 mm^2.

II. FILTER DESIGN

The proposed microstrip filter configuration is shown in Fig. 1. This filter was designed on a *Rogers RT/Duroid* 5880 substrate with 0.635 mm in thickness and with a relative dielectric constant of 2.2. For the input/output connections 50-Ohm microstrip lines are used. The microstrip BSF was designed on both substrate sides by opening aperture in the ground metallization under the low-impedance transmission line. Replacing of the pairs of RSLRs based on Koch fractal structure, introduces transmission zeroes. Final values of the presented band-stop filter design parameters are specified in Table 1.

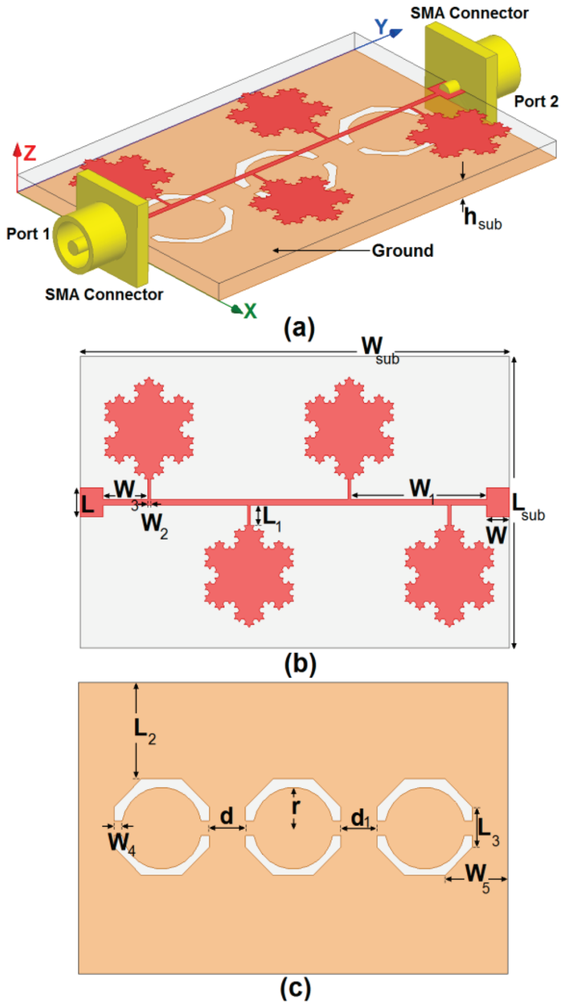

Fig.1. Geometry of proposed microstrip band-stop filter, (a) side view, (b) top layer, and (c) bottom layer

Table 1: The final dimensions of the filter

Parameter	W_{sub}	L_{sub}	h_{sub}	W
(mm)	15	10	0.635	0.8
Parameter	L_2	W_3	L_3	r
(mm)	3.4	0.4	1.35	1.4
Parameter	L	W_1	L_1	W_2
(mm)	0.9	4.75	0.7	0.1
Parameter	d	W_4	d_1	W_5
(mm)	1.25	0.3	1.25	2.2

The original curve is equilateral triangle with length of g. The triangular RSLRs with a length *g* are considered as the starting pattern for the proposed band stop filter as a fractal.

From this starting pattern, each of its four RSLRs is replaced by what is called the generator structure shown in Fig. 1 (a)

All the iterations are circumscribed inside a circumference of radios $r=\sqrt{3g/3}$. On the other hand, the perimeter increases at each new iteration. The overall perimeter for iteration is given by:

$$I_K = 3g\left(\frac{4}{3}\right)^K. \tag{1}$$

III. RESULTS AND DISCUSSIONS

The proposed filter with various design parameters was constructed, and the experimental results of the S-parameter characteristics are presented and discussed. The simulated results are obtained using the Ansoft simulation software High-Frequency Structure Simulator (HFSS) [6].

Investigation of the Koch fractal-shaped property, from electromagnetic simulation of a Koch fractal shape resonator it observed that the transmission zeroes becomes upper in magnitude with increase in iterations. This is due to the space-filtering property of fractal geometry. Controlling the transmission zeroes at the creating stop band, can be used to increase or decrease the stop-band generated by conventional filter.

The proposed filter with final design as shown in Fig. 2, was fabricated and tested that good S-parameters ($|S_{11}|/|S_{21}|$) are introduced to the filter response from 3.1 to 10.6 GHz.

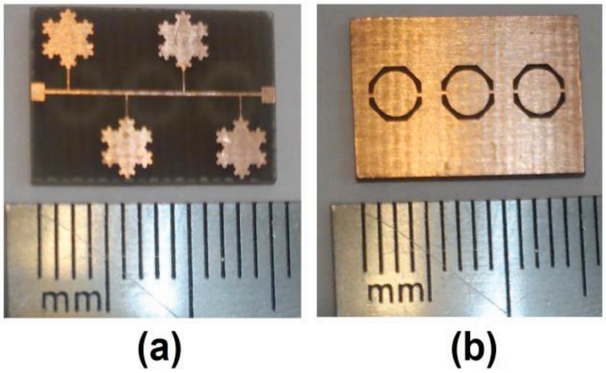

Fig. 2. Fabricated band-stop filter: (a) top view, and (b) bottom view.

Figure 3 shows the simulated and measured insertion and return loss of the filter. As shown in Fig. 3, a flat insertion and return losses are introduced to the filter response. Consequently, a very wide band-stop characteristic was achieved. The measured return and insertion losses ($|S_{11}|$ and $|S_{21}|$) are found to be better than 0.5 dB and less than 45 dB, respectively, over the entire UWB frequency range.

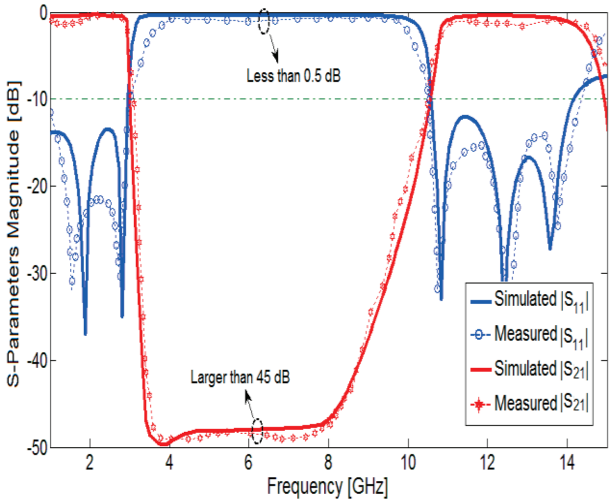

Fig. 3. Measured and simulated $|S_{11}|$ and $|S_{21}|$ characteristics for the proposed filter.

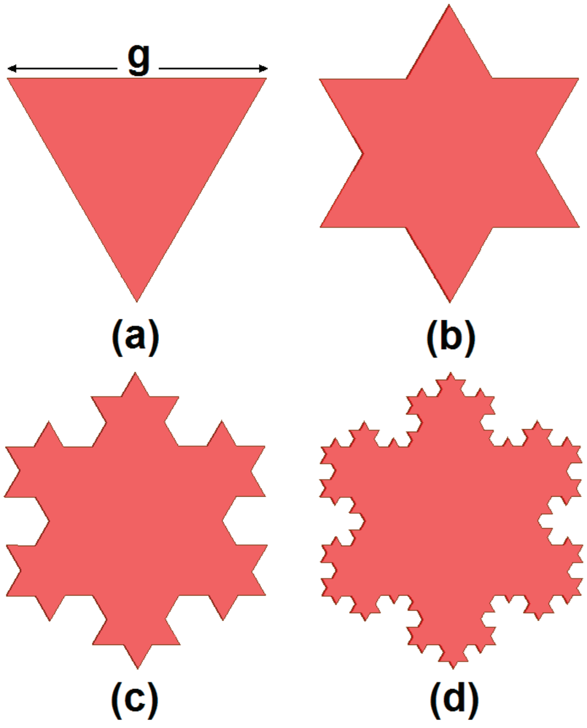

Fig. 4. Koch snowflake geometry in its different iteration stages: (a) basic geometry, (b) first iteration, (c) second iteration, and (d) third iteration.

The basic geometry of the radial stubs is an equilateral triangle of side *g*, on which repeated iterations lead to the Koch snowflake geometry as shown in Fig. 4.

The first iteration of replacing a segment with the generator is shown in Fig. 4 (a). The starting pattern is Euclidean, and therefore, the process of replacing the segment with the generator constitutes the first iteration. The generator is scaled after, such that the endpoints of the generator are exactly the same as the starting line segment. In the generation of the true fractal, the process of replacing every segment with the generator is carried out an infinite number of times. The resulting pre-fractal structure has the characteristic that the perimeter increases to infinity while maintaining the volume occupied.

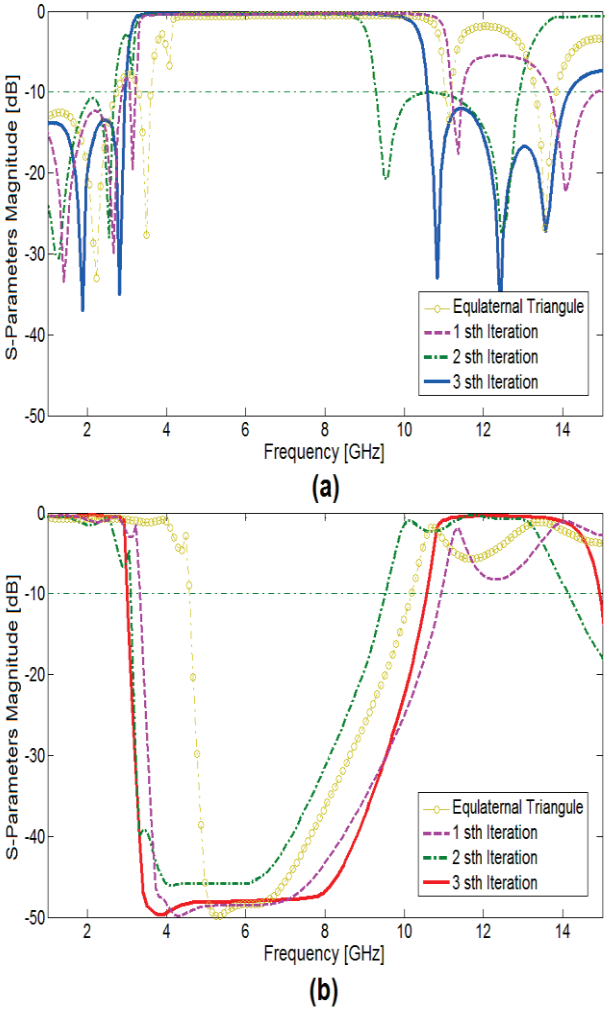

Fig. 5. Simulated S-parameters for different iterations of Koch structures: (a) $|S_{11}|$, and (b) $|S_{21}|$.

This increase in length decreases the required volume occupied for the pre-fractal band-stop filter at resonance. It has been found that:

$$P_n = (\frac{4}{3})^n \, P_{n-1}, \tag{2}$$

where P_n is the perimeter of the *n*th iteration pre-fractal structure. Theoretically, as *n* goes to infinity, the perimeter goes to infinity. The ability of the resulting structure to increase its perimeter in the successive iterations was found very promising for examining its size reduction capability as a microstrip band-stop filter. Figure 5 illustrates the simulated S-parameters of the proposed BSF, for iteration stages of the fractal geometry. It is observed that the Koch fractal geometry improves the impedance matching at the lower and upper frequencies along the bandwidth enhancement of the proposed filter. In practice, shape modification of the resulting structures is a way to increase the surface current path length compared with that of the conventional triangular resonator. As can be observed, at the third iteration the proposed band-stop filter operates very wide bandwidth from 3.1 to 10.6 GHz, which covers the UWB frequency range.

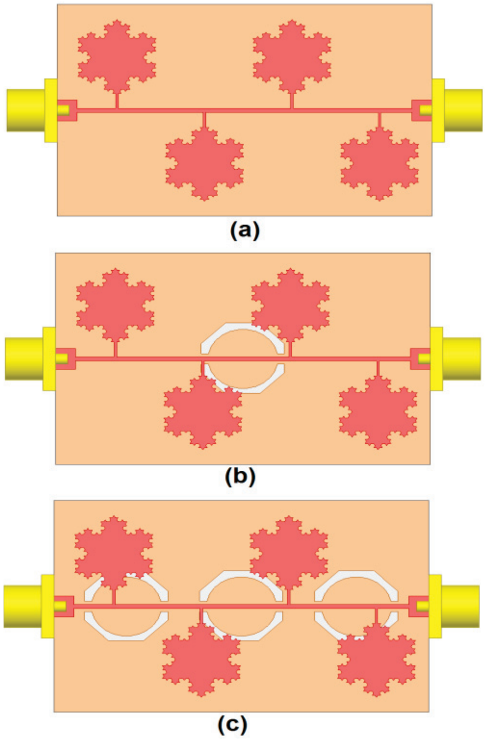

Fig. 6. (a) BSF without DGS, (b) the filter with a single DGS, and (c) the proposed filter structure.

Defected ground structure technique is now applied in the design of microstrip filters. This helps to improve the filter performance and causes a size reduction, which is considered a major benefit. This technique is currently employed to meet the increasing demand for compact structure high performance filters [4]. Various configuration of the proposed microstrip filter w/o DGSs is shown in Fig. 6.

Figure 7 shows the effects of the inserted DGS with different numbers on the return loss matching. The slots introduced at the backed ground plane layer (i.e., DGS) mainly improve the transition sharpness and widens the rejection band. This is due to the fact that the waves penetrating the structure are disturbed, causing equalization in the model phase velocity with respect to one another. This can also help in developing a more compact structure without the need to implement higher order filters with the same performance.

As illustrated, it is found that by inserting the three modified DGS of suitable dimensions in the ground plane, good impedance matching for return loss characteristics in comparison to the same filter without DGS can be achieved. As illustrated in Fig. 6 (c), the microstrip filter with slotted ground plane consisting of three modified DGS has a wider return loss bandwidth.

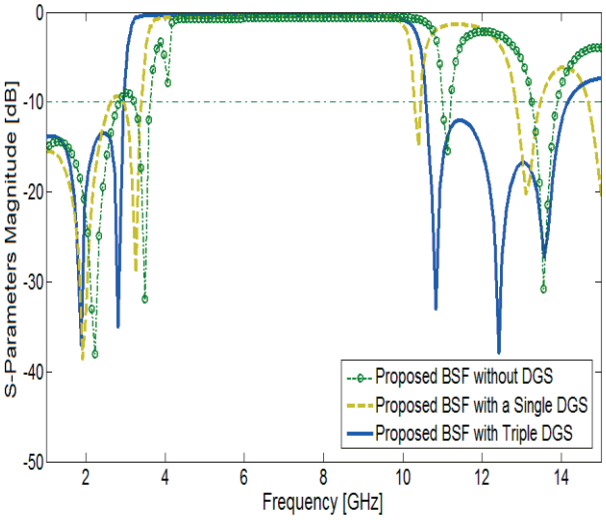

Fig. 7. Simulated $|S_{11}|$ (return loss) characteristic for the proposed BSF with and without DGSs.

Table 2 summarizes the previous designs and the proposed filter. It can be seen from Table 2, the proposed microstrip band-stop filter has a compact size with very wide bandwidth compared to the previous works. In addition, the proposed BSF has a flat rejected-band characteristic around of 3.1-10.6 GHz with an insertion loss which is larger than 45 dB and a return loss less than 0.5 dB at the centre of the band-stop frequency range.

Very good agreement is obtained between simulated and measured results. The small discrepancies can be attributed to fabrication tolerances and to the dissipative losses not taken into account in the simulation.

Table 2: Comparison of previous band-stop designs with the proposed microstrip filter

Ref.	Stop-Band (GHz)	Size (mm^2)	ε_r/h_{sub} (mm)
[7]	2.2-2.31	50×26	2.2/0.508
[8]	2.82-4.0	16×15.4	4.4/1.5
[9]	8.1-9.64	15.7×2.4	2.4/0.508
[10]	4.05-8.0	15×10	2.2/0.635
[11]	12-17.51	23×10	2.3/0.787
This work	*3.1-10.6*	*15×10*	*2.2/0.635*

IV. CONCLUSION

In this paper, a novel design of band-stop microstrip filter has been presented. The proposed filter structure is designed based on Koch fractal geometry and modified DGS. Good insertion and return losses ($|S_{11}|$ and $|S_{21}|$) are introduced to the filter response from 3.1 to 10.6 GHz, which covers the UWB frequency range. The proposed filter is promising for use in wireless technologies for UWB communications due to their compact size and excellent performance.

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