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Design of Microstrip Bandpass Filter with different Substrates using Hilbert Fractal Geometry

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***Abstract*— In this paper, a microstrip band pass filter is designed with miniaturized size for the usage in modern wireless communication systems. This filter structure is designed particularly on Hilbert fractal geometries from 0th to 3rd iteration levels. Iterations are mainly done to reduce to size of the designed filter. The main objective of this paper is reduction in size and low cost fabrication. Generally, filters are designed for ISM band applications at the resonant frequency of 2.4GHz. This filter design uses a square patch at the centre and a perturbation element at the corner of the patch to provide dual mode configuration at the output. This design is carried out on three different substrates and the performance is evaluated by analyzing the insertion and return loss parameters. Each substrate has different thickness and dielectric constant values. The simulation result provides better performance and their harmonics are also suppressed.**

Keywords*— *Hilbert fractal geometry, Microstrip bandpass filter

I. INTRODUCTION

Microstrip band pass filter (BPF) is one the most essential component in microwave circuits. The narrow band microstrip band pass filter is important in transmission of the signal from the transmitter to the receiver in order to achieve high performance in terms of low insertion loss and high return loss. For an ideal filter, insertion loss should be zero and the return loss should be infinite. This condition could not be achieved in practical conditions. Band pass filters are most widely used in wireless applications as they are used to pass the signals in particular range of frequencies. The performance of each resulting Hilbert Fractal filters are analysed using a Computer Simulation Tool (CST). In addition, it has been found that, the 3rd iteration of Hilbert geometry provides higher order of harmonic suppression[1].

Recent development in wireless communication systems provides challenges in providing high selectivity components of miniaturized sizes. These challenges stimulate the filter designers to seek out for different fractal geometries [1].

Benoit Mandelbrot coined the term fractal in 1975 which was derived from a Latin word ‘Fractus’ which means broken or irregular fragments. Fractals comes under a geometry with two important properties namely, self similarity and space filling [2].

There are several fractal geometries like Hilbert, Koch, Minkowski, Sierpinski, Peano etc., which have been widely used in different RF and microwave applications in designing miniaturized fractal filters[3]. Microstrip lines are commonly used in all transmission line applications for better realization of active and passive devices in the microwave systems[4]. Microwaves are used to describe electromagnetic (EM) waves with certain frequencies and wavelength. Depending on the technology used, the frequency boundary between RF and microwave is arbitrary[5].

A perturbation element is formed at the corner of the inner patch to excite the pass band with two transmission zeros. As we increase the number of iterations, the resonant frequency gets moved towards the centre frequency [6].

In this paper, a microstrip BPF is designed based on Hilbert fractal geometry. A square patch with calculated dimension is incorporated at the center and a perturbation element is added at the corner of the square patch. This achieves better filter response and high selectivity. The design is carried out on three different substrates and finally, compared for better insertion loss and return loss along with bandwidth and fractional bandwidth calculations.

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II. FILTER DESIGN

A. *Hilbert Fractal Geometry*

The Hilbert curve was first introduce by David Hilbert. This is one of the most interesting fractal structures as it eventually covers the entire plane even after several iterations. The schematic of Hilbert fractal geometry in several iterations are shown in Fig 1. Hilbert structure is formed using multiple iterations. It satisfies the major property of self similarity. Every part of the fractal is similar. Another property is space filling i.e., it occupies the same space irrespective of several iterations. It is a simple geometric structure which is iterated infinite number of times yet the space remains same [7].

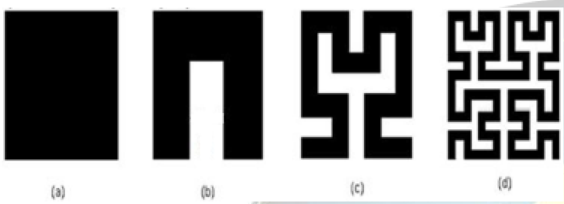


Fig. 1 Design of Hilbert fractal
(a) 0th iteration (b) 1st iteration (c) 2nd iteration (d) 3rd iteration.

B. *Design Methodology*

The bandpass filter with Hilbert fractal geometry has been designed on three substrates namely (RT/Duroid 6010, FR-4,RT/Duroid 5880). By increasing the iterations, the frequency has been shifted from 2.75 to 2.45 GHz (carried upto 3 iterations).

In order to construct a Hilbert fractal, start with the basic staple-like form. For increasing the iteration levels, this structure is made three copies. One is rotated 90° clockwise and the other is rotated 90° counter clockwise. The third is moved in *x*-axis [8]. Combining the three copies makes the next iteration. This method is processed again for further more iterations, as shown in Fig. 2.

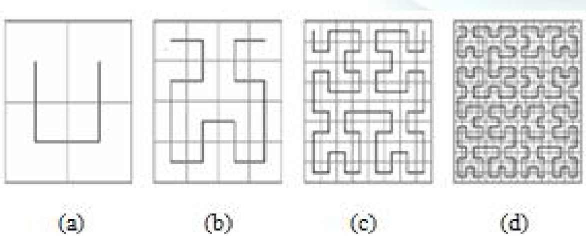


Fig. 2 Hilbert fractal curve
(a) level 0 (b) level 1 (c) level 2 (d) level 3

III. SIMULATION AND RESULTS

A. *Design using RT/Duroid 6010*

The design of Hilbert fractal filter for zeroth iteration is shown in Fig. 3. The substrate used here is RT//Duroid 6010 with a thickness of about 1.27mm and dielectric constant of 10.2 and a loss tangent of 0.0023 (tan δ). The size of the patch is common for all iterations 17x17 mm^2. Here, the input and the output ports are placed at 90 degrees opposite to each other. Iterations are continued till centre frequency is achieved.

The length of the square microstrip patch resonator, L_0, has to be calculated from,

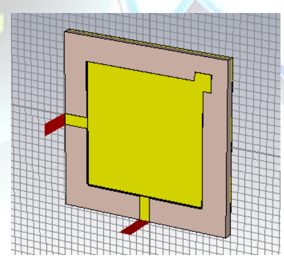
$$L_0 = 0.4\,\lambda_g, \tag{1}$$

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{r\,eff}}} \tag{2}$$

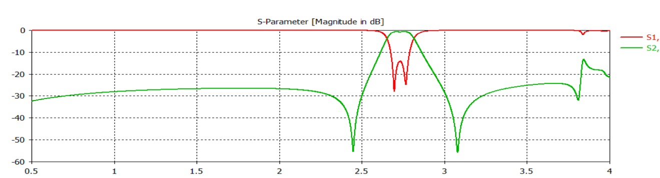
where $c = 3\times10^8$ m/s, λ_g is the guided wavelength and ε_{reff} is the effective dielectric constant [5] given by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} \tag{3}$$

The zeroth iteration starts with a ground structure made of copper, above which RT/Duroid substrate is implemented. Then, the patch with perturbation element is added. Port values are assigned and optimized for better results.



(a) Layout



(b) Simulated frequency response

Fig. 3 Zeroth iteration of Hilbert fractal filter using RT/Duroid 6010

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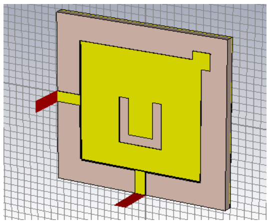

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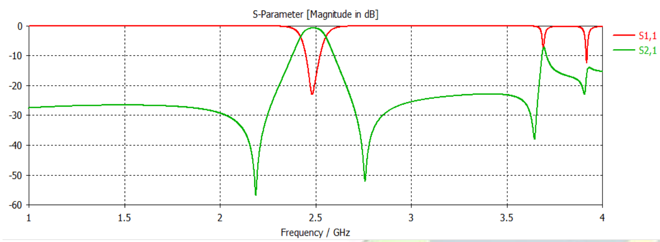
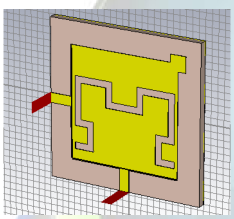


(b) Simulated frequency response

Fig. 4 First iteration of Hilbert fractal filter using RT/Duroid 6010



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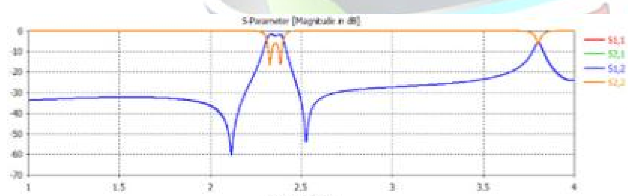


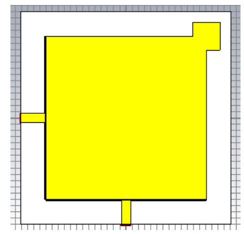
(b) Simulated frequency response

Fig. 5 Second iteration of Hilbert fractal filter using RT/Duroid 6010

Figures 4 and 5 show the design and simulation of first and second iterations of Hilbert fractal bandpass filter. It is seen that there is a shift in the centre frequency as the iteration increases. Return loss and insertion loss parameters are simulated. Similarly, the same design is carried out for FR-4 substrate and parameters are evaluated.

C. Design using FR-4

The structure is similar but with a different substrate thickness of 1.6mm and relative permittivity of 4.4 with the loss tangent of 0.025(tan δ). The size of the patch is $26x26mm^2$. The perturbation element is added at the corner with the size of 3.6mm. The zeroth iteration of Hilbert fractal using FR-4 substrate is shown in Fig. 6. Then the design is simulated to obtain the insertion loss and return loss parameters. The first and second iteration of FR-4 substrate are illustrated in Fig.7 and Fig.8 respectively,



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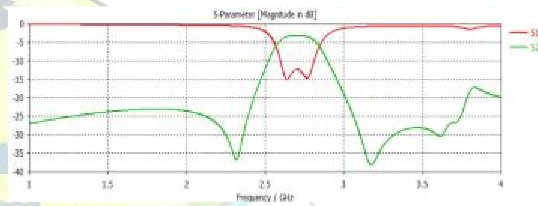
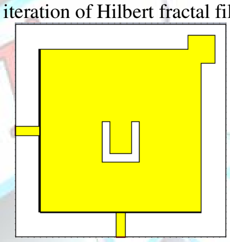


(b) Simulated frequency response

Fig. 6 Zeroth iteration of Hilbert fractal filter using FR-4



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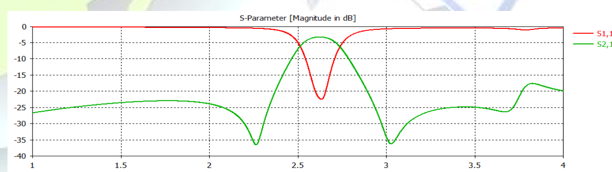
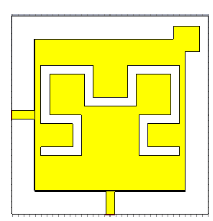


(b) Simulated frequency response

Fig. 7 First iteration of Hilbert fractal filter using FR-4



(a) Layout

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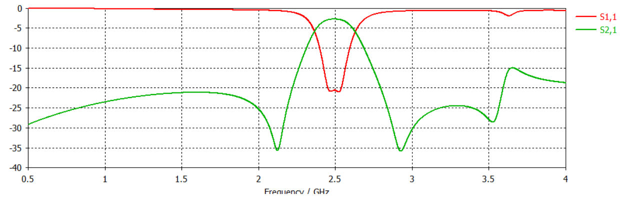
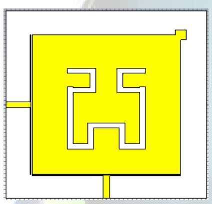


(b) Simulated frequency response

Fig. 8 Second iteration of Hilbert fractal filter using FR-4

D. Design using RT/Duroid 5880

The design of Hilbert fractal filter using RT/Duroid 5880 substrate is shown in Fig. 9. The thickness of the substrate is 0.5808mm, with the relative permittivity of 2.22 and a loss tangent of 0.0023 (tan δ). The size of the patch is 17.2x17.2 mm^2 and it is common for all iterations. Similarly, the third iteration of RT/Duroid 5880 is designed and simulated, as shown in Fig. 10.



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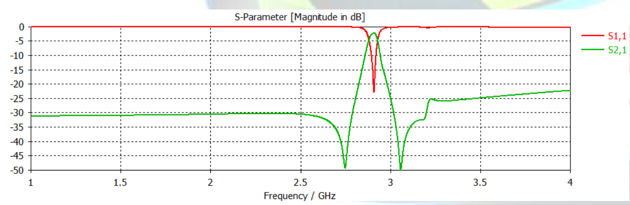
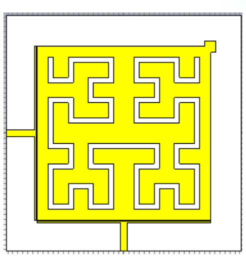


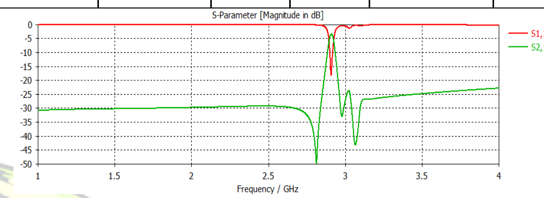
(b) Simulated frequency response

Fig. 9 Second iteration of Hilbert fractal filter using RT/Duroid 5880



(a) Layout

RT/Duroid 5880 substrate					
Iteration	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
0^{th} iteration	2.90	-11.03	-2.94	54	1.86
1^{st} iteration	2.9	-31.8	-2.27	50	1.72
2^{nd} iteration	2.9	-22.15	-2.22	72	2.41
3^{rd} iteration	2.88	-17.41	-3.2	65	2.25



(b) Simulated frequency response

Fig. 10 Third iteration of Hilbert fractal filter using RT/Duroid 5880

Substrate	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
RT/Duroid 6010	2.37	-25	-0.9	100	4.34
FR-4	2.4	-20.5	-2.7	320	13.33
RT/Duroid 5880	2.9	-22.15	-2.22	72	2.41

The design is simulated using CST software tool for Hilbert fractal geometry microstrip bandpass filter and their performances are compared for three substrates, namely, RT/Duroid 6010, RT/Duroid 5880 and FR4.

IV Filter Performance and Comparison

The structure of Hilbert fractal filter is designed using three different substrates and their performance is evaluated with respect to their insertion and return loss parameters. The corresponding values with different substrates are tabulated in Table 1, Table 2 and Table 3. The performance of the dual mode band pass filter with Hilbert fractal geometry is better in RT/Duroid 6010 substrate as compared to FR-4 substrate. As the iteration increases, the centre frequency moves towards the desired frequency (2.45GHz). Due to different dielectric constant and the thickness values for the substrate, the insertion and return loss values may vary. Generally, band pass filter passes the signal

FR-4 substrate					
Iteration	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
0^{th} iteration	2.70	-12.5	-3.15	280	10.37
1^{st} iteration	2.62	-22.4	-3.32	240	9.16
2^{nd} iteration	2.4	-20.5	-2.7	320	13.33

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at pass band and attenuates at stop band frequency. Hence, they are very much interested in the usage of wireless communication applications. The degree of coupling mainly depends on the size of the perturbation element. By optimising the size and position of the perturbation, better results could be achieved. Table 4 lists the comparison of Hilbert fractal geometry at second iteration for different substrates.

TABLE 1 FILTER PERFORMANCE OF RT/DUROID 6010

TABLE 2 FILTER PERFORMANCE OF FR-4

TABLE 3 FILTER PERFORMANCE OF RT/DUROID 5880

TABLE 4 COMPARISON OF FILTER PERFORMANCE

A. *Current density distribution*

Figure 11 shows the current density distribution of microstrip dual mode band pass filter using CST tool. The current density distribution shown here is simulated for RT/Duroid 5880 substrate in its 3rd iteration. The current densities do not uniformly distribute in the electrode surfaces. Areas with high current density are shown in red colour and that with blue are having low current density.

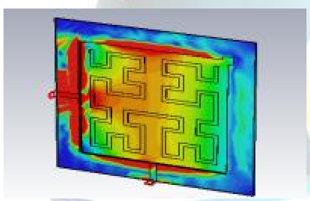
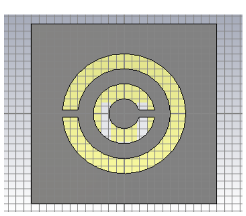


Fig. 11 Current density distribution of third iteration Hilbert fractal filter

A. *CSRR ground structure*

Complementary split ring resonators are used for harmonic suppression and also to achieve dual band frequencies in the output of the filter. It is one of the Defected Ground Structure (DGS) used to modify the ground plane. By using DGS, the filter performance is improved and the selectivity is enhanced. The single cell and multi cell CSRR structures in the ground plane of Hilbert fractal filter for FR-4 substrate are shown in Fig. 12 and Fig. 13, respectively.



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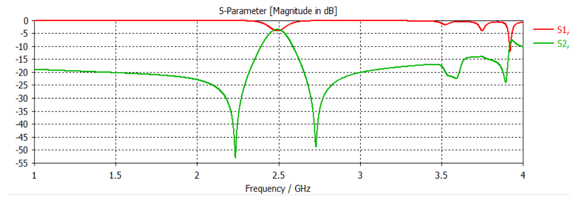
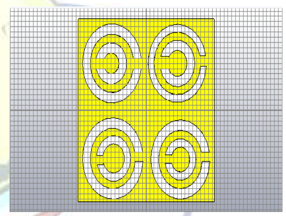


(b)Simulated frequency response

RT/Duroid 6010 substrate					
Iteration	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
0th iteration	2.75	-14	-0.8	170	6.18
1st iteration	2.46	-21	-0.8	110	4.47
2nd iteration	2.37	-25	-0.9	100	4.34

Fig. 12 Single CSRR structure in FR-4



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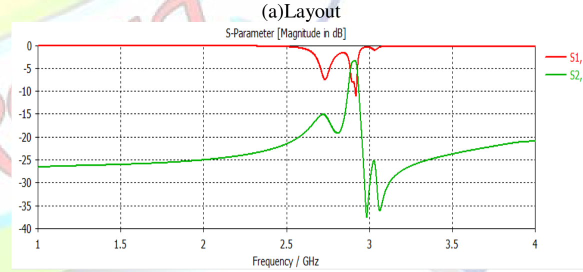

(b)Simulated frequency response

Fig. 13 Multi CSRR in FR-4

V CONCLUSION

A micro strip band pass filter based on Hilbert fractal geometry is designed and simulated. The filter is designed using three different types of substrates namely RT/Duroid 6010, 5880 and FR4. The length of micro strip patch is calculated using the thickness and dielectric constant of the substrate. The performance of the filter is evaluated using the S parameters. For an ideal filter, the insertion loss should be zero and return loss should be infinite. Among the three substrates, RT/Duroid 6010 provides better filter performance with minimum insertion loss, maximum return loss and good harmonic suppression.

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