Design of Sierpinski fractal microstrip bandpass filter on different substrates

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***Abstract*: In this paper, a dual mode microstrip bandpass filter is designed based on Sierpinski fractal geometry. The filter design uses the square patch and also a perturbation element is added at the corner of the patch for dual mode configuration. The main objective of the dual mode design is to reduce the size of the filter and to fabricate easily. By using the fractal geometry, the design can achieve high selectivity and strong coupling. The design is made on three substrates (RT/Duroid 6010, 5880 and FR-4) and their performance is simulated for return loss and insertion loss. The design process is continued up to 3rd iteration of Sierpinski fractal in order to achieve the center frequency at 2.4GHz, which can be used for WLAN applications. In order to suppress the harmonics and to improve the performance of the filter, complementary split ring resonator (CSRR) structure is implemented in the ground plane. The simulation results show the performance of the Sierpinski fractal bandpass filter with better frequency response and high selectivity.**

Keywords: Sierpinski fractal geometry; bandpass filter; CSRR DGS.

I. INTRODUCTION

In the modern wireless communication systems, the narrowband microstrip bandpass filters play an important role to transmit the signal between the transmitter and receiver. In order to achieve the better performance of the filter, the filter should be in small size and easy to fabricate. Filters are considered as two-port network (input port and output port). They are used to control the frequency response. The most widely used filter in microwave applications is the bandpass filter. The main aim of the bandpass filter is used to pass the signals in the desired range of frequencies [1].

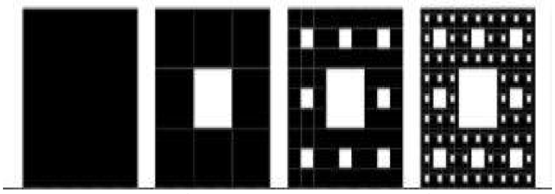
Fractals are defined either as random or deterministic. Fractals have two unique properties: space filling and self-similarity [2]. There are several fractal geometries such as Koch, Hilbert, Sierpinski, Minkowski, Peano, etc., which have been used widely in a variety of RF and microwave applications, such as in the design of miniaturized fractal filters [3].

The fractal filter provides better performance when compared to the non-fractalized filters. The filter is designed for the center frequency of 5.33GHz [4]. The perturbation element is formed at the inner corner in order to excite the passband with two transmission zeroes [5]. The resonant frequency will be move towards the lowest frequency when the number of iteration increases [6].

In this paper, the dual mode BPF is designed by using a 3rd order Sierpinski fractal geometry. The perturbation element is added at the corner of the microstrip patch in order to achieve the dual mode frequency response. The same design has been carried out for different substrates and the performance of the filter is compared with the simulation results of insertion loss and return loss. Compared to RT/Duroid 6010 and 5880, FR-4 is easily available with low cost to fabricate. And finally, the CSRR is designed in the ground plane of the filter.

II. DESIGN METHODOLOGY

Microstrip bandpass filter with Sierpinski fractal geometry has been designed on three different substrates (RT/Duroid 6010, FR-4, RT/Duroid 5880). The frequency is shifted from 2.75 to 2.4GHz by increasing the iteration (the design continues up to 3rd iteration). The schematic illustration of Sierpinski fractal geometry [2] for different iterations is shown in Fig. 1.



(a) (b) (c) (d)

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

A) *Design using RT/Duroid 6010*

The input port and output port are placed orthogonal to each other in the Sierpinski fractal filter. The layout and simulated frequency response of Sierpinski fractal filter from zero to third iteration using RT/Duroid 6010 substrate are shown in Figs. 2 to 5. The thickness of the substrate is 1.27mm, with the relative permittivity of 10.2 and a loss tangent of 0.0023 (tan δ). The size of the patch is common for all iterations 17 x 17 mm^2. The design will be continued till it achieves the center frequency.

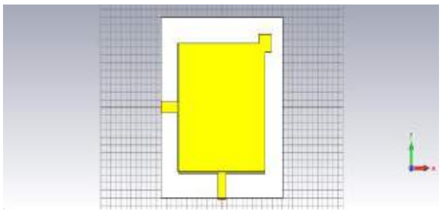
The size of the patch has been calculated from the below formula,

$$L = 0.4\lambda_g \quad (1)$$

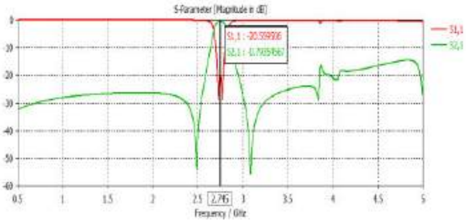
and
$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{reff}}} \quad (2)$$

where $c = 3\times10^{8}$ m/s, λ_g is the guided wavelength and ε_{reff} is the effective dielectric constant [7] given by,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} \quad (3)$$

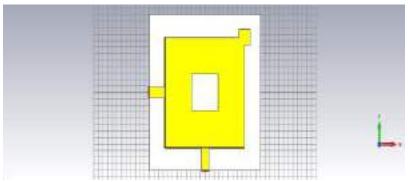


(a) Layout



(b) Simulated frequency response

Fig. 2 Zeroth iteration of Sierpinski fractal filter



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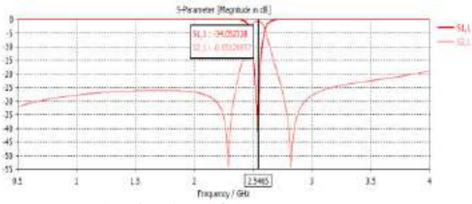
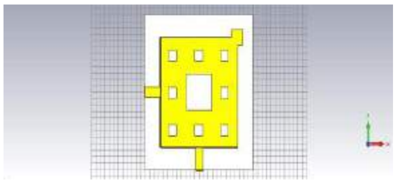


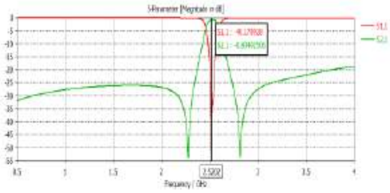
(b) Simulated frequency response

Fig. 3 First iteration of Sierpinski fractal filter

The size of the filter is reduced while the design is carried out using fractal geometry compared to non-fractalized filter. The frequency has been shifted in order to achieve the center frequency. Then, the same Sierpinski fractal structure is designed using FR-4 and RT/Duroid 5880 substrates from 0th iteration to 3rd iteration. Finally, the simulated frequency response is compared among these substrates.

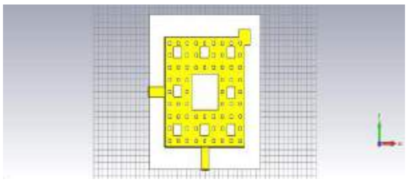


(a) Layout

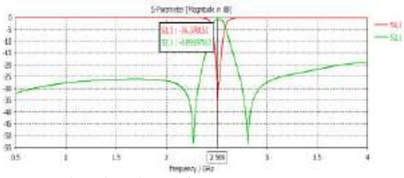


(b) Simulated frequency response

Fig. 4 Second iteration of Sierpinski fractal filter



(a) Layout

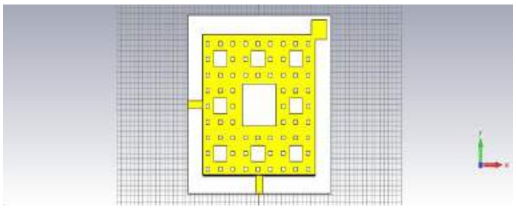


(b) Simulated frequency response

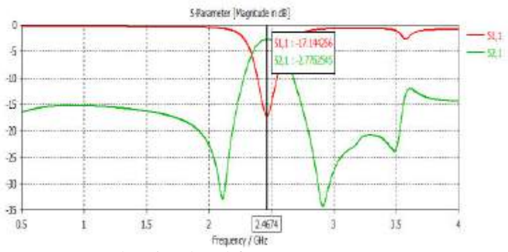
Fig. 5 Third iteration of Sierpinski fractal filter

B) Design using FR4

The design is carried out using FR4 substrate with the thickness of 1.6mm. The relative permittivity of the substrate is 4.4 with the loss tangent of 0.025(tan δ). The size of the patch is 26 x 26mm^2. The perturbation element is added at the corner with the size of 3.6mm. The layout and the simulated frequency response of Sierpinski fractal filter using FR4 for 3rd iteration is shown in Fig. 6. Then, the design is simulated to obtain the insertion loss and return loss.



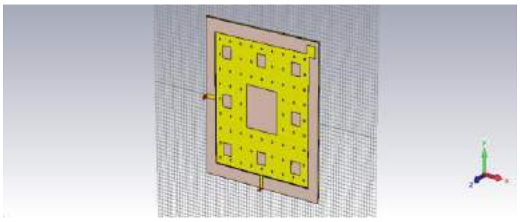
(a) Layout



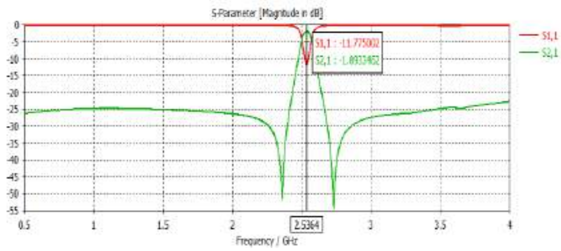
(b) Simulated frequency response
Fig. 6 Third iteration of Sierpinski fractal filter

C) Design using RT/Duroid 5880:

The design is carried out using *RT/Duroid 5880* substrate with the thickness of 0.5808mm. The relative permittivity of the substrate is 2.2 with the loss tangent of 0.025(tan δ). The size of the patch is 34.4 x 34.4mm^2. The perturbation element is added at the corner with the size of 3mm. The layout and the simulated frequency response of Sierpinski fractal filter using *RT/Duroid 5880* for 3rd iteration is shown in Fig. 7. Then, the design is simulated to obtain the insertion loss and return loss.



(a) Layout



(b) Simulated frequency response
Fig. 7 Third iteration of Sierpinski fractal filter

The performance of the filter has been simulated and analyzed. From this designed structure and with the help of center frequency, return loss, insertion loss, the bandwidth and the fractional bandwidth can also be calculated. Table 1, 2 and 3 shows the performance of the filter in three substrates.

TABLE 1 FILTER PERFORMANCE OF RT/DUROID 6010

RT/Duroid 6010					
Iteration	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
0th iteration	2.74	-20.7	-0.79	140	5.09
1st iteration	2.54	-34.0	-0.85	130	5.1
2nd iteration	2.52	-40.1	-0.83	140	5.5
3rd iteration	2.50	-36.3	-0.89	130	5.2

TABLE 2 FILTER PERFORMANCE OF FR4

FR-4					
Iteration	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW(%)
0th iteration	2.73	-17.1	-3.15	280	10.2
1st iteration	2.52	-25.5	-3.05	250	9.92
2nd iteration	2.50	-55.3	-3.13	240	9.6
3rd iteration	2.46	-17	-2.85	240	9.7

TABLE 3 FILTER PERFORMANCE OF RT/DUROID 5880

RT/Duroid 5880					
Iteration	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
0th iteration	2.92	-13.0	-1.17	110	3.7
1st iteration	2.59	-19.5	-1.32	80	3.0
2nd iteration	2.55	-16.8	-1.41	80	3.1
3rd iteration	2.50	-11.7	-1.89	80	3.2

III. COMPARISON OF FILTER PERFORMANCE

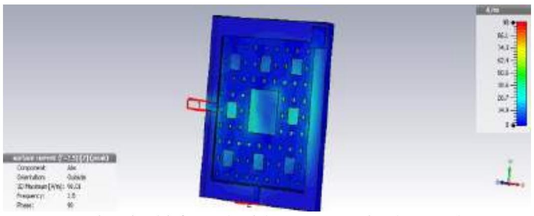
The layout of Sierpinski fractal designed on different substrates is compared with simulated frequency response, starting from 0th iteration to 3rd iteration. Due to the high dielectric constant and the thickness of the substrate, the insertion loss and return loss may vary. Mainly, the bandpass filter is used for passing the signal at passband and attenuates at stopband. So, the design of microstrip bandpass filter using the fractal geometry is used widely in wireless communication systems. The main purpose of comparing the result is to identify the filter with good coupling factor and high selectivity. The comparison results of the Sierpinski fractal BPF for third iteration are shown in Table 4.

TABLE 4 PERFORMANCE COMPARISON BETWEEN SUBSTRATES

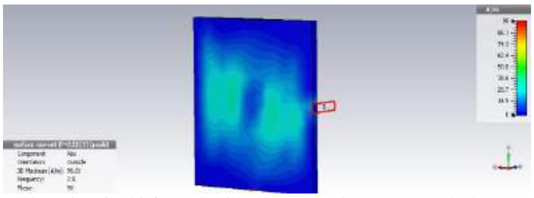
Substrate	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)	Bandwidth (MHz)	Fractional BW (%)
RT/Duroid 6010	2.5	-36.3	-0.8	130	5.2
FR-4	2.46	-17	-3.1	240	9.7
RT/Duroid 5880	2.5	-11.7	-1.8	80	3.2

IV. DEFECTED GROUND STRUCTURE

In order to enhance the performance of the filter, defected ground structure has been used. Some of the defects or etched parts in the ground plane have been considered as the DGS. It is mainly used to suppress the higher order harmonics and for stronger coupling. There are different shapes in defected ground structure. DGS has been used in the field of microstrip bandpass filter for enhancing the bandwidth of the filter and also to suppress the harmonics. The principle behind the DGS is that it has been integrated on the ground plane. The defects or etched slots will disturb the current distribution in the ground plane. These disturbances in the ground plane may change the characteristics of the filter. The current distribution of Sierpinski fractal geometry based on microstrip BPF in the patch and the ground plane without CSRR using FR4 has been shown in Fig. 8. The simulated response of the filter is shown in terms of insertion loss and return loss. The presence of higher order harmonics has been shown in the response given in Fig. 9.



(a) Sierpinski fractal without CSRR in the patch



(b) Sierpinski fractal without CSRR in the ground plane
Fig. 8 Current distribution of third iteration

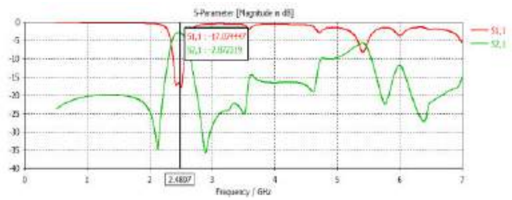
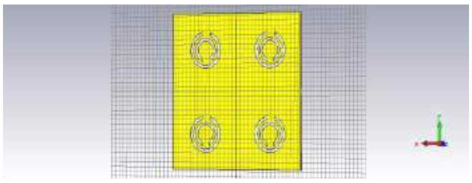
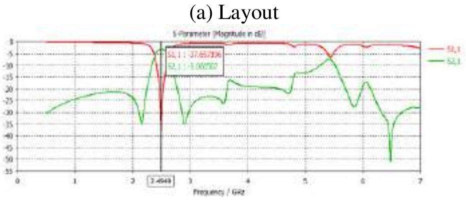


Fig. 9 Simulation result of third iteration without CSRR

By analyzing the current distribution, complementary split ring resonator is designed in the ground plane of the Sierpinski fractal BPF to improve the filter performance and to suppress the harmonics. The layout and the simulated frequency response is shown in Fig. 10.

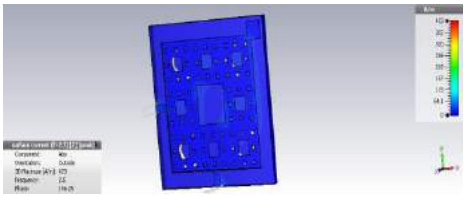


(a) Layout

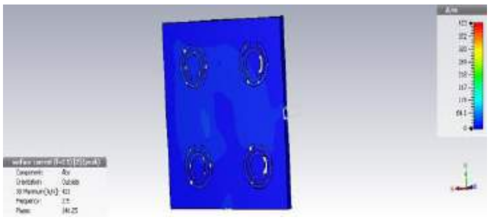


(b) Simulated frequency response
Fig.10 Third iteration of Sierpinski fractal with CSRR

After the integration of CSRR in the ground plane, the current distribution in the patch and the ground plane has been analyzed and it is shown in Fig .11.



(a) Sierpinski fractal with CSRR in the patch



(b) Sierpinski fractal with CSRR in the ground plane
Fig. 11 Current distribution of third iteration

The CSRR defected ground structure has been designed in the ground plane. Then, the current distribution changes the performance of the filter and the higher order harmonics were reduced as shown in Fig. 10. The response of the filter without CSRR is compared with the filter designed with CSRR DGS integrated in the ground plane. The performance has been tabulated and shown in Table 5.

Table 5 COMPARISON OF SIERPINSKI FILTER WITH AND WITHOUT CSRR

Sierpinski filter	Center frequency (GHz)	S_{11} (dB)	S_{21} (dB)
Without CSRR	2.46	-17.09	-3.13
With CSRR	2.5	-32.21	-3.07

V. CONCLUSION

The Sierpinski fractal BPF has been designed with the center frequency of 2.4GHz using three different substrates namely, RT/Duroid 6010, 5880 and FR-4 in the S-band range for wireless applications. The design is continued upto 3rd iteration to achieve the center frequency and the perturbation element is added at the corner to obtain the dual mode frequency response. The main advantage of the fractal geometry is compact size, high selectivity, better insertion loss and return loss compared to non-fractalized filters. Finally, the simulated frequency response has been compared for different substrates.

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