A Novel Design of Two Loosely Coupled Bandpass Filter Based on Hilbert-zz Resonator with Higher Harmonic Suppression

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***Abstract*— New characteristics of fractal design scheme has been introduced to generate compact two poles capacitively coupled microstrip bandpass filter by using additional coupling stubs for different wireless applications. The presented fractal scheme is based on specific type of Hilbert space-filling curve which is called Hilbert-zz fractal geometry. The performance of generated bandpass filter structure has been analyzed using Sonnet software package with a relative dielectric constant of 9 and a substrate thickness of 1.27 mm. Results show that these filters possess good transmission and return loss characteristics, besides higher harmonics suppressions; meeting the specifications of most of wireless communication systems.**

Keywords*: *Microstrip bandpass filter (BPF), Hilbert-zz fractal curve, filter miniaturization, narrow-band bandpass filter.

I. INTRODUCTION

An analogue bandpass filter (BPF) is a two port network which can be defined in terms of scattering parameters, S-parameters. Bandpass filter works by allowing signals in a specific band of frequencies to pass, while signals at all other frequencies are stopped. Bandpass filter is important component in microwave circuits. For the reasons of the size requirements of recent microwave communications systems, miniaturized microwave BPFs with narrowband are in high demand . Filters using various miniaturized planar and patch resonators such as the open loop, miniaturized hairpin, stepped-impedance and half-wave resonators have been proposed for either performance improvement or compactness [1].

Fractals were first defined by Mandelbrot in [2] as a way of classifying structures whose dimensions were not whole numbers. These geometries have been used previously to characterize unique occurrence in nature that where difficult to define with Euclidean geometries, including the length of coastline, density of clouds, and the branching of trees [2].The term fractal is derived from the Latin word fractus, which means broken or irregular fragments [3]. Therefore, there is need for a geometry that handles these complex shapes better than Euclidean geometry, where the Euclidean geometry have a whole number of dimensions, such as a one dimensional line, or two dimensional planes...etc.

In antennas, filters and microwave circuit designs, the use of fractal shapes makes the operational frequency of component which depends on the ratio of the electromagnetic signal's wavelength to the physical size of the component independent of its scale. This means that a fractal device structure can be constructed in small sizes, yet possessing a broad frequency range. The reason why the fractal design of antennas and filters appears as an attractive way to make these devices is two reasons; firstly because one should expect a self-similarity especially for antennas (which contains many copies of itself at several scales) to operate in a similar way at several wavelengths. Secondly, because the space-filling properties of some fractal shapes (the fractal dimension) might allow fractally shaped small devices to take better advantage of the small surrounding space [4,5].

Research results showed that, due to the increase of the overall length of microstrip line on a given substrate area as well as to the specific line geometry, using fractal curves may decrease resonant frequency of microstrip resonators, and gives narrow band responses[4,5].

Hilbert fractal curve has been used as a defected ground structure in the design of a microstrip lowpass filter operating at the L-band microwave frequency [6]. In 2005, Barra *et. al*, [7], had designed and fabricated highly miniaturized superconducting filters, by using novel resonators based on fractal layouts. His attention has been focused on Hilbert space filling curves. He has explored the miniaturization levels achievable by these resonators, emphasizing the parameters

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which allow obtaining a good trade-off between compact size and losses. Several four pole filter prototypes, with Chebychev and quasi elliptic responses, have been designed and fabricated. The modified cross-coupled spiral resonators with Hilbert configuration have been introduced for a large coupling coefficient in [8]. For comparison, the conventional cross-coupled spiral resonators are fabricated and measured herein.

A proposed microstrip bandpass filter for wireless communication has been reported in [9]. This filter is realized by using fractal shaped resonator which is etched on the bottom metal layer of the microstrip. The resonant characteristic of the fractal shaped defected grounded structure resonator is studied. Couplings between the defected grounded structure resonators and input/output port are also extracted. Then a two-pole bandpass filter is designed using the proposed fractal shaped defected ground structure resonator.

In [10], an investigation on the design of miniaturized substrate integrated waveguide unit cell loaded with Hilbert curve fractal slots. It has been found that the proposed structures exhibit a passband which is well below the cut-off frequency of the substrate integrated waveguide and hence, can be used in the design of miniaturized filter. Different orientations of the Hilbert curve are investigated and an optimum orientation which gives the best passband response is found.

In this paper, a new narrow band bandpass filter based on Hilbert zz fractal geometry has presented. The resulting filter has smaller size as compared with the classical Hilbert curve; besides it offers satisfactory return loss and transmission responses as well as higher harmonic suppression in the out-of-band responses.

II. HILBERT AND HILBERT -zz FRACTAL CURVES

Fig. 1 shows the first few iterations of Hilbert curves. It can be noticed that each successive stage consists of copies of the previous, connected with additional line segments. This geometry is a space- filling curve, since with a larger iteration, one may think of it as trying to fill the area it occupies. This geometry has self avoidance as the line segments do not intersect each other, simplicity since the curve can be drawn easily and distinguished self- similarity.

The fractal curve is fit in a square section of S as external side. For a Hilbert resonator, made of a thin conducting strip in the form of the Hilbert curve with side dimension S and order k, the length of each line segment d and the sum of all the line segments $L(k)$ are given by [7,11] :

$$L(k) = (2^k + 1)S \tag{1}$$

Both dimensions w and g are connected with the external side S and iteration level k by:

$$S = 2^k (w + g) - g \tag{2}$$

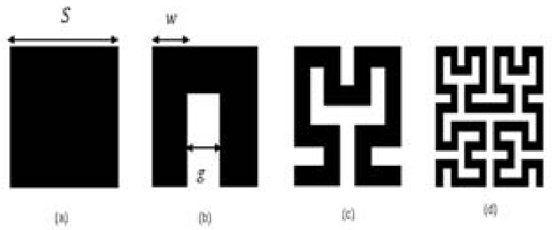

Fig.1 . Hilbert iteration; (a) Original, (b) 1st iteration, (c) 2nd iteration and (d) 3rd iteration

A space-filling curve (SFC) may be adjusted over a flat or curved surface, and due to the angles between segments, the physical length of the curve is always greater than that of any straight line that can be fitted in the surface. SFC is a curve that is large in terms of total strip length but small in terms of the area in which the curve can be included[7,11].

Fig.2 shows some specific types of reported Hilbert space filling curves which are called Hilbert zz set. The dimension of a fractal provides a detail of how much a space it fills. It is a measure of the weight of the irregularities when viewed at miniaturized scales. By the way, it can be implied from these fractal configurations, the new set has greater physical lengths as compared to fractal shapes of Fig.1 and hence more miniaturization possibilities for designing RF and Microwave microstrip filters [12].

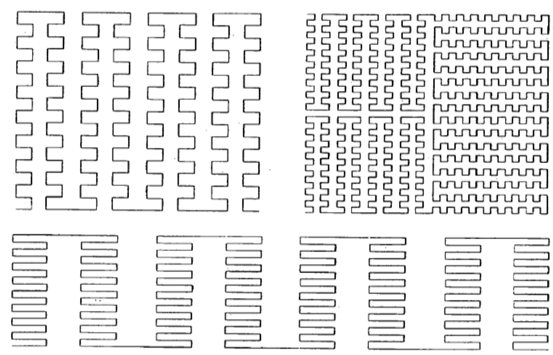

Fig.2 . Hilbert zz space filling curves

III. FILTER DESIGN

Firstly, a single resonator based on Hilbert-zz fractal geometry, has been designed at a frequency of 2.4 GHz. It has been supposed that the filter structure has been etched using a substrate with a relative dielectric constant of 9 and a substrate thickness of 1.27 mm. The resulting resonator dimensions have been found to be 3.34 × 3 mm^2 and a trace width of about 0.1 mm and gap between strips of about 0.09 mm. The output response offered by this resonator is useless to be introduced here. The same resonator with depicted dimensions and substrate specifications has been

used to build a two-resonator microstrip bandpass filter. The topology of this filter is shown in Fig.3. The overall dimensions of this filter are of 6.74 × 3 mm^2. To enhance a suitable capacitive coupling between the resonators, stubs have been added to each resonator. These stubs will increase the overall length of the resonators making it resonates at a lower frequency. It has been found that this stub provides a suitable means to make the resonator resonates at the design frequency when modeling it in the Sonnet EM simulator [13]. In this case, the field solver will compute the same resonant frequency for both resonators.
The guided wavelength, λ_g, can be calculated from following equation [1,14]:

$$\lambda_g = \frac{\lambda_\circ}{\sqrt{\varepsilon_{re}}} \tag{3}$$

where $\lambda_\circ$ is operating wavelength at the design frequency, and ε_{re} is the effective dielectric constant, given by [14], as:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} \tag{4}$$

The total strip length and side length of Hilbert-zz resonator of Fig.3 without additional stub can be calculated as:

$$L = 264f + 7g \tag{5}$$

$$S = 4(2f+g) + 3g \tag{6}$$

where $f = 2w+g$, is initial drawn strip during modeling. On the other hand, the total curve length in the case of existing coupling stub can be calculated by:

$$L = 264f + 7g + S + r \tag{7}$$

where r is the connecting segment between Hilbert-zz resonator and coupling stub.

It is found that the bandpass filter based on Hilbert-zz fractal resonators offers a higher degree of miniaturization, as compared to 2nd and 3rd iteration of the conventional Hilbert fractal resonators due to its higher packaging capabilities. Also, this filter possesses a noticeable compactness over the conventional half-wavelength resonator filter [15].

IV. Performance Evaluation

Filter structure, depicted in Fig.3, has been modeled and analyzed at an operating frequency, in the ISM band, of 2.4 GHz using Sonnet electromagnetic simulator.

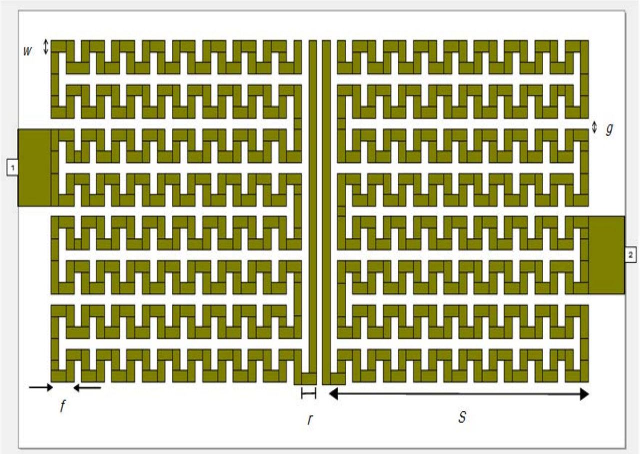

Fig.3 . The modeled layout of Hilbert zz resonators BPF

The simulated responses of return loss, S11, and transmission, S21, responses of this filter are shown in Fig.4. In this figure, pass region has been allocated at a center frequency of 2.4 GHz with a bandwidth of 90 MHz , –10.4 dB return loss and –0.42 dB insertion loss .

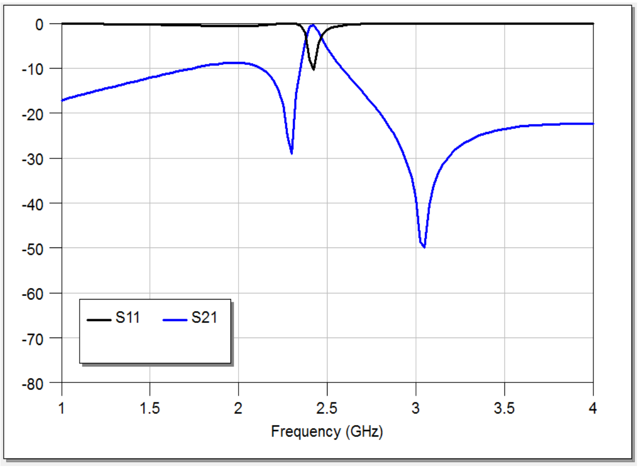

Fig.4 . The return loss and transmission responses of Hilbert zz fractal BPF designed for 2.4 GHz

This filter offers an adequate quasi-elliptic transmission response with transmission zeros that are asymmetrically located around 2.4 GHz.
The I/O ports positions and edge spacing are important parameters that motivate the resulting multi-resonator filter performance [16]. Figures 5 and 6 show the resulting filter responses corresponding to different values of the coupling stub length. It is clear, from these figures; the variation in stub lengths affects the resonant frequency, as well as its effect on the transmission zeros. It is also pointing that return loss values changed to levels from about –10.413 to –0.202 dB

and the insertion loss values differ from –0.404 to –13.222 dB that are with respect to *d* values from *d* = 3 mm down to *d* = 0 mm.

Fig. 7 shows the out-of-band responses of the two Hilbert-zz filters. It can be concluded from this figure, the output response has no tendency to support higher harmonics which conventionally accompany the bandpass filter performance.

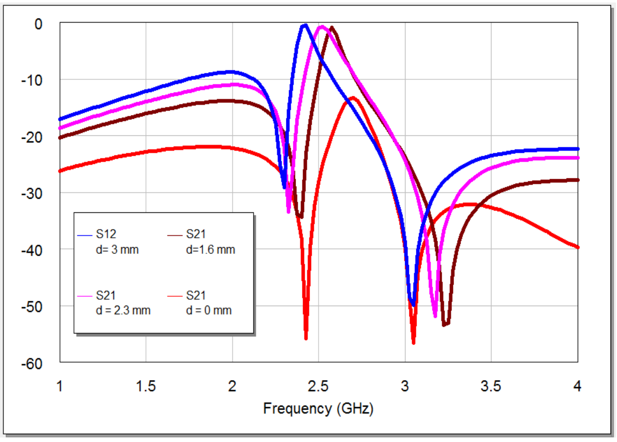

Fig.5 . The transmission responses (S21) of the filter structure based on Hilbert zz curve with respect to different stub lengths (d)

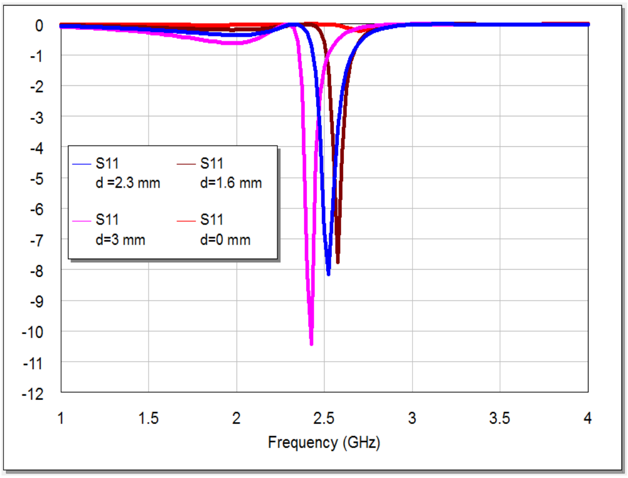

Fig.6 . The return loss responses (S11) of the filter structure based on Hilbert zz curve with respect to different stub lengths (d)

Figs. 8 and 9 demonstrate the surface current patterns on the conducting surface of both resonators at the design frequency where red color indicates higher coupling effect while blue indicates lower coupling effect.

It clear from these figures that only at the design frequency the effective modes are induced and coupled to each other leading to the required filter performance, whereas at the other frequency, no modes are excited as expected. In these figures, the same color visualization is used as an indication for the current densities. It is clear that highest current densities occur at the resonant frequency.

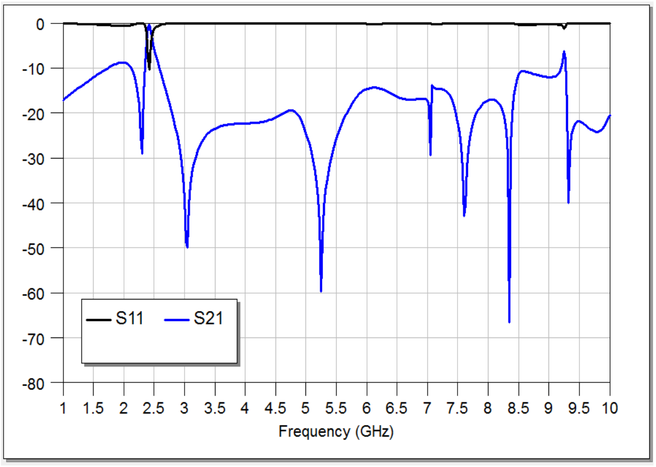

Fig.7. The out-of-band responses of the filter structure based on Hilbert zz curve with coupling stub as depicted in Fig.3

It is worth to mention that the filter dimensions can easily be varied according to the frequency requirements by choosing suitable *w* and *g* that control the side length and total strip length of fractal resonators.

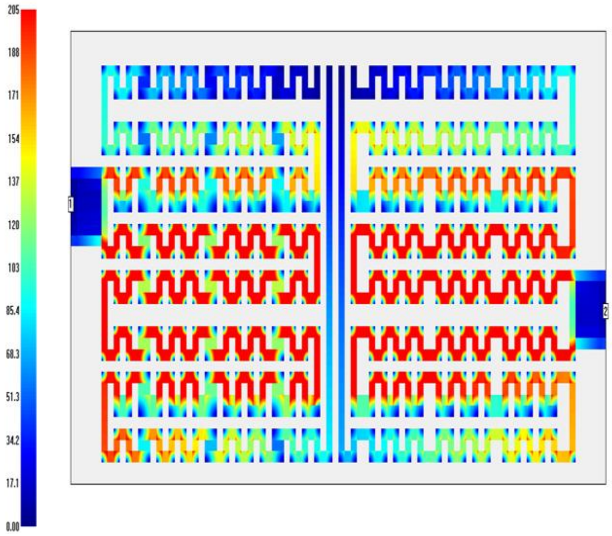

Fig.8 . Current density distribution at the conducting surface of stubbed Hilbert zz bandpass filter simulated at a resonant frequency of 2.4 GHz

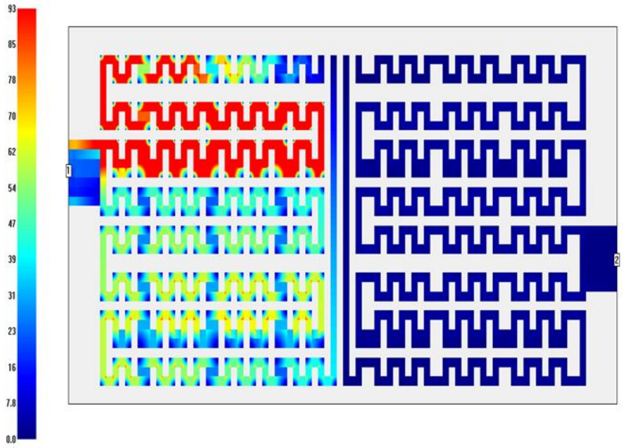

Fig.9. Current density distribution at the conducting surface of stubbed Hilbert zz bandpass filter simulated at a resonant frequency of 3 GHz

V. CONCLUSION

A new narrow band quasi elliptic two poles microstrip bandpass filter design for the purposes of modern wireless communication systems has been firstly introduced in this paper. The presented filter structure has been composed of dual coupled resonators which are based on Hilbert-zz fractal curve. The specific space-filling property for the proposed filter structure results in a high degree of miniaturization with reasonable passband performance. Also, the out of band of proposed filter structure doesn't enhance higher harmonic frequency orders which is most desired property for filter performance.

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