New Compact Bandpass Filter With Tuning Stubs Based on 2nd Iteration of Hilbert Fractal Geometry

Yaqeen S. Mezaal

Department of Computer Techniques , Al-Yermuk University College

Email: yakeen_sbah@yahoo.com

ABSTRACT

A novel design of miniaturized microstrip bandpass filter is presented for use in modern wireless communication systems. The proposed filter structure is composed of dual fractal-based microstrip resonators. The structure of each resonator is in the form of the Hilbert fractal curve geometry. Two single-mode resonators with structures based on the 2nd Hilbert fractal-shaped geometries have been modeled at a design frequency of 2.4 GHz (ISM Band). The resulting filter structures based on these resonators, show considerable size reduction compared with the other microstrip bandpass filters based on other space-filling geometries designed at the same frequency. Another set of bandpass filter designs based on the same resonators but with a tuning stub has been also presented, in an attempt to provide practically useful means to tune the filter to the specified performance with a considerable tuning range. The performance of the resulting filter structures has been evaluated using a method of moments (MoM) based software package, Microwave Office 2007, from Advanced Wave Research Inc. Results show that the proposed filter structures possess fine return loss and transmission responses besides the size reduction gained, making them suitable for use in a wide variety of wireless communication applications. Furthermore, performance responses show that the second set of filters, based on Hilbert shaped resonators support the 2nd harmonic suppression.

KEYWORDS:
Bandpass filter (BPF), Hilbert fractal curve, filter miniaturization, tuning Stubs

تصميم جديد لمرشح امرار نطاقي مصغرمبني على اساس منحني هلبرت الجزئي بامكانية التنغيم مبني على اساس التكرار الثاني للهندسه الجزئيه

يقين صباح مزعل

قسم هندسة تقنيات الحاسبات / كليه اليرموك الجامعه

الخلاصة

يعرض في هذا البحث تصميم جديد لمرشح امرار نطاقي مصغر الحجم للاستخدام في انظمة الاتصالات الحديثة. ان بناء المرشح المقترح يتألف من مرنانين من نوع الشريحة الدقيقة شكلهما مبني على اساس الترتيب الهندسي الجزئي لمنحني هلبرت. تم تصميم عدة مرشحات ذات مرنانات تتبع شكل منحني هلبرت للتكرارت المختلفة حتى التكرار الثاني. اظهرت المرشحات الناتجة انها تمتلك تخفيضا كبيرا بالحجم مقارنة بالمرشحات الاخرى المبنية على اساس المرنانات الاخرى المالئة للفراغ المصممة عند التردد نفسه. وجرى كذلك تصميم مجموعة اخرى من المرشحات تستخدم المرنانات السابقة نفسها ولكن باضافة عنصر تنغيم في محاولة لتوفير اداة للمصمم للوصول الى الاداء النهائي للمرشح دون اللجوء الى اعادة تصميمه. تم اجراء حسابات الاداء لجميع المرشحات باستخدام الحقيبة البرمجية (MWO 2007) من شركة (AWR) **التي تجري المحاكاة الكهرومغناطيسية على** وفق طريقة إيجاد العزوم. **بينت نتائج المحاكاة ان المرشحات المقترحة ذات اداء جيد بالاضافة الى التخفيض المتحقق بالحجم كما انها توفر وسيلة تنغيم واخمادا للتوافقيات الثانية مما يجعلها مناسبة للاستخدام في تطبيقات الاتصالات الحديثة المختلفة.**

INTRODUCTION

Fractal geometry has found extensive applications in almost all the fields of science and art, since the pioneer work of Mandelbrot about three decades ago [Mandelbrot, 1983]. Among these fields are the physical and engineering applications. In electromagnetics, fractal geometries have been applied widely in the fields of antenna and passive microwave circuit design, due the fantastic results gained in the miniaturization and the performance as well. Bandpass filter (BPF) is one of the most important components in microwave circuits. To meet the size requirement of modern microwave communications systems, compact microwave BPFs with narrowband is in high demand. Recently, there has been an increasing interest in planar BPFs due to their ease of fabrication. Filters using various planar resonators such as the open loop, miniaturized hairpin, stepped-impedance, quarter-wave, and quasi-quarter-wave resonators have been proposed for either performance improvement or size reduction.

Dramatic developments in wireless communication systems have imposed new challenges to design and produce high selectivity miniaturized components. These challenges stimulate microwave circuits and antennas designers to seek out for solutions by investigating different fractal geometries [Chen, *et.al,* 2007, Xiao, *et.al*, 2007, Wu, *et.al*, 2008].

Different from Euclidean geometries, fractal geometries have two common properties, space-filling and self-similarity. It has been shown that the space-filling property of fractals can be utilized to reduce filter size. Research results showed that, due to the increase of the overall length of the microstrip line on a given substrate area as well as to the specific line geometry, using fractal curves reduces resonant frequency of microstrip resonators, and gives narrow resonant peaks[Crnojevic, et.al, 2006, Kim, et.al, 2006, Xiao, et.al, 2007, Wu, et.al, 2008].

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 [Chen, et.al, 2007]. Sierpinski fractal geometry has been used in the implementation of a complementary split ring resonator [Crnojevic-Bengin, et.al, 2006]. Split ring geometry using square Sierpinski fractal curves has been proposed to reduce resonant frequency of the structure and achieve improved frequency selectivity in the resonator performance. Koch fractal shape is applied to mm-wave microstrip bandpass filters integrated on a high-resistivity substrate. Results showed that the 2nd harmonic of fractal shape filters can be suppressed as the fractal iteration level increases, while maintaining the physical size of the resulting filter design [Kim, et.al, 2006]. Minkowski-like and Koch pre-fractal geometries have been successfully used in producing high performance miniaturized dual-mode microstrip bandpass filters [Ali, 2008, Ali, et.al, 2009].

In this paper, new microstrip bandpass filters, based on Hilbert fractal geometry, have been presented as a candidate for use in compact communication systems. The proposed single-mode bandpass filters have been found to possess compact sizes with accepted return loss and transmission responses.

THE HILBERT FRACTAL CURVE

The Hilbert fractal curve, as outlined in **Figure (1)**, consists in a continuous line which connects the centers of a uniform background grid. The fractal curve is fit in a square section of *S* as external side. By increasing the iteration level *k* of the curve, one reduces the elemental grid size as $S/(2^k - 1)$; the space between lines diminishes in the same proportion. 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 [Barra, *et.al,* 2004] :

$$L(k) = (2^k + 1)S \qquad (1)$$

The main idea here is to increase the iteration of the Hilbert curve as much as possible in order to fit the resonator in the smallest area. However, it has been found that, when dealing with space-filling fractal shaped microstrip resonators, there is a tradeoff between miniaturization (curves with high *k*) and quality factor of the resonator. For a microstrip resonator, the width of the strip *w* and the spacing between the strips *g* are the parameters which actually define this tradeoff [Barra, *et.al*, 2004]. Both dimensions (*w* and *g*) are connected with the external side *S* and iteration level *k* ($k \geq 2$) by

$$S = 2^k (w + g) - g \qquad (2)$$

From this equation, it is clear that trying to obtain higher levels of fractal iterations; this will lead to lower values of the microstrip width, thus increasing the dissipative losses with a corresponding degradation of the resonator quality factor. Hence, for these structures, the compromise between miniaturization and quality factor is simply defined by an adequate fractal iteration level. However, it has been concluded, in practice, that the number of generating iterations required to reap the benefits of miniaturization is only few before the additional complexities become indistinguishable [Gianvittorio, 2003].

FILTER DESIGN AND PERFORMANCE EVALUATION

At the begining, a single resonator based on the 2nd iteration Hilbert fractal geometry, has been designed at a frequency of 2.4 GHz. It has been supposed that the modeled filter structures have been etched using a substrate with a relative dielectric constant of 10.8 and a substrate thickness of 1.27 mm. The resulting resonator dimensions have been found to be 6.125 mm × 6.125 mm, and a trace width of about 0.35 mm. The guided wavelength λ_g at the design frequency and the stated substrate parameters is calculated by [Hong, *et.al*, 2001, Chang, *et.al,* 2004]:

$$\lambda_g = c \big/ f\sqrt{\varepsilon_{eff}} \tag{3}$$

where $\varepsilon_{eff} = (\varepsilon_r + 1)/2$.

The same resonator with depicted dimensions and substrate specifications has been used to build a two-resonator microstrip bandpass filter. The input/output feed tab positions and spacing between the resonators are the most important parameters affecting the filter performance [Hong, *et.al*, 2001, Swanson, 2007]. The topology of this filter is shown in **Figure (2)**. The overall dimensions of this filter are of about 6.125 mm × 12.45 mm. The corresponding return loss and transmission responses are shown in **Figure (3)**.

It is clear, from **Figures (3),** that the resulting bandpass filters based on the 2nd iterations Hilbert fractal geometries offer good quasi-elliptic transmission responses with transmission zeros that are symmetrically located around the design frequency with return losses are of about 13.2 and insertion losses of about 0.235.

FILTER DESIGN WITH TUNING STUB

The bandpass filters, with the layout shown in **Figures (2)**, have been remodeled but with an additional stub connected to one end of each resonator, keeping the resonator side length *S*, the inter-resonator spacing and the tap positions constant . **Figures (4)** shows the layout of the new filters based on the 2^{nd} iteration Hilbert fractal geometry with stubs. The stub length has been varied from zero (no stub exists) to a maximum value of *S* (the resonator side length) in steps of one-quarter *S*. Four projects, corresponding to the new filter with four different values of the added stub length, have been implemented in the EM solver. **Figures (5)** and **Figures (6)** demonstrates the transmission(S_{21}) and return loss(S_{11}) responses of the four cases. It is clear that the additional stub provides a useful tuning feature, where a stub of a length *S* provides a tuning frequency range of about 300MHz for 2^{nd} iteration respectively which are considered important in practice. Furthermore, it has been found that, besides the frequency tuning the additional stub presents, it also affects the overall filter performance. **Figures (7)** shows the out-of-band transmission responses of the two filters; with and without stubs for 2^{nd} iteration resonator filters. It is clear that, the filter with stub offers better 2nd harmonic suppression than the other filter does. Inspection of **Figures (7)** reveals that, the presented filter in both iteration levels offer lower a resonant frequency when provided with a tuning stubs. This is attributed to the fact that the additional stub will make the overall length of the resonator larger, and hence resonates at a lower frequency. Appropriate dimension scaling might be carried out to bring the resonance to be at the design frequency.

The proposed filter designs can be applied to many other wireless communication systems; the filter dimensions can easily be scaled up or down depending on the required operating frequencies. **Figure(8)** demonstrates the surface current distribution on the conducting surface of both resonators at the design frequency.

CONCLUSIONS

A new quasi two-pole microstrip bandpass filter design for use in modern wireless communication systems has been introduced in this paper. The proposed filter structures have been composed of dual coupled resonators which are based on 2nd iteration Hilbert fractal curves. The space-filling property the proposed filter structure possesses, results in a high degree of miniaturization with reasonable passband performance. Consequently, the proposed technique can be generalized as a flexible design tool for compact microstrip bandpass filters for a wide variety of wireless communication systems. Also, it has been found that adding a tuning stub to each resonator provides the designer with a practically useful means to tune the resulting filter response to the specified design frequency. Furthermore, performance responses show that the new filter has less tendency to support 2nd harmonic.

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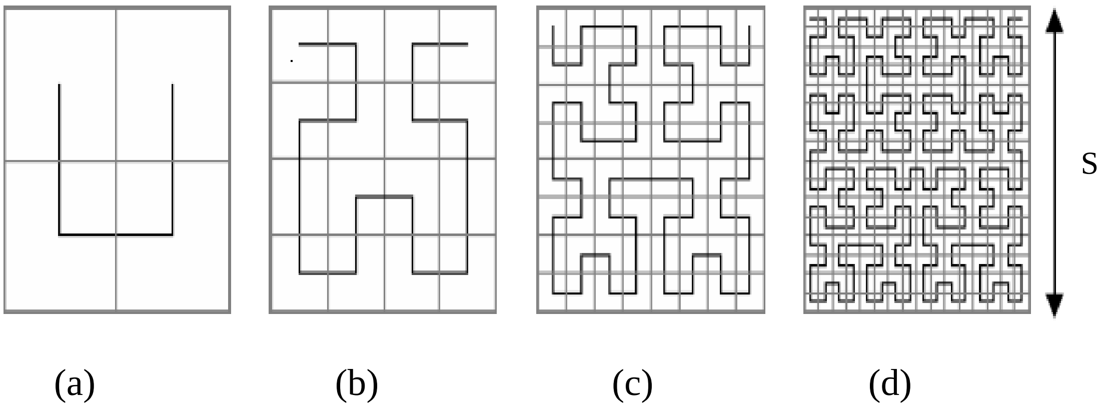


Figure. (1) Hilbert curve steps of growth: (a) 1st iteration (b) 2nd iteration (c) 3rd iteration, and (d) 4th iteration

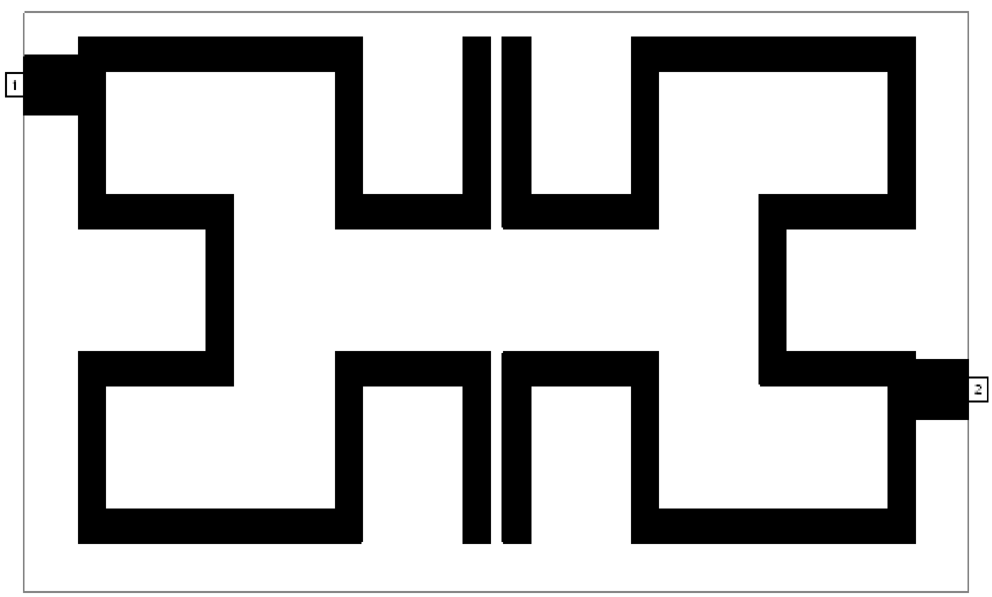


Figure.(2) The layout of the two-pole microstrip bandpass filter based on the 2nd iteration Hilbert curve geometry

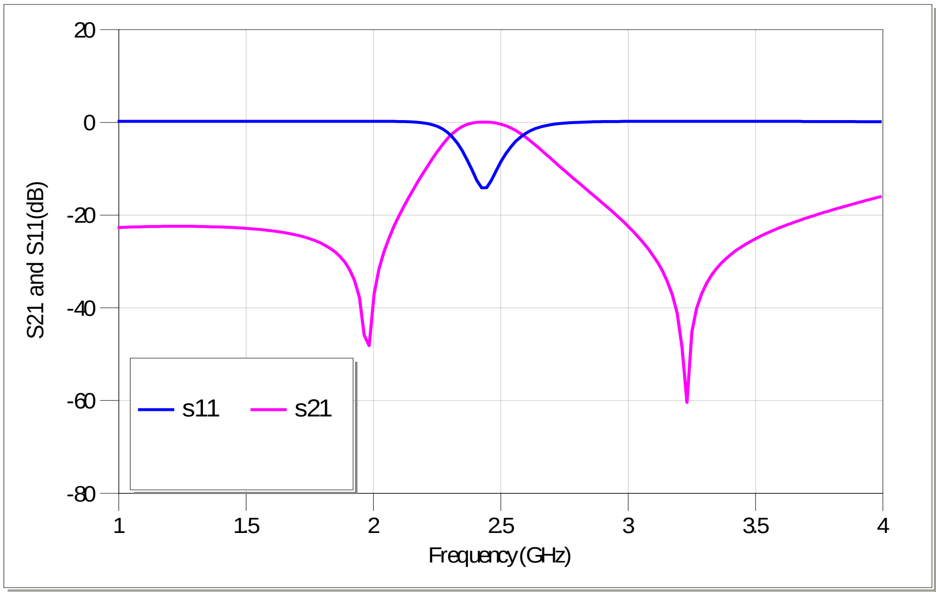


Figure.(3) The return loss (S_{11}), and transmission (S_{21}) responses of the filter structure based on the 3rd iteration Hilbert curve geometry depicted in Fig.(2)

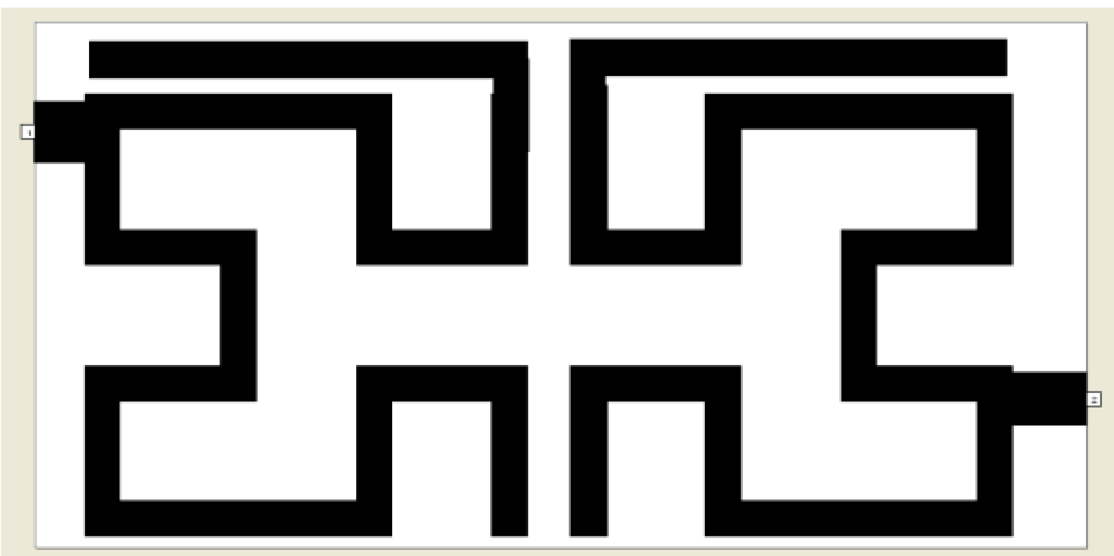


Figure.(4) The layout of the modeled two-pole microstrip bandpass filter based on 2nd iteration Hilbert resonators with tuning stubs

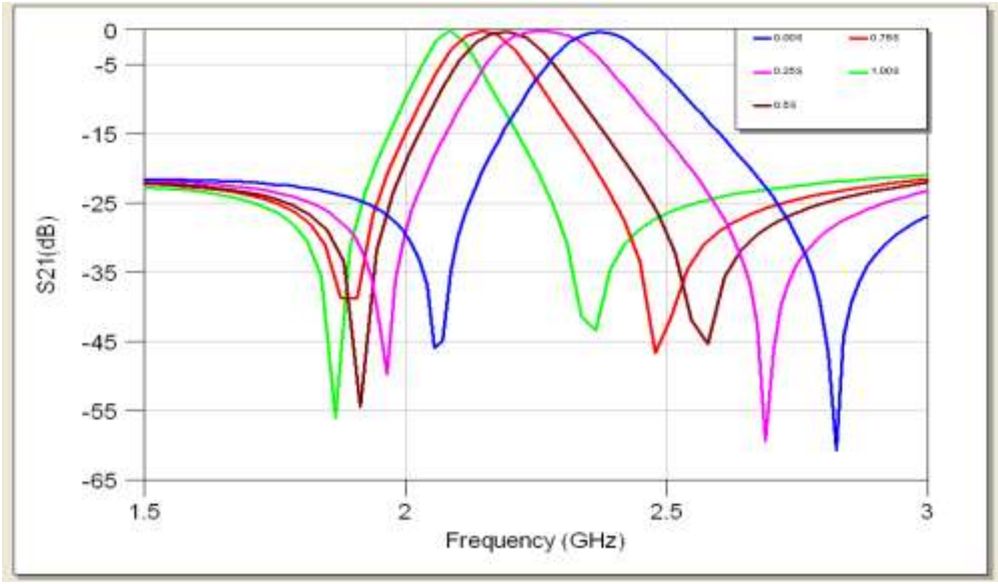


Figure.(5) The transmission responses (S_{21}) of the filter structure based on the 3rd iteration Hilbert curve geometry with stub depicted in Fig.(4)

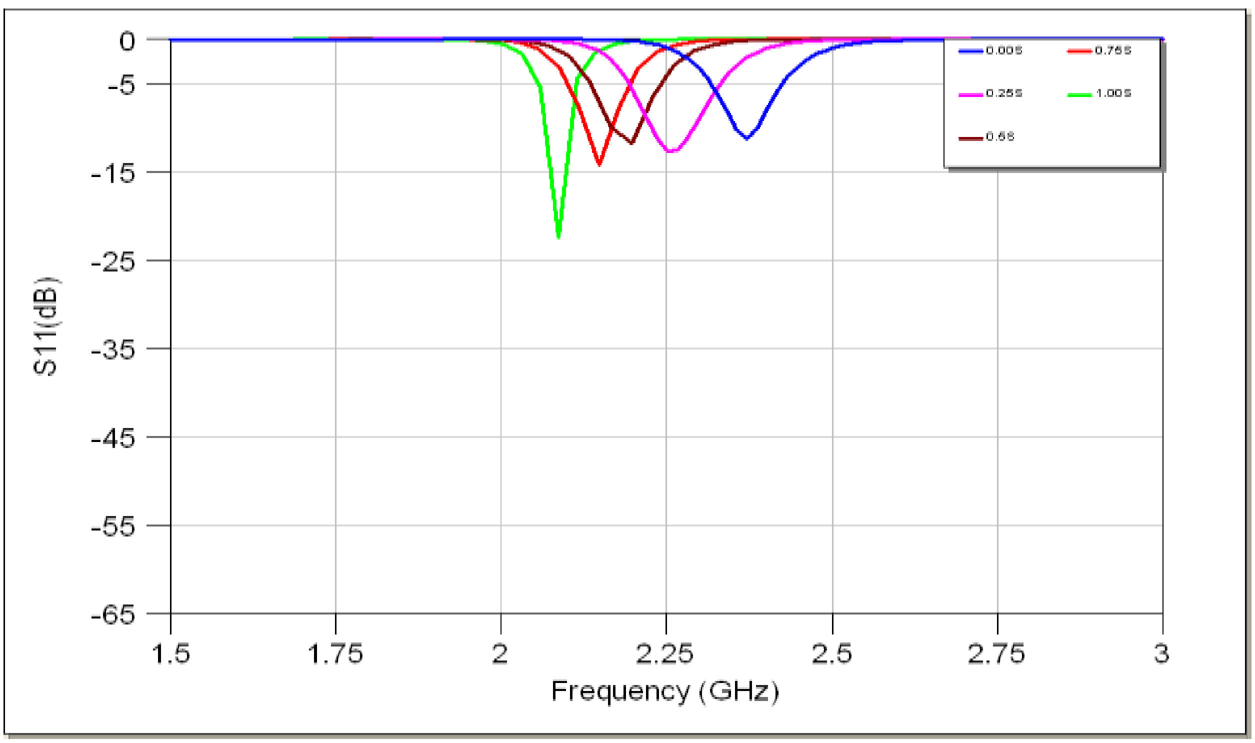


Figure.(6) The return loss responses (S_{11}) of the filter structure based on the 3rd iteration Hilbert curve geometry with stub depicted in Fig.(4)

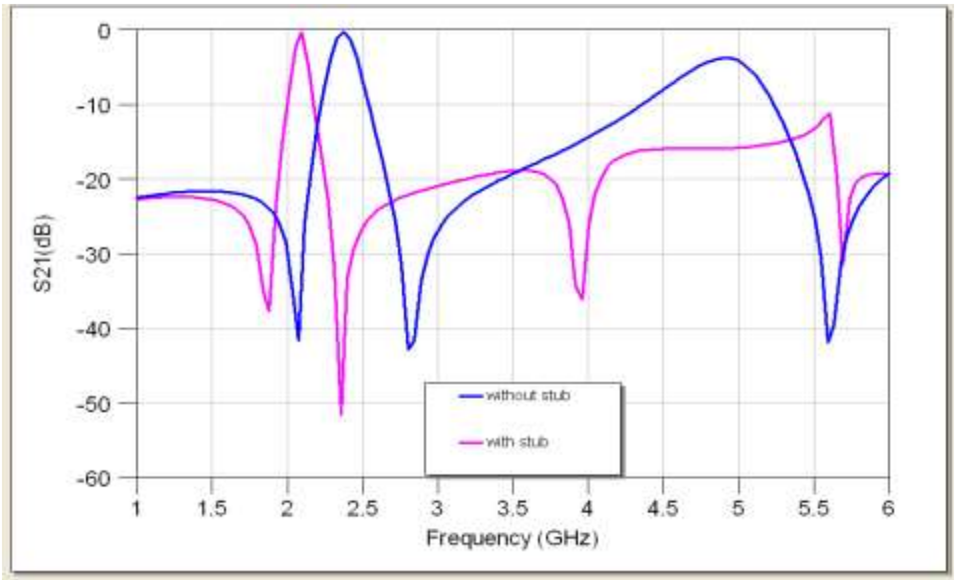
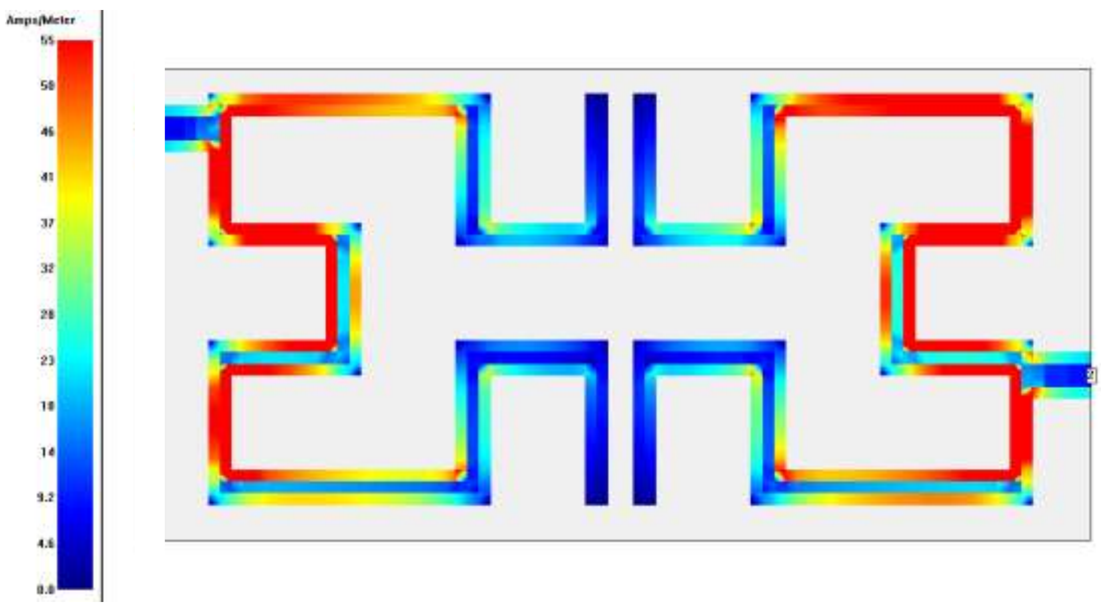


Figure.(7) The out-of-band transmission responses of the proposed filters based on the 3rd iteration Hilbert curve geometry; with and without stubs.



Figure(8) Current density distribution at the conducting surface of the 2^{nd} iteration stubbed Hilbert bandpass filter simulated at a resonant frequency of 2.4 GHz