MINIATURIZED BANDPASS FILTER BASED ON PEANO FRACTAL GEOMETRY WITH HIGHER HARMONIC SUPPRESSION

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ABSTRACT

A novel design for compact microstrip bandpass filter design is presented for use in the application of modern wireless communication systems. The proposed filter structure is composed of two fractal-based microstrip resonators. The structure of each resonator is in the form of the Peano fractal curve geometry. Two microstrip single-mode resonators with structures based on the 2nd Peano fractal-shaped geometries have been modeled at a design frequency of 2.4 GHz. 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. The performance of the resulting filter structures has been evaluated using a method of moments (MoM) based software package, Microwave Office 2009, from Advanced Wave Research Inc. Results show that the proposed filter structures possess good 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 new resonator has less tendency to support the higher harmonics.

KEYWORDS: Microstrip bandpass filter (BPF), Peano fractal curve, filter miniaturization, tuned microstrip bandpass filter

تصميم لمرشح امرار نطاقي مصغرمبني على اساس منحني بيانوالهندسي الجزئي بامكانيه حذف التوافقيات ذات الرتب العاليه

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اجراء حسابات الاداء لجميع المرشحات باستخدام الحقيبة البرمجية (MWO ٢٠٠٧) من شركة (AWR) التي تجري المحاكاة الكهرومغناطيسية على وفق طريقة إيجاد العزوم. بينت نتائج المحاكاة إن المرشحات المقترحة ذات اداء جيد بالاضــافة الــى

التخفيض المتحقق بالحجم كما انها توفر وسيلة تنغيم وإخماد للتوافقيات الثانية مما يجعلها مناسبة للاستخدام في تطبيقات الاتصالات الحديثة المختلفة.

INTRODUCTION

Fractal geometry has been used 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. In modern wireless and mobile communication systems, filters are always playing important and essential roles. Planar filters are particularly popular structures because they can be fabricated using printed circuit technology and they are suitable for commercial applications due to their compact size and low-cost integration .

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 Peano 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 PEANO 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 $S/(3^k - 1)$; the space between lines diminishes in the same proportion. For a Peano 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 [Ali and Mezaal, 2009] :

$$L(k) = (3^k + 1)S \tag{1}$$

The main idea here is to increase the iteration of the Peano 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 [Ali and Mezaal, 2009, Barra, *et.al,* 2004]. Both dimensions (*w* and *g*) are connected with the external side *S* and iteration level *k* ($k \geq 2$) by

$$S = 3^k (w + g) - g \tag{2}$$

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 first, a single resonator based on the 2nd iteration Peano 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 4.27 mm × 4.27 mm, and a trace width of about 0.365 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 4.75 mm × 8.7 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 Peano 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 11 and insertion losses of about 0.4.

Figure (4) shows the out-of-band transmission responses of the two filters for 2nd iteration resonator filters. It is clear that performance response has fewer tendencies to support higher harmonics which conventionally accompany the bandpass filter performance.

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 (5)** shows the linear phase response for S_{11} and S_{12} with respect to different frequencies. **Figure(6)** and **Figure(7)** demonstrate the surface current distribution on the conducting surface of both resonators at 2.4 GHz and 2.5 GHz frequencies, where red color indicates higher coupling effect while blue color indicates the opposite effect. It is clear from these figures that the nature of current distribution changes with the variation of operating frequency.

It is necessary to mention that the proposed design of quasi elliptic response 2nd iteration Peano bandpass filter in this paper suppresses higher harmonics without additional stubs with relative dielectric constant of 10.8 and dielectric thickness of 1.27 as compared with [Ali and Mezaal, MAPE 2009] that suppresses only the 2nd harmonic by using Chebychev response 3rd iteration

Peano bandpass filter which uses dielectric constant of 9.8 and dielectric thickness of 0.508 with additional stubs.

CONCLUSIONS

A new quasi elliptic response 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 Peano 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 performance responses show that the new filter has less tendency to support successive harmonic.

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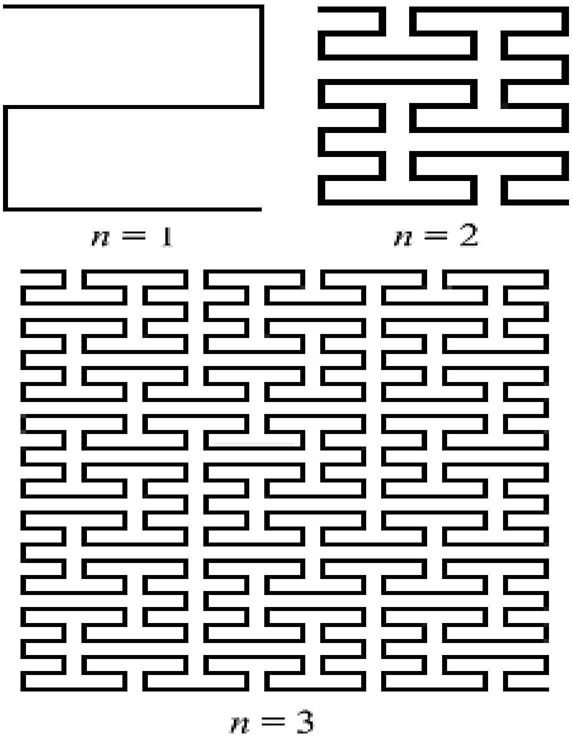

Figure 1. The first three iteration levels of the Peano fractal curve generation process

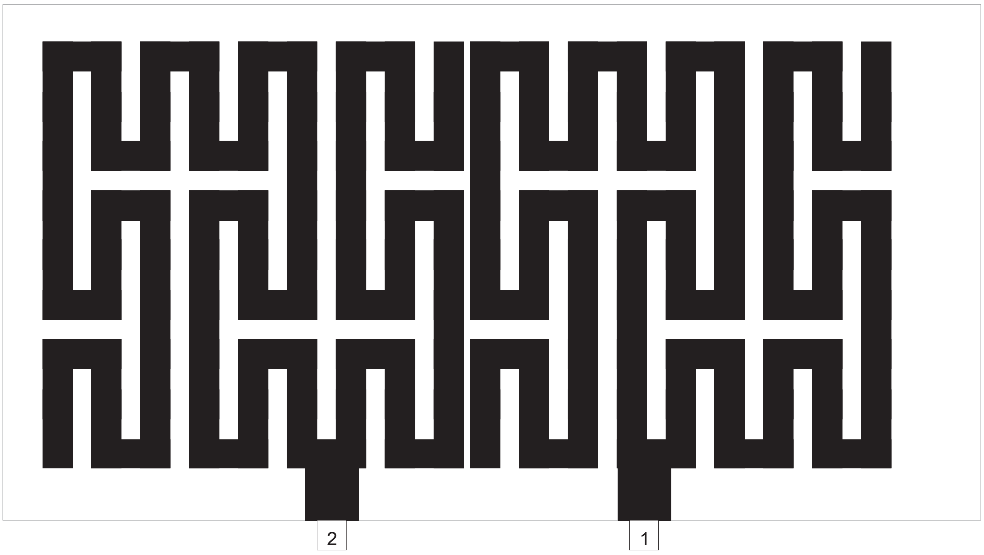

Figure 2. The modeled microstrip bandpass filter with two resonators based on 2nd iteration Peano curve geometry

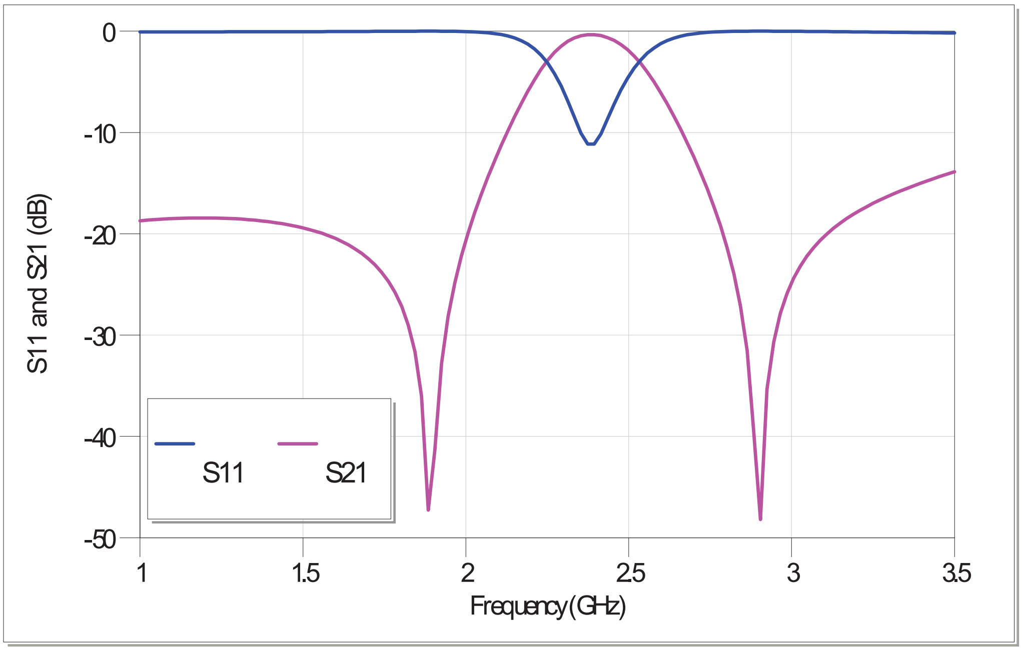

Figure 3. The return loss and transmission responses of the resulting 2nd iteration fractal two-resonator microstrip bandpass filter

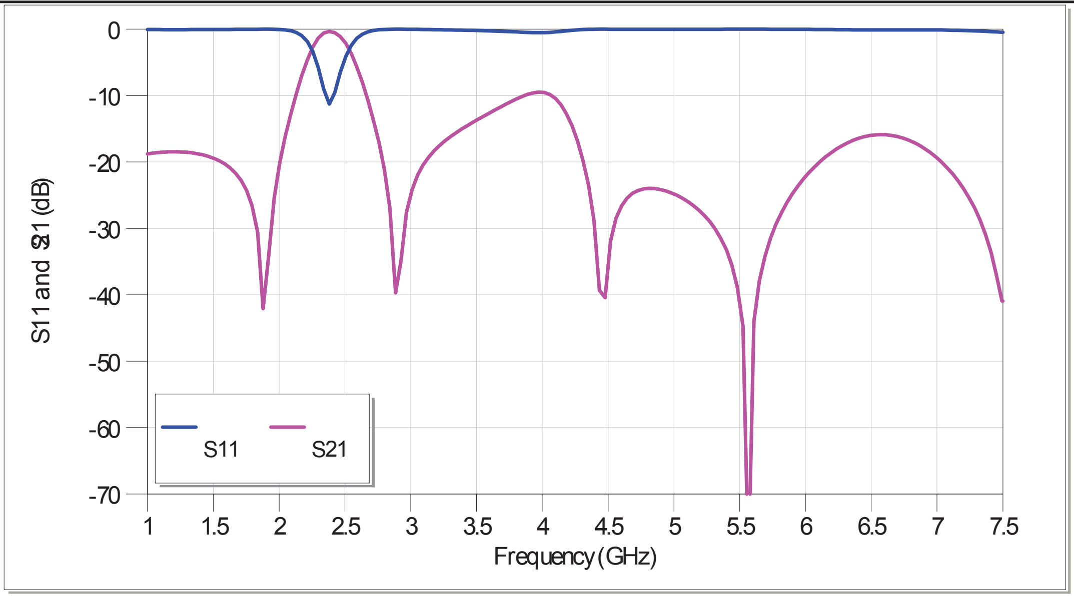

Figure 4. The out-of-band transmission responses of the proposed filters based on the 2nd iteration Peano curve geometry.

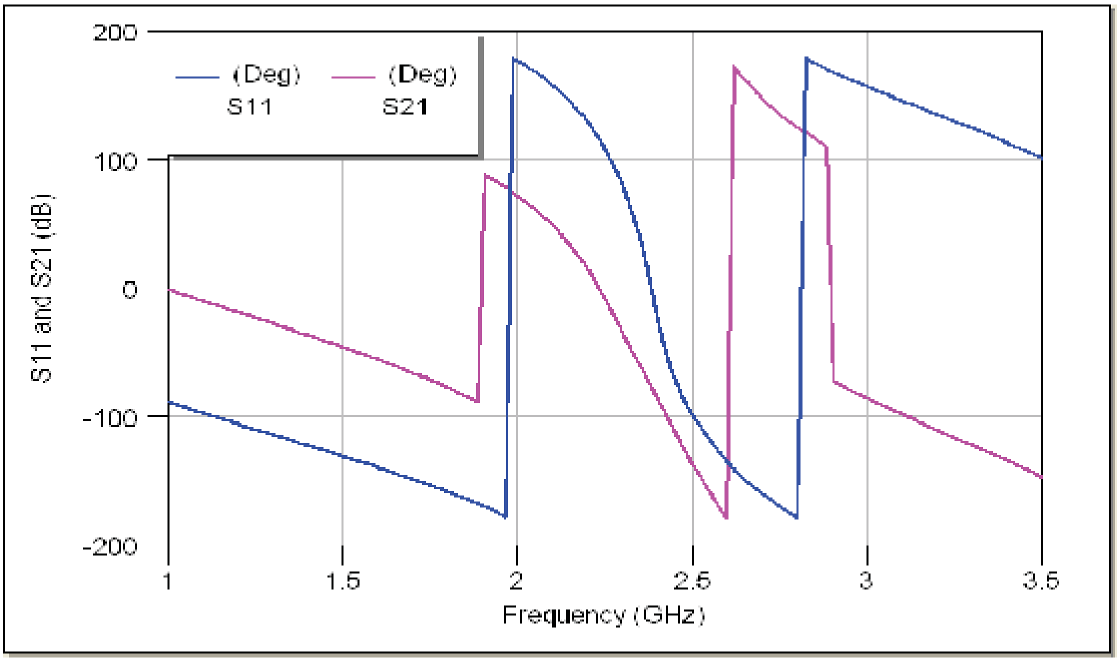

Figure 5. The phase responses of the resulting 2nd iteration fractal two-resonator microstrip bandpass filter

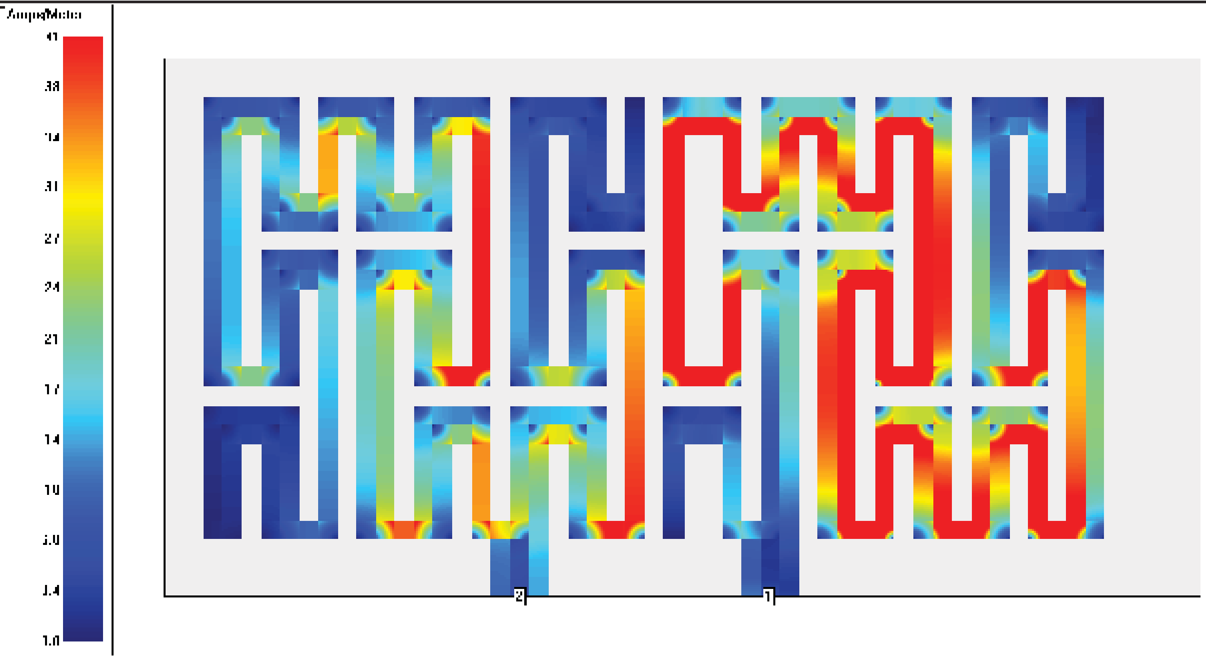

Figure 6. Current density distribution at the conducting surface of the 2nd iteration stubbed Peano bandpass filter simulated at a resonant frequency of 2.4 GHz

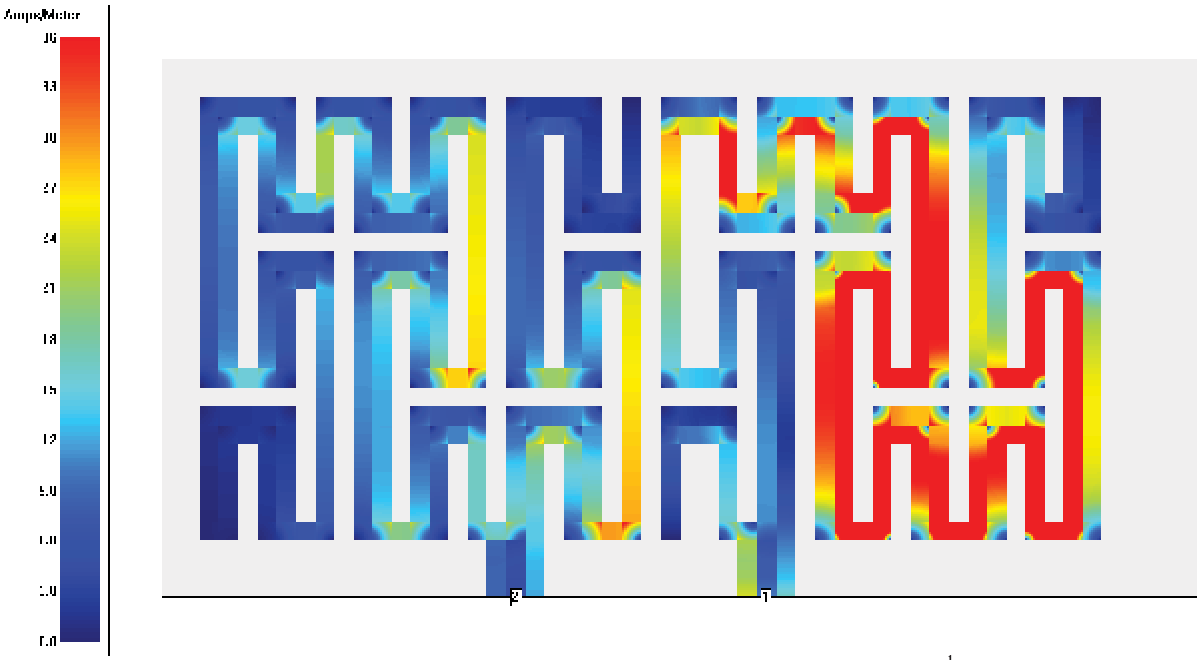

Figure 7. Current density distribution at the conducting surface of the 2nd iteration stubbed Peano bandpass filter simulated at a resonant frequency of 2.5 GHz