NOVEL 3-D HILBERT MICROSTRIP RESONATORS

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ABSTRACT: *Recently, planar microstrip resonators employing two-dimensional (2-D) Hilbert curves were introduced, outperforming existing solutions. However, very little attention has been paid to multilayer resonators with embedded three-dimensional (3-D) curves. In this paper, four novel 3-D resonators are compared using full-wave EM simulations. It is shown that the 3-D Hilbert resonator outperforms all others, achieving very high values of the unloaded quality factor.*

Key Words: *Microstrip Resonators; Fractals.*

1. INTRODUCTION

A bottleneck in the miniaturization of passive components such as resonators and filters originates from the fact that resonating structures need to be of a certain size relative to the operating wavelength. Traditional capacitively coupled microstrip configurations incorporate half-wave resonators and therefore occupy large substrate areas, especially in the case of low operating frequencies.

Traditional miniaturization techniques are based on folding straight line resonator in order to fit it in a smaller area. However, miniaturization of planar resonators (while keeping the resonant frequency constant) tends to reduce their quality factor (Q), because of additional dissipative losses caused by the current density increase. Although this effect can be minimized by using superconductive materials, [1]-[3], new solutions are sought, employing low-cost manufacturing procedures and materials.

Fractal curves are well known for their unique space-filling properties. Recently, a number of applications of different fractal shapes emerged, mostly in the antenna design, [4], and metamaterial surfaces, [5]. Fractal-shaped planar resonators, [6], revealed superiority of the two-dimensional (2-D) fractal structures over the conventional non-fractal ones, both in quality factor increase and in circuit size reduction. However, almost no attention has been paid to multilayer resonators with embedded three-dimensional (3-D) fractal curves, [7].

Multilayer technologies, such as Thick-film (TF) or Low Temperature Co-fired Ceramics (LTCC), allow fabrication of long transmition lines folded over several layers, thus occupying relatively small substrate areas. TF technology, whose significance has recently been on the rise primarily thanks to the development of ceramic multi-chip modules (MCMs), offers significant potentials for the development of microwave passive components, since it is capable of combining high level of integration, low cost and high volume production with the high electrical performances needed for microwave devices. Due to its multilayer nature and inherent quality, TF technology opens up new opportunities for the development of novel 3-D structures.

In this paper, novel configurations of TF microstrip resonators are presented, incorporating embedded 3-D curves in the resonator. Four 3-D curves are analysed and compared: two 3-D meander curves, a 3-D spiral and a 3-D Hilbert fractal curve.

2. NOVEL RESONATOR CONFIGURATIONS

All configurations presented in this paper are based on the traditional capacitively coupled microstrip resonator with 50-Ohm feeding microstrip lines and gaps equal to 200 um. The resonators are constructed on a 625 um thick Alumina substrate having relative dielectric constant εr=9.6 and dielectric loss tangent equal to 0.0006.

The conventional microstrip resonator is replaced with various four-layer 3-D microstrip structures, having the same line width and spacing (typically around 200 um). Conductors in different layers are separated by the 50 um thick dielectric layers, having εr=9.6 and dielectric loss tangent 0.0006, and connected by vias. Via diameters are found by simulation so that the microstrip and via impedances are matched.

A. 3-D Meander Resonator

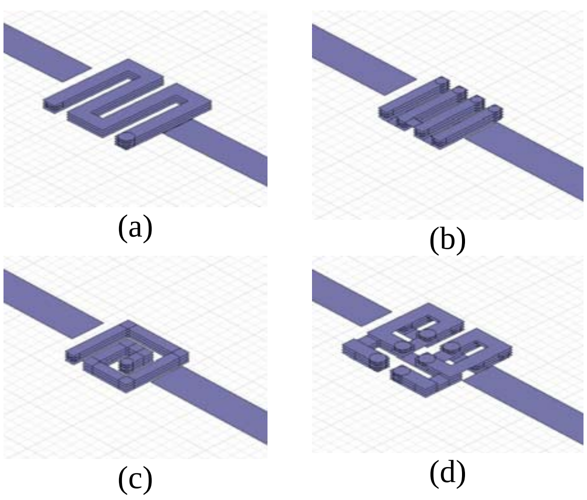
Planar capacitively coupled resonators incorporating 2-D meander curve and its variants are often encountered in the literature. Therefore, the first choice was to incorporate a 3-D meander in the resonator. Two configurations were examined: one in which four 2-D meander curves were stacked along the Z-axes, denoted 3-D meander X-Y, Figure 1 (a), and the other where 2-D meanders were formed in the X-Z plane and then stacked along the Y-axes, 3-D meander X-Z, Figure 1 (b).

B. 3-D Spiral Resonator

Since spiral inductors outperform their meander counterparts, a large variety of planar single- and dual- rectangular- and log- spiral inductors are often employed in resonator design. In some filtering applications, [8], planar spiral inductors are placed on different layers thus creating a multilayer structure. In this paper, a 3-D rectangular spiral inductor is embedded in the capacitively coupled resonator, Figure 1 (c).

C. 3-D Hilbert Resonator

A 3-D Hilbert fractal curve obtained after three iterations is embedded into resonator, Figure 1 (d). The Hilbert curve has the same length and occupies the same volume as the 3-D meander X-Y discussed above. However, due to the particular shape of the Hilbert curve, the size of turns is reduced compared to the meander curve, thus resulting in weaker coupling between the turns.



(a) (b)

(c) (d)

Figure 1 Novel 3-D resonators: (a) 3-D meander X-Y, (b) 3-D meander X-Z, (c) 3-D spiral, (d) 3-D Hilbert

3. COMPARISON OF THE PROPOSED CONFIGURATIONS

Performances of the resonators were determined by a full-wave finite-element simulation method, using a commercially available software package Ansoft HFSS ver. 8.5. All material characteristics and dimensions were kept within boundaries of widely available standard TF procedure. Line widths and spacing of different configurations were varied simultaneously to achieve the same resonant frequency. The proposed configurations were compared in terms of dimensions and unloaded and loaded Q-factor. Comparisons were also performed with equivalent 2-D resonators covering the same substrate area. Simulation results showed that expanding from 2-D to 3-D did not produce significant improvements in the case of non-fractal curves such as spiral and meander. However, 3-D Hilbert resonator proved to be superior to its 2-D counterpart, revealing much higher QU and potential for miniaturisation. Insertion loss responses, s_{21}, dB, for all 3-D configurations discussed in this paper are shown in Figure 2, and numerical results are given in Tables 1 and 2 for various 2-D and 3-D configurations respectively, where s_{21}^{0} denotes insertion loss at resonant frequency.

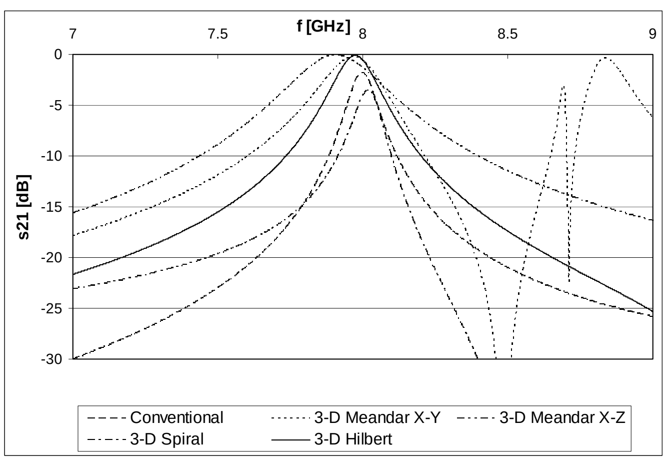


Figure 2 Comparison of the insertion loss, s_{21}, dB, for conventional capacitively coupled resonator and proposed 3-D configurations

TABLE 1 Numerical results for 2-D resonators

Resonator Type	2-D Meand. X-Y	2-D Spiral	2-D Hilbert
line width and spacing, um	310	250	310
resonator length, mm	2.17	1.75	2.17
f_r, GHz	8.17	8.14	8.17
s_{21}^0, dB	-0.262	-6.6	-0.42
Q_L	49	145	79
Q_U	**837**	**186**	**857**

TABLE 2 Numerical results for novel 3-D resonators

Resonator Type	Conventional	3-D Meand. X-Z	3-D Meand. X-Y	3-D Spiral	3-D Hilbert
line width and spacing, um	n/a	200	290	200	283
resonator length, mm	6.73	1.4	2.03	1.4	1.981
f_r, GHz	8	7.91	7.97	8.02	7.98
s_{21}^0, dB	-1.82	-0.09	-0.215	-3.56	-0.099
Q_L	83	25	37	84	50
Q_U	**242**	**1234**	**767**	**150**	**2218**

As expected, inclusion of 3-D curves into resonator resulted in significant decrease in dimensions as well as in the increase of Q-factor when compared to conventional planar capacitively coupled variant. An exemption to this is the 3-D spiral resonator. Although having very narrow -3dB bandwidth (around 1%), 3-D spiral resonator introduces very high insertion loss, thus making its overall QU one of the lowest. However, it could be applied successfully by the use of superconductive materials.

3-D Hilbert resonator, although covering larger substrate area then other configurations, demonstrated very high values of unloaded Q. Simulations have shown that this advantage can further be exploited by decreasing line widths and spacing in the 3-D curve, that can be easily done in the LTCC technology.

4. CONCLUSION

In this paper, four novel multilayer microstrip resonators were analysed by full-wave EM simulations and compared in terms of loaded and unloaded quality factor. All dimensions were kept in accordance with standard TF procedure.

3-D Hilbert resonator showed to be superior to all other configurations examined, both 3-D and 2-D, thus demonstrating the benefits to be gained from the employment of multilayer fractal shapes in resonators and filters.

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