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A Novel Fractal Inductor for RF Applications

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Abstract— **In this paper, a novel fractal inductor was presented. This inductor provides a high quality factor of 19.8 at a frequency of 9.1GHz with SRF of 47.1 GHz. The simulations are carried out using Full wave High Frequency Structural Simulator (HFSS) for a single layered 0.18µm technology. The simulation results show an improvement in quality factor by 22% over conventional fractal inductor and results also shows an improvement in SRF by 21% over conventional fractal inductor.**

Keywords— Quality factor (Q); Self Resonant Frequency (SRF).

I. INTRODUCTION

Increasing demand for more advanced RF systems such as Low Noise Amplifier (LNA), Voltage Controlled Oscillator (VCO), matching networks and inductive load requires on-chip inductors. One of the most important characterics of inductor is Quality Factor (Q).The Quality factor significantly effects the performance of RF circuits and systems. The performance of inductors at high frequencies limited by substrate losses and high resistance [1][2][3]. Therefore the development of novel inductor designs that are capable of operating at high quality factor and Self Resonant Frequency (SRF) in standard CMOS process is the major challenges in RF applications. In the literature several types of electrical devices have been proposed like high capacitance fractal capacitor in a single layered process [4] and fractal inductor with high inductance [5][6][7] based on well known fractal space filling curves.

This paper investigates inductor based on Hilbert curve in a loop fashion has been proposed and is shown in fig 1.Significant increase in quality factor and SRF are observed, when compared with conventional Hilbert fractal space filling curves.

The paper is organized as follows. In section II fractal structures and inductance calculations are discussed. section III describes proposed fractal inductor as compared with conventional fractal inductor, finally conclusions are drawn in section IV.

II. FRACTAL GEOMETRY

A. Space filling curve

Space filling curve that can be defined as a trace that, fills every point within the bounded area. These curves are typically defined by an iterative process. The first such a curve introduced by Peano followed by other space filling curves such as Hilbert, Moore, Osgood,lebesgue and Siepinki etc.,[8] have the property to cover the entire 2D space and another property of these curves is the ability split the space into separate regions using a simple continuous curve. The space filling curves described by initiator and generator. Such a curve is shown in fig 2. In this paper, 1st iterative Hilbert curve has been considered and is applied to single layered planar inductor shown in fig 3(a). The obtained fractal curve is shown in fig 3(c).

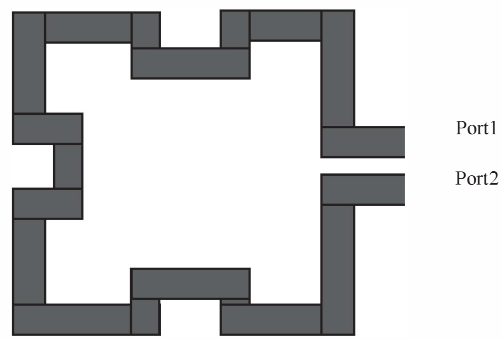


Fig.1.Hilbert based fractal inductor in a loop

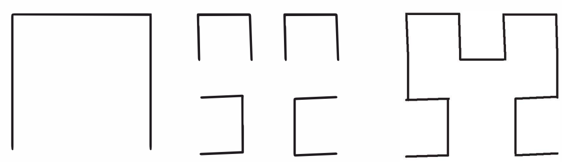
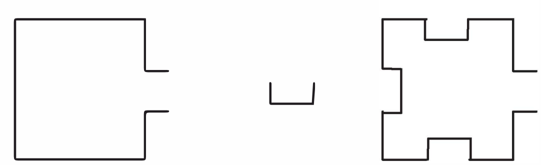


Fig.2.Construction of conventional Hilbert space filling curve



(a) Initiator (b) generator (c) 1st step process
Fig.3. construction of Hilbert curve in a loop

B. Inductance calculation

Knowledge of series inductance is crucial while designing on inductors for RF applications. The inductance represents the energy magnetic energy stored in the device. In 1946, Grover formulates an expression for inductance calculations. Green house later applied for square shaped inductor [9].According

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to green house entire structure is sub divide into segments and calculate inductance by summing the self inductance of individual segments and mutual inductance between any two parallel segments. The model has the form

$$L_T = L_S + M^+ - M^- \quad (1)$$

Where L_T total series inductance, L_S is the sum of inductance of all segments, M^+ is the sum of positive mutual inductance, M^- is the sum of negative mutual inductance.

At higher frequencies current does not penetrate into the body of conductor but travels along the surface of conductor. The magnetic vector potential at any point in the space due to conductor carrying current $I_1 e^{-\beta_1 z}$ with an assumption the cross section of the conductor is infinitesimally small as compared with length of the conductors is given by

$$A_z(x,y,z) = \frac{\mu_0 I_1}{4\Pi} \int_{-l_1/2}^{l_1/2} \frac{e^{-\beta_1 z}}{\sqrt{(x-0)+(y-0)+(z-z')}} dz' \quad (2)$$

Any two pair of conductors carrying currents with magnitudes $I_1 e^{-\beta_1{}^z}$ and $I_2 e^{-\beta_2{}^z}$ separated by a distance'd' as shown in the Fig.4.

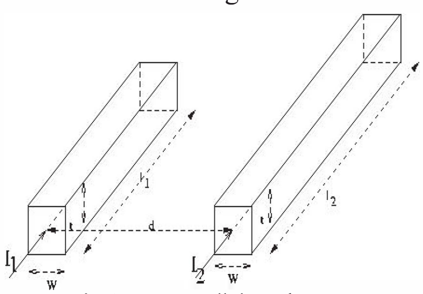

Fig 4. Two parallel conductors

The total magnetic flux associated with the second conductor, having length l_2, due to first conductor carrying I_1 is given by

$$\emptyset_{21} = \frac{\mu_0 I_1}{4\pi} \int_{-\frac{l_2}{2}}^{\frac{l_2}{2}} \int_{-\frac{l_1}{2}}^{\frac{l_1}{2}} \frac{e^{-j\beta_1 z^{|}}}{\sqrt{(d)^2+(z-z^{|})^2}} dz^{|} dz \quad (3)$$

The mutual inductance between the conductors is given by the expression

$$M_{21} = \frac{\mu_0 I_1}{4\pi l_2}\left[\frac{\phi_{21}}{e^{-j\beta z z}}\right] \quad (4)$$

C. Definition of Quality Factor

Several definitions has been proposed for the Quality Factor Among those, the fundamental is

$$Q = 2\pi . \frac{Energy\ stored}{Energy\ loss\ in\ one\ oscillation\ cycle} \quad (5)$$

The Quality factor can also be expressed using Y-parameters

$$Q = \frac{-im(y11)}{re(y11)} \quad (6)$$

D. Definition of Self Resonant Frequency

Ideally Inductor would have zero Resistance and Capacitance. But in practice, Inductor has some parasitic Resistance and Capacitance. SRF of an inductor is the lowest Frequency at which an inductor resonates with its self capacitance.

$$\text{SRF} = \frac{1}{2\pi\sqrt{\text{LC}}} \quad (7)$$

III. Results and Discussion

The design, modeling and simulation of fractal inductor are obtained using an Electromagnetic Simulator HFSS provided by Ansys Corporation. The proposed fractal inductor is as shown fig 5. From the simulation results as shown in fig.6 and fig.7, it is observed that the proposed fractal inductor have 22% improvement in quality factor with 21% improvement in self resonant frequency over conventional fractal inductor. The simulation is also carried out for variable widths such as 22 µm, 15 µm, 12 µm for the proposed fractal inductor. The simulation results are shown fig 8. From the results higher quality factors are obtained for wider widths.

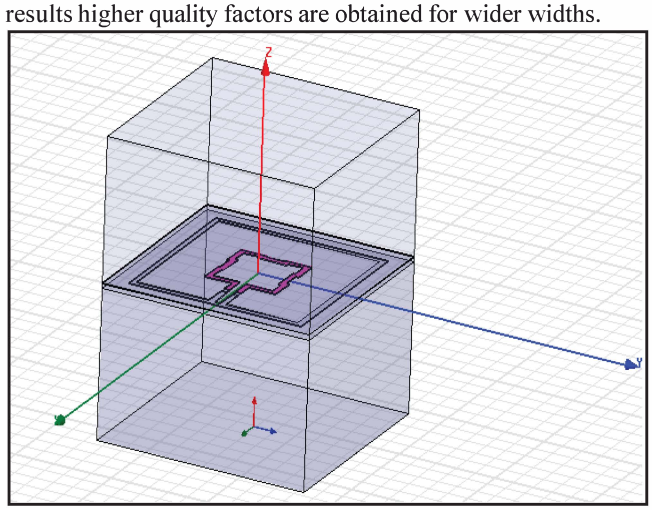

Fig.5. Simulated Fractal Inductor using HFSS 3-D view

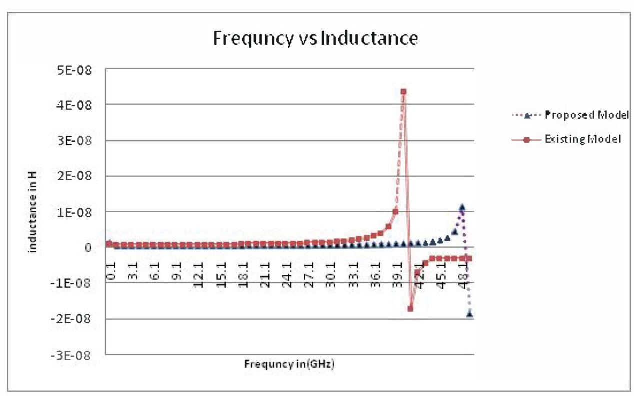

Fig.6. frequency vs inductance

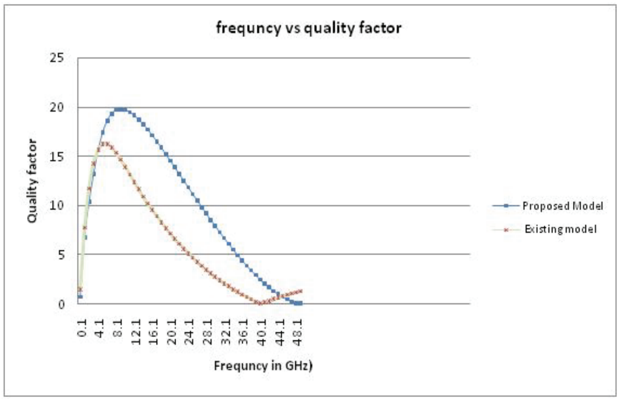

Fig. 7. Frequency vs quality factor

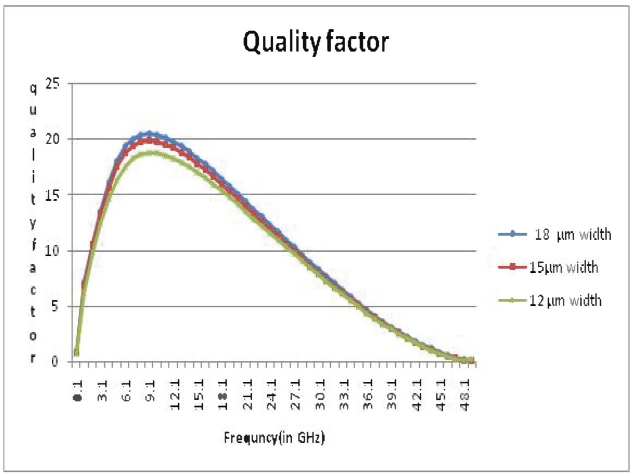

Fig.8. Frequency vs quality factor with different widths

IV CONCLUSION

In this paper, a new Hilbert fractal inductor in a loop fashion has been proposed .The performance between the conventional and proposed models have been simulated and compared by using HFSS .The results shows that the proposed design has 22% improvement in Quality factor with 21% improvement in SRF over conventional fractal inductor. The proposed design of Hilbert fractal inductor is useful for High frequency application

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