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# Design and Modeling of Miniature On-Chip Spiral Inductor for DC-DC Converter

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**Abstract.** In this paper, we study the effect of the technological parameters of on chip inductor, the characteristics of on chip inductor is simulated using the MATLAB simulation. All of inductor is fabricated in the standard silicon process with metal layers. The simulated results are accurate only when technological parameters used in ensemble, such as the metal conductivity, metal thickness, oxide thickness between the top metal and the substrate, and substrate conductivity on inductance, quality factor and self-resonant frequency.

***Keywords:*** *Integrated inductor, technological parameter, spiral inductor*

## 1. Introduction

One may that has assisted designers in satisfying demands for small size and low cost is the possibility of using on chip inductive devices in silicon radio frequency integrated circuits. On chip inductor play important roles in impedance matching, tuning and filtering. On aspect that limits their use is the amount of consumed silicon area. Overall die size is a direct driver in production cost. However, the continuing advance of process technologies, such as providing thicker and higher conductivity metal [1], thicker and lower permittivity dielectric layers, and lower conductivity substrate [2], makes high quality on chip passive devices more readily available [3]. Many design and analysis techniques of chip inductors have been investigated to correlate performances with technological parameters.

This paper contains of as follows Section II discuss about design and modeling of the spiral inductor, Section III about results and discussion of different technological parameters and Section IV about conclusion.

## 2. Design and modeling of square inductor

The lateral parameters of a spiral are shown in Figure 1. The main parameters are the number of turns ($n$), the metal width ($w$), the spacing between adjacent turns ($s$), the inner and outer diameters ($d_{in}$ and $d_{out}$), and the average diameter ($d_{avg}$). The fill ratio ($\rho$) is given by either of the following expression [4]:



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$$\rho = \frac{d_{out}-d_{in}}{d_{out}+d_{in}} = \frac{n(w+s)-s}{d_{avg}} \quad (1)$$

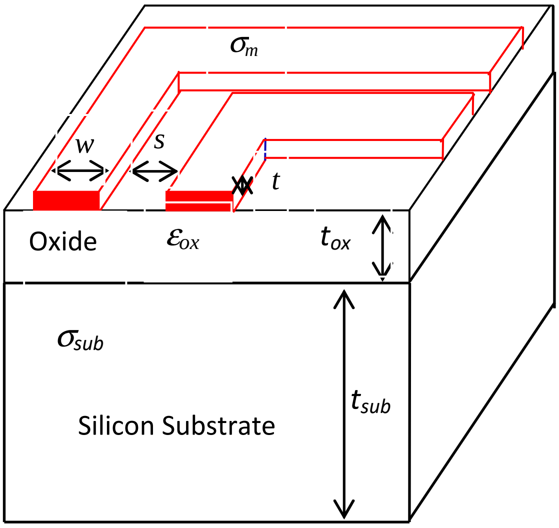



Fig. 1: Transverse section of a spiral planar inductor

where:

- $t_{ox}$ Thickness of oxide layer (distance between the substrate and coil)
- $t$ Metal thickness
- $\sigma_m$ metal conductivity
- $\sigma_{si}$ Substrate conductivity
- $\rho_{Si}$ Substrate resistivity
- $\varepsilon_{ox}$ Permittivity of the dielectric between substrate and coil
- $t_{sub}$ Substrate thickness
- $\varepsilon_{Si}$ Permittivity of the substrate

The model for a micro inductor is shown in Figure 2 [5]. The spiral π model includes the series inductance (*Ls*), the series resistance (*Rs*), the feed-forward capacitance (*Cs*), the inductor to substrate capacitance (*Cox*), and the substrate resistance (*Rsi*) and capacitance (*Csi*).

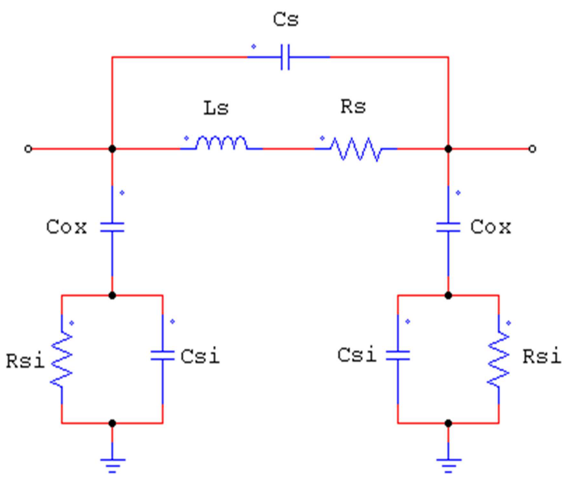



Fig. 2. Equivalent electrical model

The inductance (*Ls*) calculation of spiral inductor is determined by approximate expressions derived in [6]. The expressions include electromagnetic principles using current sheet approximations obtained for discrete inductors. The equation for the series inductance:

$$L_s = \frac{2\mu.n^2.d_{avg}}{\pi}\left[\ln\left(\frac{2{,}067}{\rho}\right) + 0{,}178.\rho + 0{,}125.\rho^2\right] \quad (2)$$

where $\mu$ is the magnetic permeability of free space ($\mu=4\pi\cdot10\text{-}7\ H/m$).

The series resistance is calculated by the following equation [7]:

$$R_s = \frac{l}{\sigma.\delta.w.\left(1-e^{\frac{-t}{\delta}}\right)} \quad (3)$$

where *l* and *w* are the length and width of the spiral, $\sigma$ is the metal conductivity, *t* is the metal thickness, and $\delta$ is the skin length given by [8]:

$$\delta = \sqrt{\frac{2}{2.\pi.f.\mu.\sigma}} \quad (4)$$

where *f* is the frequency

The series resistance expression models the increase of resistance at higher frequencies due to the skin effect [9].

The series capacitance Cs represents the parasitic capacitive coupling between input and output of the inductor, can be estimated using the following formula [10]:

$$C_s = \frac{t.\varepsilon_0.l^2}{s} \quad (5)$$

where, $\varepsilon_0$ is the permittivity of free space.

*Csi* and *Rsi* are the capacitance and resistance of the silicon substrate and *Cox* is the oxide capacitance between the spiral and the silicon substrate calculated [11] as:

$$C_{ox} = \frac{1}{2}l.w\frac{\varepsilon_{ox}}{t_{ox}} \quad (6)$$

$$R_{si} = \frac{2}{l.w.G_{sub}} \quad (7)$$

$$C_{si} = \frac{1}{2}l.w.C_{sub} \quad (8)$$

where *Gsub* and *Csub* are the conductance and capacitance per unit area of the silicon substrate and *tox* is thickness of the oxide layer separating the spiral and the substrate.

The efficiency of integrated micro coil is calculated [12] according by relation:

$$Q = 2\pi.\frac{\text{Stocked energie}}{\text{dissipated energie}} \quad (9)$$

## 3. Results and discussion

The simulation procedure pursued for the analysis of inductor is meshing and porting of the device. After porting S-parameters are obtained to calculate inductance and Quality factor. Now from S-parameters, Y-Parameters are obtained. Using Y-Parameters the inductance and quality factor values are intended using the expressions revealed in Equation (10) and Equation (11) respectively.

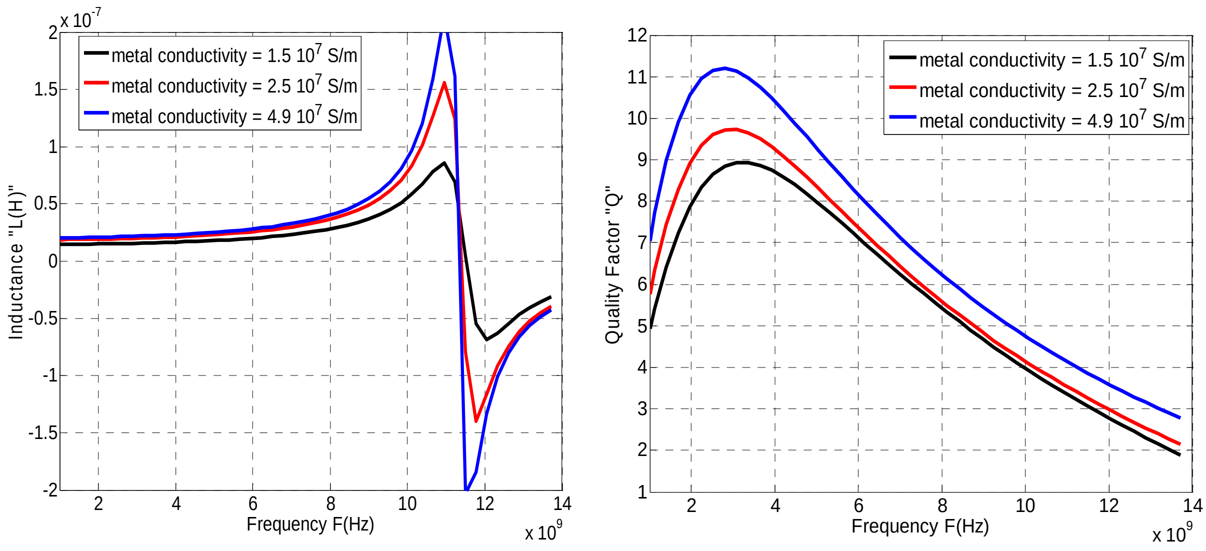
$$L = \frac{\mathrm{Img}\left(\frac{1}{Y_{11}}\right)}{2.\pi.f} \tag{10}$$

$$Q = \frac{\mathrm{Img}\left(\frac{1}{Y_{11}}\right)}{\mathrm{Real}\left(\frac{1}{Y_{11}}\right)} \tag{11}$$

A MATLAB simulation was achieved to study the influence of different technological parameters on the value of the inductance and quality factor.

### 3.1.Metal conductivity

Figure (3.a) show how the metal conductivity influences on inductance value. Changing the metal conductivity nearly cannot modify inductance value. Figure (3.b) show how the metal conductivity influence on Quality factor value. It can be seen that increasing the metal conductivity increases the quality factor value. The self resonant frequency will not be changed by the metal conductivity. The inductor with higher metal conductivity has higher Q because it has lower series resistance.




(a) (b)

Fig. 3: Effect of the metal conductivity: (a) on inductance, (b) on quality factor

### 3.2.Metal thickness

Figure (4.a) illustrates how the metal thickness influences on inductance value. Varying the metal thickness approximately cannot change inductance value. Figure (4.b) show how the metal thickness influences on quality factor value. The maximum quality factor of the inductor could be enhanced by escalating the metal thickness. The self resonant frequency will not be changed by the metal thickness. The inductor with higher metal thickness has higher quality factor because it has lower series resistance.

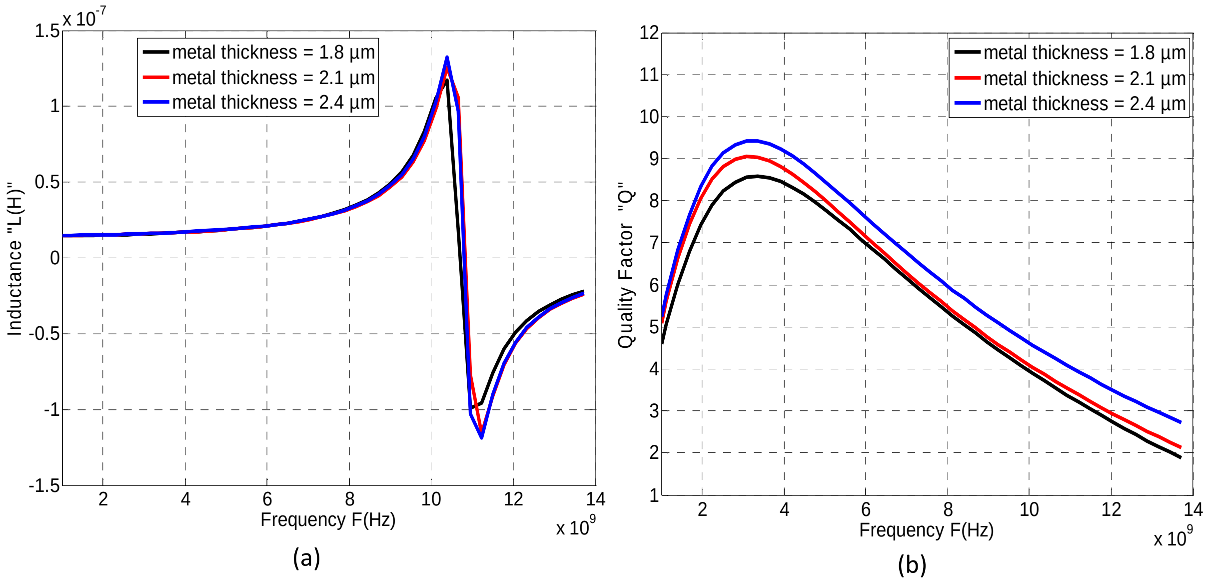



Fig. 4: Effect of the metal thickness (a) on inductance, (b) on quality factor

## 3.3. Oxide thickness

Figure (5.a) demonstrates how the oxide thickness influences on inductance value. Changing the oxide thickness almost cannot vary inductance value. Figure (5.b) illustrates how the oxide thickness influences on quality factor value. A wider oxide layer diminishes the capacitance of the silicon substrate, which advances the self resonant frequency. Mounting the oxide thickness will elevate the quality factor and the self resonant frequency.

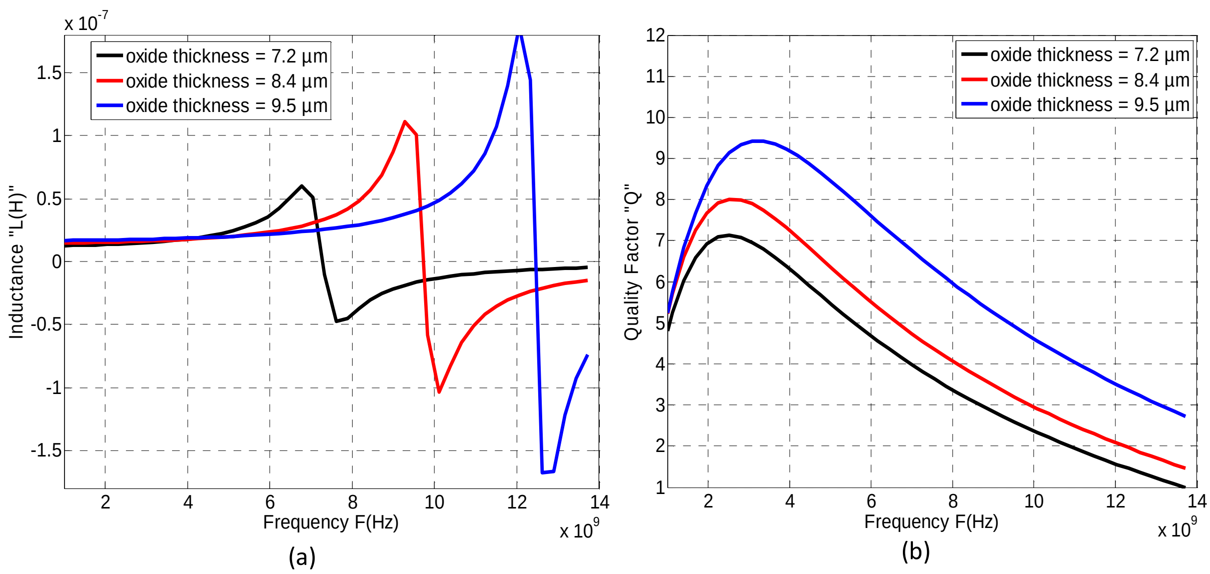



Fig. 5: Effect of the oxide thickness (a) on inductance, (b) on quality factor

## 3.4. Substrate conductivity

Figure (6.a) illustrates how the substrate conductivity influences on inductance value. Changing the substrate conductivity almost cannot alter inductance value. Figure (6.b) illustrates how the substrate conductivity influences on quality factor value. As the substrate conductivity reduces the quality factor augment. It is clear that substrate conductivity is the key bounding factor for the quality factor in a certain frequency band.

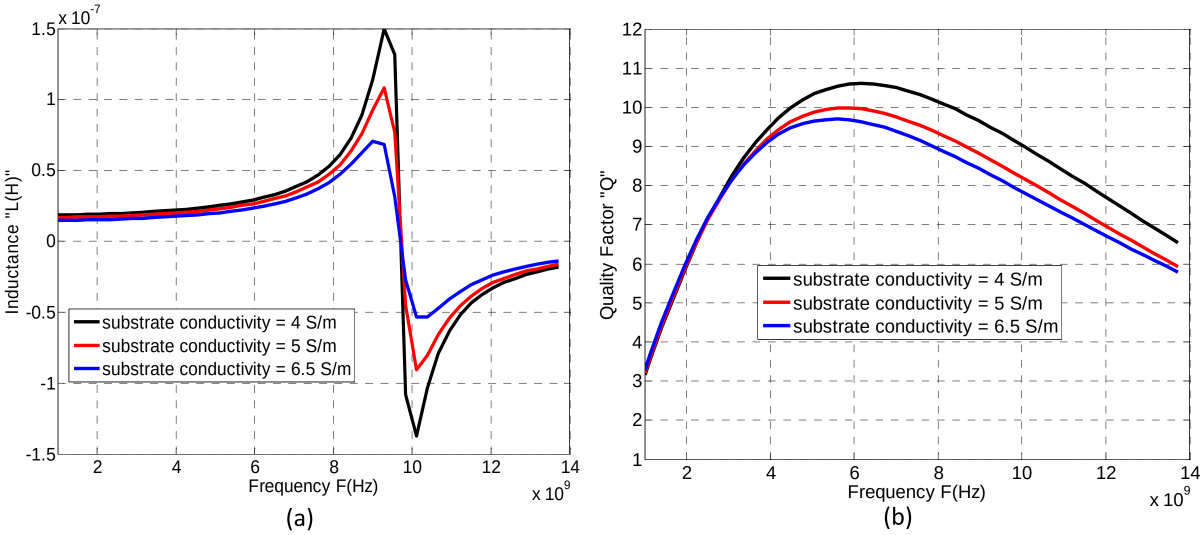



Fig. 6: Effect of the substrate conductivity (a) on inductance, (b) on quality factor

## 4. Conclusion

The square spiral inductor is designed for RF circuits in this paper. The parametric characteristics of this design was presented and the design procedure outline its performance in terms Quality factor and inductance. Better performance of the design is obtained with the optimized parameters from three values. Maximum value of quality factor obtained in the analysis is 2 at 4 GHz and the self resonant frequency of 11 GHz.

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