Modeling of on-Chip Solenoid Integrated Inductor for High Q-Factor Applications

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Abstract – A new structure of the solenoid inductor is presented in this paper. The proposed solenoid inductor has been simulated in a standard 0.18um one-poly-six-metal (1P6M) CMOS process. The proposed inductor products higher quality factor and inductance value in compare with the traditional designs. Furthermore, the new structure shows more improvement in the peak of quality factor so the number of turn increases.

Keywords: solenoid inductor, high quality, high inductance, on chip.

I. Introduction

Monolithic inductors are widely used in CMOS RF circuits, such as LNA and VCO. There are three mainly design considerations of the on-chip inductor, including the quality factor, the self-resonance frequency and the inductance value.

The quality factor of the inductor significantly affects the performances of the RF circuits and systems. Usually, the wide metal width was adopted to achieve the high-Q inductor at the price of the lower self-resonance frequency. There are several previous works done to improve the Q factor, using either standard CMOS plus post micromachining.[2]

The implementation of a high quality solenoid inductor on the silicon substrate is still a challenge. The energy loss in monolithic inductors on silicon substrate is severe because of the low resistivity of the substrate. This low resistivity of the substrate produces a strong eddy current in the substrate causing degradation in the quality factor.[5]

Therefore, special RF design techniques have been developed for realizing high quality solenoid inductors. These include the use of high resistivity silicon substrate to minimize magnetic coupling, etching of the silicon substrate under the inductor to minimize the capacitive coupling, and the use of thick oxide to reduce the capacitance of the substrate. However, these methods require techniques which are not available in the standard CMOS process.[4]

This paper presents a novel solenoid inductor structure. In the following part, first the most important parameters of solenoid inductor are explained; later, the structures of the solenoid and the proposed novel solenoid inductors are described. At the end, the simulation results are presented to evaluate the proposed design and compared against the conventional structure.

II. Characteristic of Solenoid Inductor

Conventional solenoid inductor is shown in Fig. 1. To characterize a solenoid inductor, three parameters are usually employed as the figure-of-merits, i.e., Q-factor, inductance, and SRF. These parameters determine the performance of a solenoid inductor.[3]

There are several definitions for the Q-factor; however, the most fundamental definition is the one proportional to the ratio of energy storage to the energy loss per cycle in the device. For a solenoid inductor, it can be calculated as follows:[1],[4]
\[ Q = -\frac{\text{Im}(y_{11})}{\text{Re}(y_{11})} \]  
(1)

The \( L \) value of an inductor is frequency-dependent. For on-chip solenoid inductors, \( L \) is an increasing function of the frequency. This is primarily due to the coupling capacitance, which boosts the effective inductance. Therefore, \( L \) is determined as [7]:

\[ L = \frac{\text{Im} \left( \frac{1}{y_{21}} \right)}{2\pi f} \]  
(2)

At a certain frequency, resonance will occur due to the parasitic effects of the substrate and the distribution characteristic of metal tracks. Resonance frequency is maximum frequency that inductor will shows induction status and in the higher frequencies from it inductor behaved as a capacitance. Therefore, SRF is determined as [1]:

\[ F = \frac{1}{2\pi \sqrt{L_{eq} C_{eq}}} \]  
(3)

III. Metal Layer Structure

In this paper, Solenoid inductor is simulated with a silicon IC technology. In the IC technology, there are several levels of metal above the oxide isolation layer (OIL), and each layer has a special thickness and a separation between them. Solenoid inductor generally makes use of one or more metal layers [6]. In the most conventional design, the solenoid is build with one turn in the one of the metal layers and the end it connects to other layer [7]. Our proposed solenoid inductor structure is illustrated in Fig. 2.

![Fig. 2 proposed solenoid inductor (W=15um, 2R=100um)](image)

The simulation results for solenoid inductor with conventional and proposed structure show the quality factor and the inductance values in Fig. 3, 4.
Therefore, to achieve the highest possible quality factor and higher inductance we have to increase number of turns while resonance frequency decreases.

A new configuration for improving the quality factor and inductance value is presented in this paper. In this configuration, as shown in Fig. 2, metal turns are built in different metal layer alternately.

IV. Simulation Results

The proposed configuration has been simulated by SONET simulator. The proposed configuration is compared with a conventional solenoid inductor. Figure 5 shows the structure overview of the metal and dielectric layers used in the present work’s simulation. Figure 6 shows the comparison between the new design and the conventional inductor’s inductance. It is clear that the inductance values in the various radiuses of proposed inductor are higher from conventional inductor in the frequency 1GHz, while W is 15um. Figure 7 shows the comparison of the quality factor between the proposed and conventional configurations. The new inductor shows a higher Q-Factor value in the frequency 1GHz and various radiuses (2R=60um-180um, w=15). A dielectric layer in SONNET is shown in Table 1. Comparison of the simulation results between the proposed design and the conventional solenoid inductor configuration are shown in table 2.
V. Conclusion

In this paper, a new solenoid inductor structure is proposed. Compare to the conventional solenoid inductor, the performances of the proposed solenoid inductor are superior to the conventional inductor. Moreover, the new structure is compatible with the IC technology and therefore is promising to be used in the system integration. The simulation results showed that the new geometry of inductor has a higher quality factor and inductance value.

References


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