A Novel Approach: Square Spiral Inductor for RF Telemetry Application

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ABSTRACT

This paper presents the design of square spiral inductor on FR4 substrate for different number of turns. Various simulations based on the incipient models were done by varying geometric parameters. Here, we vary the number of turns from 5 to 9 and find out their effect on Inductance (L), Quality factor (Q) and Self resonant frequency (SRF).The development of inductors for RF telemetry applications is studied. For, this square spiral inductors were also fabricated on FR4 substrate by designing the Layout of the inductor using Tanner L-edit tool. Simultaneous change of different parameters with number of turns is presented that allow circuit designer to optimize the integrated inductor in RF telemetry with minimum cost, risk and time. The dependency of inductor performances as inductance, quality factor and self-resonant frequency on geometric dimensions and process technology parameters are described.

General Terms

Radio Frequency, spiral inductors, simulation, fabrication.

Keywords

Spiral inductor optimization, Q factor, self-resonant frequency, inductive link, telemetry.

1. INTRODUCTION

Radio Frequency Telemetry System combines Radio Frequency (RF) technology with novel micro-inductor antennas and signal processing circuits for RF telemetry of real time, measured data, from MEMS sensors, through electromagnetic coupling with a remote powering/receiving device [1]. In radio frequency integrated circuits (RFICs), spiral inductor represents one of the major components of the RF ICs that dominates circuit performance and most frequently used passive devices in modern RFICs. A successful design and simulation of RFICs depends on accurate modeling and characterization of spiral inductors. To date a lot of research efforts has been made in the area of modeling, optimization and design of spiral inductors whereas very less effort has been devoted for systematic analysis and characterization of spiral inductors [2-3].

Wireless communication systems are on rapid growth and has stimulated research in low-cost, low-power, and high-performance CMOS RF integrated-circuit (IC) components for system-on-chip solutions [4]. The inductor is a basic component and very vital in designing radio frequency matching networks, load circuits of voltage controlled oscillators, filters, mixers and many other RF circuits [5]. Spiral inductors are used to realize high value inductance. In this paper the performance analysis of square spiral inductor using HFSS v11.0 tool is presented. Geometry parameters of the inductor structure and process technology parameters are varied in order to determine how they affect the inductor performance such as inductance, Q-factor and SRF [6]. Self resonant frequency and S-parameters were calculated for various numbers of turns. The effect of number of turns of inductor on Q and inductance were simulated and it was found that inductor with more number of turns gives best quality factor and inductance. The values of Q and Inductance are highly suitable for on chip Bio-MEMS inductor used in RF telemetry application [1]. Finally, square spiral inductors were also fabricated on FR4 substrate by designing the Layout of the inductor using Tanner L-edit tool. This detailed characterization and performance analysis will help RF IC designer to select a desired high performance square spiral inductor to make the design cost effective.

2. CHARACTERIZATION OF SQUARE SPIRAL INDUCTORS

The most widely used spiral inductors are square in structure. Fig. 1 shows the model that is most often used to characterize a square spiral inductor [8]. Inductors were designed using commercially available high frequency structure simulator tool (HFSS v11.0) for different number of turns from 5 to 9 by taking into considerations that 0.5 mm thick copper metal spiral was placed on 1.6 mm thick FR4 substrate.

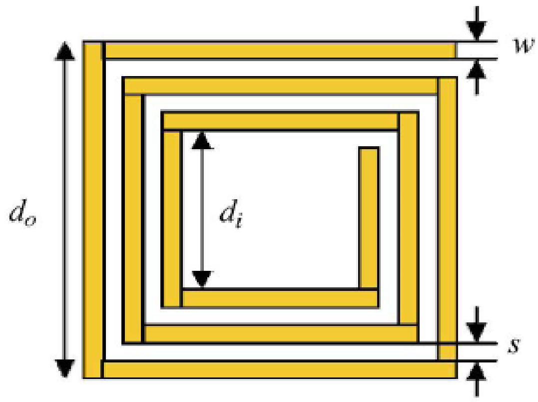

Fig 1: Dimensions of square spiral Inductor

On the other hand, a simulation-based approach provides more flexibility to the designer to select an inductor of desired performance and to make the design cost effective [7]. Here, we vary the number of turns from 5 to 9, the outer diameter (d_{out}) of the inductors, from 44mm, 52mm, 60mm, 68mm, to 76mm with the dimensions width (w) = 2mm, spacing (s) = 2mm, and inner diameter (d_{in}) = 8mm for every inductor.

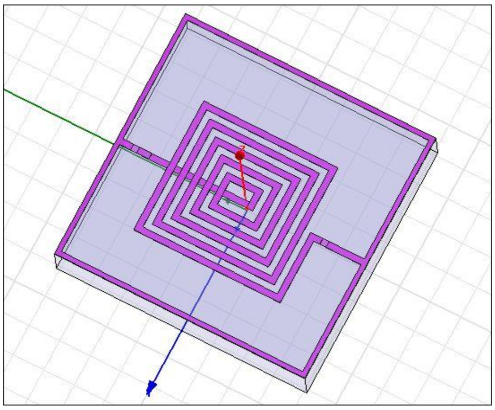

Fig 2: Inductor design with n = 5 and d_{out} = 44mm

For the performance analysis and characterization of inductors, the simulator calculates the S-parameter and then converts to Y-parameter [9], from which Inductance and Quality factor are extracted by equation (1) and (2) respectively.

$L = -img(1/Y_{11})/2*pi*f$ ------------ (1)

$Q = img(Y_{11})/real(Y_{11})$ ------------ (2)

Where Y_{11} is the input admittance and *f* is the operating frequency. Self-resonance of a circuit occurs at a frequency when its reactance equals to zero value. Therefore at SRF inductance and Q are zero. SRF and peak Q are extracted from the Q plot.

3. RESULTS AND DISCUSSION

The S-parameters and Self Resonant Frequency of inductors having 5 turns to 9 turns was calculated and S_{12} of 5 turn inductor was come out to be -41.49 at 92 MHz (fig. 4), similarly the S_{12} of 6, 7, 8, and 9 turn inductor was -41.58 at 68 MHz, -43.09 at 51 MHz, -46.20 at 43 MHz, and -44.39 at 34 MHz respectively (fig. 5, fig. 6, fig. 7 and fig. 8).

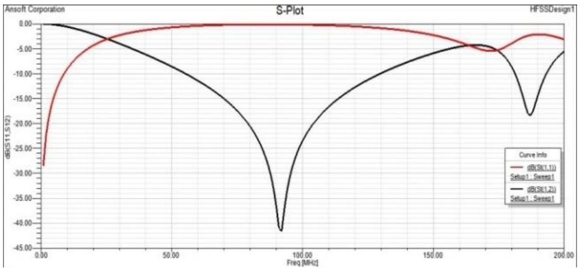

Fig 3: 5 turn S-parameter

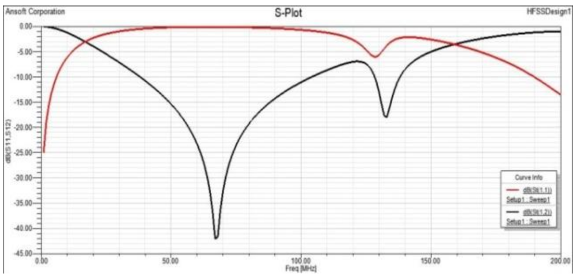

Fig 4: 6 turn S-parameter

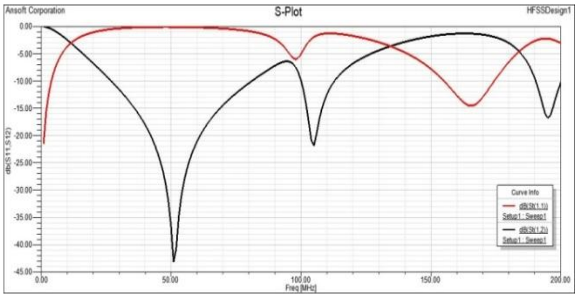

Fig 5: 7 turn S-parameter

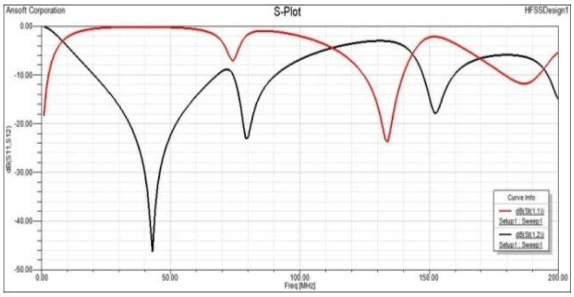

Fig 6: 8 turn S-parameter

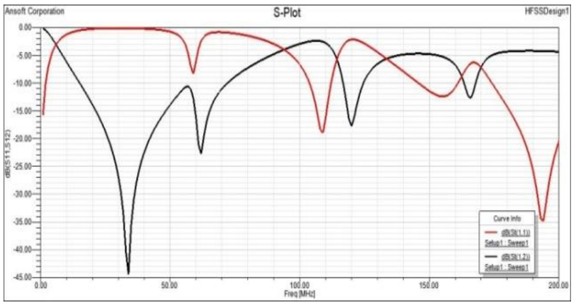

Fig 7: 9 turn S-parameter

A set of spiral inductors were designed with various geometric dimensions and technology parameters and simulated using HFSS tool. Number of turns of inductor is an important geometrical layout parameter to consider since it determines the overall size and performance of the inductor. By increasing the number of turns from 5 to 9, inductance is improved by 0.7 µH to 5 µH, quality varies from 15 to 19 and SRF falls down from 92 MHz to 34 MHz.

In order to find out the effect of number of turns on inductance (L), Quality factor (Q) and SRF (Self Resonant frequency), a number a graphs are plotted as shown here:

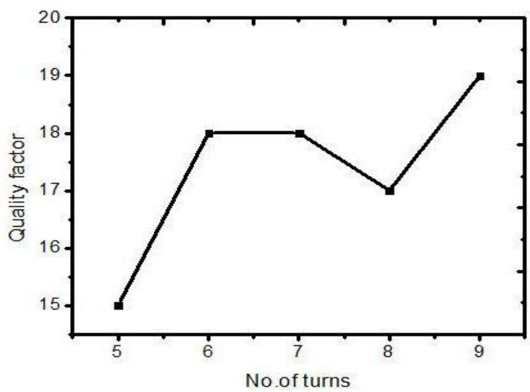

Fig 8: Change in Q with respect to no. of turns

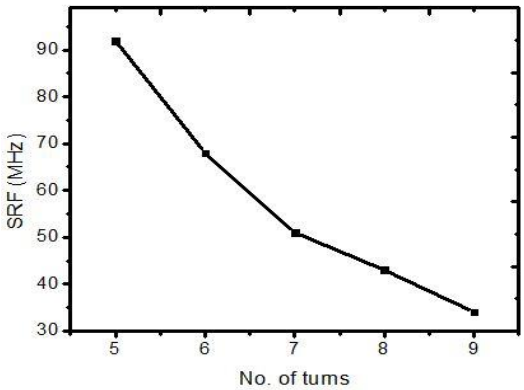

Fig 9: Change in Self Resonant Frequency with respect to no. of turns

4. FABRICATION OF SQUARE SHAPE SPIRAL INDUCTOR

The primary requirement for fabrication of square spiral inductor is the layout design. HFSS simulation model design is edited using the Tanner L-edit tool. While it is primarily a VLSI design tool, it is also flexible enough to do micromachining design and printed circuit board layout. The square spiral inductors are fabricated on Fr4 substrate by designing the Layout of the inductor using Tanner L-edit tool. Inductors were designed for different number of turns by taking into considerations that 0.5 mm thick copper metal spiral was placed on 1.6 mm thick Fr4 substrate.

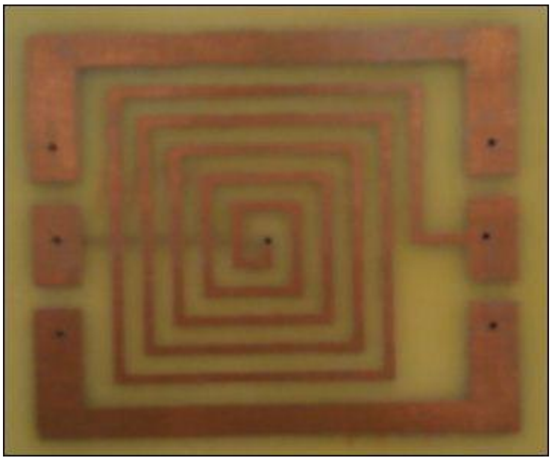

Fig 10: Fabricated 5-turn Square spiral inductor

5. CONCLUSION

Systematic characterization of square spiral inductor on FR4 substrate using HFSS v11.0 simulation tool is discussed. Performances of square spiral inductors are analyzed with the variation on layout geometry parameters and different process technology parameters. By increasing the number of turns from 5 to 9, inductance is improved by 0.7 µH to 5 µH, quality varies from 15 to 19 and SRF falls down from 92 MHz to 34 MHz. Layout is designed using Tanner L-edit tool and square spiral inductors are fabricated on Fr4 substrate. An inductive link can be formed between a pair of fabricated square spiral inductors and subsequent testing results can be used for calculation of power transfer efficiency. In Future the electronic Interface with the proposed Inductor can be used in various RF telemetry applications [10-11].

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7. REFERENCES

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