Sample Translation

Electronic Engineering

- See below for the original Chinese manuscript.
- **A native-speaker of English who has studied this field** proofreads the translated English.
- The quality of the translated manuscript is suitable for publication in an international journal.

Abstract

In this article, a simplified equivalent circuit in a proposed closed form expression is combined with a triangularity *Q*-curve (quality factor) design methodology (TQ) for spiral inductors to obtain automated optimal design. At first, a closed-form expression is combined with a dual-port equivalent circuit model that contains substrate electromagnetic coupling effect to describe the characteristics for TSMC 0.35 μm process to produce the spiral inductor. The *Q*-curve triangularity characteristic relationship is to verify the accuracy of the model. After comparison of simulated and measured values for S11, the total error and the error for inductance value are lower than 0.71% and 7% respectively. In summary, the enumeration method is used to design all structure to satisfy 1.5 nH and 3.0 nH and obtain the relationship between *Q-curve* peak and triangularity characteristic, which is also used as the condition for optimal spiral inductor. TQ design methodology obtains almost the same optimal structural characteristic as the enumeration method, but only uses half the time. Furthermore, under the restriction of multiple conditions based on physical principles, the design of spiral inductors can approach process limits and optimal performance. TQ methodology will become an effective tool to accomplish SoC (System on a chip) RF IC (radio frequency integrated circuit).

KEYWORDS: Automatic Design, Triangularity, *Q*-factor, Low Frequency Slope, High Frequency Slope, Self Resonant Frequency, RFIC

I. Introduction

While pursuing the wireless communication market development, the use of low-cost and high-performance CMOS (complementary metal oxide semiconductor) technology is the common solution to create system on chip (SoC) technologies [1]. However, the progress of SoC radio frequency (RF) integrated circuits (IC) is dependent on the design efficiency and automation of integrated spiral inductors. In addition, to satisfy the requirement of an accurate inductance value is also a key point for present design.

Spiral inductors are produced on silicon chips to meet the inductance requirement of RF IC. With the assistance of electromagnetic simulation software, the design method [2] needs to calibrate the simulation environment as well as geometrical dimensions to obtain a spiral inductor structure that can meet the circuit requirements. This is a time-consuming and ineffective design method whereby the mass production of a testkey inductor database is established [3]. This not only expensive but also fails to meet circuit requirements. Developing closed form expressions for the physical structure of scalable silicon spiral inductors to find a design method that meets requirements can be divided into two classes: one is the equation developed on geometrical structural dimensions or based on the concepts of electromagnetic physics, using a massive amount of testkeys to obtain empirical formula for curve fitting [4-5]; the other is to use electromagnetic physics-based algorithms [6-9]. Although the empirical formula for curve fitting has a very simple correlation that is suitable for automatic design applications, it has to use a massive amount of curve fitting parameters and therefore it results in insufficient accuracy for calculations. The algorithm proposed by Greenhouse in 1974 has sufficient accuracy and scalability. However, the calculation process is too complicated and not suitable for automatic design.

Abstract

本论文，提出以具体的解析式(closed form expression)的简化等效电路模型，结合螺旋电感的Q值 (quality factor)曲线三角形特征的设计法 (triangularity Q-curve design methodology, TQ)，获得集成螺旋电感的最优化自动设计。首先采用具体的解析式(closed-form expression)结合包含基底电磁耦合效应的双埠形等效电路模型，描述TSMC 0.35μm制作螺旋电感过程的特性。通过Q值曲线三角形特征关系验证模型的准确度。通过比较仿真值与测量值，S11的总误差(totalμ0.35 error)与电感值的误差都分别低于0.71%和7%。总而言之，以列举法(enumeration)设计满足1.5 nH及3.0 nH的所有结构，获得Q值曲线顶峰与三角形特征的特殊关系，并作为最优化螺旋电感特性的限制条件。 TQ设计法获得的最优化结构特性与列举法几乎一样，但是时间却减少了一半。此外，在基于物理基础的多目标条件的限制下，设计的螺旋电感特性可接近制作过程极限并达到最优化要求。TQ法将成为实现单晶片(System on a chip, SoC)射频集成电路(radio frequency integrated circuit, RFIC)的利器。

KEYWORDS: Automatic Design, Triangularity, *Q*-factor, Low Frequency Slope, High Frequency Slope, Self Resonant Frequency, RFIC

I. Introduction

针对无线通讯市场发展，应用低价高效的 CMOS (complementary metal oxide semiconductor)技术，被公认为实现单晶片的解决方案[1]；然而，单晶片射频集成电路的研发速度受制于集成化螺旋电感 (integrated spiral inductor)的设计的效率和设计的自动化程度。高品质因子平面螺旋电感的自动化设计开发，是一项对于系统单晶片的发展而言非常地重要的技术，在满足电路需求的准确感値的同时，迎合电路应用需求频段的最佳效能，也是目前设计的重点之一。

在硅晶片上制作符合射频积体电路需求感値的螺旋电感，通过电磁模拟软件协助的设计方式[2]，除了需要校正仿真环境之外，也必须一再地调校几何尺寸，以获得满足电路需求的螺旋电感结构。这是一种既费时又低效的设计方法；藉由大量制作测试键以建立电感元件资料库[3]，除了花费不菲外，同时也无法准确 满足电路之需求；发展可调节的(scalable)硅基螺旋电感的物理结构的具体

的解析式，以获得满足需求的设计方式，又分类成二大类：一是以几何结构尺寸或基于电磁物理理论所发展的方程式，透过大量测试键 (testkeys)获得拟合的(curve fitting)经验方程式(empirical formula) [4-5]；另一是运用电磁物理为基础的算法(physics-based algorithms) [6-9]。虽然拟合的经验方程式具有非常简洁的关系式，适合自动设计的应用，但却必须引用大量拟合参数，导致计算的准确度不足；而 Greenhouse 在 1974 提出的算法虽然具有足够的准确度及可调节性，但计算过程过于复杂，并不适合自动化设计。