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Coupled Spiral Inductor for RF Applications

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Abstract. Realization of coupled spiral inductor using standard CMOS process parameters (TSMC 0.18µm and 1P6M) has been simulated using EM simulator. The coupled spiral inductor provides higher quality factor of 33%, with small degradation in inductance to standard stacked inductor of same dimensions.

Keywords: Self Inductance, Quality factor, Mutual Inductance, Vector Magnetic Potential.

1. Introduction

The inductors of high quality factor are highly required in RF applications. The high quality factor inductors are reported in literature [1,2]. The proposed spiral inductor is useful in wireless local area networks where there is no silicon area restriction. The tunability of the tunable spiral inductor [3] can be further improved using coupled spiral inductor shown in Fig.1.

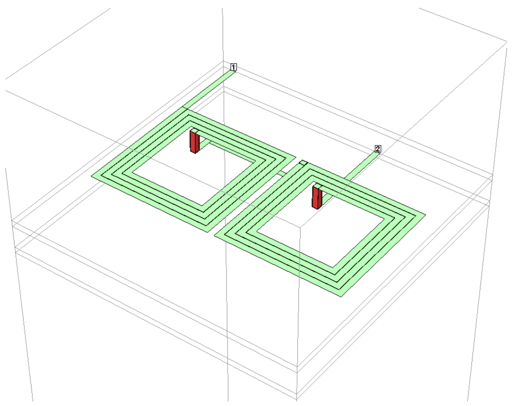

Fig. 1: Coupled Spiral Inductor

2. Inductance calculation

The inductance of the Spiral inductor can be calculated by Maxwell's equations and also by field solvers. Greenhouse developed an algorithm for computing the inductance of planar rectangular spirals. The Greenhouse method states that the overall inductance of a spiral can be obtained by computing the self-inductances of individual segments plus positive and negative mutual inductance between all possible wire segment pairs. For instance an N turn spiral have $4N$ self-inductance terms, $2N(N-1)$ positive mutual inductance terms, and $2N^2$ number of negative mutual inductance terms. Although many empirical formulas exist in the literature for the estimation of spiral inductors inductance [4,5,6,7], Greenhouse method provides a good approximation in finding the inductance. The coupled spiral inductor's inductance is calculated using

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Greenhouse method [8]. The performance of the tunable inductor can be further improved by using the coupled spiral inductor as base inductor.

3. Mutual Inductance calculations

The mutual inductance between any two conductors, which are part of the structure, is calculated as fallows. Consider, two conductors separated by a distance "d" and carrying currents in to the conductor along z-axis with current magnitudes as $I_1 e^{-\beta_1 z}$ and $I_2 e^{-\beta_2 z}$ as shown in the Fig. 2.

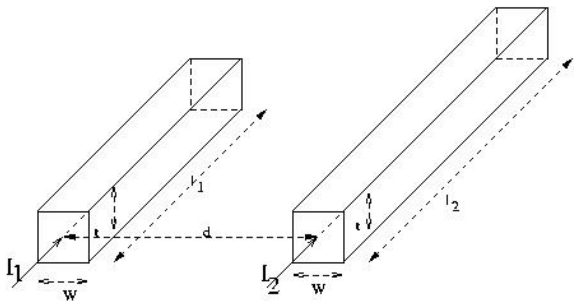

Fig. 2: Two-conductor structure

The vector magnetic potential at any point in the space due a conductor carrying $I_1 e^{-\beta_1 z}$ is given by the equation .1

$$A_z(x,y,z)=\int_{-l_1/2}^{l_1/2}\frac{\mu_o I_1 e^{-\beta_1 z}}{4\Pi\sqrt{(x-x')+(y-y')+(z-z')}}dz' \qquad (1)$$

Here, the dimensions of the conductors, part of the spiral, are such that, the cross section of the conductor is infinitesimally small as compared with length of the conductors. With this assumption, if the current is uniform throughout the conductor and the conductor length is less than the wavelength, then the above equation becomes

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

The magnetic flux density B and the vector magnetic potential A are related by the equation (3)

$$B=\nabla \mathrm{X} A \qquad (3)$$

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

$$\phi_{21}=\int_S B.ds \qquad (4)$$

Using stokes theorem, the above equations becomes

$$\phi_{21}=\int_{l_2} A_Z(d,0,z).dz \qquad (5)$$

$$\phi_{12}=\frac{\mu_0 I_1}{4\Pi}\int_{-\frac{l_2}{2}}^{\frac{l_2}{2}}\int_{-\frac{l_1}{2}}^{\frac{l_1}{2}}\frac{e^{-j\beta_1 z}}{\sqrt{(d)^2+(z-z')^2}}dz'\,dz \qquad (6)$$

By re-orientation of the integral

$$\phi_{12} = \frac{\mu_0 I_1}{4\Pi} \int_{-\frac{l_1}{2}}^{\frac{l_1}{2}} \int_{-\frac{l_2}{2}}^{\frac{l_2}{2}} \frac{e^{-j\beta_1 z}}{\sqrt{(d)^2 + (z - z')^2}} dzdz' \qquad (7)$$

Expanding the term inside the integral using the Maclausin's theorem up to 4th order terms and then solving the integration, we will get the total flux associated with the second conductor due to first conductor carrying the current I_1. The mutual inductance between the conductors is given by the expression

$$M_{12} = \frac{\mu_0 I_1}{4\pi} \frac{\phi_{12}}{I_2 e^{-j\beta_2 z}} \qquad (8)$$

The mutual inductance calculated from the Greenhouse method and the integration method is shown in the Fig. 2. The results shows, the mutual inductance almost equal either of the methods.

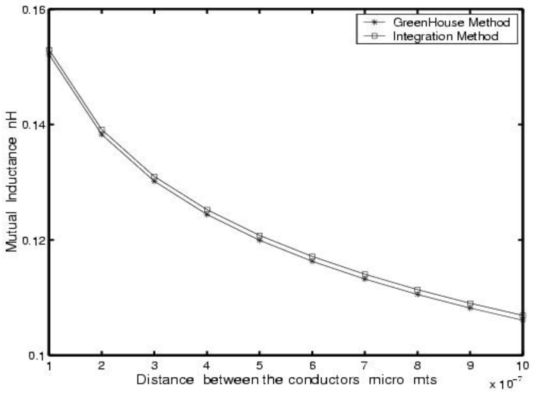

Fig. 3: Mutual Inductance Vs. distance between the conductors

4. Results

The coupled inductor, planar spiral inductor and stacked spiral inductor are simulated using SONNET EM (Evaluation) simulator making use of Taiwan Semiconductor Manufacturing Co. Ltd (TMSC) 0.18µm technology parameters. From the results, as shown in Fig. 4, Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9, the coupled spiral inductor are having higher Quality factor. The Quality factor of the coupled spiral inductor is also studied for different turn widths, such as W=10µm as well as W=15µm. The simulation results are presented in Fig.5 and Fig 6. It is reasonable to have higher Quality factor and decrease in inductance with increase in turn width of the spiral inductor, which is also proved using EM Simulator results. From the results Fig. 7 and Fig. 8, the coupled inductors are also having higher Quality factor, but degradation in inductance as compared to stacked spiral inductor.

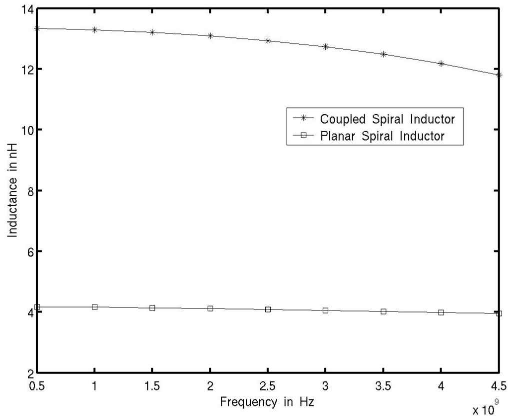

Fig.4: The inductance of the coupled spiral Inductor against planar spiral inductor. The dimension of the spiral inductor W =10µm, spacing between the turns(S) =0.6µm, thickness of the turn (t) =0.6µm and the number of turns (N) =4.

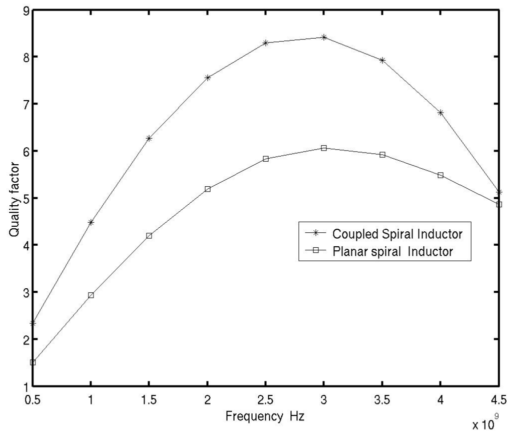

Fig.5: The Quality factor of the coupled spiral Inductor against planar spiral inductor. The dimension of the spiral inductor W =10µm, spacing between the turns(S) =0.6µm, thickness of the turn (t) =0.6µm and the number of turns (N) =4.

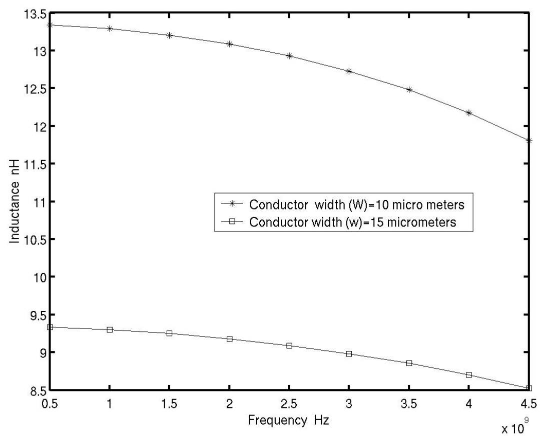

Fig.6: The inductance of the coupled spiral Inductor, for different turn widths, W =10µm, and W =15µm, and spacing between the turns (S) =0.6µm, thickness of the turn (t) =0.6µm and the number of turns (N) =4.

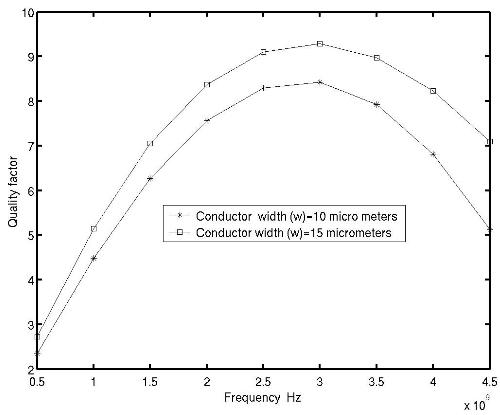

Fig. 7: The Quality factor of the coupled spiral Inductor, for different turn widths, W =10µm, and W =15µm, and spacing between the turns (S) =0.6µm, thickness of the turn (t) =0.6µm and the number of turns (N) =4.

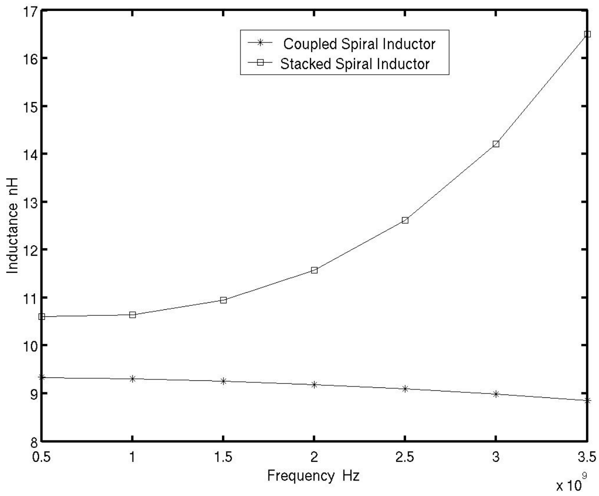

Fig. 8: The inductance of the coupled spiral Inductor and stacked spiral inductor, for different turn widths, W =10μm, spacing between the turns (S) =0.6μm, thickness of the turn, (t) =0.6μm and the number of turns (N) =4.

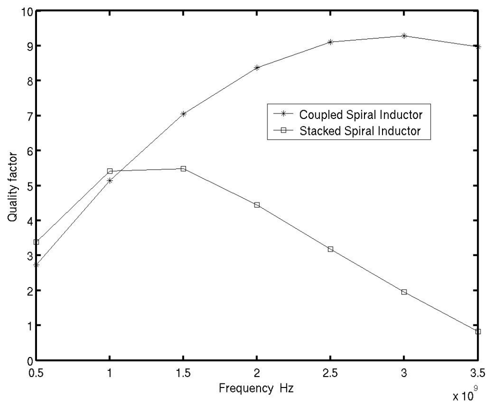

Fig. 9: The Quality factor of the coupled spiral Inductor and stacked spiral inductor, for different turn widths, W =10μm, spacing between the turns (S) =0.6μm, thickness of the turn (t) =0.6μm and the number of turns (N) =4.

5. Conclusion

The coupled inductor are providing high quality factor of 33% as compared to standard stacked inductor of same dimensions with small degradation in self inductance.

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