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Variable RF Inductor on Si CMOS Chip

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1. Introduction

We propose a novel variable inductor on Si CMOS chip, whose inductance is nH-order for GHz application. The fundamental structure is the same as the conventional plane-type spiral inductor. The inductance value can be varied by sliding a metal plate above the inductor horizontally.

For accurate impedance matching in RF circuits, it is required to vary the values of capacitance, inductance and resistance. There are many reports about an on-chip variable capacitor and resistor. However, an on-chip variable inductor is hardly reported. We have previously reported the on-chip variable inductor using thin-film metallic glass in Fig.1 (a) [1][2]. The glass metal is used in order to change the height of spiral. Because of ten times higher resistivity of glass metal than that of Al and Cu, it is difficult to improve Q-factor. Since the spiral inductor structure in this work is the same as the usual spiral inductor on Si CMOS chip, low resistivity metal material such as Al and Cu can be used, resulting in that high Q-factor inductor is expected.

In this paper, we describe the principle of the novel variable inductor and simulation and measurement results. The 3D FEM simulation was performed using Ansoft HFSS (ver.8.0.25).

2. Principle of Variable Inductor

Figure 1(b) shows a schematic of the variable inductor in this work. The metal plate is placed above the spiral inductor and is slid horizontally. The metal plate disturbs the magnetic flux which penetrates the inductor; change of the magnetic flux results in the change in inductance. The sliding system of the metal plate will be implemented using the comb type actuator which is fabricated by the usual MEMS technology[3]. Figure 2 shows magnetic flux distribution for x=0[μm] and x=120[μm]; x is the overlap length of the spiral inductor and the metal plate. As shown in Fig. 2(b), it can be seen that the magnetic flux is disturbed by the metal plate, resulting in the change of the inductance.

3. Results and Discussion

Design parameters of the spiral inductor are (1) number of turn is 3.5, (2) line width is 25μm, and (3) side length of rectangular spirals 250μm as shown in Fig. 1(b). The spiral inductor is fabricated using the standard 0.18μm CMOS process. The metal is Cu.

Inductor characteristics were measured by a 2-port vector network analyzer (Agilent, 8720ES) using GSG probe heads (Cascade, ACP40). The inductor Y parameter (Y^{ind}) is obtained by de-embedding the pad Y parameter (Y^{pad}) from the raw Y parameter (Y^{raw}). Inductance L and Q-factor is calculated as follows [4].

$$L = \frac{1}{\omega} I_m\left(-\frac{1}{Y_{12}^{ind}}\right) \quad and \quad Q = \frac{I_m\left(1/Y_{11}^{ind}\right)}{R_e\left(1/Y_{11}^{ind}\right)}. \qquad (1)$$

Figure 3 shows s-parameters of the inductor after de-embedding at x=0 [μm]; Fig. 3(a) is s_{11} and s_{12} in a Smith-chart, and Figs. 3(b) and 3(c) are magnitude and phase of s_{12} and s_{21}. Both measured and simulation data are shown. In the 3D FEM simulation, the substrate is modeled to have the relative dielectric constant of 11.9 and resistivity of 5Ωcm. From Figs. 3(a)(b), the self-resonance frequency of this inductor is found to be 10[GHz]. It is noted that the simulation results represent the measured data.

Figure 4 shows the simulation results of L and Q of the variable inductor at f=5[GHz] as a function of metal plate position x. At x=0[μm], the spiral is not covered by the metal plate, while at x=250[μm] the spiral fully covered by the metal plate. L decreases with increase in x, because the magnetic flux density decreases with x as shown in Fig. 2. The value can be changed from 1.8[nH] to 1.3[nH], *i.e.*, ΔL/L≈17%. Q-factor hardly changed. Figure 5 shows the measured L and Q of the fabricated inductor at f=5[GHz] as a function of metal plate position x. The metal plate is slid manually using the micromanipulator. L decreases with increase in x as expected by the simulation. The changing ratio was found to be ΔL/L≈7%, which is smaller than that is estimated. This may be because (1)the exact values of metal plate size is not modeled, (2)the exact distance h between the spiral and metal(see Fig. 1(b)) is not modeled, and (3) exact value of the Si substrate resistivity is not known. It should be noted that the variable inductor exhibits qualitatively the desired characteristics.

4. Conclusion

We propose a novel variable inductor, which consists of the conventional spiral inductor and the metal plate above the spiral. The fabricated inductor has several nH-order inductances and the changing ratio of ΔL/L≈10%.

References

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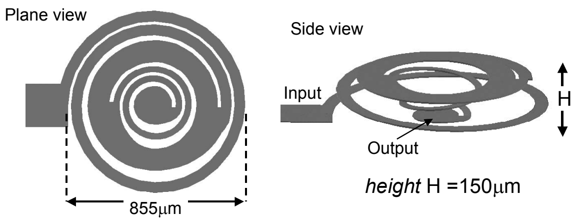
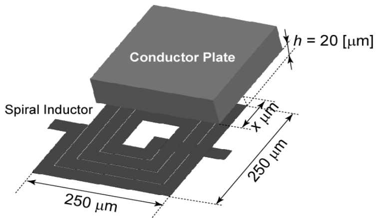
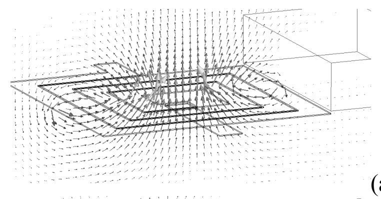


(a) Previous variable inductor[1]. Inductance value is changed by changing the height.

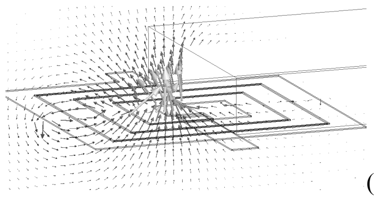


(b) The variable inductor proposed in this work. Inductance value is changed by sliding the metal plate horizontally.

Fig. 1. Structure of variable inductors.



(a) x = 0 [μm]



(b) x = 125[μm]

Fig. 2. Change of magnetic field distribution.

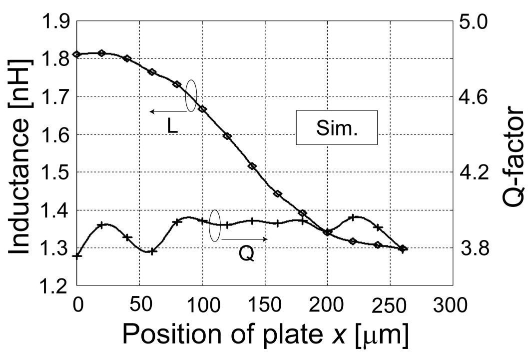
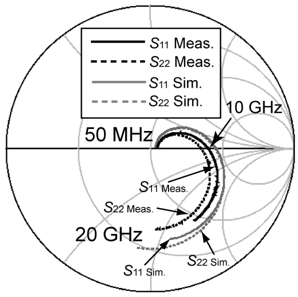
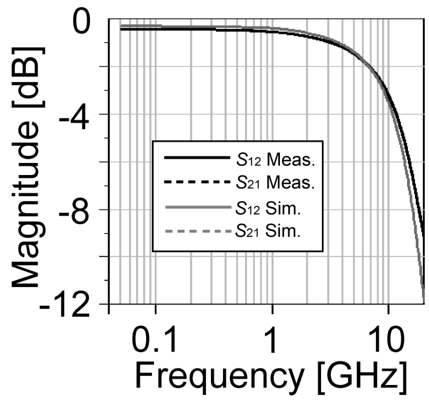


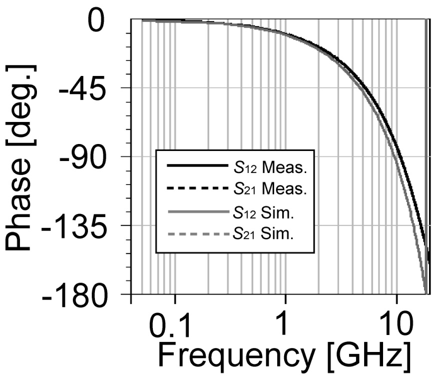
Fig. 4. L and Q at f=5[GHz] (Simulation)



(a) S_{11} and S_{22}.



(b) S_{12} and S_{21}. (Magnitude)



(c) S_{12} and S_{21}. (Phase)

Fig. 3 S-parameters of the inductor. Simulation and measured data are shown. Position of the metal plate is x=0 [μm].

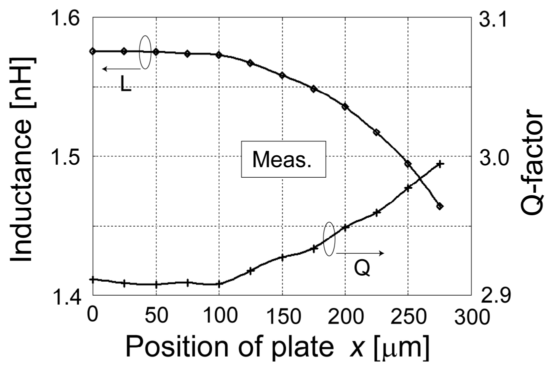


Fig. 5 L and Q of the fabricated inductor at f=5[GHz] (Measurement)