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The Design of a New Linear MEMS Variable Inductor

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Abstract: In this paper, we introduce a new structure of linear MEMS variable inductor which can be tuned using CCT method and we use a reticulated plate to varies the inductance. One of the advantages of this structure is a light weight relative to the integrated upper plate. The proposed structure consists of an inductor, movable ring plate and an electrostatic actuator system. In our tunable inductor, the electrostatic actuator is employed for mechanical movement. The simulation results show that, the minimum and maximum tuning range of our tuning inductor is 53% and 79% respectively and we have the linear change in inductance.

Keywords: MEMS, Variable Inductor, electrostatic actuator

I. INTRODUCTION

Radio frequency microelectromechanical system (RF MEMS) is a technology that enables the batch fabrication of miniature mechanical structures, devices, and systems for microwave and wireless communication applications. There are four basic RF MEMS components have been reported so far: (i) the switch; (ii) the (tunable) capacitor; (iii) the (tunable) inductor and (iv) the antenna.

The Inductor is an important electrical component and has been used in electrical and electronic circuits such as VCO (Voltage Controlled Oscillators). Inductors are divided into fixed-inductance and variable-inductance types. Inductor with variable inductance is the main element of the frequency based circuits such as tunable filters [1], voltage controlled oscillators[2-4], frequency agile radios[5], reconfigurable impedance matching networks [6], RF wireless devices, phase shifters[7] and low noise amplifiers [8].

Based on their actuation type, tunable passives can be classified as: electrostatic, thermal, piezoelectric, or magnetic. Among them, electrostatic actuation can offer the highest actuation speed and the lowest DC power consumption. In addition, the biasing network of electrostatic actuators is relatively straightforward. As such, there has been extensive research on developing electrostatically tunable passives and particularly capacitors and several devices with wide tuning range have been reported in the literature [9-11].

The tunable inductors can be divided into four categories: discrete tuned (DT), metal shielding tuned (MST), magnetic core tuned (MCT) and coil-coupled tuned (CCT). The discrete tuned inductor often uses microswitches [12-15] or micro relays [16,17] to increase or decrease the effective coil length of the inductor, but the combination of the micro switches or micro relays will reduce the Q-factor of the inductor. The metal shielding tuned inductor is realized using moveable metal structure with large range, resulting in the magnetic flux of the inductor changed [18].The magnetic core tuned inductor is realized using solenoid inductor imbedded with magnetic-core conductor whose permeability can be changed when applying magnetic field [19, 20]. The coil-coupled tuned inductor mainly adjusts its mutual inductance between the primary coil and the secondary coil of the inductor [21-23].

In this paper, we introduce a new structure which can be tuned using CCT method and we use a reticulated plate to varies the inductance. One of the advantages of this structure is a light weight relative to the integrated upper plate. As a result, require less force to move upper plate. Our design simulated with COMSOL software and finally the comparison of proposed structure with the other tunable inductors.

II. DESIGN OF A NOVEL TUNABLE INDUCTOR

Our proposed variable inductor is based on magnetic coupling. In this design, a movable plate changes the magnetic field and magnetic flow of the inductor and then an inductor with variable inductance can be accessed.

The proposed structure consists of an inductor, movable ring plate and an electrostatic actuator system. When the voltage is applied, the movable plate which is placed on a movable beam, moves to the inductor and change its magnetic flow, finally the inductance is changed and a tunable inductor is achieved. The schematic of tunable inductor is shown in Fig.1. According to the Fig.1, the basic inductor is a ring shaped two-turn 10μm-thick with square dimension structure. The space between inductor turns is 10μm.

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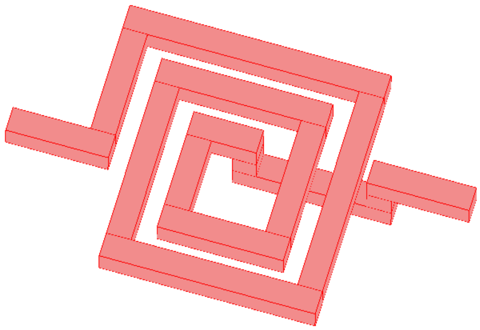

Fig.1. the schematic of proposes tunable inductor

III. TUNING MECHANISM

The proposed novel inductance tuning is based on magnetic coupled mechanism. When a movable metal plate moves to the fixed inductor, cuts all or a portion of magnetic field of the inductor and induces voltage and current. Based on Lenz-Law the magnetic field of induced currents is opposite of the basic magnetic field which will be decreased overall magnetic field. This reduction in the magnetic field will reduce the inductor stored magnetic energy and hence the inductance of the inductor will be decreased. In the proposed tunable inductor, the electrostatic actuator is employed for mechanical movement.

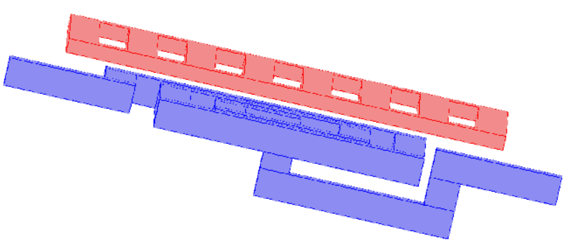

Fig.2.The fixed inductor and moveable plate structure based on magnetic coupling (isometic view)

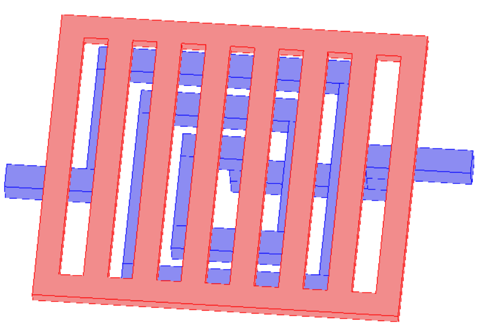

Fig.3.The tunable inductor with magnetic core (up view)

As depicted in Fig.2 and Fig.3, the movable plate has some holes. These holes introduce some advantages such as weight reduction and low required force to plate displacement. According to Fig.4, there is maximum space between the fixed inductor and fulls-of-hole movable plate.

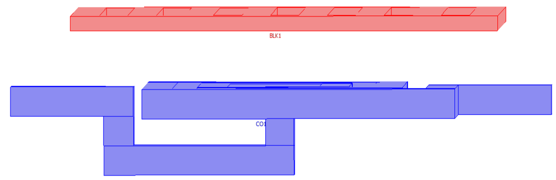

Fig.4.The tunable inductor after actuation applied and movement of the movable plate ((front view)

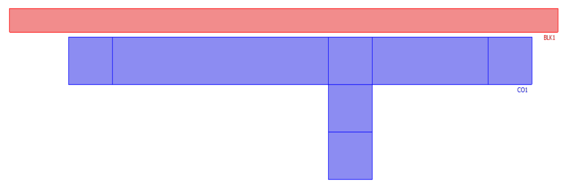

Fig.5. The tunable inductor befor actuation (front view)

The electrostatic actuator has been employed for the displacement of the movable plate because of its benefits, such as the smaller size of the device, low power consumption and actuation simplicity in comparison with the other types, especially piezoelectric counterpart and so on. The movable plate is connected to a support which is a cantilever-beam with fixed-free degrees of freedom. The support acts as one of the electrostatic electrodes. It is assumed that the space between the ground electrode, which is placed on the upper substrate, and the support electrode to be 20μm. When the actuation voltage is applied, the movable cantilever-beam will almost displace 20μm and is moved to the ground electrode, hence the movable plate is spaced with basic inductor and tuning is achieved.

IV. SIMULATION RESULTS

The proposed stricture is simulated with finite element method software COMSOL and the results are shown in Fig.6-12.

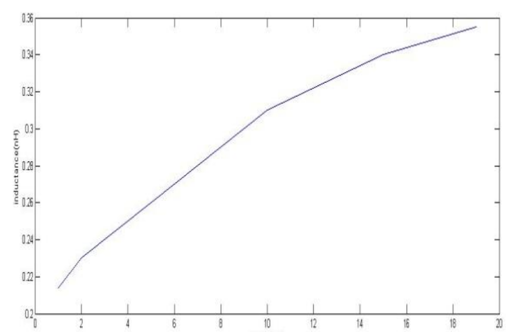

Fig.6. The inductance change of proposed tunable inductor

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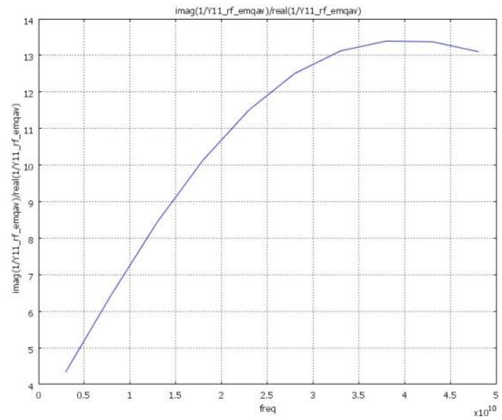

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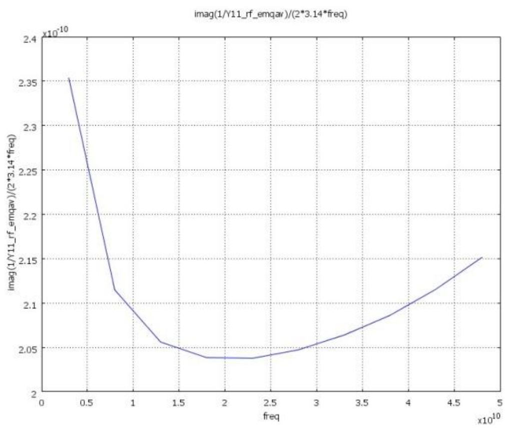
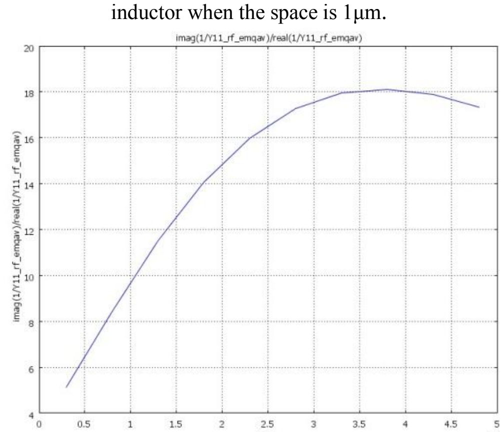


b)

Fig.7. a)Quality factor and b) The inductance of proposed tuning inductor when the space is 1µm.



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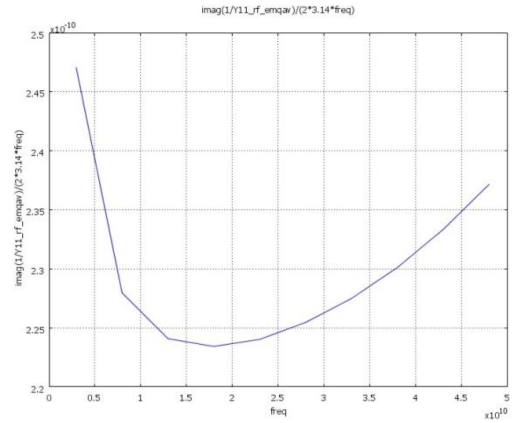
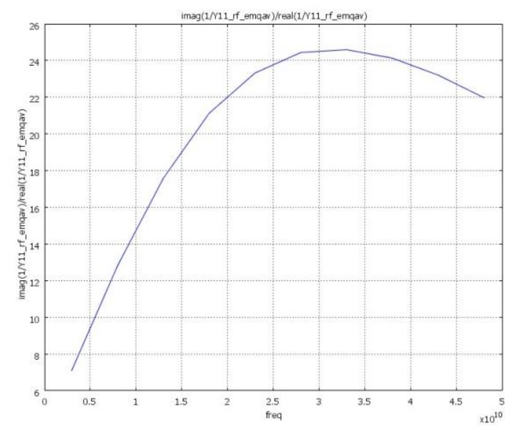


b)

Fig.8. a)Quality factor and b) The inductance of proposed tuning inductor when the space is 2µm



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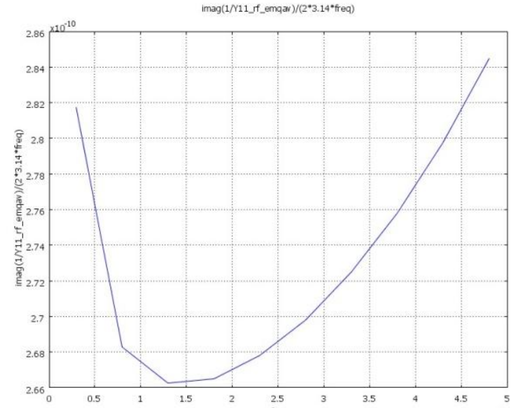

b)

Fig.9. a)Quality factor and b) The inductance of proposed tuning inductor when the space is 5µm

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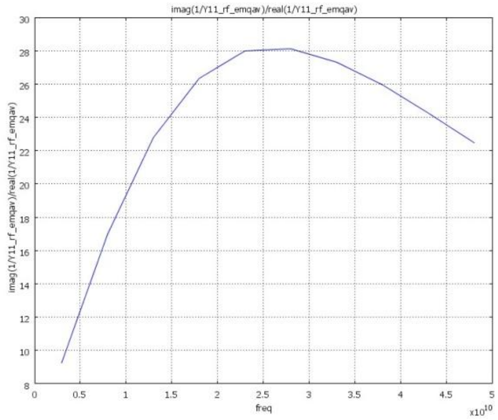

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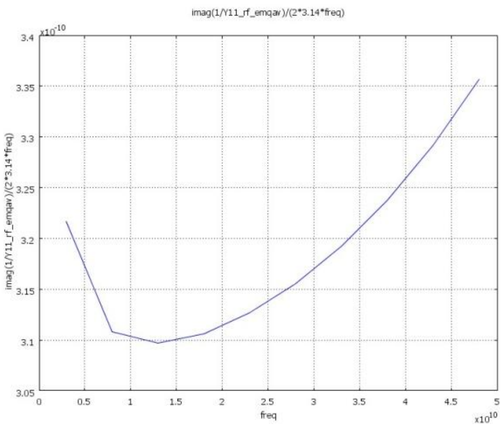
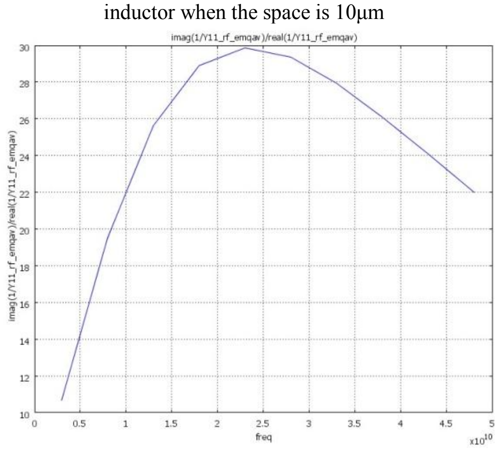


b)

Fig.10. a)Quality factor and b) The inductance of proposed tuning inductor when the space is 10μm



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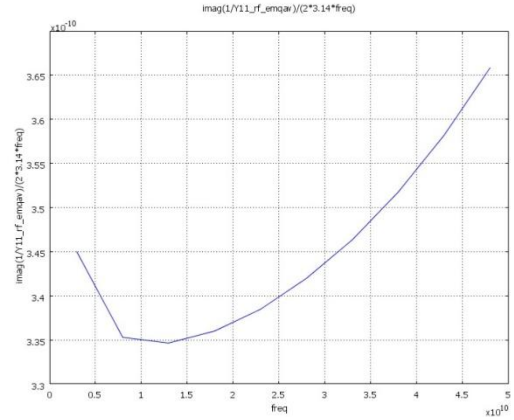

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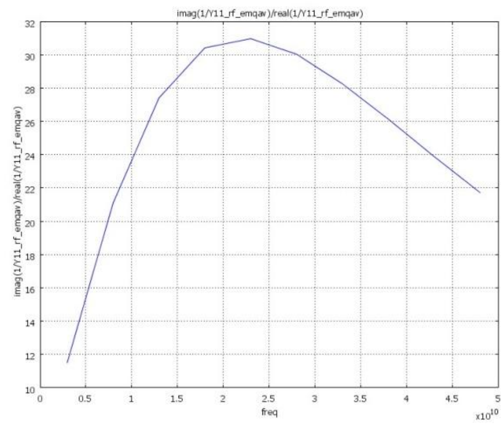
Fig.11. a)Quality factor and b) The inductance of proposed tuning inductor when the space is 15μm



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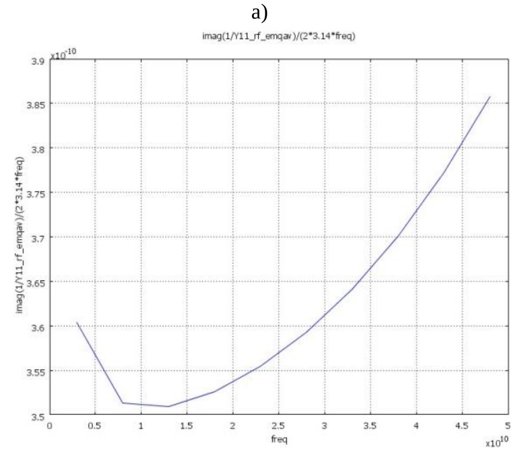

b)

Fig.12.a) Quality factor and b) The inductance of proposed tuning inductor when the space is 20μm

According to Fig.6-12, when the space between movable reticulated plate and the inductor is increased, the inductance and quality factor of proposed structure is increased. When the frequency is increased, the quality factor is first increased and then decreased. The maximum quality factor is depending on the space between movable plate and inductor. When the space between movable plate and inductor is fixed, the tuning range of the proposed

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structure is 10% based on the simulation results. The simulation results are shown in table I .

TABLE I
Simulation Results

frequency	Inductance before plate displacement (nH)	Inductance after plate displacement (nH)	Quality Factor		Tuning Range
			Before Actuation	After Actuation	
3	0.235	0.36	4.3	11.5	53%
8	0.21	0.351	6.5	21	67%
13	0.206	0.35	8.5	27.5	70%
18	0.204	0.353	10.1	30.5	73%
23	0.204	0.356	11.5	31	74%
28	0.205	0.36	12.5	30	75%
33	0.206	0.365	13.1	28.3	77%
38	0.208	0.37	13.4	26.1	78%
43	0.211	0.377	13.4	24	79%
48	0.215	0.385	13.1	21.7	79%

Regarding to the table1, the minimum and maximum tuning range of our tuning inductor is 53% and 79% respectively. The best response is when the frequency is 30GHz which will have %77 tuning range and the quality factor of 13 and 30 before and after actuation, respectively.

V. CONCLUSION

Simulation results show that the our inductor have the linear change when the plate move up and down (Fig.6). This is a very important advantage in designing of electronic device. One of the benefits of the new design is its performance at high frequencies.

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