# TUNABLE MEMS CAPACITOR FOR $m$M AND $\mu$M WAVE GENERATION

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Abstract: We present the design of tunable capacitor based on MEMS simulated using COMSOL Multiphysics, which is an emerging engineering software environment used for modelling and simulation of any physical based structure. This model includes an electrostatic simulation for a given distance. The response time obtained is 5μs.The tunable capacitor is a typical component in various microelectromechanical systems (MEMS) for electromagnetic fields in the radio frequency range 300 MHz to 300 GHz. Also the design of a tunable inductor has been presented which can be combined with tunable capacitor to generate a high frequency range is obtained which has applications in wireless local loop, satellite communication, radar, terrestrial microwave links and specialized laboratory experiments.

**Keywords:** MEMS (micro electro mechanical systems)

## 1. INTRODUCTION

Micro-Electro-Mechanical Systems, or MEMS, is defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of micro fabrication. A variable capacitor is a capacitor whose capacitance may be intentionally and repeatedly changed mechanically or electronically. Tunable parallel-plate capacitors are wide used in RF MEMS. They are used in microrelays, micromirrors, micro actuators, micro switches, micro position sensors, voltage controlled oscillators (VCO), resonators, tunable filters, on-chip matching networks, passive filters, power amplifiers, radio transmitters and other tuning circuits for electrostatic actuation and sensing.

## 2. TUNABLE MEMS CAPACITOR

The tunable MEMS capacitor is consisting of two parallel plates. Out of the two plates one is movable and the other is fixed. There is presence of dielectric material in between these plates. The motion of the variable plate can be altered by either by varying the position of the plate or by the application of voltage/pressure.

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

where $C$ is the capacitance , $A$ is the area of overlap of the two plates, $\varepsilon_0$ is the electric constant ($\varepsilon_0 \approx 8.854\times10^{-12}$ F m$^{-1}$), $d$ is the separation between the plates, and $\varepsilon_r$ is the relative static permittivity (sometimes called the dielectric constant) of the material between the plates (for a vacuum, $\varepsilon_r = 1$).
The modelling of tunable MEMS capacitor is consisting of four sections. The sections are discussed below:

### 2.1 Building geometry -

Ten solid blocks were built. The blocks were built by using the specifications, which includes information regarding their position (x- , y- , z- coordinates) and size (width, depth, height). A cylinder was built which acted as a connector in between two plates. Then all these entities were integrated by using union. Then the lower plate (which is fixed) was built with two solid blocks and integrated by forming another union. Thereafter a block was built which enclosed all the entities built till now.

### 2.2 Material Definition -

The materials for the plates (electrodes) and the dielectric were defined by using the material browser window. For electrodes Al metal was used and $SiO_2$ was used as dielectric.

### 2.3 Meshing –

Meshing of the built geometry was done and the type of meshing used was free tetrahedral meshing.

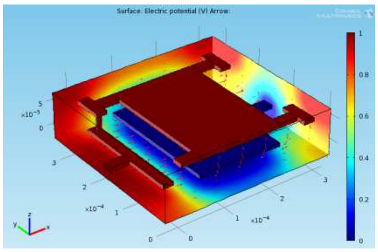
### 2.4 Results -

In the Model Builder window, Study 1 was right clicked and Compute option was chosen for computation purpose.
Then by using Derived values->Global evaluation(present in model builder window) and surface plot we were able to get the final 3-D plot of the model along with the capacitance value, which was found to be 0.08 pF.

### 2.5 Boundary conditions –

Potential boundary conditions are applied to the capacitor plates and bars. A port condition maintains the potential 1 V at the upper plate and the connecting bars, whereas the lower plate is kept at ground potential. For the surface of the surrounding box, apply conditions corresponding to zero surface charge at the boundary,

$$\mathbf{n} \cdot \mathbf{D} = 0$$



3D-view of the model

## 3. TUNABLE MEMS INDUCTOR

The Inductor is an important electrical component and has been used in electrical and electronic circuits such as VCO (Voltage Controlled Oscillators), filters etc. Inductor with variable inductance is the main element of the frequency based circuits such as tunable filters, voltage controlled oscillators, frequency agile radios, reconfigurable impedance matching networks, RF wireless devices, phase shifters and low noise amplifiers.

The modelling of spiral inductor is consisting of five sections:

### 3.1 Building Geometry –

By using import button in import section the file, spiral_inductor.mphbin, was imported to model builder window & Wireframe Rendering button was clicked on the Graphics toolbar.

### 3.2 Material Definition –

Two materials were used – one for the conductor and the other one was air . The properties of the material used for the conductor were defined properly .The materials were applied to the respective domains.

### 3.3 Defining Magnetic and Electric Fields –

Some specific boundaries were selected to be used as terminal and ground. The boundaries that were not assigned were considered to be electrically and magnetically insulated by default.

### 3.4 Meshing –

Meshing of the built geometry was done and the type of meshing used was free tetrahedral meshing. Further, from the pre defined list in the element size section, coarse option was chosen and Build All command was used to build the required mesh.

### 3.5 Results –

In the Model Builder window, Study 1 was right clicked and Compute option was chosen for computation purpose.

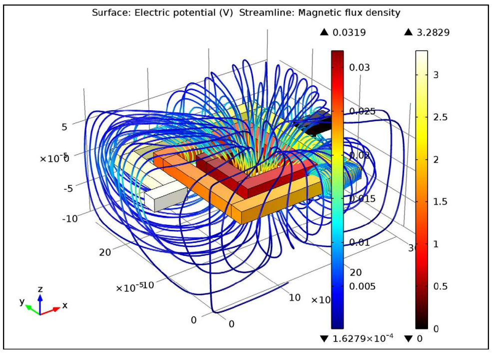
Thereafter in order to combine an electric potential distribution plot on the surface of the inductor with a streamline plot of the magnetic flux density in the air surrounding it , the following steps were followed :

From the Results section, 3D plot group was chosen and then surface option was selected .In the settings window of surface, ‘Thermal’ was chosen from colour table list.

By expanding the results, ‘data sets’ node was obtained .Solution 1 was added and in the geometry entity level list, the required boundaries were specified.

From the Results>3D Plot Group 2, Streamline option was chosen and the required settings were done in the settings window of Streamline.

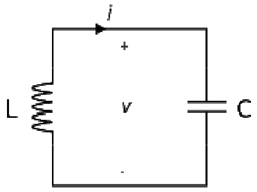
By using Results>Derived Values and Global Evaluation, the inductance value was found to be 0.755nH.The following representation of spiral inductor was obtained –



Model of Spiral Inductor

## 4. LC OSCILLATOR

An LC circuit, also called a resonant circuit, tank circuit, or tuned circuit, consists of an inductor, represented by the letter L, and a capacitor, represented by the letter C. When connected together, they can act as an electrical resonator, an electrical analogue of a tuning fork, storing energy oscillating at the circuit's resonant frequency.LC circuits are used either for generating signals at a particular frequency, or picking out a signal at a particular frequency from a more complex signal. They are key components in many electronic devices, particularly radio equipment, used in circuits such as oscillators, filters, tuners and frequency mixers.



LC Oscillator Circuit

The resonance effect occurs when inductive and capacitive reactance are equal in magnitude. The frequency at which this equality holds for the particular circuit is called the resonant frequency. The resonant frequency of the LC circuit is

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Where L is the inductance in Henry, and

*C* is the capacitance in Farad.

The angular frequency $\omega_0$ has units of radians per second.

The equivalent frequency in units of Hertz is

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}.$$

## 5. RESULT AND DISCUSSIONS

Table showing capacitance values for different dielectric materials obtained by varying the distance in between the plates.

| Distance between the Plates (in micrometer) | Capacitance (in pico Farad) (dielectric – $SiO_2$) | Capacitance (in picoFarad) (dielectric – Polymide) | Capacitance(in picoFarad) (dielectric – Nylon) |
|---|---|---|---|
| 9 | 0.217 | 0.1953 | 0.2232 |
| 12 | 0.17 | 0.1528 | 0.1765 |
| 15 | 0.1414 | 0.127 | 0.1451 |
| 18 | 0.122 | 0.1096 | 0.1253 |
| 21 | 0.108 | 0.09072 | 0.1108 |
| 24 | 0.097 | 0.08752 | 0.1002 |
| 27 | 0.089 | 0.07998 | 0.09141 |
| 30 | 0.082 | 0.07387 | 0.08442 |
| 33 | 0.0767 | 0.06883 | 0.07867 |
| 36 | 0.072 | 0.06549 | 0.07382 |

Capacitance v/s Distance

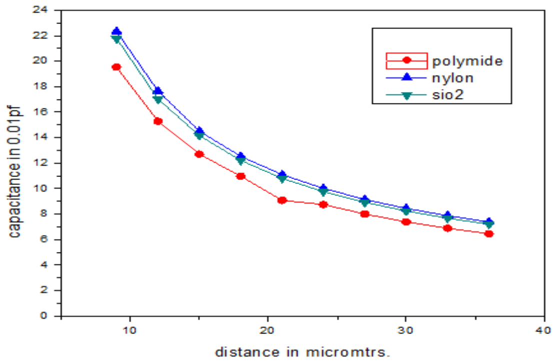


Table showing the frequencies generated by varying the inductance and capaitance values.

| Inductance(I) (in nH) | Frequency(F) (in GHz) (for C=0.08pF) | Frequency(F) (in GHz) (for C=0.0844pF (dielectric – nylon)) | Frequency(F) (in GHz) (forC=0.0738pF (dielectric- polymide)) | Frequency(F) (in GHz) (for C=0.08234pF (dielectric- $SiO_2$)) |
|---|---|---|---|---|
| 0.755 | 20.478 | 19.9 | 21.32 | 20.18 |
| 0.08326 | 61.6 | 60.03 | 64.2 | 60.78 |
| 0.13619 | 48.2 | 46.9 | 50.2 | 47.5 |
| 0.48001 | 25.6 | 25 | 26.74 | 25.3 |
| 0.75958 | 20.41 | 19.6 | 21.2 | 20.12 |

Frequency v/s inductance

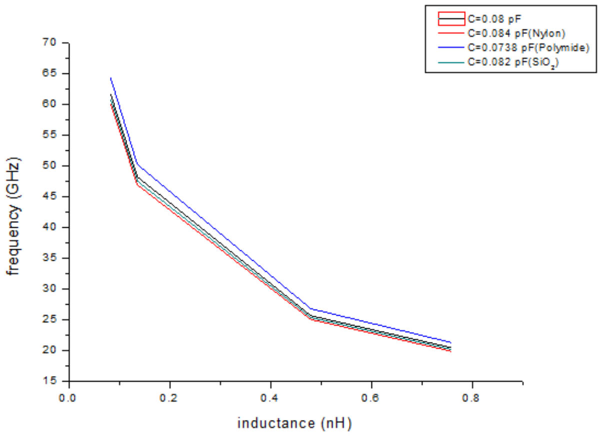


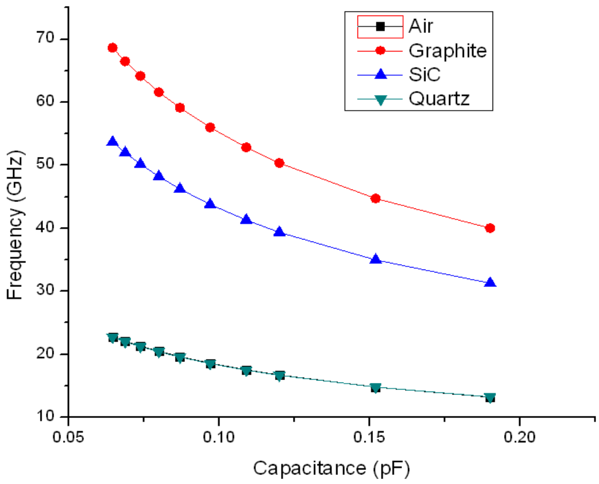
Table showing frequencies generated for different dielectric and inductor core materials.

| Dielectric | Frequency( in GHz) for different core materials | | | |
|---|---|---|---|---|
| | Graphite (L=0.08326 nH) | Air (L=0.755 nH) | SiC (L=0.1361 nH) | Quartz (L=0.7595 nH) |
| Air (C=0.0211pF) | 119.9 | 39.87 | 93.88 | 39.75 |
| PTTE (C=0.0422 pF) | 84.8 | 28.196 | 66.38 | 28.11 |
| Polyethylene (C=0.0485 pF) | 79.0 | 26.3 | 61.92 | 26.22 |
| PVC (C=0.06123 pF) | 70.42 | 23.4 | 55.11 | 23.33 |
| PMMA (C=0.06334 pF) | 69.2 | 23.014 | 54.18 | 22.94 |
| Polymide (C=0.0738 pF) | 64.14 | 21.32 | 50.2 | 21.25 |
| $SiO_2$ (C=0.08234 pF) | 60.78 | 30.185 | 47.52 | 20.124 |
| Nylon (C=0.0844 pF) | 59.9 | 19.93 | 46.94 | 19.87 |
| Glass(Quartz) (C=0.08867 pF) | 58.5 | 19.45 | 45.79 | 19.39 |
| Borosilicate (C=0.1013 pF) | 54.74 | 18.198 | 42.849 | 18.143 |
| $Al_2O_3$ (C=0.1203 pF) | 50.23 | 16.69 | 39.32 | 16.649 |
| ZnO (C=0.1752 pF) | 41.63 | 13.838 | 32.582 | 13.796 |
| $Si_3N_4$ (C=0.2048 pF) | 38.5 | 12.79 | 30.135 | 12.76 |

Table showing freuencies generated by varying the inductor core material and using the capacitance values obtained by changing the distance in between the two plates , where polymide is used as a dielectric material.

| Distance (in µm) | Capacitance (in pF) | Frequency in GHz (for different core materials) | | | |
|---|---|---|---|---|---|
| | | Air (L=0.755nH) | Graphite (L=0.08326nH) | SiC (L= 0.13619nH) | Quartz (L=0.75958nH) |
| 9 | 0.19 | 13.2 | 40.01 | 31.28 | 13.24 |
| 12 | 0.152 | 14.8 | 44.73 | 34.98 | 14.8 |
| 15 | 0.12 | 16.72 | 50.35 | 39.36 | 16.67 |
| 18 | 0.109 | 17.54 | 52. 83 | 41.3 | 17.49 |
| 21 | 0.097 | 18.59 | 56 | 43.78 | 18.54 |
| 24 | 0.087 | 19.63 | 59.13 | 46.23 | 19.57 |
| 27 | 0.07998 | 20.48 | 61.6 | 48.22 | 20.419 |
| 30 | 0.07387 | 21.31 | 64.17 | 50.178 | 21.24 |
| 33 | 0.0688 | 22.08 | 66.49 | 51.99 | 22.01 |
| 36 | 0.06459 | 22.79 | 68.63 | 53.66 | 22.72 |

Frequency v/s capacitance



## 6. CONCLUSION

This paper provides a simple and easy way for generation of mm and µm waves, which finds wide applications in areas like radio astronomy, remote sensing, high speed point to point wireless local area networks, broadband internet access, wireless HD, radar systems, weapon system, security screening, medicine, aviation air-to-ground communications, shortwave international and regional broadcasting, maritime sea-to-shore services, GMDSS communication, terrestrial microwave links and satellite communication. The prime advantages of using the way of generation presented in this paper includes reduced cost, better performance, improved reproducibility, selectivity, sensitivity, accuracy and reliability, tolerance towards noise and minimization of power dissipation.

## 7. REFERENCES

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