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Measurement of Capacitance in MEMS Accelerometer to Detect Low Frequency Tremors in Parkinson's Disease

G.R.K. Prasad[a], K. Srinivasa Rao[b] and P.S. Srinivas Babu[c]

[a]*Corresponding author, Assistant professor, ECE Dept, K.L. University, Vaddeswaram, Andhra Pradesh, India. Emails: phanitvb@gmail.com*
[b-d]*UG Student, ECE Dept, K.L. University, Vaddeswaram, Andhra Pradesh, India*

Abstract: This Paper proposes a high sensitive and easy method to calculate the variation of capacitance between the moving plates of an accelerometer**.** If a load is applied on the surface of proof mass of proposed structure, it causes the variation in potential between the plates when one plate is grounded and the other is applied a voltage. With the variation in voltage, there will be the variation in the capacitance between the plates. The capacitance between the plates is measured with respect to variation in distance and voltage. The voltage sensitivity and the capacitance sensitivity is calculated. The Capacitive sensitivity with respect to voltage is 3.24e-5µf/volts and the capacitive sensitivity with respect to distance between the plates is 4.11e-4farads/µm and the voltage sensitivity is 1.13v. The Simulations are done with COMSOL Multi Physics FEM tool

Keywords: Sensitivity, Capacitance, COMSOL. FEM tool.

1. INTRODUCTION

In the modern world, MEMS have outperformed many conventional fields like bio technology, medicine, communications, automation, manufacturing and made its mark. These miniature devices do more than their size in many ways. More over their simple circuitry and robust nature made them widely acceptable. The significance of these devices is fetched by their reliability, small size, low cost, low power consumption etc. The variety of devices range from pressure sensors to positional sensors and type of measurement from actuation to acceleration[1]. Actuation is a measurement of the act performed by the particular device. In simple, its operation is in negation to a sensor. It can be of any type like hydraulic, electrical, mechanical and pneumatic.

Here in this paper electrical actuation is observed. Electrical voltage is given as input and displacement of the plates is observed as action. The change in capacitance and various other parameters determines the sensitivity of the device[2-4]. The main advantage of these electrical actuators in MEMS is low electric power is sufficient to obtain the desired results and the given input is almost clean from external environmental issues. They offer high precision, less noise and immediate feedback response.

2. VARIABLE CAPACITANCE

Most of the available devices in market are piezo-electric but they also have their limitations in operating temperature and many other factors like sensitivity[5], damping ratio, pull in voltage etc.. With the all above disadvantages, an advanced technique which is sensitive to variations in aspects like displacement is proposed. For both the static and dynamic applications it gives accurate frequency response as its natural frequency which in other terms conveys that the sensitivity levels are high. When a force F is applied to one of the plates of the system, the capacitance is varied accordingly when displacement occurred due to force applied on one of the plates:

$$C = \in \frac{A}{d}$$

where, $\in$ = dielectric constant

A = area of the parallel plates

d = distance between the two plates

Two parallel plates are present with one plate as fixed and the other plate as movable with a separable distance of *d*. A dielectric medium is present in between them[6]. When the movable plate moves a certain distance *x* then the capacitance changes in the following way.

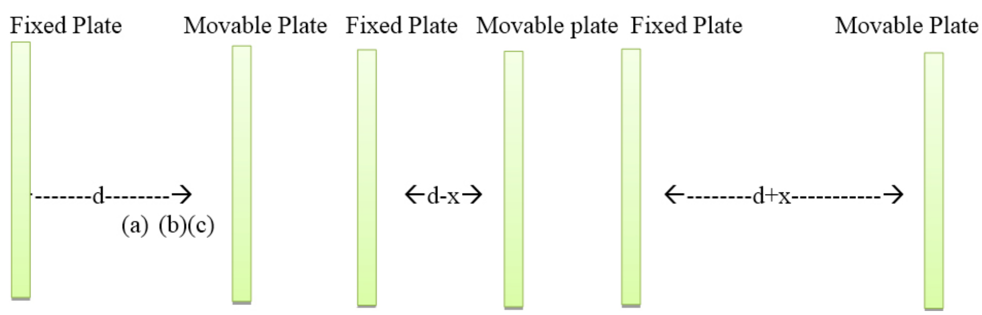


Figure 1: Fixed and movable parallel plates with varying distance *x*

The capacitive variation can be observed from the Figure 1 and variance represented by the equations shown below. When movable plate is moving towards fixed plate:

$$C = \in \frac{A}{d - x}$$

And when movable plate is moving away from fixed plate:

$$C = \in \frac{A}{d + x}$$

In electric actuators, the plates move with the change in polarity of the electric charge carriers. If any change in polarity occurs the movable starts to move in opposite direction. The amount of charge present is considered to be constant irrespective of its polarity then the voltage and capacitance are inversely proportional to each other which is represented as:

$$Q = CV$$

$$C \,\alpha\, \frac{1}{V}$$

Here Q = charge in Coulombs, C = capacitance in Farads, V = voltage in Volts

3. SENSITIVITY

The MEMS sensors sensitivity generally depends on the frequency i.e. inversely proportional to the square of it. It is the voltage identified in terms of *g*. The frequency depends on spring constant and mass of the system. Mass is dependent on the dimensions and material of the system. Spring constant depends on E. Here in this case, the change in capacitance describes the response of the sensor for an applied input which is indeed considered as the sensitivity of this device.

$$\Delta C \cong \frac{2\varepsilon A m}{k d^2}.$$

Here ΔC is the change in capacitance

$$S = \frac{\varepsilon A m}{k d^2}$$

where, m = mass of the system

K = spring constant

The above equation indicates that the sensitivity is inversely proportional to spring constant of the system and the values of area and mass are also in proportion towards sensitivity.

$$\text{Spring Constant } k = 3\frac{E\pi r^4}{4L^3}$$

R = radius of the cylindrical limbs

L = length of the cylindrical limbs

E = Poisson's ratio of the material used

It is not necessary that the frequency values calculated are equivalent to practical values. This involves a phenomenon called damping ratio. This particular variation is dependent on the dielectric medium which is present in between the parallel plates, in least scenario air also acts as a dielectric and effects damping factor[7]. The natural frequency can be directly calculated by:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

In a vibrating device, the stiffness of the component changes the frequency parameter. The device is optimized continuously to reduce the deformation. Because when the deformation increases the reliability of the system decreases and the material gets tampered. This effects the output parameters. Further the maintenance cost increases and durability decreases. With the effective stiffness the frequency now changes to:

$$f = \frac{1}{2\pi}\sqrt{\frac{keff}{meff}}$$

where, *keff* = effective stiffness, *meff* = effective mass

Effective mass is the function of effective thickness and frequency. In actuators pull-in voltage restricts its operation range by causing instability. Pull-in voltage is the range through which an actuator can perform precisely without any major errors. When the applied input voltage is too low then the device fails to sensitize and if the applied voltage is too high the movable plate moves very closer such that the device performs inaccurately[8]. It is advisable that the displacement is not beyond one-third of the actual separation between the parallel plates. The material properties and the thickness of the dielectric materials matters a lot in calculating the pull-in voltage. It is always a tradeoff between power usage and actuation range.

$$\text{Xpull-in} = \sqrt{\frac{8kd1^3}{27\varepsilon A}}$$

Here, $d1 = d - \text{T}\,\dfrac{1 - \text{C1}}{\text{C2}}$

where, d = distance between the parallel plates

T = thickness of dielectric material

C1, C2 are the capacitance values

4. RESULTS AND DISCUSSION

The deflection of the system that is confronted in the form of displacement is illustrated in Figure 1. For the respective eigen frequency values the displacement is obtained in *um*. It proves the phenomenon that eigen frequency values are inversely proportional to displacement. The variable capacitance values are indicated in Table 1. The values perfectly conclude that with the increase in voltage the capacitance is decreased in the levels of pf. This proves from the equation above Q = CV, which clearly indicates that capacitance is inversely proportional to voltage. The capacitance is also decreased when the distance between the plates is increased in steps of 100um which is a basic concept that when distance increases the strength of the parameters decreases. To optimize the nature of the plates with good capacitance values it is preferable to reduce the distance between the plates to an extent. The voltage vs capacitance graph in Figure 2 drawn with basis of values in table 1 shows the peak and mediocre values for better understanding.

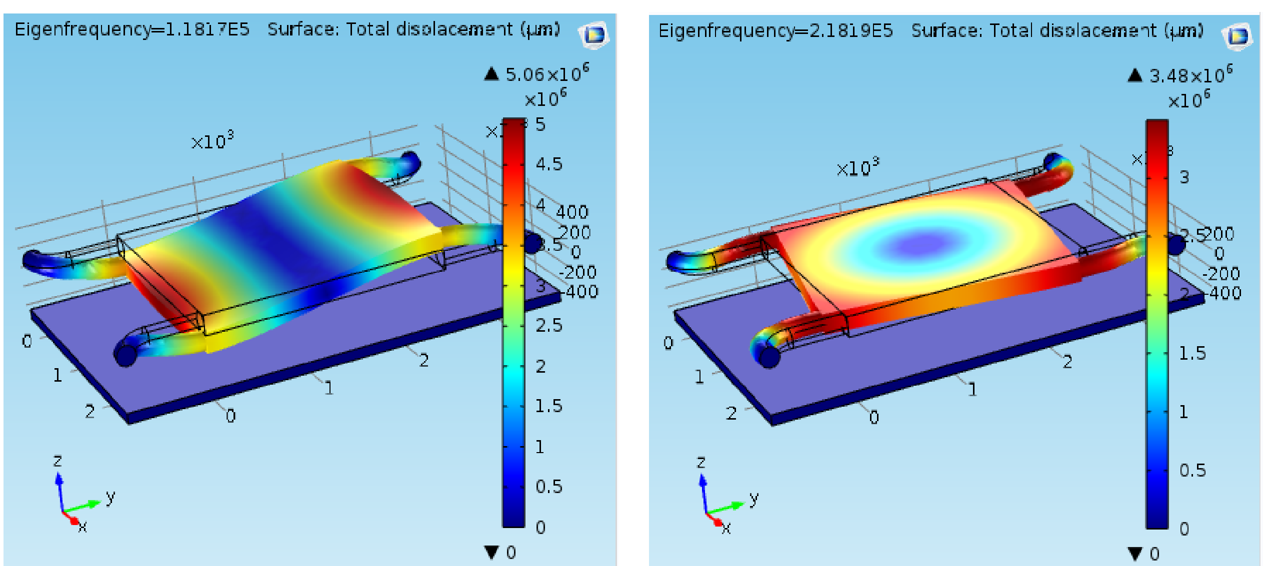


Figure 2: Different eigen values and its displacements

Table 1
Capacitance Values at Different Gaps for Various Voltages

VOLTAGE	*CAPACITANCE (pF)*			
(Volts)	*300µm*	*400µm*	*500µm*	*600µm*
1	2.19E-9	6.71E-10	7.11E-10	8.92E-10
2	1.1E-9	3.35E-10	3.56E-10	4.46E-10
3	2.39E-10	2.24E-10	2.37E-10	2.97E-10
4	1.79E-10	1.68E-10	1.78E-10	2.23E-10
5	1.44E-10	1.34E-10	1.42E-10	1.78E-10
6	1.2E-10	1.12E-10	1.19E-10	1.49E-10
7	1.03E-10	9.58E-11	1.02E-10	1.27E-10
8	8.97E-11	8.38E-11	1.11E-11	1.12E-10
9	7.98E-11	7.45E-11	9.84E-12	9.92E-11
10	7.18E-11	6.71E-11	8.87E-12	8.92E-11

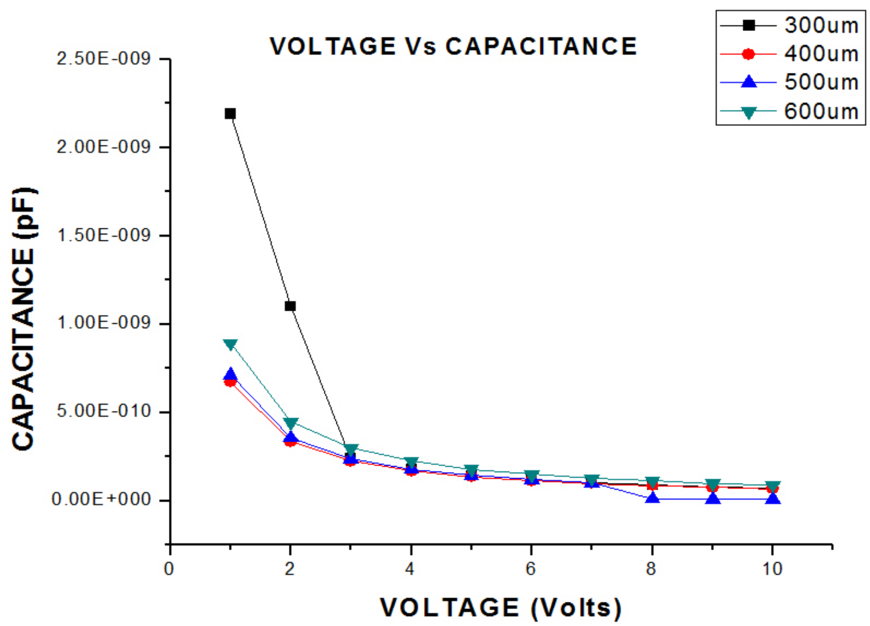
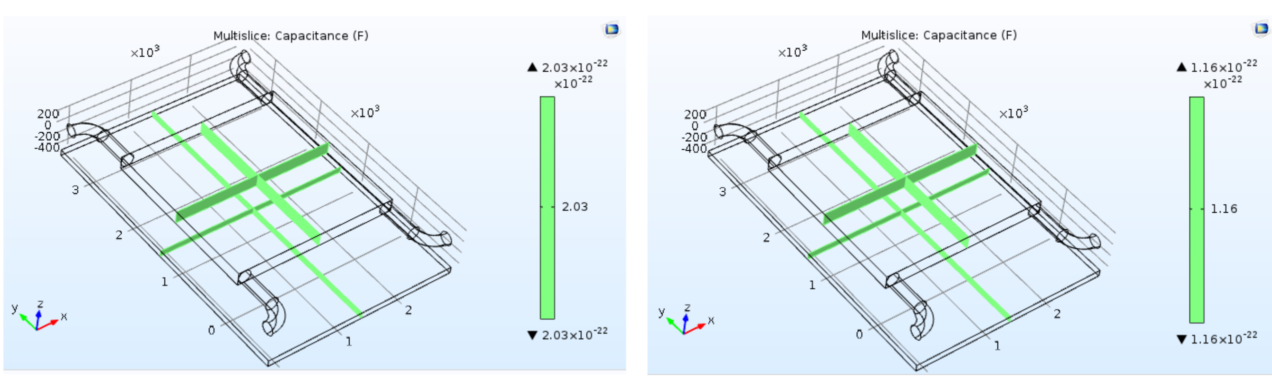


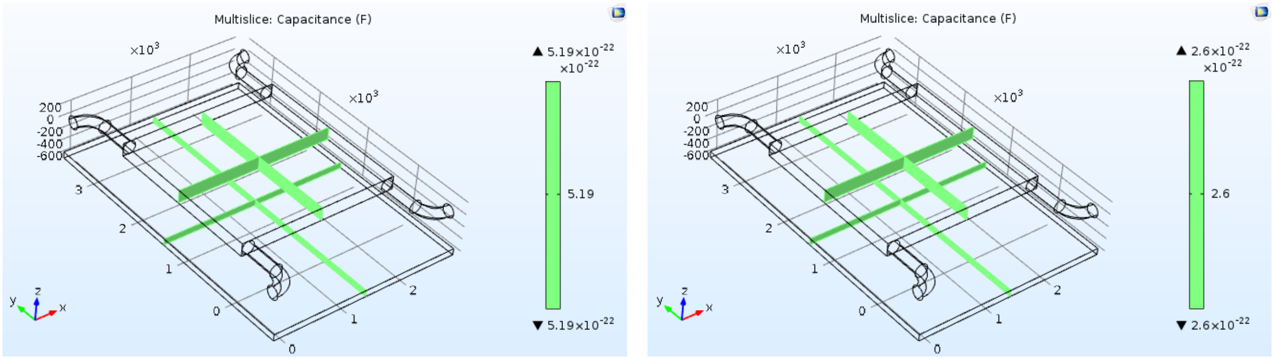
Figure 3: Voltage Vs Capacitance has been plotted for various gaps and observed that as gap between plates decreases, the capacitance increases

4.1. Simulated Results of Voltage vs Capacitance

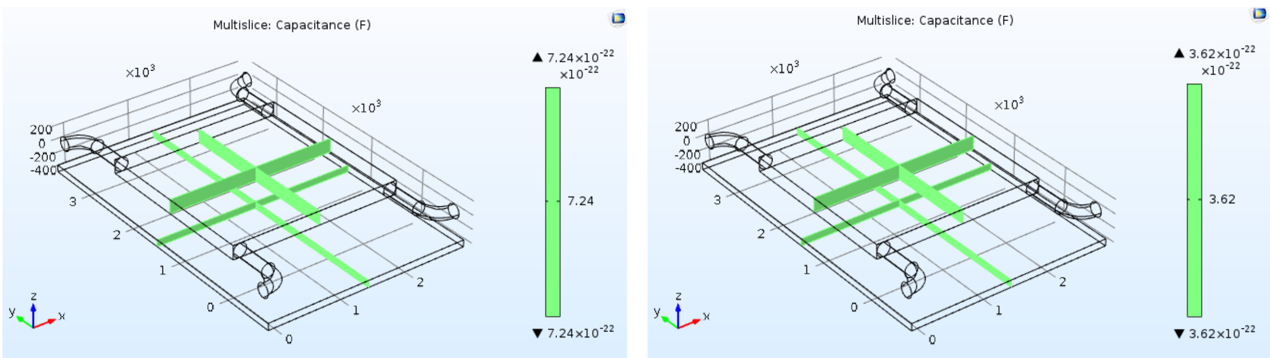
300µm gap



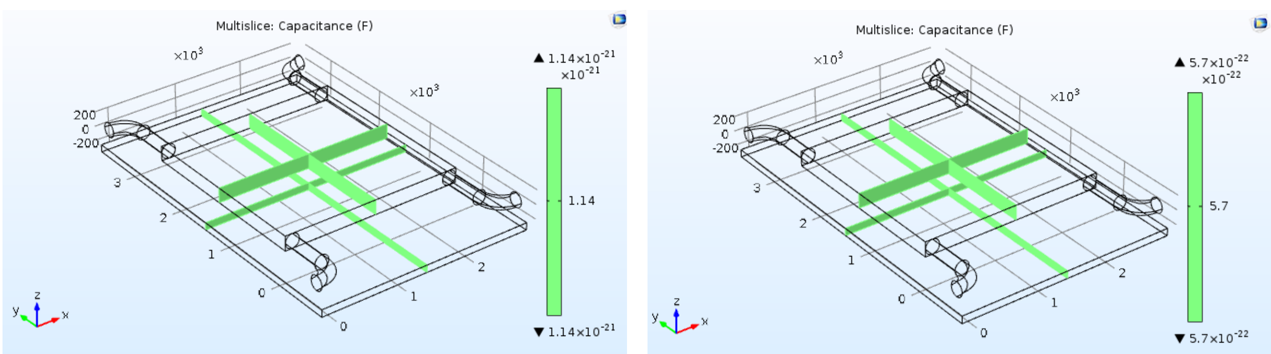
400µm gap



500µm gap

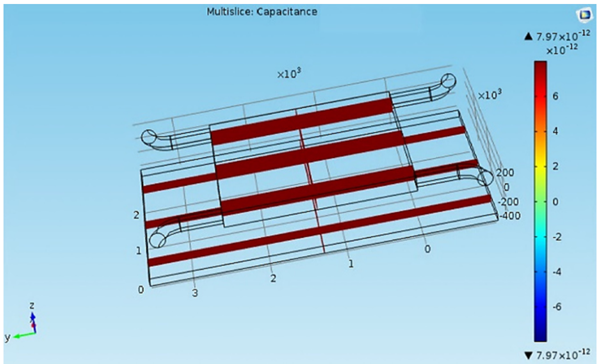


600µm gap

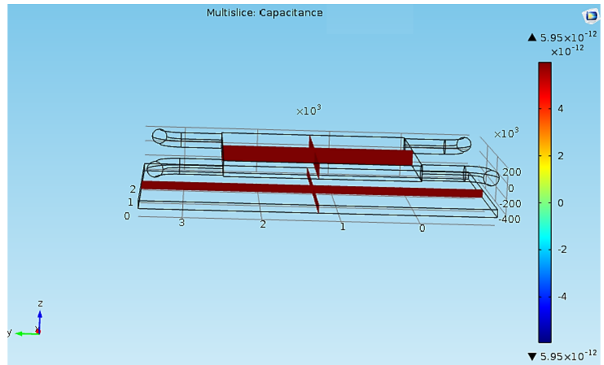


The varied capacitance values are shown above when the distance between plates is varied in 100um steps. The median range of the minimum and maximum values are depicted and the lower distance between the plates has higher capacitance values. The Table 2 below shows the same that in the range of 100-500um variable distance the capacitance values altered in the levels of 7-25pf.

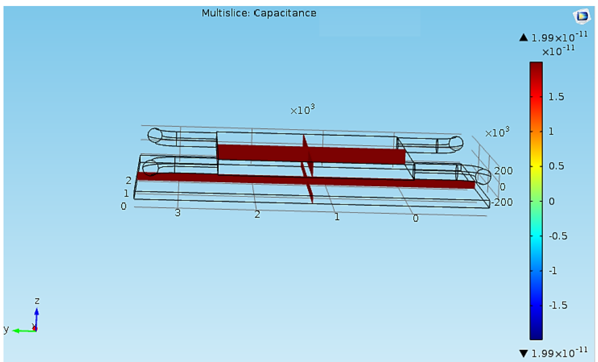
Distance Between the plates(um)	*Capacitance(Pf)*
500	7.97
400	8.95
300	19.9
200	20.3
100	25.4



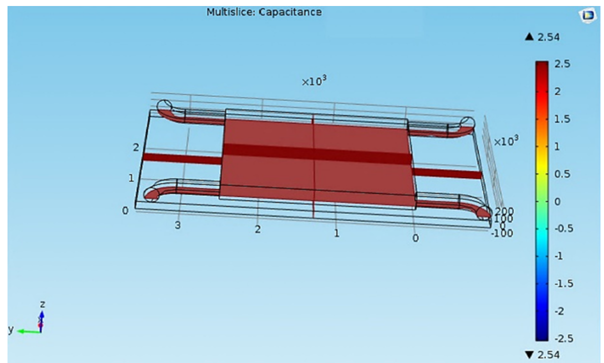
Capacitance when *d* = 500um



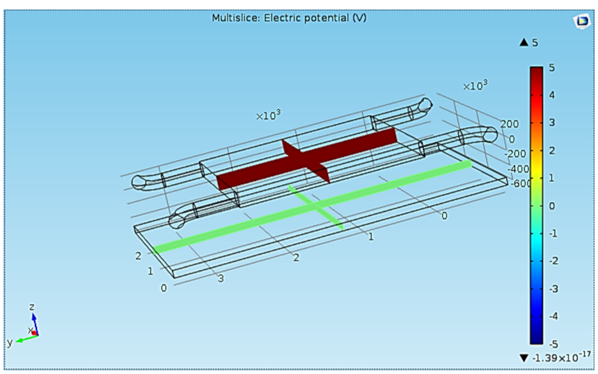
Capacitance when *d* = 400um



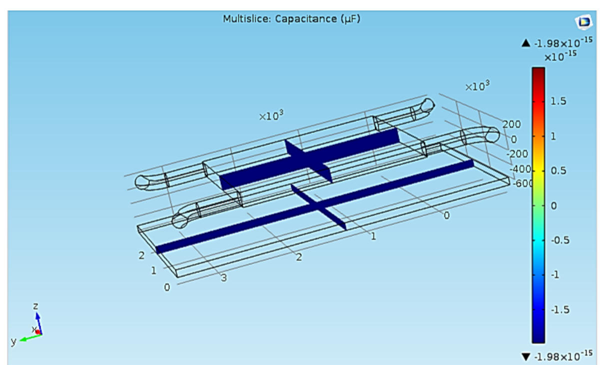
Capacitance when *d* = 300um



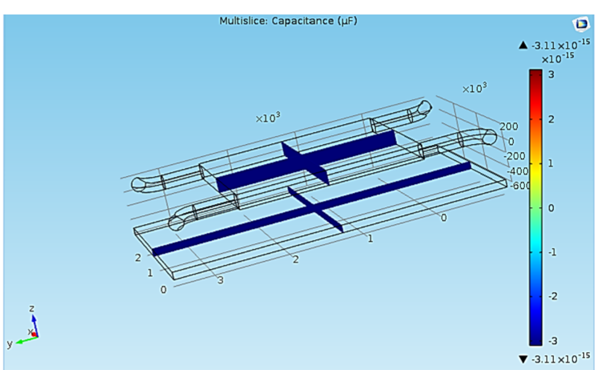
Capacitance when *d* = 100um



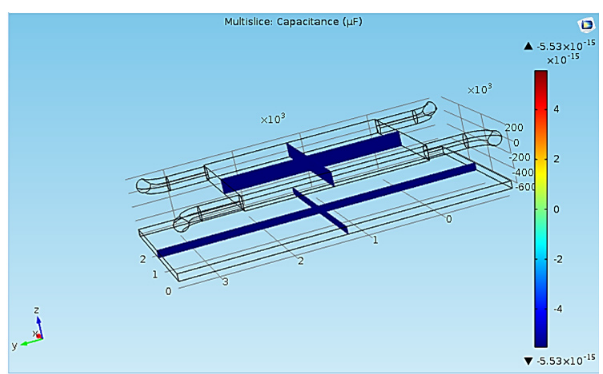
input voltage = 5v



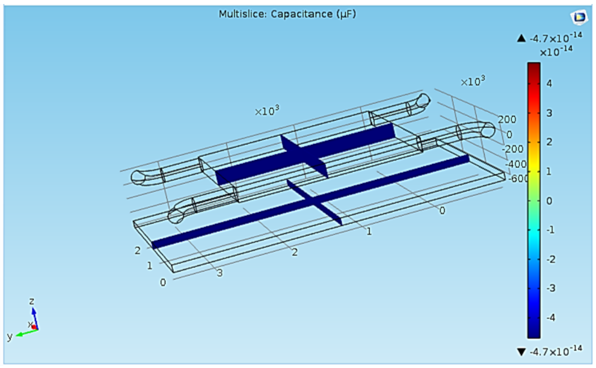
input voltage = 5v



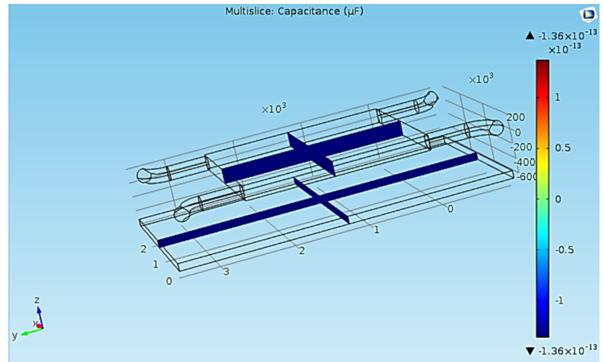
input voltage = 4v



input voltage = 3v



input voltage = 1v



input voltage = 0.5v

It can be concluded from the analysis that the sensitivity of the system is high when the distance between movable plate and fixed plate is varied. It is least effected when voltage is applied below 5*v*. The sensitivity is specially high only when exactly 5*v* is applied. So the variable capacitance is most sensitive to changes in distance between the plates and to *t*.

5. CONCLUSION

The design is Simulated using COMSOL Multi Physics FEM tool, and with respect to the variation in distance between the plates of the proposed structure in which one plate is grounded and another plate is applied some voltage. We have observed that on application of boundary load the distance between the plates was varied and the voltage also varies. With this voltage, the capacitance between the plates also changes. We have also calculated the capacitive sensitivity with respect to displacement and voltage variation, their values are 3.24e-5µf/volts and 4.11e-4farads/µm.

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