

# Study of Capacitance in Electrostatic Comb-Drive Actuators

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**Abstract**—The objective of this work to study capacitance in electrostatic comb-drive actuators. The proposed work is carried out by selecting the electrostatic physics domain in Comsol/Multiphysics software, which is based on the finite element method (FEM). Voltage is applied to movable comb fingers and ground is applied to fixed comb fingers. Due to the applied voltage and ground, capacitance is established between the comb fingers. Further to enhance to capacitance and hence power handling capacity, increase in the number of comb fingers up to 150 is done. Capacitance values are obtained from the simulated results. The range of the capacitance value obtained is  $3.0524 \times 10^{-14}$  F to  $6.1674 \times 10^{-12}$  F as the comb fingers increased from 1 to 150. These capacitance values are compared with the theoretical values. Fringe capacitance is accounted in the theoretical calculation using the palmer formula. This type of MEMS based electrostatic comb drive actuators are used in micro switches and micro grippers.

**Keywords**— Comb-Drive, FEM analysis, Fringe capacitance, micro grippers.

## I. INTRODUCTION

In Micro Electro Mechanical Systems (MEMS), comb-drives are used as both sensors and actuators. As a result, they have been considered as important structure in MEMS [1]. They have been under intense study for the last few years. Normally these comb drives have two sets of fingers, one is fixed and other is moving. The actuation and the sensitivity both are dependent in a major way on the electrostatic configuration of the comb structure. By applying voltage to these fingers, the fixed finger can be moved through a desired distance. Similarly the change of capacitance is occurred due to the movement of the movable fingers with respect to the fixed fingers. Change in position of fingers can be sensed. As a result, accurate estimation of the electrostatic configuration of the drives is crucial in both design and interpretation of devices such as micro switches, micro grippers etc.

## II. THEORETICAL BACKGROUND

While parallel-plate capacitor generate sensing and actuation across planer electrode facing each other, a different class of capacitors take advantage of capacitance generated from sidewalls of electrodes. Such capacitors provide alternative fabrication and operation modes compared with parallel-plate capacitors. They involve interdigitated fingers (IDT) to increase the edge coupling length. Two sets of electrodes are placed in the same planer parallel to the substrate. Generally, one set of fingerlike electrodes is fixed on-chip while a second set is suspended and free to move in

one or more axes. Since the interdigitated fingers are shaped like the teeth on a comb, such configuration is commonly referred to as the comb-drive device.

In case of parallel plates, capacitance is given by the equation 1.

$$C = \frac{\epsilon_0 \epsilon_r A}{d} \text{ ---- (1)}$$

In case of comb-drives, capacitance for a single finger is given by the equation 2.

$$C = \frac{\epsilon_0 \epsilon_r l_0 t}{d} \text{ ....(2)}$$

Where,

$\epsilon_0$  is absolute permittivity,  $\epsilon_r$  is relative permittivity,  $l_0$  is common length,  $t$  is thickness of the finger,  $A$  is common area between the plates.

### Fringe capacitance:

In many electrostatic actuators that are fabricated by current micromachining processes, the nominal gap between the electrodes is not negligible relative to the lateral dimensions of the deformable capacitor. Therefore, fringing fields are considerable and must be accounted for when modeling the electrostatic forces. Many different formulae for computing fringing fields appear in literature [2]. The capacitance between a pair of electrode fingers is contributed by vertical surfaces of the finger in the overlapped region, as well as by fringe capacitance fields. Capacitances derived from multiple finger pairs are connected in parallel. Hence, the total capacitance is a summation of capacitance contributed by neighboring fingers. Fringe capacitance is given by palmer formula as mentioned in equation 3[3].

$$C_f = \epsilon \frac{WL}{G} \left( 1 + \frac{G}{\pi W} \left( 1 + \ln \left( \frac{2\pi W}{G} \right) \right) \right) \times \left( 1 + \frac{G}{\pi L} \left( 1 + \ln \left( \frac{2\pi L}{W} \right) \right) \right) \text{ ---- (3)}$$

Where,

L=Length of comb finger

W=Width of comb finger

G=Gap between the comb fingers

For the N number of comb fingers, capacitance is given by equation 4.

$$C = N \frac{\epsilon_0 \epsilon_r l_0 t}{d} + C_f \text{ ....(4)}$$

## III. MODELING AND SIMULATION

The proposed model is simulated using Comsol/Multiphysics software and the steps involved in the modeling are as follows. All blocks are in micrometer with the silicon as the material. Boundary and loading conditions are assigned to model by assigning voltage and ground to the

movable and fixed comb fingers. Schematic diagram of the single comb-drive actuator as shown in Figure 1.

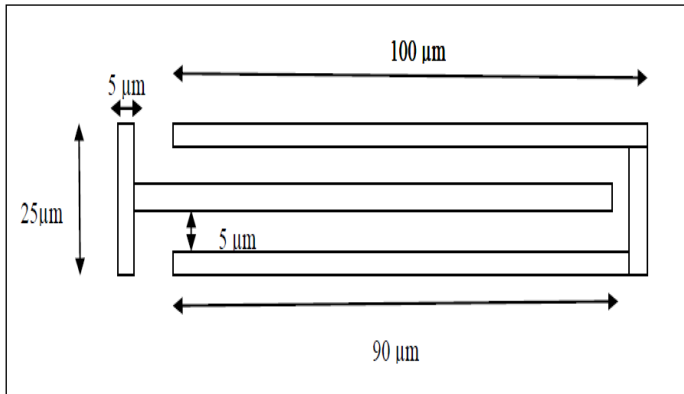


Figure 1. Schematic diagram of MEMS comb-drive actuator  
Steps involved in modeling simulation of the comb drive actuators.

### 1. Geometry modeling

Various blocks are built as shown in the figure 1 with the thickness of 5 μm. Geometry [4] obtained in Comsol/Multiphysics is shown in the Figure 2. Entire comb-drive geometry is covered with the air block.

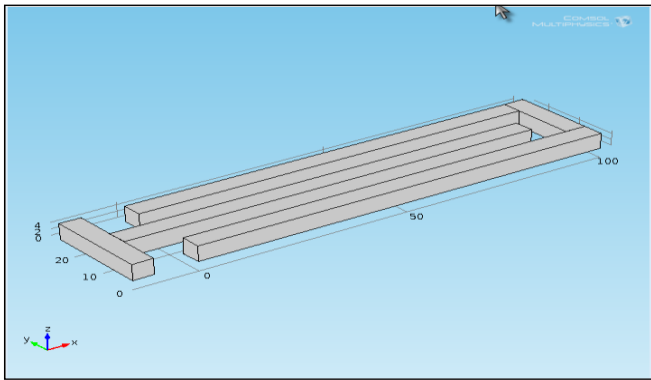


Figure 2. Geometry of MEMS comb-drive actuator

### 2. Material property and boundary conditions

The electrostatic comb-drive actuator is modeled and simulated using silicon as material with properties [5] as mentioned in the Table I

Table I Material properties of silicon

Properties	Silicon
Young's Modulus	170e9[Pa]
Poisson's Ratio	0.28
Density	2329[kg/m <sup>3</sup> ]
Thermal Expansion Coefficient	2.6e-6[K <sup>-1</sup> ]
Thermal Conductivity	130[W/(m*K)]
Relative Permittivity	11.7

Voltage is applied to T shaped electrode. Ground is applied to U shaped electrode.

### 3. Meshing

Entire comb-drive model is meshed with the physics controlled normal meshing. Meshed model is shown in Figure 3.

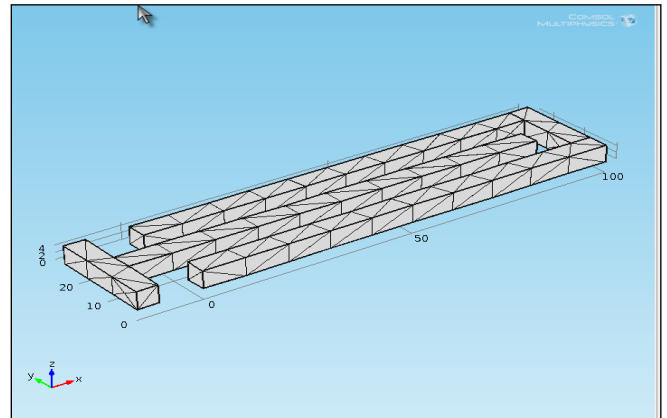


Figure 3. Meshed model of MEMS comb-drive actuator

### 4. Computation

Potential distributions in comb-drive actuator model are as shown in the figure 4.

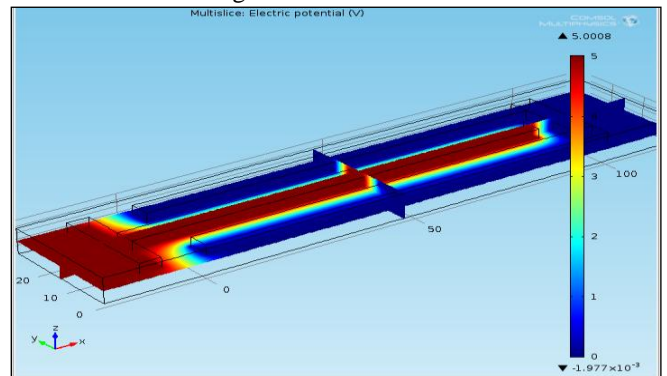


Figure 4. Electric potential distributions in the model

## IV. RESULTS

After the simulation process, to evaluate capacitance, in the model builder window under results right click on the derived values and select the global evaluation, clicks on global evaluation, then click replace expression electrostatic=>terminals=>capacitance and the click plot. The capacitance value is displayed as  $3.0524 \times 10^{-14}$  F for the single set of comb finger. Obtained capacitance value is shown in the figure 7. Further to enhance capacitance and sensitivity, increase the number of comb fingers up to 150. Capacitance values are obtained from the simulated results. Range of the capacitance value obtained is  $3.0524 \times 10^{-14}$  F to  $6.1674 \times 10^{-12}$  F for the comb fingers 1 to 150. Different number of comb fingers shown in the figure 5 and figure 6.

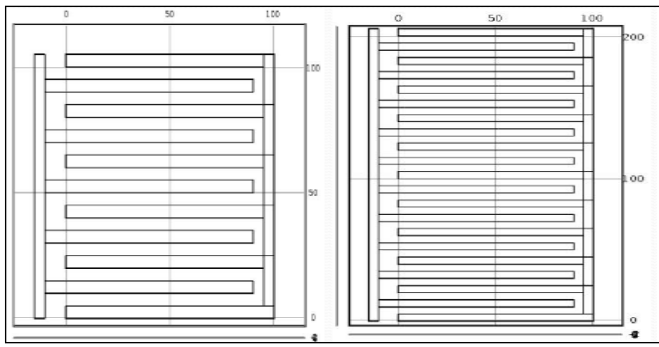


Figure 5. Comb-drive actuator with comb fingers 5 and 10

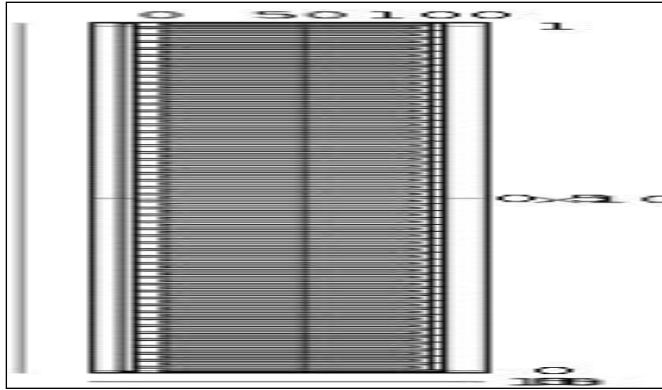


Figure 6. comb-drive actuator with comb fingers 50

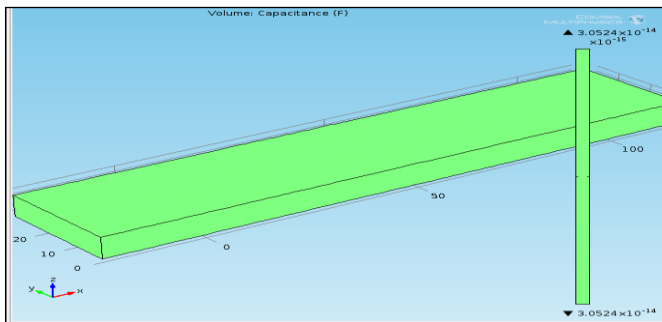


Figure 7. capacitance values for the comb finger having the one set of comb finger

Table II shows that variation in the capacitance wrt to increase in the number of comb fingers.

Table II variation of capacitance

Number of comb fingers	Capacitance in Farad
1	$3.0524 \times 10^{-14}$
5	$1.5488 \times 10^{-13}$
10	$3.1042 \times 10^{-13}$
20	$8.8236 \times 10^{-13}$
30	$1.2428 \times 10^{-12}$
50	$2.0640 \times 10^{-12}$
70	$2.8873 \times 10^{-12}$
100	$4.1181 \times 10^{-12}$
120	$4.9364 \times 10^{-12}$
150	$6.1674 \times 10^{-12}$

From the simulated results of capacitance, graph is plotted. Figure 8 shows that variation of capacitance value with respect to the increased number of comb fingers.

Table II Variation of the capacitance wrt to comb fingers

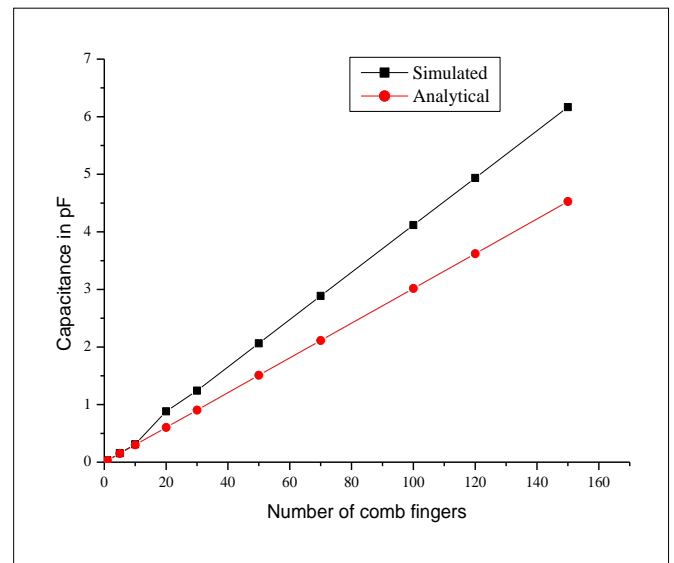
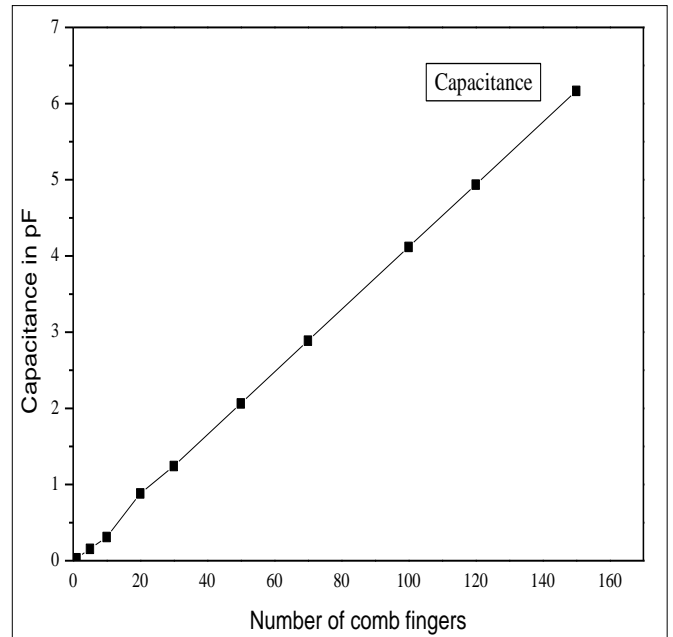


Figure 9 Comparison of the simulated and theoretical capacitance values

From the figure we can observe that there is linearity in variation of the capacitance as comb fingers increased from 1 to 150. Fringe capacitance is accounted while doing the analytical calculation using the palmer formula. Graph reveals that almost match between the simulated and theoretical values of capacitance.

Table III comparison between the theoretical and simulated values of capacitance

comb fingers	Capacitance in Farad (simulated)	Capacitance in Farad(theoretical ) $C_t$	Fringe Capacitance $C_f$ in Farad	$C_{total}=C_t+C_f$ in Farad
1	$3.0524 \times 10^{-14}$	$2.8819 \times 10^{-14}$	$0.1403 \times 10^{-14}$	$3.0222 \times 10^{-14}$
5	$1.5488 \times 10^{-13}$	$1.4392 \times 10^{-13}$	$0.07015 \times 10^{-13}$	$1.50935 \times 10^{-13}$
10	$3.1042 \times 10^{-13}$	$2.877 \times 10^{-13}$	$0.1403 \times 10^{-13}$	$3.0173 \times 10^{-13}$
20	$8.8236 \times 10^{-13}$	$5.7550 \times 10^{-13}$	$0.2806 \times 10^{-13}$	$6.0356 \times 10^{-13}$
30	$1.2428 \times 10^{-12}$	$0.863 \times 10^{-12}$	$0.04209 \times 10^{-12}$	$0.905 \times 10^{-12}$
50	$2.0640 \times 10^{-12}$	$1.4388 \times 10^{-12}$	$0.07015 \times 10^{-12}$	$1.50895 \times 10^{-12}$
70	$2.8873 \times 10^{-12}$	$2.0143 \times 10^{-12}$	$0.09821 \times 10^{-12}$	$2.1125 \times 10^{-12}$
100	$4.1181 \times 10^{-12}$	$2.877 \times 10^{-12}$	$0.1403 \times 10^{-12}$	$3.0173 \times 10^{-12}$
120	$4.9364 \times 10^{-12}$	$3.453 \times 10^{-12}$	$0.16836 \times 10^{-12}$	$3.62136 \times 10^{-12}$
150	$6.1674 \times 10^{-12}$	$4.316 \times 10^{-12}$	$0.21045 \times 10^{-12}$	$4.52645 \times 10^{-12}$

## V. CONCLUSIONS

In this work a 3D electrostatic comb drive actuator is modeled & simulated accounting for different number of comb fingers using the Comsol / Multiphysics software. Comb fingers varied from 1 to 150 then respective capacitance values are obtained for the respective number of comb fingers .The range of the capacitance value obtained is  $3.0524 \times 10^{-14}$  F to  $6.1674 \times 10^{-12}$  F. Simulated and theoretical values are compared, a close match is observed between them.

## REFERENCES

- [1] Chang Liu, "Foundations of MEMS", Pearson International Edition 2006, ISBN 0-13-199204-X.
- [2] Vitaly Leus and David Elata, "Fringing field effect in electrostatic actuator", Technical report ETR-2004-2 may2004.
- [3] Mehran Hosseini , Guchuan Zhu , Yves-Alain Peter," A new formulation of fringing capacitance and its application to the control of parallel-plate electrostatic micro actuators", Analog Integr Circ Sig Process (2007) 53:119–128.
- [4] S. Mukhopadhyay and N. Majumdar, "Use of the neBEM solver to Compute the 3D Electrostatic Properties of Comb Drives", Proceedings of ICCES'05, TechScience Press (2005).
- [5] Nitaigour Premchand Mahalik, "MEMS", Tata McGraw-Hill publishers, Third edition 2007, ISBN-13:978-0-07-063445-9.
- [6] Ndu Osonwanne and Jason V. Clark "MEMS Comb Drive Gap Reduction beyond Minimum Feature Size:A Computational Study" Excerpt from the Proceedings of the COMSOL Conference 2010 Boston
- [7] Prime Faraday Technology Watch "An Introduction to MEMS" January 2002.
- [8] M. Steven Rodgers, Sridhar Kota, Joel Hetrick, Zhe Li, Brian D.Jensen. "A New Class Of High Force, Low-Voltage, Compliant Actuation Systems" Intelligent Micromachine Department, Sandia National Laboratories Albuquerque, New Mexico 87185-1080.
- [9] Tai-Ran-Hsu "MEMS & Microsystems: Design, Manufacture, and Nanoscale Engineering" Tata McGraw Hill Publishers, 2004 Edition, ISBN 007048709X.
- [10] Sam Jebar Kumar1, Enoch Amoatey Tetteh2, E. Paul Braineard, "A study of why electrostatic actuation is preferred and a simulation of an electrostatically actuated cantilever beam for mems applications" Volume 6, Issue 5, pp: 441-446 ©IJESET.