International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 6, June-2016

A Review on the effect of fringing field of capacitor

Priyanka Devi[1], Naveen Rawat [2]

1 PG Student, Department Of Electronics and Communication Engineering
2 Assistant Professor, Department Of Electronics and Communication Engineering
Prannath Parnami Institute, Chaudharywas, Hisar, Haryana 112413, India

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ABSTRACT

Transduction in microelectromechanical systems (MEMS) or nanoelectromechanical systems (NEMS) is mainly based on electrostatic excitation. Electrostatics forces in these devices are found on the approximation of parallel plate capacitance with or without fringing effects. As the dimension of the devices reduces from micro to nano-scale, the fringing effect plays an important role. This work presents a new formulation for tackling the fringing field, in which the effect of fringing field is modeled as a variable serial capacitor. Based on this model, a robust control scheme is constructed using the theory of input-to-state stabilization and back stepping state feedback design.

Keywords: **FEM , MIM , MOS , MEMS , NEMS**

I. INTRODUCTION

For MEMS technology field, the accurate determination of capacitance is an important issue because which affects the performance of capacitive devices. For example, the fringing field capacitance should be considered to exactly determine the electromechanical behavior of a curled cantilever beam. Moreover, for the semiconductor industry, the capacitance estimation of the MIM capacitor, interconnection, and MOS capacitor also affect the performance of the whole circuit. The three-dimensional fringing fields must be taken into consideration if the wires or microstructures are short. Therefore, how to fast and accurately determine the three-dimensional capacitance becomes a major task in order to improve device quality. There are several types of capacitors usually used nowadays, such as parallel-plate capacitors, MIM capacitors, comb capacitor etc. Among the aforesaid kinds of capacitors, parallel-plate capacitor can be regarded as a typical and basic model of capacitor. However, most parallel plate capacitance models lead to very large errors due to the rapid size-shrink of devices encountered in the present day. Thus, analyzing the characteristics of a parallel-plate capacitor with fringing field effect is essential.

II. LITERATURE REVIEW

In this paper, Movable suspended microstructures are the common feature of sensors or devices in the fields of Complementary-Metal-Oxide-Semiconductors and Micro-Electro-Mechanical Systems which are usually abbreviated as CMOS-MEMS. To suspend the microstructures, it is commonly to etch the sacrificial layer under the microstructure layer. For large-area microstructures, it is necessary to design a large number of etching holes on the microstructure to enhance the etchant uniformly and rapidly permeate into the sacrificial layer. This paper aims at evaluating the fringe capacitance caused by etching holes on microstructures and developing empirical formulas. The formula of capacitance compensation term is derived by curve-fitting on the simulation results by the commercial software ANSYS. Compared with the ANSYS simulation, the deviation of the present formula is within 5%. The application to determine the capacitance of an electrostatic micro-beam with etching holes is demonstrated in a microstructure experiment, which agrees very well with the experimental data, and the maximum deviation is within 8%. The present formula is with simple form, wide application range, high accuracy, and easy to use. It is expected to provide the micro-device designers to estimate the capacitance of microstructures with etching holes and predominate in the device characteristics [1].

In this paper, An accurate computation of electrical force is significant in analysing the performance of micro and nanoelectromechanical systems. Many analytical and empirical models are available for computing the forces, especially, for a single set of parallel plates. In general, these forces are computed based on the direct electric field between the overlapping areas of the plates and the fringing field effects. Most of the models, which are based on direct electric field effect, considers only trivial cases of fringing field effects. In this paper, we propose different models which are obtained from the numerical simulations. It is found to be useful in computing capacitance as well force in simple and complex configurations consisting of an array of beams and electrodes. For the given configurations, the analytical models are compared with the available models and numerical results. While the percentage error of the proposed model is found to be under 6% with respect to the numerical results, the error associated with the analytical model without the fringing field effects is around 50%. The proposed model can be applied to the devices in which the fringing field effects are dominant [2].

This paper describes a equation that describes the relationship between the applied voltage and the resulting electrostatic force within comb drives is often used to assist in choosing the dimensions for their design. This paper re-examines how some of these dimensions—particularly the cross-sectional dimensions of the comb teeth—affect this relationship in vertical comb drives. The electrostatic forces in several vertical comb drives fabricated for this study were measured and compared to predictions made with four different mathematical models in order to explore the amount of complexity required within a model to accurately predict the electrostatic forces in the comb **drives [3].**

In this paper The Fringing Electric Field (FEF) element design consideration has been discussed in this paper. This type of sensor is planned to be used for the Non-Destructive Test (NDT) measurement of a moisture level in soil for irrigation system in the field and green house. The effect of soil type and its moisture level has been taken into account by preparing several types of soil moisture level in the lab by performing measurement and calculation as proposed by several papers. It has been shown that the FEF parameters such as the dielectric constant, numbers of finger for FEF design and the working frequency played an important role for FEF design considerations. The performance of the FEF element sensor had been compared with the commercial sensor for benchmarking [4].

In this paper is mathematical analysis of the contribution of fringing effect in sensing performance of electrostrictive capacitive sensors. Study on capacitive sensors having separation between plates in nanometric range and area in centimetric range reveals that error due to fringing effect is of the order of 10-5 and therefore can be neglected particularly for area greater than 5x10-4 sqm. In case of nanometric capacitive sensors having both area of plates and separation between them in nanometric range, the percentage error due to fringing effect has been found to be as high as 8.53% and therefore cannot be ignored for sensitivity consideration of capacitive sensors. The study also includes variation of fringing effect with distance between plates and area of plates in micrometric and millimetric capacitive sensors and it is observed that error is on higher side to be ignored. Few of capacitive sensors exhibiting minimum contribution from fringing effect have also been suggested for constructional design [5].

This paper presents the development of a Twin-T oscillator comprising polymer coated parallel plates as a sensor for ocean water salinity monitoring. This sensor employs a parallel plate capacitor design, with sea water serving as the medium between plates. Novalac resin and a proprietary commercial polymer (Accuflo™) were investigated as corrosion protective coatings for the copper electrodes of the capacitor. Electrochemical Impedance Spectroscopy (EIS) was employed to evaluate corrosion inhibition of polymer coating in sea water. A detection circuit was designed and simulated using P-spice and then implemented in Printed Circuit Board (PCB). EIS results indicate that Accuflo exhibits better corrosion inhibition in ocean water than Novolac. Further, the use of Twin-T oscillator based detection circuit resulted in enhanced sensitivity and better detection limit. Experiments performed using ocean water samples resulted in oscillator frequency shift of 410 Hertz/power supply unit (Hz/PSU). Oscillator frequency drift was reduced using frequency-to-voltage converters and sensitivity of 10 mV/PSU was achieved [6]

This paper presents a simple formula considering three-dimensional fringing fields for the parallel-plate capacitor. The three-dimensional fringing capacitances formula is developed from curve-fitting on numerical results. The deviation is within 10% compared with simulation data. The present solution is with higher accuracy, wider application range, and more explicit physical meanings than other published works. The fringing capacitance model is expected to be applicable to the evaluation of interconnect capacitance for IC industry and the design of capacitive devices for MEMS [7]**.**

The electric field distribution produced by any disposition of insulating and conducting materials is a key aspect in electrical design, but exact values can only be obtained in simple geometries. In this work, using commercially available F.E.M. software we show the influence of the edge-effect on the electric field distribution of a two parallel-plane conducting plates system surrounded by an insulating medium taking into account the thickness of the conducting plates. We compare our results with previous published works. Finally, we obtain the relationship between capacitance and insulation characteristics, insulation gap, plate dimensions and plate thickness [8].

A numerical method is presented for determining the static charge distribution and capacitance of around disk capacitor. Based on equivalent surface charge distributions, an integral equation subject to the boundary conditions is transformed into an algebraic equation by using the method of moments. In the proposed scheme to eliminate the discretizing errors often encountered in other techniques, annular patch sub domains are introduced, not only to improve the accuracy of solutions, but also to reduce the matrix size of the resultant equation. By solving the transformed algebraic equation, the charges per unit area on the interfaces are numerically determined. With use of the free charge on plates obtained by using annular patches, the capacitance is more accurately calculated. The equipotential lines around a round disk capacitor are also calculated. In order to show the usefulness of this method, the employed scheme is applied to a single circular disk with an exact solution, and to the dielectric filled capacitor partially covered by plates. Those results are examined and discussions are also made to support the validity of the presented scheme [9].

Though the effect of fringing field in electrostatic parallel-plate actuators is a well-understood phenomenon, the existing formulations often result in complicated mathematical models from which it is difficult to determine the deflection of the moving plate for given voltages and hence, they are not suitable for accurate actuation control. This work presents a new formulation for tackling the fringing field, in which the effect of fringing field is modeled as a variable serial capacitor. Based on this model, a robust control scheme is constructed using the theory of input-to-state stabilization (ISS) and backstopping state feedback design. This method allows loosening the stringent requirements on modeling accuracy without compromising the performance. The stability and the performance of the system using this control scheme are demonstrated through both stability analysis and numerical simulation [10].

III. HOW TO CALCULATE FRINGING FIELD?

In the most popular model of electrostatic parallel-plate actuators, only the main electrical field (perpendicular both electrodes) is considered and the capacitance of the structure is computed by

$$C = \varepsilon WL/G \qquad (1)$$

where W and L are the width and the length of electrodes, respectively, G indicates the separation distance, and ε is the permittivity in the gap. This formulation leads to a simple model of parallel-plate devices, but it is not accurate when the gap size separating the electrodes is comparable to the geometrical extent of the plates. The capacitance of the structure including the effect of fringing field can be computed by Laplace formula. Although this formula can be used in finite element methods (FEM) and leads to very accurate estimation of the real values in a static manner, it is not susceptible to analytic calculations. Assuming zero thicknesses for the plates, several approximate analytical formulae have been developed for the capacitance in the presence of the fringing field. A number of other formulae have also been recommended assuming finite thicknesses for the electrodes. Although the recommended equations consider fringing field in the modeling of parallel-plate capacitors, these formulations provide only approximate expression and are not mathematically simple. In particular, these formulae are highly nonlinear and it is difficult to determine the deflection of the moving plate for a given capacitance. Therefore they are not suitable for predicting the applied voltages for actuation control.

IV. DERIVATION OF ELECTROSTATIC FORCE

Electrostatic actuation is the most common type of force generation, electromechanical energy conversion scheme in micromechanical systems. It is the most excellent example of an energy-storage transducer. Such transducers store energy when either mechanical or electrical work is done on them. Assuming that the device is lossless, this stored energy is conserved and later on converted to the other form of energy. Electrostatic actuation is produced by the electric field of a capacitor. Figure.1 illustrates the two basic configurations of a capacitor for electrostatic actuation of a MEMS device: the parallel plate and the inter digitated comb capacitor configurations. The inter digitated comb capacitor is dominated by the fringe electrostatic field, and the parallel plate capacitor is dominated by the direct electrostatic field.

In Parallel Plate Capacitor arrangement one of the plates is made movable by applying bias voltage. When an electric field is excited between two parallel plates, there will be an attractive force acting on both plates to bring them closer and minimize the electrical potential energy of the system This produces displacement, a mechanical form of energy. The energy stored (W) at a given voltage, V is given by equation 5:

$$W = \frac{1}{2}CV^2 = \frac{\varepsilon A V^2}{2d} \qquad 2$$

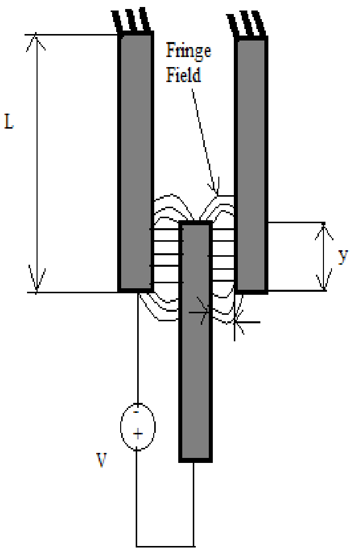
And force (F) between the plates is given by equation 6:

$$F = \frac{\varepsilon A V^2}{2d^2} \qquad 3$$

Where, ε = permittivity of material between the parallel plates

A = plate area
d = gap between the plates
C = capacitance between the plates

For a fixed voltage, the electrostatic force is inversely dependent on the separation squared between the capacitor plates. So, the electrostatic force drops as the plates get farther apart. This force is also linearly proportional to the plate area. Large area with close gap separation is required for generating force of significant magnitude which imposes fabrication difficulties. For a parallel plate capacitor shown in figure 1(b), the capacitance is inversely proportional to the gap between the capacitor plates and the force is inversely proportional to the gap between the capacitor plates square. The capacitance and the force of the parallel plate capacitor are highly nonlinear.



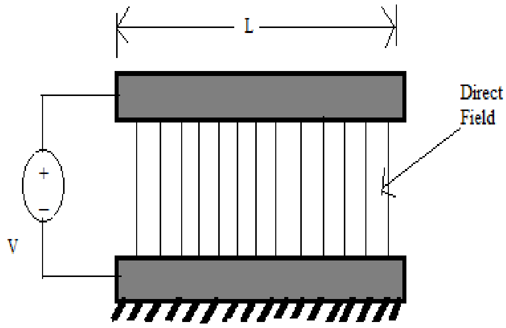


Figure 1(a): Interdigitated Comb Capacitor **Figure 1(b): Parallel Plate Capacitor**

When a voltage under a certain threshold is applied, an electrostatic attractive force brings the plate closer to the ground whereas the displacement induced mechanical restoring force balances the electrostatic force, and system equilibrium is reached when the two forces equate.

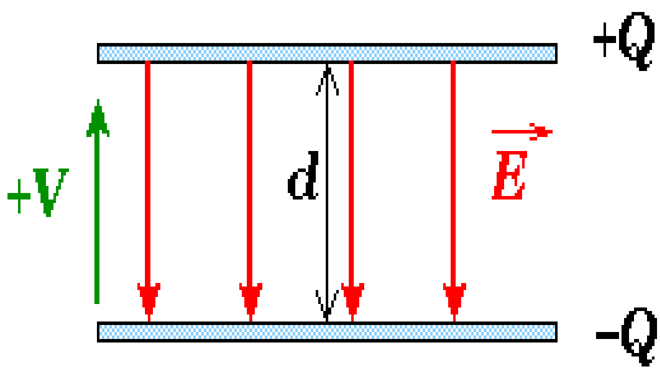


Figure 2: Planar Capacitor Actuator [4].

Though the electrostatic and mechanical forces have different dependencies on the displacement of the plate, and when the voltage exceeds the threshold level, the mechanical force cannot balance the electrostatic force. The plate experience a positive force gradient and accelerates away from that particular equilibrium point. This threshold voltage is the pull-in voltage shown in figure 2.

CONCLUSION

The electrostatic force is a function of how the capacitance between the teeth changes with respect to their relative vertical positions. Traditionally, a poor estimate of the capacitance, that does not include the fringe electric fields around the tops and bottoms of the comb teeth, has been used to calculate electrostatic forces.

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