

Abstract

# A Flexible PCB-Based MEMS Field Mill with a Vertical Movement Shutter Driven by an Electrostatic Actuator<sup>†</sup>

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**Abstract:** This paper describes a simulated MEMS field mill that utilizes a vertical movement shutter powered by an electrostatic actuator. The design is based upon a Flexible PCB substrate to enable faster prototyping and lower cost. The simulation results show that if the system operates at a resonance, a 10 kV/m field will induce a current of 53 pA, resulting in a charge induction efficiency of 5.3 pA/(kV/m).

**Keywords:** electric-field mill; electrostatic actuator; Flexible PCB; vertical movement; MEMS

## 1. Introduction

Electric-field sensors are designed to measure electric-field strength. Microelectromechanical system (MEMS) electric-field sensors have gained significant popularity in recent years due to their small size, lightweight, low power consumption, and low cost [1]. Some of their common applications include voltage measurement in power systems, fault diagnosis in electrical equipment, electrostatic hazard warning, etc. Some MEMS electric-field sensors mimic conventional field mills by utilizing a shutter that moves laterally [2,3]. However, these sensors face a problem where their sensitivity is considerably reduced when the shutter is largely deflected in a strong field. To overcome this issue, some sensors use a shutter that moves vertically [4,5], which compensates for the displacement. In recent years, many MEMS devices on Flexible Printed Circuit Board (FPCB) have been reported [6]. The FPCB incorporates a polyimide substrate and copper layers, allowing for the fabrication of MEMS devices with reduced cost and increased efficiency through commercialized manufacturing.

This paper presents a simulation of a MEMS electric-field sensor with a vertical movement shutter driven by electrostatic forces. The sensor is designed based on upon a FPCB substrate. The resonant frequency and sensor performance in a dc field are simulated.

## 2. Sensor Design

The sensor's operation is depicted in Figure 1. The shutter and sensing electrodes are both grounded. When the shutter moves up and down within an electric field, the sensing electrodes detect variations in the field caused by the changes in the fringing effect. As a result, varying charges are induced, leading to the generation of an alternating current if shutter moves periodically.

The design of the sensor is illustrated in Figure 2, and it includes a shutter, sensing electrodes, and a bottom driving electrode. The shutter is supported by four 1000  $\mu\text{m}$  long S-shaped micro springs. The sensing electrodes have a size of 60  $\mu\text{m}$   $\times$  1000  $\mu\text{m}$ , and there are 12 sensing electrodes on each side of the sensor. The size of the electrostatic driving electrode is 920  $\mu\text{m}$   $\times$  1200  $\mu\text{m}$ . There are two grounded guard lines of 140  $\mu\text{m}$   $\times$  1200  $\mu\text{m}$  on both sides of the driving electrode to reduce noise from the driving signal on the sensing



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electrodes. The distance between the shutter and the driving electrode is 100  $\mu\text{m}$ . The thickness of the polyimide is 25  $\mu\text{m}$  and the copper is 18  $\mu\text{m}$  thick.

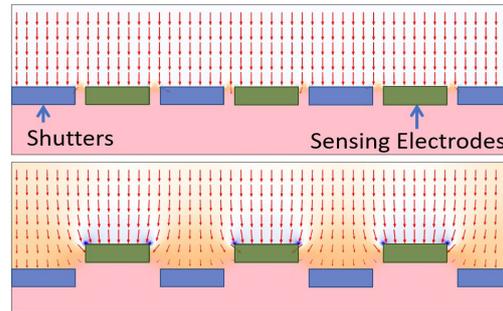


Figure 1. Operation principle.

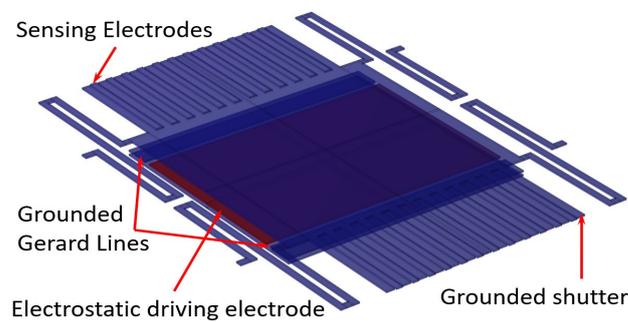


Figure 2. Sensor design.

### 3. Results and Discussion

COMSOL Multiphysics was used for the simulations. Figure 3 shows the shutter’s downward movement when pulled by the driving electrode. Figure 4 depicts the distribution of the electric field between the driving electrode and the surrounding grounded structures. We can see that the sensing electrodes are minimally affected by the driving voltage. The shutter resonant frequency is 493 Hz. When a 200 V is applied to the driving electrode, the shutter’s downward displacement is 5.7  $\mu\text{m}$ , and the induced charge on the sensing electrodes is 2.5 fC. At resonance, with a Q factor of  $\sim 100$ , the driving voltage will only be about 20 V, and the noise current is calculated to be 0.4 pA. In an electric field of 10 kV/m, the motion results in an induced charge of 0.17 pC, while at rest (0 V drive) the induced charge is 0.153 pC. When operating at the resonant frequency, the generated current is calculated to be 53 pA, and the efficiency of charge induction is 5.3 pA/(kV/m). The sensing signal is 130 times stronger than the driving noise. The efficiency of charge induction is comparable to [7].

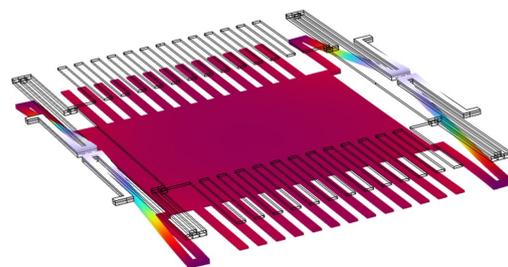
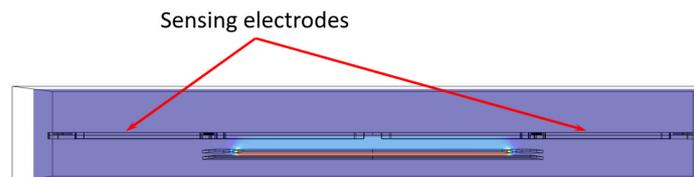


Figure 3. Shutter movement.



**Figure 4.** Driving electric-field distribution.

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