Microsensor for Atmospheric Electric Fields

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Why a new measurement system?

Electrical field mills (EFM) are today's gold standard for measuring static E-fields and have been developed for over a century. While the underlying shutter principle is simple and elegant, many implementations suffer from mechanical wear and from the massive field distortions due to grounded components. Other limitations are typical size and weight.

These basic draw-backs inhibit deeper insights into many processes of atmospheric electricity such as field distributions inside thunderclouds or initation of upwards lightning from tall structures.

At the same time other well-known approaches (capacitive sensors, electro-optical sensors) fail for static fields.

The key element why EFMs work is the chopping-induced modulation of the field E leading to a comfortable current changing with the chopping frequency,

$$i(t) = \varepsilon_0 E \frac{\mathrm{d}A(t)}{\mathrm{d}t},$$

with $A(t)$ being the overlap area of shielding and measurement electrodes.

Other approaches try to modulate E by using vibrating plates or reeds to generate an output proportional to E at a known frequency. These approaches are around for several decades but are used almost exclusively for charge or potential measurement.

Our approach

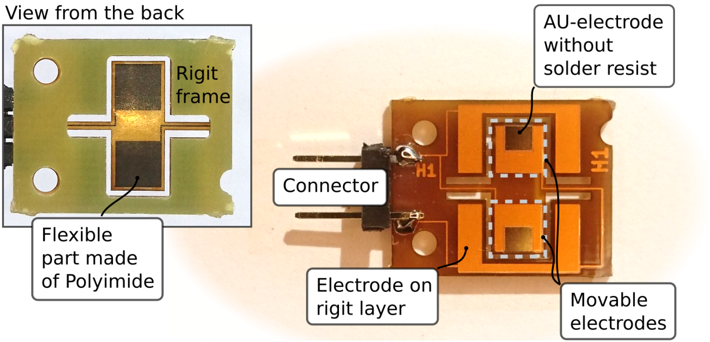
We transduce the static E-field to a mechanical motion at a certain frequency. For that, we use the electrical force F acting on a compliant structure with alternating charges $Q(t)$, generated by a voltage $u(t)$

$$F(t) = Q(t)E = C\,E\,u(t).$$

The capacitance C is given by the geometry of the transducer.

The motion can then be converted into an output voltage by an optical readout, having the advantage of zero crosstalk between the actuation and the readout.

$$\Rightarrow u_{\text{out}} \propto E\,u(t)!$$

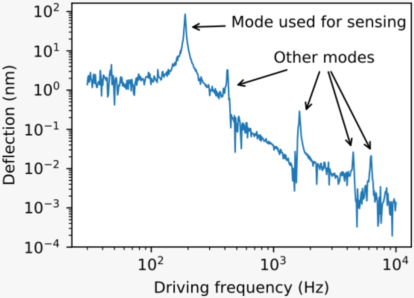


The compliant part made of polyimide consists of two torsional springs supporting a “paddle” with two electrodes. The dimensions of the PCB are 20 mm × 16 mm.
The devices have been fabricated by Leiton[1].

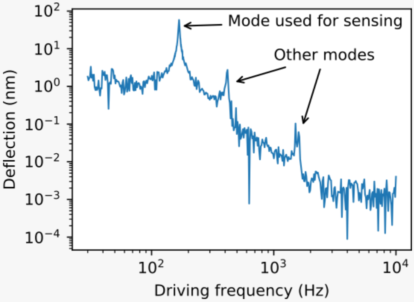
[1] https://www.leiton.de/technology-rigid-flex.html

Two such devices (named 'G1','H1') were tested in the lab with a laser-Doppler vibrometer (LDV, Polytec MSA-400) for functionality and to search for optimum modes for operation:

Device 'G1'



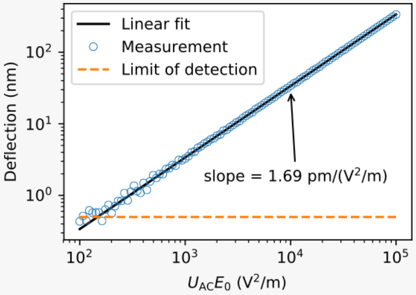
Device 'H1'



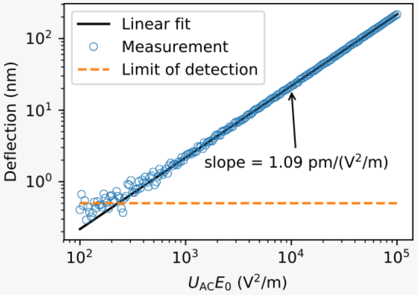
These tests perfomed with $E = 10\,\mathrm{kV/m}$ (provided by parallel field plates) and $u(\omega) = U_{\mathrm{AC}} \sin(\omega t)$, $U_{\mathrm{AC}} = 2.5\,\mathrm{V}$.

Responsivity and Limit of Detection

Device 'G1'



Device 'H1'



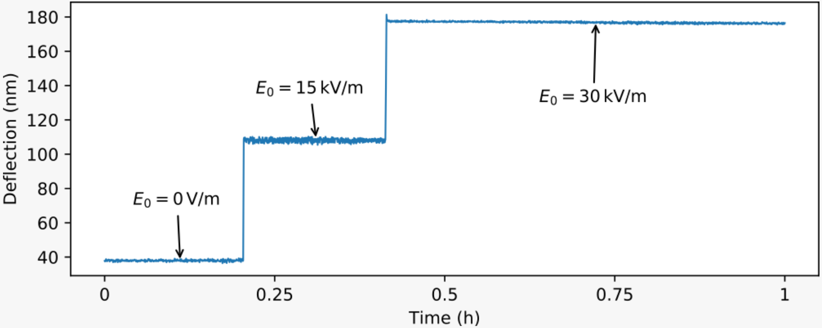
Limit of detection restricted by LDV to ~ 0.5 nm at ~ 190 Hz.
Responsivity (slope) for E_0 tunable by U_{AC} (thus also smallest detectable E_0^{min}).

e.g: G1: $E_0^{min} \sim 150\,\mathrm{V/m}$ for $U_{AC} = 1\,\mathrm{V}$
$E_0^{min} \sim 15\,\mathrm{V/m}$ for $U_{AC} = 10\,\mathrm{V}$

Long-term Behaviour

How stable is the PCB sensor?

Device 'G1' with $U_{AC} = 2.5\,\mathrm{V}$



Within $\sim$1 h stable enough, longer ($\gtrsim$ 1 day) measurements revealed significant drift. (Data not accessible at the moment)

Conclusion & Outlook

- Alternating Charge Sensor a promising alternative to EFMs
- Tunable sensitivity
- Longterm drift needs to be better understood
- Practical readout and packaging to be implemented
- Outdoors measurements!