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MEMS Based Field Mill for Measuring Hybrid Electric Fields

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Summary: In this paper we report a microsystem-based sensor system allowing measurement of static and low-frequency electric fields. The micro-electro-mechanical system is electrostatically actuated in-plane. A microcontroller unit is incorporated for generating signals for excitation but also to evaluate the signal after amplification via a digital lock-in amplifier. It is successfully shown that the system can measure DC and AC electric fields.

Keywords: MEMS, electric-field, AC+DC, hybrid field, measurement

Introduction

The measurement of electric fields has been a subject of interest for many decades, with various methods developed to quantify static fields. However, the increasing complexity of modern energy systems, which are progressively transitioning to hybrid configurations due to the integration of renewable energy sources and the need for long-distance transmission, has created a demand for more versatile measurement systems. Traditional electric field mills are typically limited to static field measurements, which constrains their applicability in these evolving energy landscapes [1]. In response to this need, we present a micro-electro-mechanical system (MEMS)-based measurement system designed to measure both static (DC) and low frequency, dynamic (AC) components of electric fields. This MEMS-based Field Mill (MEMS-EFM) [3] uses silicon-on-insulator (SOI) technology and is electrostatically actuated in-plane. The system incorporates a microcontroller unit (MCU) for signal generation and evaluation, utilising a digital lock-in amplifier to enhance the accuracy and reliability of the measurement.

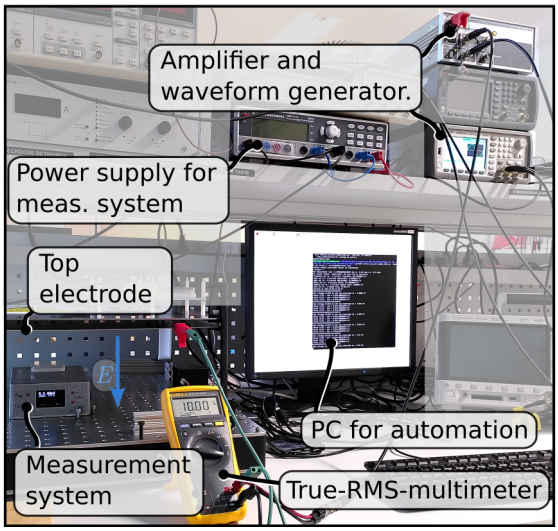

Fig. 1: Fully automated measurement set-up: The outer electric field E is created by applying the hybrid voltage from the high voltage amplifier to the top electrode above the measurement system which is positioned on a grounded plane.

Motivation

There are many ways to measure electric fields, but until now no compact system is available to measure reliable AC and DC [1]. This paper focuses not on improved sensitivity of the MEMS-EFM for DC such as done in [3] but on additional possibilities by the lock-in to measure also low-frequency components of the electric field.

Measurement Set-up

The sensor system, which provides cover for the fragile microsystem. The MEMS is located below an insulated floating electrode. The electronic circuitry for supplying the electrostatic actuation and amplifying the induced currents to voltage to be read by the ADC of the MCU is shown in Fig. 2. The amplification of the transimpedance amplifiers used to convert the currents generated by the MEMS is 100 MΩ. Both electrostatic drives were supplied with peak to peak voltages of $\leq$15 Vpp at 382 Hz which is the half of the resonance frequency of the MEMS. The hybrid voltage for the electric field was generated by a high-voltage amplifier (9200A, Tabor Electronics) while the amplifier input signal was provided by a waveform generator (Keysight 33500B). The voltage was applied to a electrode of 50 cm $\times$ 50 cm size made of stainless steel. The distance between the electrode that holds the voltage and a grounded sensor system is 0.125 m. A true RMS multimeter was used to

measure the resulting values of the AC and DC components. The insulator around the MEMS is of 6 mm height and is produced by rapid prototyping. The MEMS is located below the rectangular part on top of a white insulator. This metal part is electrically floating and was machined from aluminum and acts also as field concentrator, increasing the field in an area of approximately 20 mm^2 above the MEMS.

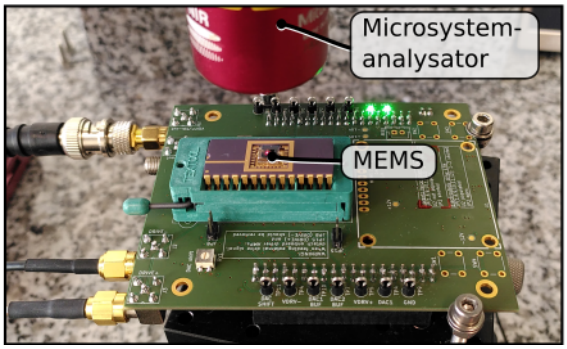

Fig. 2: Evaluation PCB with an electric field sensor in a ceramic package below Micro-System-Analyzer. All in- and outputs were supplied via lab equipment.

MEMS

The micro-systems were processed from custom designed layouts in the clean-room of ISAS-TUWIEN. The improved designs are based on the best prior chip-layouts where especially drive- and/or sensing electrodes were enhanced. The chips were wire-bonded into ceramic dual line standard packages enabling simple exchange in combination with a universal DIP sockets (Textool) as part of the actuation and evaluation circuit. Figure 3. depicts exemplary layout-data and the SEM image of a fabricated micro-sensor. Figure 4 shows the results of a measurement with hybrid electric field. At higher AC-fields of more than 1200 VRMS/m the amplifier saturates. In the lower-left part of the diagram, at low values of the external field, the deviation from the fitted slope is visible. This is due to resolution limit which is estimated to be 80 VRMS/m for AC fields of 50 Hz.

Conclusion

The results show that it is possible to measure DC and AC components of the electrostatic field using one single sensor system. The discussed system, which is incorporating a micro-controller for signal generation, acquisition and evaluation is a complete stand-alone device which can be used battery-powered. The signal evaluation at DC or at a given low frequency is implemented via a digital lock-in with adaptable demodulation frequency. The resolution limit was determined to be 80 VRMS/m.

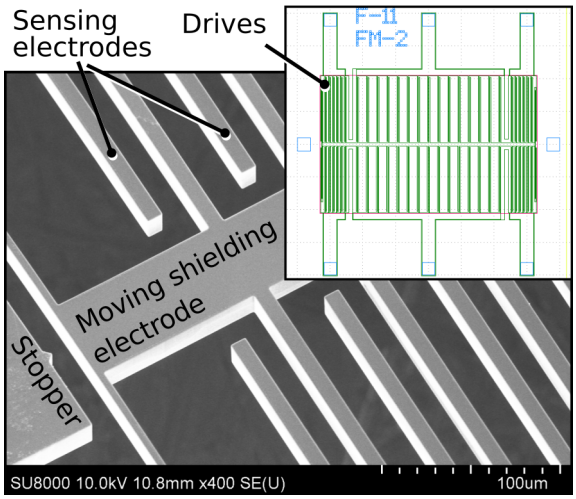

Fig. 3: SEM picture of a fabricated structure. The complete structure was etched into the 20 µm thick device layer of an SOI-wafer. The inset show a MEMS example layout. Side length of a single chip is 5 mm.

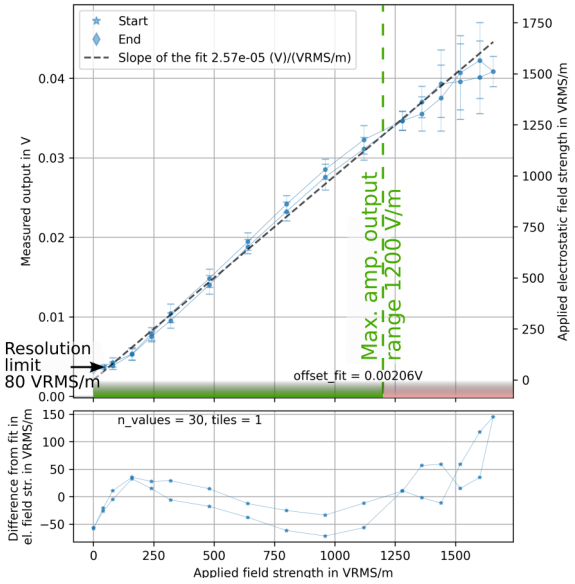

Fig. 4: Measured results for the MEMS supplied with different AC-fields of 50 Hz super-imposed on a DC-field of 400 V/m.

References

[1] W. Hortschitz, et al. *Measurement Science and Technology*, 35, 5, 052001, (2024), IOP Publishing; doi: 10.1088/1361-6501/ad243a

[2] Chen, T., et al. (2024). DC electric field sensor in a grounded enclosure with height adjustable pin., *Journal of Electrostatics*, 129, 103936; doi: https://doi.org/10.1016/j.elstat.2024.103936

[3] Wang, G., et al. (2024). A Review on Resonant MEMS Electric Field Sensors. *Micromachines*, 15(11), 1333.; doi: 10.3390/mi15111333