ELECTROMECHANICAL MICROCOMPONENTS FOR PRECISION APPLICATIONS

Anu Kärkkäinen[1], Panu Helistö[2] Aarne Oja[1] and Heikki Seppä[1]
[1]VTT Automation, Measurement technology,
PO BOX 1304, 02044 VTT, Finland
[2]Centre for Metrology and Accreditation, Electricity, Time and Acoustics,
Otakaari 7B, 02150 Espoo, FINLAND
Tel: +358 9 456 4377; Fax: +358 9 456 7029
e-mail: anu.karkkainen@vtt.fi

ABSTRACT

A new EC funded project EMMA, ElectroMechanical Microcomponents for Precision Applications, has started recently. The aim of the project is to develop micromecanical capacitive transducers suitable for electricity metrology. An ac and a dc voltage reference, an AC/DC converter, and a low frequency voltage divider have been demonstrated already and will be elaborated further in the project. A promising new field is to study MEMS transducers in high frequency applications.

1 INTRODUCTION

The high performance of micromechanical systems (MEMS) has already been demonstrated in various commercially available sensors like accelerometers, gyroscopes, and pressure sensors. MEMS structures are promising candidates also for metrological transducers. The mechanical properties of MEMS sensors provide a high potential for significant improvement in transducer performance. It can be expected that micromechanical structures formed of single crystalline silicon achieve stability far better than 0.01 ppm/h. Also the single crystal structures have no hysteresis and the thermal expansion coefficient of silicon is low.

In addition to the stable mechanical properties, MEMS sensors have several other advantages.. They are batch fabricated which results in small size and low cost. The power consumption of capacitive MEMS transducers is very low and they can have a very high input impedance. Compared to semiconductor devices, a low $1/f$ noise level is expected because of the larger size of the active element and low power consumption. MEMS transducers can be also tuned to operate over wide dynamic range (0.1 – 100 V) and wide frequency range. An important advantage of the MEMS technology is also that the sensor can be integrated with the measurement electronics which is significant in high frequency applications.

2 GOALS OF THE PROJECT

The 3-year and 3,4 MEuro EMMA project aims to improve the electromechanical stability of micromechanical transducers. All the project participants are experts in the field of Micro System Technology (MST) or metrology. The project is coordinated by VTT (FIN) and other participants are Centre for Metrology and Accreditation (FIN), Fluke Precision Measurement Ltd. (UK), VTI Hamlin Ltd. (FIN), University of Twente (NL), Physikalisch-Technische Bundesanstalt (GER),and Netherlands Meetinstitut (NL).

Some effort has already been made to exploit micromachining in metrology [1]–[3]. However, the prototype sensors demonstrated in these studies have significant deficiencies and do not qualify for reference use as such. The goal of EMMA project is to demonstrate that it is possible to realize both a dc and an ac voltage reference, high precision inertial sensor and a high frequency field sensor using Micro System Technology (MST).

Currently the performance of capacitive MEMS sensors is limited by their electromechanical stability. Charges trapped on the insulating surfaces can create significant electrostatic forces even in the absence of an external biasing voltage. In micromechanical structures, an additional effect is the capacitance change caused by displacement of elastically suspended microstructures due to spurious electrostatic forces. The amount of trapped charges in the capacitive MEMS components fluctuates in time due to various tunnelling processes.

One of the primary tasks of EMMA project is to solve how to eliminate trapped charges on the surfaces of micromechanical electrodes. Novel fabrication methods will be developed to increase the surface conductivity for preventing surface charging.

2.1 Dc voltage standard

The diagram of a MEMS dc voltage reference transducer is presented in figure 1. The MEMS component is a see-saw with four electrodes. It is made by bulk micromachining. The electrodes on the left-hand side are used to detect a displacement. A dc voltage into the upper electrode of the left hand side imposes the displacement into the set value. The ratio of the capacitors is compared to the voltage divider acting as a set value for the controller. When the ratio is one third of

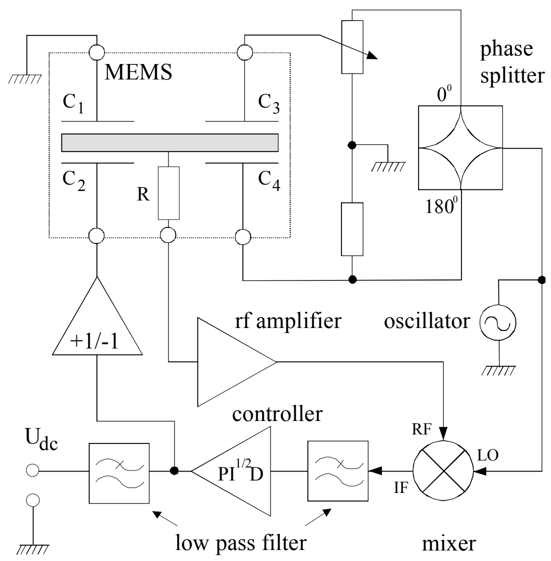

Figure 1: Realisation of a microelectromechanical dc voltage reference [4].

the full gap, the dc voltage equals the so called pull-in voltage, which is used as a stable voltage reference.

VTT has experimentally demonstrated the transducer shown in figure 1 [5]. About 1 ppm stability over several days has been measured for a 25 V DC voltage reference.

2.2 Ac/dc voltage reference

A MEMS ac voltage source can be realized by driving an ac current via a moving plate into a fixed electrode and stabilizing the current into the voltage maximum in the level of 10^{-4}. A stable and frequency independent ac voltage source is then obtained. In practise, parasitic capacitance may prevent from making an ideal current source by modifying the $I_{rms}U_{rms}$ characteristics of the circuit. The problem can be avoided by adding a coil in parallel with the system, but the method, unfortunately, engages the frequency. A better solution is to use piston mode and to make the active capacitance as high as possible. Also guarding of the stray capacitances with an extra electrode solves the problem. To eliminate vibrations and gravity a seesaw type component is preferred to a cantilever.

MEMS ac/dc converters have the advantage that their input impedance can be tuned to any value from near infinite to zero. There are no MEMS based ac voltage references commercially available at the moment.

2.3 High precision inertial sensor

MEMS inertial components can be used in accurate low-power inertial applications where the size and the price of the component are critical (e.g., mobile phones).

VTI Hamlin is a commercial manufacturer of inertial sensors. The sensors have applications for example in automotive and telecommunication industry. However, there are commercial applications where 1–2 orders of magnitude higher stability is required.

2.4 High frequency field sensor

Thermal devices relying on a heating effect such as thermistor mounts suffer from sensitivity to ambient temperature changes, limited dynamic range and long settling times. They are inherently integrating devices, measuring only average power. Diode sensors provide the ability to measure the envelope and modulation and have the advantage of greater dynamic range, but they suffer from temperature sensitivities and problems with impedance matching. These sensors can not easily be integrated with signal conditioning or measurement electronics.

MST can provide several advantages to hf field sensors. First, because the active area of MEMS tranducers is large compared to semiconductor devices, low $1/f$ level can be achieved. Second, the zero or low power consumption results in minimal heat generation in the sensor and hence minimal thermal effects in sensor operation. Third, it is possible to integrate the sensor with the measurement electronics which can significantly improve sensor performance in noisy environment.

3 CONCLUSIONS

The aim of EMMA project is to study, develop and test micromechanical capacitive transducers for electrical metrology. VTT has experimentally demonstrated an ac and a dc voltage reference, an AC/DC converter, and a low frequency voltage divider based on Micro System Technology (MST). A promising new field is to study Microelectromechnical systems (MEMS) in high frequency applications. Because of expected low $1/f$ noise, low power consumption and possibility for integrated structures (one chip design), MEMS based devices have potential as new electrical references also in high frequency applications.

References

[1] B.P. van Drieënhuizen, R.F. Woffenbuttel, "Integrated Electrostatic RMS-to-DC Converter using IC-Compatible Surface Micromachining" Proc. Transducers 95, Stockholm, Sweden, June 1995, pp. 130 - 133.

[2] M. Suhonen, H. Seppä, A.S. Oja, M. Heinilä and I. Näkki, "AC and DC Voltage Standards Based on Silicon Micromechanics", Conference Digest of CPEM 98 (1998) 23.

[3] T. Sillanpää, A.S. Oja and H. Seppä, "Micromechanical Silicon Scale", in Digest, CPEM98, Washington DC., July 1998, pp.106 -107.

[4] H. Seppä, J. Kyynäräinen, and A.S. Oja, "Microelectromechanical Systems in Electrical metrology", CPEM