

# Challenges for the future of MEMS motion sensors in Mil/Aerospace applications

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## Introduction

It is certainly obvious for everybody that MEMS motion sensors are the source of a major revolution in the automotive, consumer, IT and industrial market. We all use on a daily basis MEMS accelerometers in our car, in our computer or in our mobile phone. It is certainly less apparent to everybody that MEMS motion sensors are also invading high end applications in the Mil/Aerospace and high end industrial markets.

MEMS motion sensors and more specifically MEMS accelerometers are starting to replace established, expensive and fragile high-end electromechanical devices, offering the same or even better performance at lower cost, lower power consumption smaller size and greater strength. Today some of these sensors are already fully qualified for civilian and defence programs, offering advantageous opportunities for back up systems on most recent Airbus and Boeing airplanes or new and unexpected solutions for harsh environments applications such as gun launched smart munitions<sup>1</sup>.

Anyway, MEMS accelerometers are still struggling to reach tactical grade quality and bias stability and thermal drift are still obstacles to overcome for high-end inertial navigation systems. Sensor bias drift can lead to intolerant integral error.

## Precision MEMS technologies

In the world of motion sensors, Colibrys has a unique position in the market. It focuses on high-end markets with an appropriate business model fully compliant to Mil/Aerospace requirements and with technologies specifically designed for performance. In order to make an ultra-high precision and stable MEMS accelerometer, there are three key technical issues to be addressed: a highly stable MEMS sensing element, an excellent assembly and packaging technology and very high quality electronics.

The use of high quality Silicon as raw material and the capability of the design to meet performance with manageable manufacturing tolerances as well as the sensor manufacturing, assembly and packaging using a Multi Chip Manufacturing (MSM) approach have already largely been developed<sup>1</sup>.

The electronics associated with the MEMS is certainly of the most crucial element to get expected tactical grade performance.

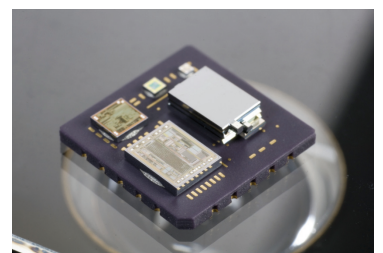


Fig 1: Open view of an open loop MS9000 accelerometer from Colibrys

### Electronics; open loop and close loop approach.

There are two ways to operate a capacitive MEMS sensor. For the open loop approach, the mechanical plate deflection is measured through the associated capacitance change. This concept has extremely low power consumption but has limitations in terms of the ultimate bias stability and linearity. For an open-loop sensor, using micromachining processes, the mass can usually be well defined, while the typical tolerance of damping and stiffness could vary within  $\pm 20\%$  of their nominal values. Mechanical spring constant is function of silicon or glass material properties, which is dependent on temperature, and most importantly mechanical spring suffers from assembly and packaging stress. The stability drift of an open-loop MEMS inertial sensor is almost only dependent on the mechanical control of these mechanical parameters. Typically open loop sensors are good where  $\pm 100$  ppm stability and 12 to 16 bit resolution are needed.

To the contrary, closed-loop accelerometer regulates the proof mass motion in a nearly fixed position and the inertia is compensated by feedback forces. The performance in this second case is mostly determined by feedback, i.e., electrostatic force generated by high stability voltage. Therefore, the sensitivity and bias to manufacturing tolerances can be considerably reduced. Closed-loop sensors will cover the stability of  $\pm 10$  ppm, the linearity of  $1 \mu\text{g}/g^2$  and the resolution range of 20 to 24 bits and beyond.

### Close loop system design

To face the future market requirements and offer solutions to the need for a tactical grade MEMS accelerometer, Colibrys has decided to develop a new digital sensor using high-order sigma-delta loop. A 5th-order sigma-delta closed-loop regulation as shown in the next figure has been designed and is under development instead of using a traditional analog closed-loop control approach. This technique can dramatically improve the sensor nonlinearity and noise level. Linearity improvements come from the very narrow seismic mass displacement window of  $\pm 10$  nm, and by electronically tuning the mass median position. Noise could be improved as damping no longer restricts from the gas inside the cavity but from the electrostatic feedback forcing: high quality factor can thus be chosen. In order to reduce low-frequency noise level and electronics induced bias drift, smart choice of actuation voltages and correlated double sampling (CDS) have been implemented. Due to high oversampling and noise-shaping, the requirements for analog circuits are considerably reduced.

### Measurement results

Noise tests have been performed in a state-of-the-art quiet room with special ground mechanical decoupling, resulting in a noise floor of  $30 \text{ ng}/\sqrt{\text{Hz}}$ . A noise level of  $1.7 \mu\text{g}/\sqrt{\text{Hz}}$  is achieved in 300 Hz bandwidth, which is in excellent accordance with simulations. Long term stability drift measurements over 60 hours show values as good as  $\pm 100 \mu\text{g}$  ( $\pm 10$  ppm) in absence of temperature control or algorithm compensation. Bias stability of rms value  $\pm 5 \mu\text{g}$  over one hour have also been achieved. Preliminary temperature tests were performed in the range of  $-30^\circ\text{C}$  to  $+80^\circ\text{C}$  and show a bias temperature sensitivity of  $200 \mu\text{g}/^\circ\text{C}$ , and a scale factor temperature sensitivity of less than  $40 \text{ ppm}/^\circ\text{C}$ . It is worth noticing that the sensor thermal behaviors can easily be fitted by first-order linear models. Thermal modeling can be further used to compensate characteristics of sensors over the full temperature range.

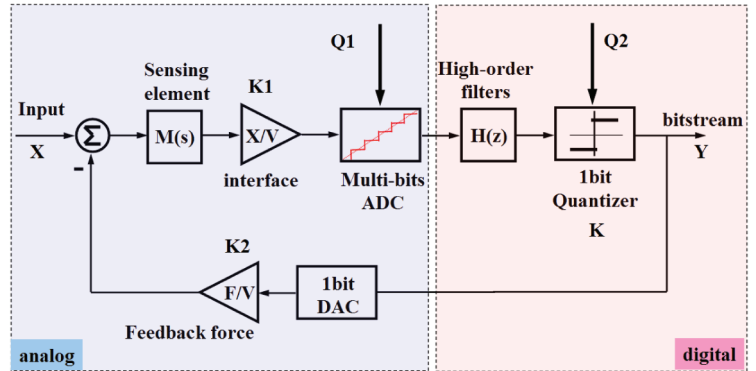


Fig 2: Schematic of the Colibrys sigma delta close loop electronic concept

Closed-loop MEMS accelerometers can considerably reduce the sensitivity to manufacturing tolerance. Tests show that MEMS accelerometers, which operate in such high-order sigma-delta closed-loop, have the potential to match performance of expensive amorphous quartz macro electro-mechanical sensors and even outperform them in noise, robustness and cost.

### Opportunities for new applications

The qualification of the MEMS technology for high end Mil/ Aerospace applications with all the associated advantages such as high performance at lower cost, compatibility to harsh environments, lower power consumption and smaller size is a real enabler for new applications and new opportunities such as:

- Tactical grade inertial applications (air, land and sea guidance and navigation, AHRS...)
- Platform stabilization and north finding applications
- High stability mil/aerospace and industrial tilt applications

As well as pure industrial applications such as:

- Civilian land navigation
- Strong motion and seismic measurements
- Structure health monitoring
- etc

Colibrys is a world-leading supplier of standard and semi-custom high-end MEMS based motion sensors into the Energy, Mil/Aerospace and Industrial & Instrumentation markets for use especially in harsh-environment and/or safety critical applications. Colibrys accelerometers, developed for a broad spectrum of functions include extremely low noise and shock resistant seismic sensors, high stability and high shock inertial accelerometers, low power tilt accelerometers and DC coupled capacitive vibration and shock sensors. ■

### Reference

1. MEMS Motion Sensors, the solution for harsh environments in defence applications, World System defence, 2010 – Volume 2, p 189



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