High Performance Low Volume MEMS for Aerospace Defense, Industrial and Energy Applications

Felix Rudolf
Colibrys
International MEMS Industry Forum,
Grenoble, 6 - 7 Octobre 2014
Colibrys is focusing on **Mil/Aerospace, Energy, Industrial and Instrumentation markets**

**Challenges**

- Large variety of applications
- Low to medium volumes for each application: 1000’s to 100’000’s
- Specific’s for each application
  - Performance
  - Environmental
  - Application know-how/ terminology
  - Design and Qualification standards
DRIVING FORCES FOR HIGH PERFORMANCE ACCELEROMETERS

Replacement of electromechanical devices by MEMS

- Cost
- Robustness (e.g. shock)
- Size
- Power

Electromechanical accelerometers and geophones

MEMS accelerometers
HIGH PERFORMANCE APPLICATIONS AND KEY DRIVERS

- **Inertial**
  - Aerospace defence, Personal navigators
  - Bias stability, linearity (VRE), robustness, radiation (space and aeronautics)
  - Qualification to aeronautics standards: DO xxx DAL

- **Drilling**
  - Tilt, Vibration
  - High temperature 150°C to 200°C, robustness: multiple shocks
  - Specific environmental test conditions

- **Seismic**
  - Earthquake monitoring, Seismic Imaging, structural monitoring
  - Noise, power

- **Vibration**
  - Automotive testing, Train: bogie monitoring
  - Large BW, Noise, multiple shocks

- **Space**
  - Radiation tolerance design and testing, design standards
APPLICATIONS OF ACCELEROMETER PLATFORMS

Open loop:

- Large range of applications in aerospace, industrial and energy markets

- Inertial
  - Guidance and control
  - Drilling
  - Tilt

- Vibration
  - Testing
  - Train monitoring

- Seismic
  - Structural health monitoring

Closed loop

- Highly specialized applications in Aeronautics, instrumentation and energy markets

- Inertial
  - Navigation, north finding

- Seismic
  - Earthquake monitoring
  - Seismic imaging
OPEN LOOP PRODUCT PLATFORMS AND APPLICATIONS

Markets

- Mil / Aero
  - Homeland security
  - Seismic monitoring
  - SHM

- Industrial
  - Earthquake
  - Railway technology

- Energy
  - Oil & gas exploration
  - Mining
  - Directional drilling

Products

- Seismic
  - Navigation, guidance
  - AHRS, flight recorder
  - Gun hard guidance

- Inertial
  - Railway technology
  - Automotive testing
  - Process control

- Vibration
  - Aircraft testing
  - Helicopter testing

- Tilt
  - Platform stabilization
  - Range finding
  - North finding
  - Drilling & survey
  - High T MWD
MEMS TECHNOLOGY

» highly stable MEMS
  - Common basis for both accelerometer platforms

» Proven bulk micromachining, out of plane MEMS technology
  - High stability Spring-Mass-capacitor plates: 2.5 pm* plate position stability
  - Brownian noise < 20 ng/√Hz
  - Controlled gas damping for bandwidth and VRE control

» Silicon die and ASIC are packaged in a hermetically sealed ceramic housing

* Measured with closed loop system

High Performance Low Volume MEMS, Felix Rudolf, Colibrys
International MEMS Industry Forum, Grenoble, 6 - 7 October 2014
ACCELEROMETER PLATFORMS

- Open loop electronics

Measurement of capacitance change

Closed loop electronics (servo)

Electrostatic force balances the inertial force

Typical characteristics

<table>
<thead>
<tr>
<th></th>
<th>Open loop</th>
<th>Closed loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>LCC 9 x 9 mm</td>
<td>PCB 40 x 40 mm</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 10 mW, 3.3 V</td>
<td>0.1 to 0.5 W, 20V</td>
</tr>
<tr>
<td>Stability</td>
<td>50 to 100 ppm</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Linearity</td>
<td>500 ppm</td>
<td>&lt; 30 ppm</td>
</tr>
<tr>
<td>Noise SNR 1 Hz BW</td>
<td>120 dB</td>
<td>Up to 150 dB</td>
</tr>
</tbody>
</table>
→ Open loop approach is best choice in terms of
  - Size
  - Power
  - Complexity, Reliability
  - Cost
  - Same product family offers large range of
    - Full scale accelerations: 1 to 100 g
    - Bandwidth/damping: 100 Hz to 5 kHz

→ Goal: push the performance to its limits
  - Bias stability: 1000 ppm → 100 ppm
  - Nonlinearity: 1% → 0.05%
  - Noise: S/N 1 Hz BW 100 dB → 120 dB

→ 1st phase: Improve MEMS, completed

→ 2nd phase: Improve ASIC (Ongoing)
**Highly stable MEMS capacitive sensor**
- Use of the same electrodes for forcing and position detection (timesharing)

**Analogue front end electronics**
- Capacitive mass position detection,
- High voltage switches to generate force pulses and signal for position detection

**Digital filter**
- 5th order sigma delta control loop
- Generation of 1 bit feedback force: force pulse applied to top or bottom electrode
TEST BOARD DESIGN

- MEMS & Temp sensor packaged inside a standard JLCC-44 package

- Test board (mock-up)
  - Dual MEMS control
  - Discrete analog electronic front-end
  - FPGA for digital filtering, decimation & control sequencing
  - Clock oscillator
  - Ethernet communication interface
  - Single power supply

- Potential for size, power and cost reduction (ASIC, SiP)
PERFORMANCE OF CLOSED LOOP ACCELEROMETER

- **Temperature range**
  - [-40°C ; +80°C]

- **Bias temperature slope**
  - Mean value < 120mg
  - < 50 µg/°C
  - 20 µg/°C typical

- **Low hysteresis**

- **Excellent bias residues**
  - Peak < 50 µg
  - RMS < 20 µg

Bias residues after 3rd order polynomial calibration

Bias 20 µg RMS or 1.3 ppmFS
SHORT-TERM BIAS STABILITY

**Allan variance**
- Despite poor environment conditions, 10 sec of data observation is enough to get micro-g signal precision.
- Signal stability is guaranteed at observation time of at least up to 300 sec.

**Sensor meets performance of best navigation grade accelerometers**

**Bias instability**
- White noise + external vibration noise
- Short-term bias stability: 1 µg or 0.07 ppm of FS
Noise-transfer function

Noise-shaping pushing energy in high frequency

White noise
- 1 µg/√Hz
- Noise bandwidth: 300 Hz
- Equivalent to 18 bit resolution

This inertial sensor designed for aeronautics is also good basis for seismic monitoring applications

Noise
1 µg/√Hz
CONCLUSIONS

High performance MEMS devices are needed
- It is an enabler for high value systems; MEMS will outpace the competition from other (expensive) technologies
- The key issue is the low volume related to these applications → difficult to operate a MEMS fab efficiently considering only the in-house needs.
- The challenge is therefore to address several markets with the same platform to drive volumes

Colibrys Strategy:
- Address the world market with standard products based on two accelerometer platforms:
  - High performance devices for a wide range of applications
  - Ultra high performance for very specific applications: navigation and seismic
- Increase the volume by addressing the market with standard products for a large number of applications in the high-end market
- Custom specific products through strategic partnerships

This allows addressing the high-end low-volume MEMS market in a commercially successful way