MEMS-Sensors for Automotive Business

1. Short Overview Bosch
2. MEMS Background and Portfolio
3. Future Trends in MEMS for Automotive Business

Robert Bosch GmbH
Dr. Georg Bischopink
Vice President Engineering
Sensor Development
### Bosch 2015 Key Figures*

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bosch Group</strong></td>
<td>- 70.6 billion euros in sales</td>
</tr>
<tr>
<td></td>
<td>- 375,000 associates</td>
</tr>
<tr>
<td><strong>Mobility Solutions</strong></td>
<td>- One of the world’s largest suppliers of automotive technology</td>
</tr>
<tr>
<td><strong>Industrial Technology</strong></td>
<td>- Leading in drive and control technology, packaging, and process technology</td>
</tr>
<tr>
<td><strong>Energy and Building Technology</strong></td>
<td>- Leading manufacturer of security technology</td>
</tr>
<tr>
<td></td>
<td>- Global market leader of energy-efficient heating products and hot-water solutions</td>
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<tr>
<td><strong>Consumer Goods</strong></td>
<td>- Leading supplier of power tools and accessories</td>
</tr>
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<td></td>
<td>- Leading supplier of household appliances</td>
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*Preliminary figures as of 01.15
MEMS-Portfolio Automotive

**Acceleration sensors**
- Central/peripheral acceleration sensor for occupant protection
- Low-g acceleration sensors for VDC, RoSe and active suspension
- Low-g acceleration sensor (3-axis) for navigation and non-safety applications

**Angular rate sensors**
- Rollover sensor for occupant protection
- Yaw rate sensor for VDC
- Angular rate sensor (3-axis) for navigation and non-safety applications

**Inertial sensors**
- Combined inertial sensor (3-axis) (yaw rate and acceleration sensor) for VDC and RoSe
- Combined inertial sensor (6-axis) (yaw rate and acceleration sensor) for navigation and non-safety applications

**Pressure sensors**
- Low pressure sensor for engine control
- Mid-pressure sensor for transmission control
- Pressure sensor for occupant protection
- High pressure sensor for engine and brake systems

**Mass flow sensors**
- Mass flow sensor for engine management
# MEMS-Portfolio Consumer

## 3-axis sensors
- Accelerometer
- Gyroscope
- Magnetometer

## 6-axis sensors
- eCompass
- IMU

## 9-axis sensors
- Absolute Orientation Sensor
- Application Specific Sensor Nodes (incl. μC)

## Environmental
- Barometric Pressure Sensor
- Integrated Environmental Unit

## Microphones
- Analog and digital MEMS microphones (Akustica)
- High quality voice input for mobile devices

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**Sensor data-fusion software ties everything together**
Trend towards combi sensors reduces volume increase
Top 10 MEMS Suppliers (2015)

Bosch by far world’s largest MEMS supplier

Top 10 MEMS manufacturers by revenue, in millions of US dollars - foundry sales not included
Source: IHS MEMS Competitive Analysis 2015 – Preliminary results
Bosch by far world’s largest MEMS automotive supplier
### SMI7: Inertial Sensor Platform

<table>
<thead>
<tr>
<th>Spec</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Cruise Control</td>
<td>SMI700 BGA7x7</td>
</tr>
<tr>
<td>Active Front steering</td>
<td></td>
</tr>
<tr>
<td>Roll-Stability Control</td>
<td>SMI710 BGA7x7</td>
</tr>
<tr>
<td>Active Damping</td>
<td></td>
</tr>
<tr>
<td>Rollover Sensing</td>
<td>SMI720 BGA7x7</td>
</tr>
</tbody>
</table>

#### Customer benefit / features:
- Three-axis $\Omega_z a_{xy}$ combined rotation and acceleration inertial sensor
- Designed for ESP® and premium VDC functions
- Three communication interfaces available: SPI, PSI5, and CAN
- Excellent stability over temperature and lifetime
- Standard SMD package: BGA 7x7 x 1.5 mm³
- RoHS compliant
- Superior signal performance and implemented self-tests
- Applicable in systems up to ASIL D requirements
- Fully digital signal processing
- On-chip self-monitoring based on Bosch VDC component experience
- 16-bit digital output via serial peripheral interface (SPI)
- Two SPI versions with in-frame or out-of-frame communication selectable
## Specification SMI700

<table>
<thead>
<tr>
<th><strong>Target Specification</strong></th>
<th><strong>Target Application</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional parameters</strong></td>
<td><strong>Premium active safety systems</strong></td>
</tr>
<tr>
<td>Measurement axis</td>
<td>( \Omega z )</td>
</tr>
<tr>
<td>Measurement range</td>
<td>+/- 300 °/s</td>
</tr>
<tr>
<td>Sensitivity (nominal)</td>
<td>100 LSB / °/s</td>
</tr>
<tr>
<td>Sensitivity variation</td>
<td>+/- 3%</td>
</tr>
<tr>
<td>Offset variation</td>
<td>+/- 3 °/s</td>
</tr>
<tr>
<td>Noise (rms) @ 60Hz</td>
<td>0.2 °/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Operating conditions</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>3.3 V, 5 V</td>
</tr>
<tr>
<td>Supply current</td>
<td>max. 27 mA</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-40°.....125 °C</td>
</tr>
<tr>
<td>Start up time</td>
<td>max. 350 ms</td>
</tr>
<tr>
<td>( f_{-3dB} ) (rate channel)</td>
<td>11.2 Hz, 18 Hz, 20.6 Hz, and 77.5 Hz</td>
</tr>
<tr>
<td>Package</td>
<td>BGA 7 x 7 x 1.5 mm³</td>
</tr>
<tr>
<td>ISO26262</td>
<td>ASIL D</td>
</tr>
</tbody>
</table>
The Precision of Yaw Rate Sensors

Device sensitivity
- mechanical sensitivity: 
  \[ S_m \approx 5.2 \text{ pm} / (°/s) \]
- electrical sensitivity: 
  \[ S_e \approx 2.3 \times 10^{-18} \text{ F} / (°/s) \]

Resolution limit 
- amplitude change \( \approx 4 \times 10^{-15} \text{ m} \)
  (compares to \( \approx 0.00001 \times \text{Si-Si distance} \) or \( \approx \text{radius of atomic nucleus} \))
- capacitance change \( \approx 2 \times 10^{-21} \text{ F} \)
  (compares to charge variation of \( \approx 0.06 \text{ electrons (at 5V)} \))
The Idea behind Mobility Sensors

Consumer
- e.g. mobile
- no safety relevance
- short product availability

Automotive
- e.g. ESP
- safety-critical
- long product availability

SMx130
- non-safety
- automotive applications

- AEC-Q100 qualification
- Product availability > 10 years
- Increased testing scope
- Limited quality and change management

Cost efficient compared to sensors optimized for functional safety
Applications for Mobility Sensors

- Car Key Module
- Telematics
- Navigation
- Toll Collection
- Bank Angle
- Inclination Measurement
- Vehicle Dynamics Data Logging
- Platform Stabilization
- eCall
- Car Alarm

Overview of applications will follow!!!
Applications for Micromirrors

Consumer
- Embedded projection
- Interactive projection
- Gesture recognition
- CE-LIDAR

Emerging automotive applications
- Head lamps
- Head up displays
- Long range LIDAR
- Short range LIDAR
µ-Mirror for LIDAR

Wafer-Level-Packaging (WLP)
Application headlight or other
(interior sensing, seat occupation, ...)
Advantages / “USP”

- Hermetical tightness already during MEMS Process
- Perfect Protection against humidity and dust during assembly and in use (mirror moves at very high speed, >210 mph)
- Antireflective coating minimizes optical loss of the glass window
- Tilted glass window to further minimize reflections
μ-Mirror for Laser-based Headlight

MEMS μ-mirror  Headlight lenses

Sample picture: Audi

Intensity [a.u.]
Deflection angle [°]

-16 -12 -8 -4 0 +4 +8 +12 +16

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μ-Mirror SMO150 for Headlight

General properties MEMS

- Magnetic drive
- Scan frequencies up to 200 Hz
- Optimisation for 450 ± 10 nm
- Hermetically sealed
- Robust

Packaging concept

- Aluminium-base with handling-/alignment mark
- Additional marks on μ-Mirror
- Electrical Contact of (separate) driver electronics via Flex-PCB
- Magnet with flux concentrator on backside of MEMS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (preliminary)</th>
</tr>
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<tbody>
<tr>
<td>Mirror area</td>
<td>1.5 x 5 mm²</td>
</tr>
<tr>
<td>Optical area</td>
<td>0.81* 4.36 mm²</td>
</tr>
<tr>
<td>Mechanical angle</td>
<td>± 6°</td>
</tr>
<tr>
<td>Reflectivity mirror</td>
<td>&gt; 99% @ 440nm – 460nm</td>
</tr>
<tr>
<td>Reflectivity window</td>
<td>&lt; 0.5% @ 440nm – 460nm</td>
</tr>
<tr>
<td>Tilt angle window</td>
<td>9°</td>
</tr>
</tbody>
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Elongated mirror with flexible contacting
Enhanced flexibility for system design and package
Rail Road Tracker

**Features**
- localization & geo-fencing,
- record of mileage data,
- monitoring of temperature of transported freight,
- misuse detection,
- 6 years self-sustaining

**MEMS Sensor**
- 3D acceleration,
- 3D Hall, temperature

**Interfaces**
- Bluetooth LE, GPS,
- GSM (data to cloud),
- hub for peripheral sensors

**External customers**
- SBB Cargo
- hvle
- DB Schenker
- Stahlberg Roensch
- A GL
- Wascosa
- Rail Cargo Austria

**AMRA: Asset Monitoring for Rail Applications**

**Automotive Electronics**
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Transport Condition Monitoring

Vision: End to End Condition Monitoring

- Localization over GPS
- Localization and Condition data
- SensorCloud
- RFID gate
- TraQ-Sensor
- TraQ Gateway
- KLT
- KLT
- KLT
- INST
- SensorCloud
- Gateways

Result

Sensors

- Acceleration
- Temperature
- Humidity
- Light

Decision

- Mechanical shock ➔ Parts rejection
- Excessive humidity ➔ Parts to drying stock
- Opened box (light) ➔ Detection of theft