Motion Sensors for Vehicle Dynamics
Safety and Comfort due to enhanced functionality

Vehicle Dynamics Expo – Stuttgart - 2008-05-06
Jens Thurau – VTI Technologies OY
VTI – a Finnish company
• Headquarter and Development in Finland
• MEMS-Production in Finland
• Packaging in Finland and Mexico
• Approx. 80M€ net sales with 700 employees

Sensor elements, components and sensing solutions:
• Acceleration
• Inclination
• Pressure
#1 in high accuracy low-g accelerometers
- Automotive -> ESC / ABS / suspension
- Medical -> Cardiac Rhythm Management (CRM)

3D-MEMS technology
- Most robust MEMS architecture
- Advanced sensing applications
- Own design and production
Low g Accelerometers in a Vehicle

Other applications:
- Engine Vibration Compensation
- Driver Assist-Lane Departure
- Active Suspension Control
- Adaptive Cruise Control
- Navigation/Telematics
- Heart beat detection
- Vehicle Security
- Leveling

Axis: Vertical
Application: Rollover, ECS
Range: 4.0g to 12g

Axis: Longitudinal
Application: EPB, Hill-Hold, 4x4 ABS
Range: 20% Inclination = 0.2g to 1.5g

Axis: Lateral
Application: ESC
Range: 1.5g to 2.0g
Sensors for Electronic Controlled Suspension

**Vertical Control Key Functions:**
- Keep the car body stable
- Understand the system input (wheel movement)

**Vertical Body Movement:**
3 x low-g acceleration sensor:
-1g ... (+1g offset) ... +3g
\( f_{\text{max}} > 100\text{Hz} \)

**Vertical Wheel Movement:**
4 x mid-g acceleration sensor:
-12g ... (+1g offset) ... +14g

... or:
- 4 x hall potentiometer as wheel height sensor
- 2 axis gyro sensor high performance

Distributed modules sensor fusion difficult
Sensors for Electronic Stability Control & Co.

Horizontal Control Key functions:
- ESC basic function at minimum
- Roll Stability, Hill Holder & other Lateral Vehicle Dynamic functions

ESC minimum:
Lateral low-g acceleration sensor
Vertical axis gyroscope

Hill-Holder-Function:
Low-g accelerometer with excellent offset stability
same axis as 4x4 ABS

Complexity & Flexibility
in measurement requirements:
different accuracies & ranges

Vehicle Dynamics & Roll Stability
+ Use of existing sensors
Various concepts
Trends in ESC System Integration

- Complex integration -> specification enhancements
- Accurate measurement in vibrating environment
- Combined Airbag ECU/ESC or ABS/ESC
- High-end solutions with 6 degree of freedom (IMU-like solutions)

Photos courtesy of Continental Teves, Autoliv and TRW.
Automotive Digital Platform

1 Housing for all requirements
Product Concept

- Sensing element
- Metal lid
- Premolded DFL housing
- Digital ASIC
- Premolded DFL housing
MEMS heart
acceleration sensing elements
3D-MEMS Sensing Element Tool Box

- Silicon KOH wet etching
- Glass Wafer Structuring
- Bulk DRIE Etching
- KOH Spring Forming
- Glass Anodic Bonding
- Metal/Coating Surfaces
- Glass Vertical Contacts
- SOI Middle Wafer
3D-MEMS Accelerometers

Bulk mass structure with 300\(\mu\)m material thickness = big mass

Direct mechanical damping of MEMS structure due to inert gas

\[ F = m \cdot a \]
Sensing Elements

Single Axis (X or Y)
SCA810 / SCA830

Single Axis (Z)
SCA820

Multi Axis (XY or XYZ)
SCA2100 / SCA3100

single mass deflection

4 mass deflection
Function of 3-axis sensing element
Principle of Operation Multi Axis
Principle of Operation
Multi Axis
X acceleration

Click the picture to start the animation.
Y acceleration

Click the picture to start the animation.
Z acceleration

Click the picture to start the animation.
X and Y acceleration

Click the picture to start the animation.
X, Y and Z acceleration

Click the picture to start the animation.
Multi Axis Signal Conditioning

\[
\begin{pmatrix}
X \\
Y \\
Z \\
d
\end{pmatrix}
= 
\begin{pmatrix}
g_{11} & g_{12} & g_{13} & g_{14} \\
g_{21} & g_{22} & g_{23} & g_{24} \\
g_{31} & g_{32} & g_{33} & g_{34} \\
g_{41} & g_{42} & g_{43} & g_{44} \\
\end{pmatrix}
\times
\begin{pmatrix}
a_1 \\
a_2 \\
a_3 \\
a_4
\end{pmatrix}
\]

\(X, Y, Z\) measurement vectors
\(d = \text{diagnostics} = \text{continuous self test}\)
\(a_x = \text{acceleration vector input}\)
\(g_{xx} = \text{gain factors}\)
Fail Safe Features

"Self Diagnostics"
Digital Accelerometer Fail Safe Features

<table>
<thead>
<tr>
<th>ASIC &amp; communication</th>
<th>SCA8x0</th>
<th>SCA21x0</th>
<th>SCA31x0</th>
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<tr>
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<tr>
<th>MEMS integrity</th>
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<tr>
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<tr>
<td>Continuous self test</td>
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<td>SAT saturation warning</td>
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<td>✔️</td>
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</table>
3-axis acceleration vector addition

\[ + \hat{\mathbf{a}}_1 + \hat{\mathbf{a}}_2 - \hat{\mathbf{a}}_3 - \hat{\mathbf{a}}_4 \equiv 0 \]

Continuous Self Test \equiv \text{o.k.}
Additional self-tests – 3-axis

Start-up test / Static test (STS)

Sensor checks on SPI request that the resultant is 1g static acceleration.

\[ \text{STS} (a_x, a_y, a_z) = \]
\[ a_x^2 + a_y^2 + a_z^2 \equiv 1^2 \]
\[ = \text{earth gravity} \]

SAT saturation warning
In case that the acceleration input signal is outside the defined protocol the sensors sets a SAT flag in order to warn that the given value is higher than the SPI output can display.
Challenges in Application
Combination ESC and Rollover

♦ Longitudinal: Hill Holder Functions require excellent, stable signal
e.g. 30mg offset stability / 0.5g data range
♦ Lateral: Electronic Stability Control
e.g. 100mg offset stability / 2.0g data range
♦ Vertical: Rollover
e.g. 5g
♦ Solution:

\[ Y = 1.50g \]  
\[ X = 0.75g \]  
\[ Z = 6.00g \]
Harsh environment

♦ ABS hydraulic unit with intensive vibration
  ♦ Hydraulic valve actuation
  ♦ Hydraulic block movement on rough road

♦ Sensing element with
  ♦ inert gas damping
  ♦ mechanical overhead

♦ Excellent performance even during vibration

♦ Lifetime tests passed!
  (automotive standard and applicational)
ADP products in 1 housing

<table>
<thead>
<tr>
<th></th>
<th>ESC (+/- 2g)</th>
<th>ESC +more (+/- 6g)</th>
<th>inclination</th>
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<tr>
<td></td>
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<tr>
<td>3-axis</td>
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<tr>
<td></td>
<td>Standard</td>
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</table>

X: available versions / O: potential versions on demand / -: version not planned
Thank you!