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)

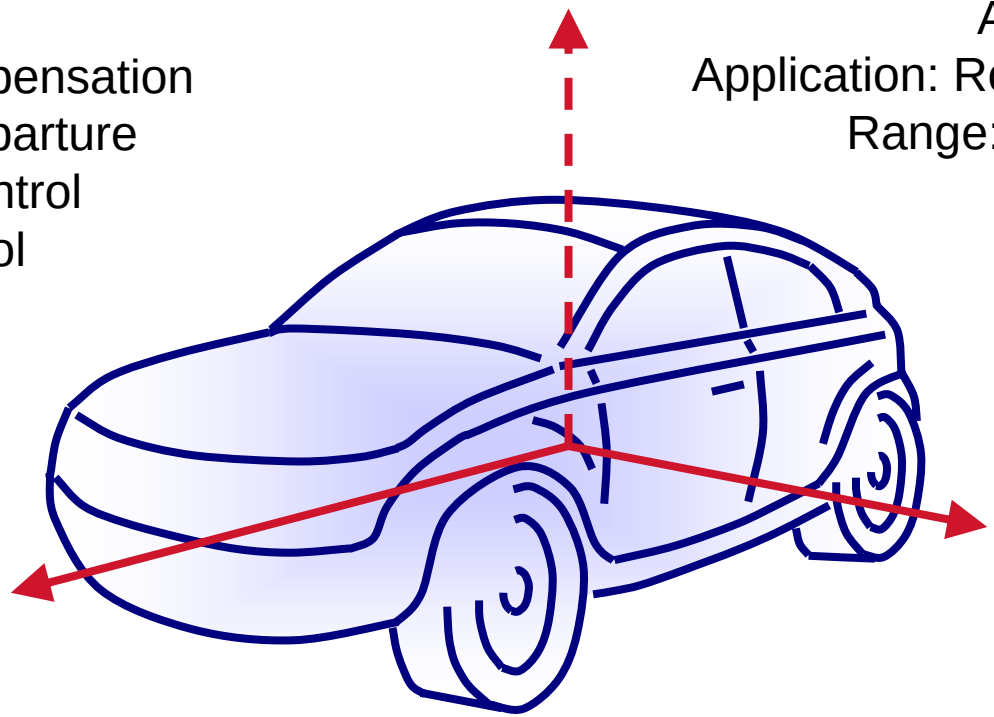
3D-MEMS technology

- 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

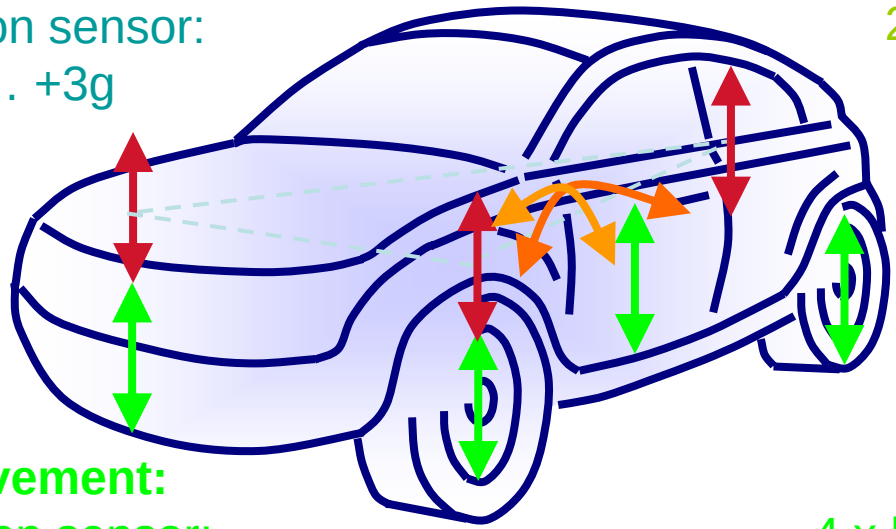
Vertical Control Key Functions:

- Keep the car body stable
- Understand the system input (wheel movement)

Distributed modules
sensor fusion difficult

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

… or:
2 axis gyro sensor
high performance



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

… or:
4 x hall potentiometer
as wheel height sensor

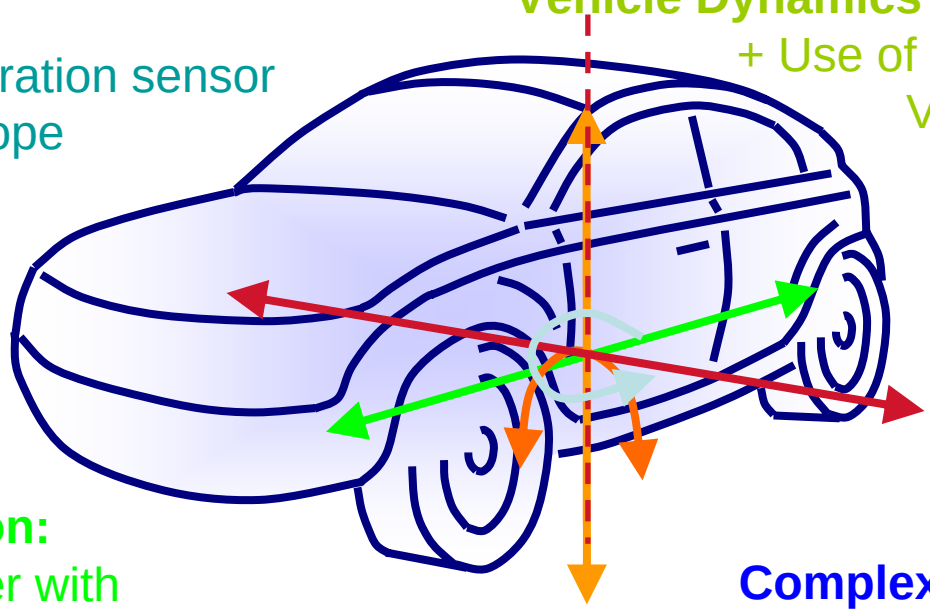
Sensors for Electronic Stability Control & Co.

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

Vehicle Dynamics & Roll Stability
+ Use of existing sensors
Various concepts



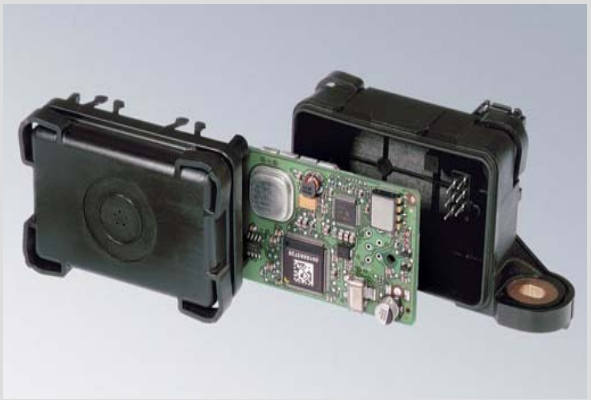
Hill-Holder-Function:
Low-g accelerometer with
excellent offset stability
same axis as 4x4 ABS

Complexity & Flexibility
in measurement requirements:
different accuracies & ranges

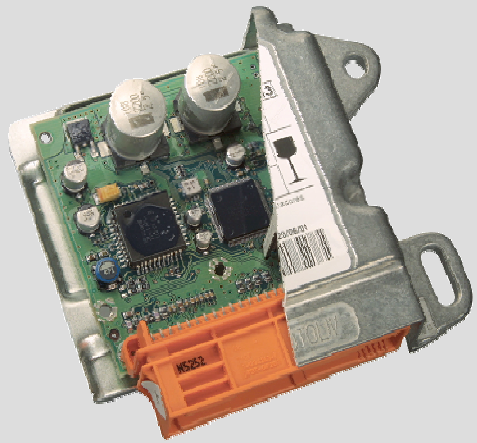
Trends in ESC System Integration

- 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)

ESC Sensor Cluster / IMU



Integrated Chassis Controller Airbag Controller Integration



Integration in ABS Hydraulic Electronic

Photos courtesy of Continental Teves, Autoliv and TRW.

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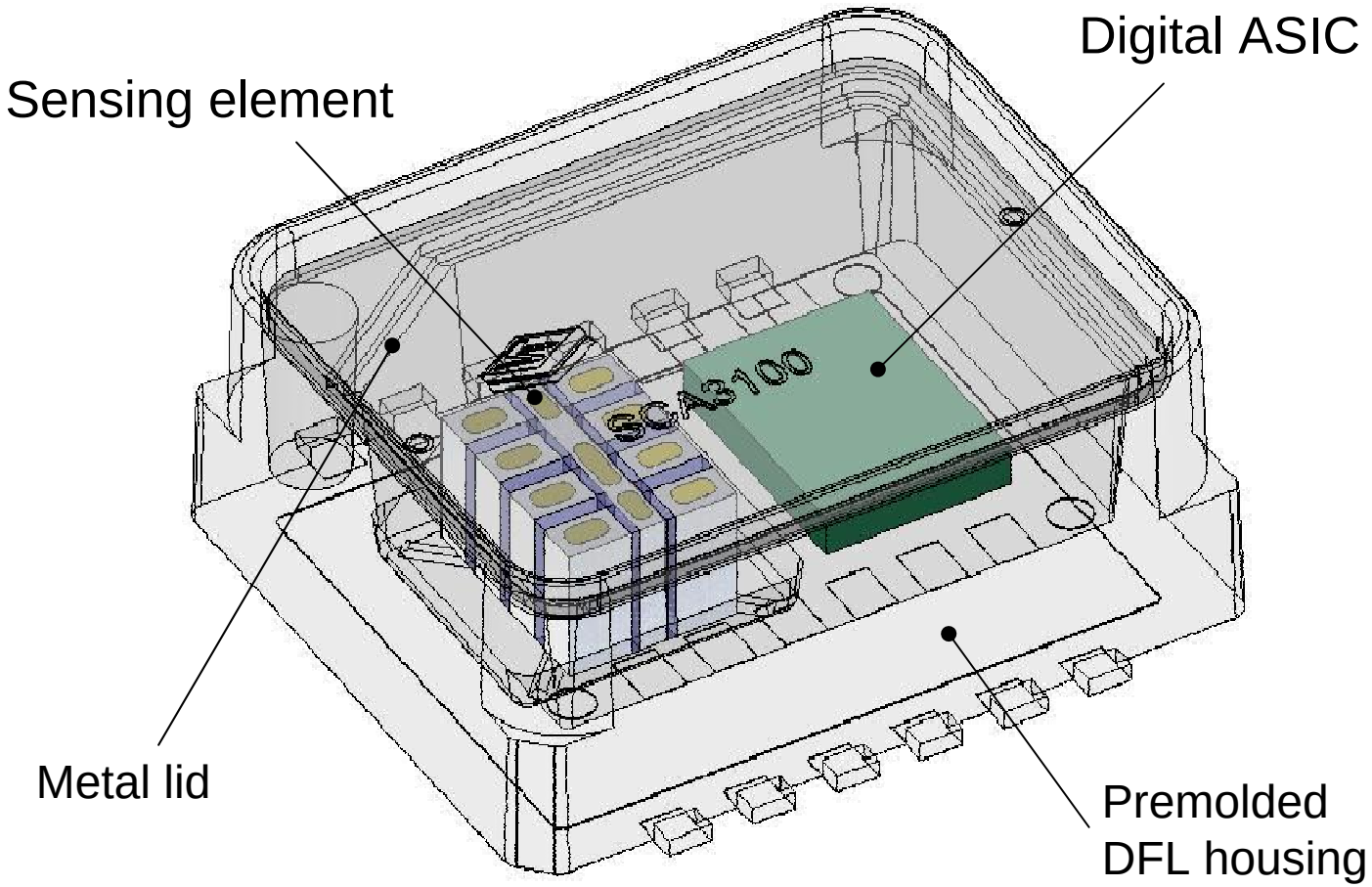
Automotive Digital Platform

1 Housing for all requirements

Product Concept



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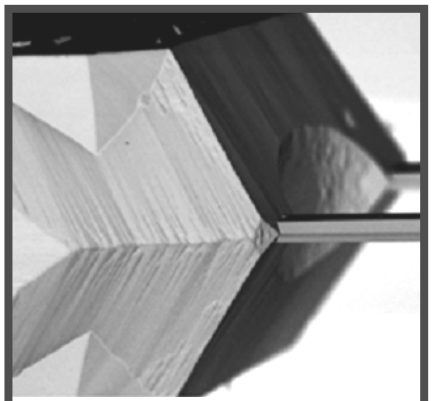
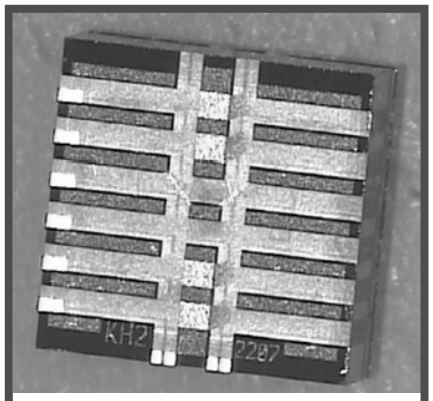
MEMS heart

acceleration sensing elements

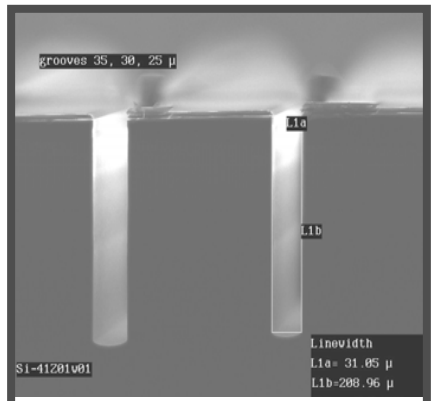
3D-MEMS Sensing Element Tool Box



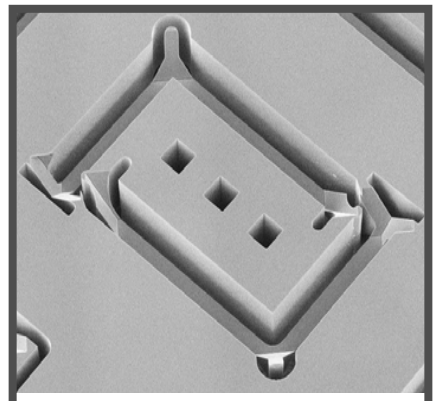
Silicon
KOH wet etching



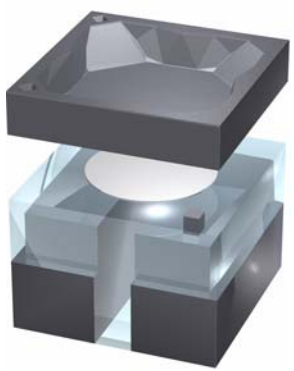
Glass
Wafer Structuring



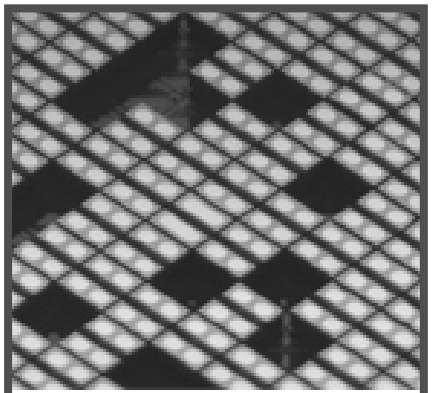
Bulk DRIE
Etching



KOH
Spring Forming

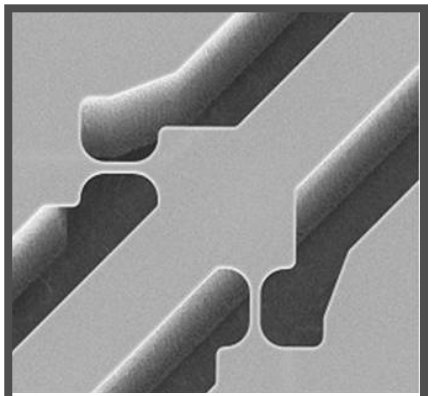


Glass
Anodic Bonding



Metal/Coating
Surfaces

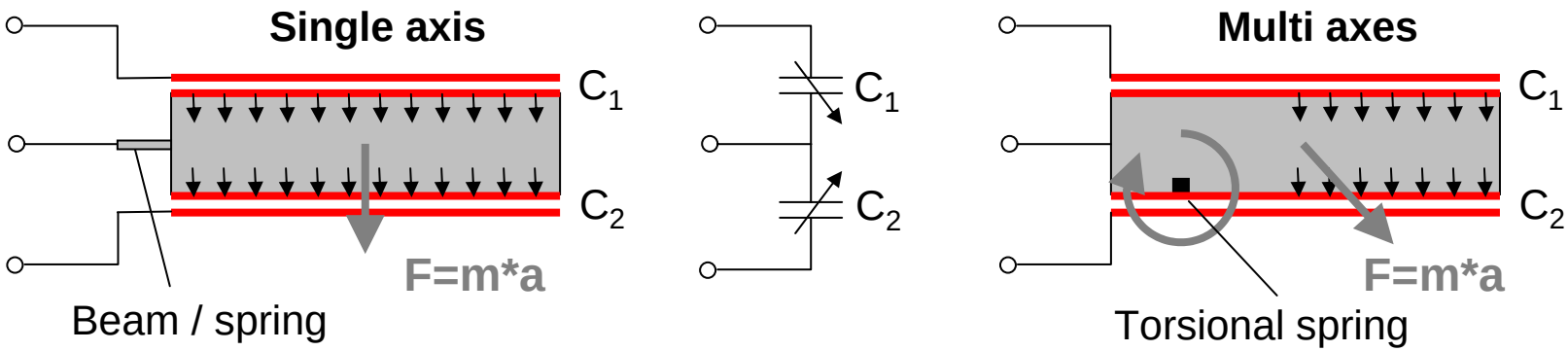
Glass
Vertical Contacts



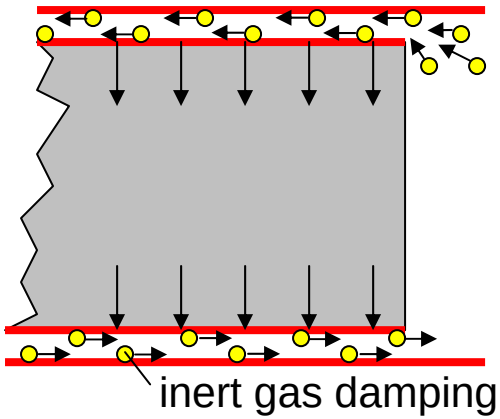
SOI
Middle Wafer

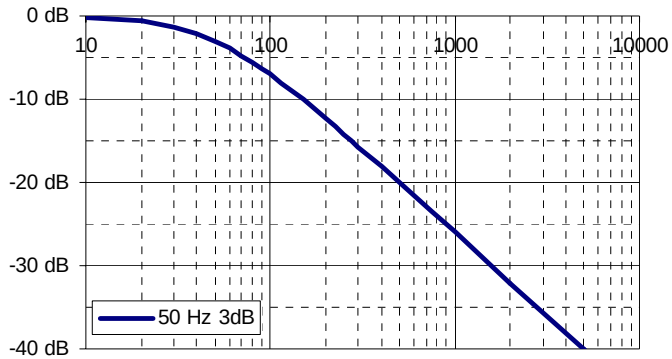
3D-MEMS Accelerometers

Bulk mass structure with 300µm material thickness = big mass



Direct mechanical damping of MEMS structure due to inert gas



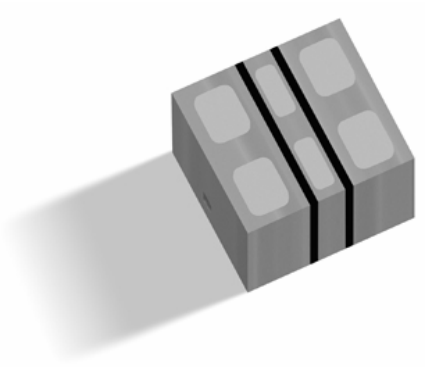


at ~10Hz … (product specific)

Sensing Elements

Single Axis (X or Y)

SCA810 / SCA830



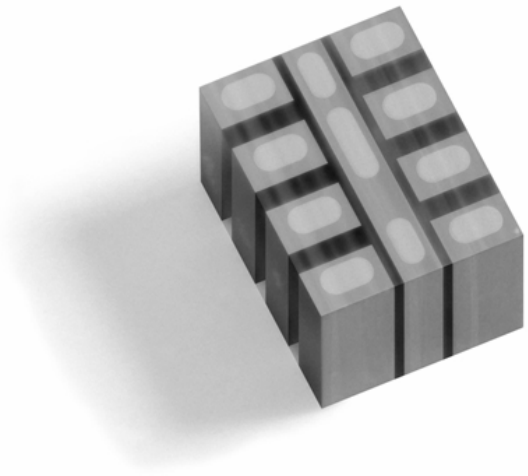
single mass deflection

Single Axis (Z)

SCA820

Multi Axis (XY or XYZ)

SCA2100 / SCA3100



4 mass deflection

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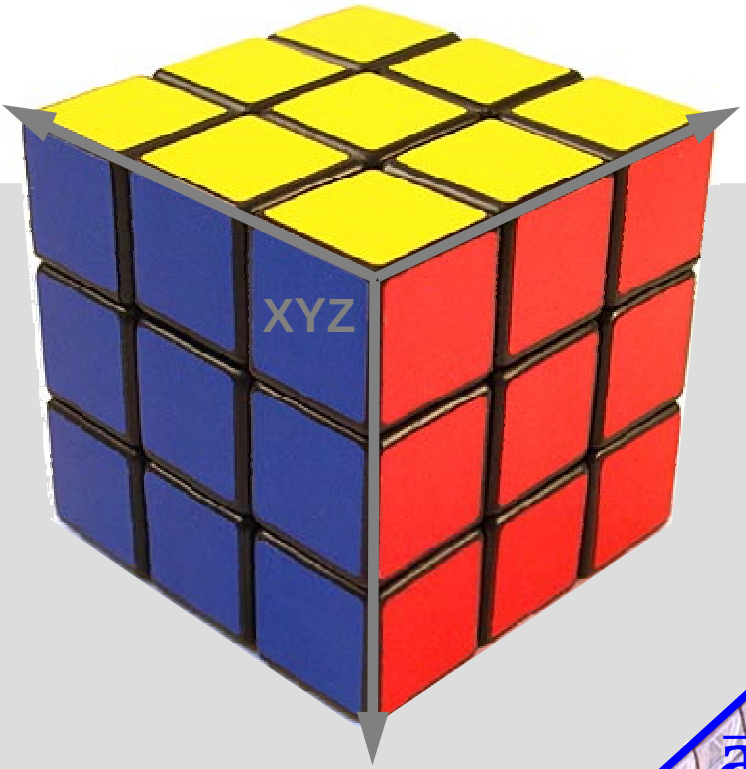
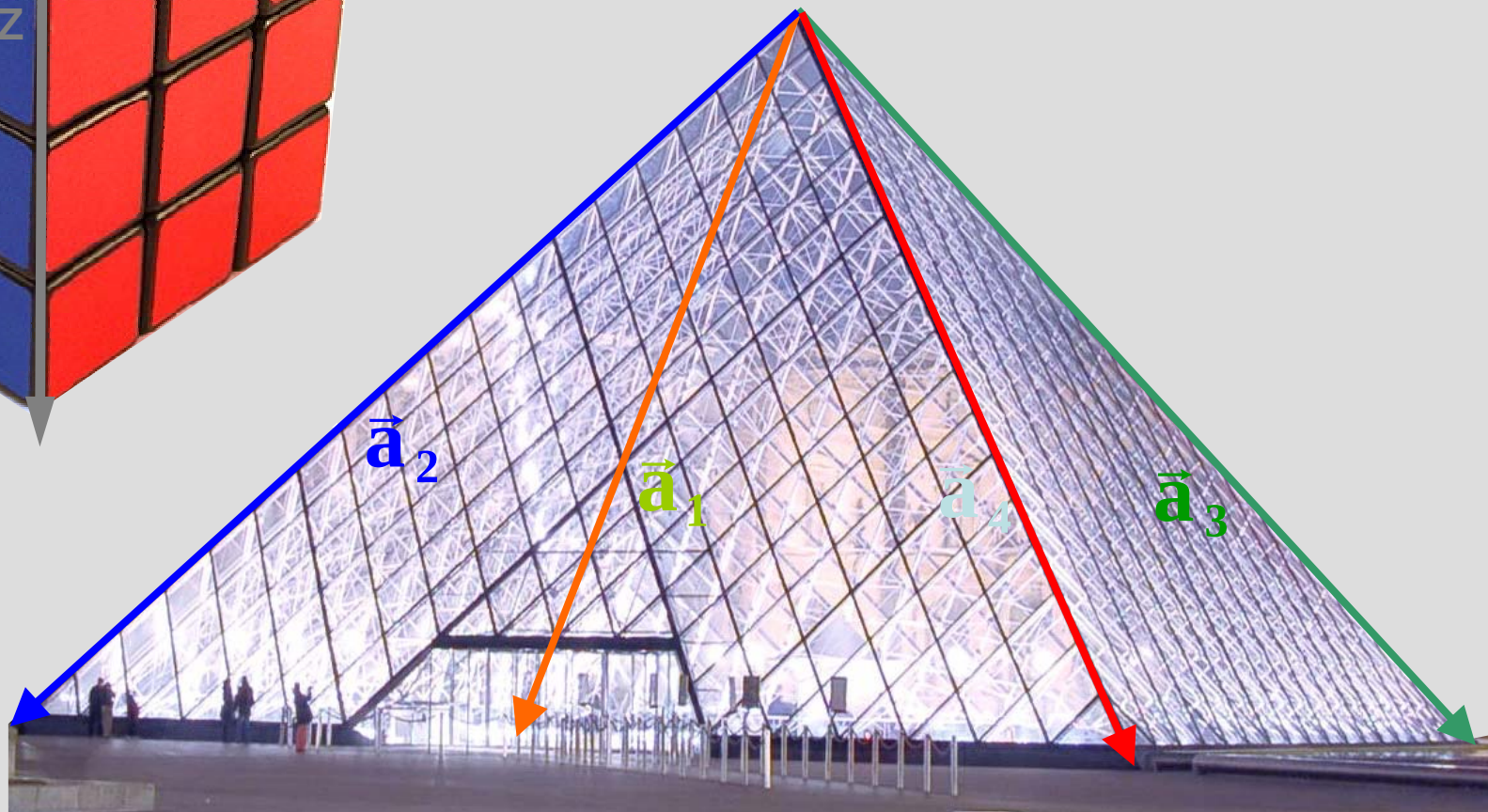
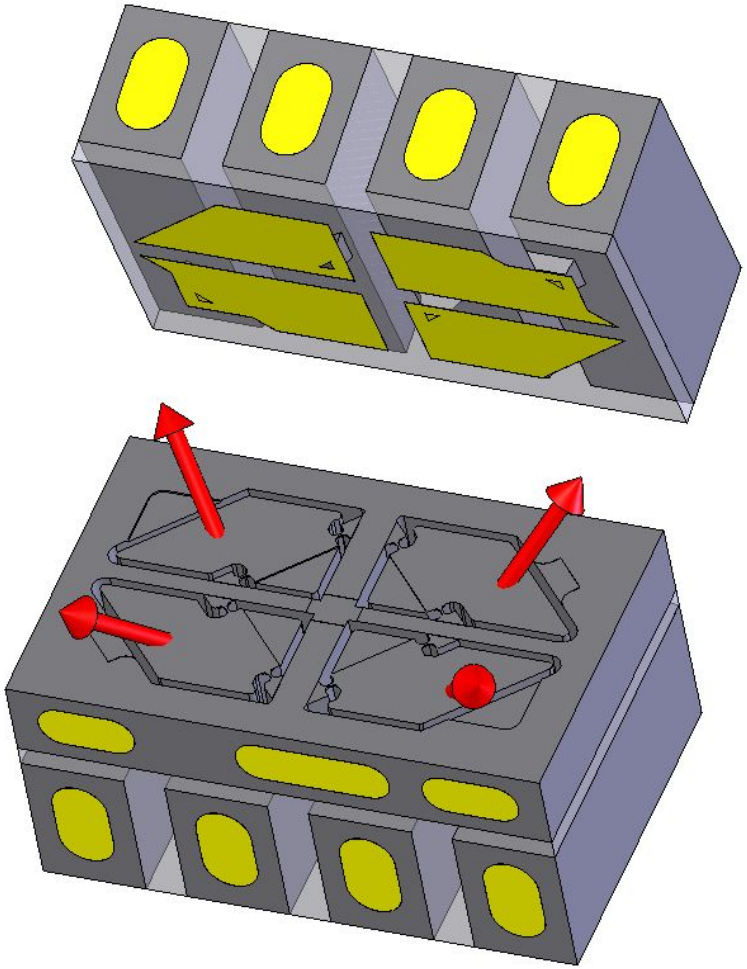
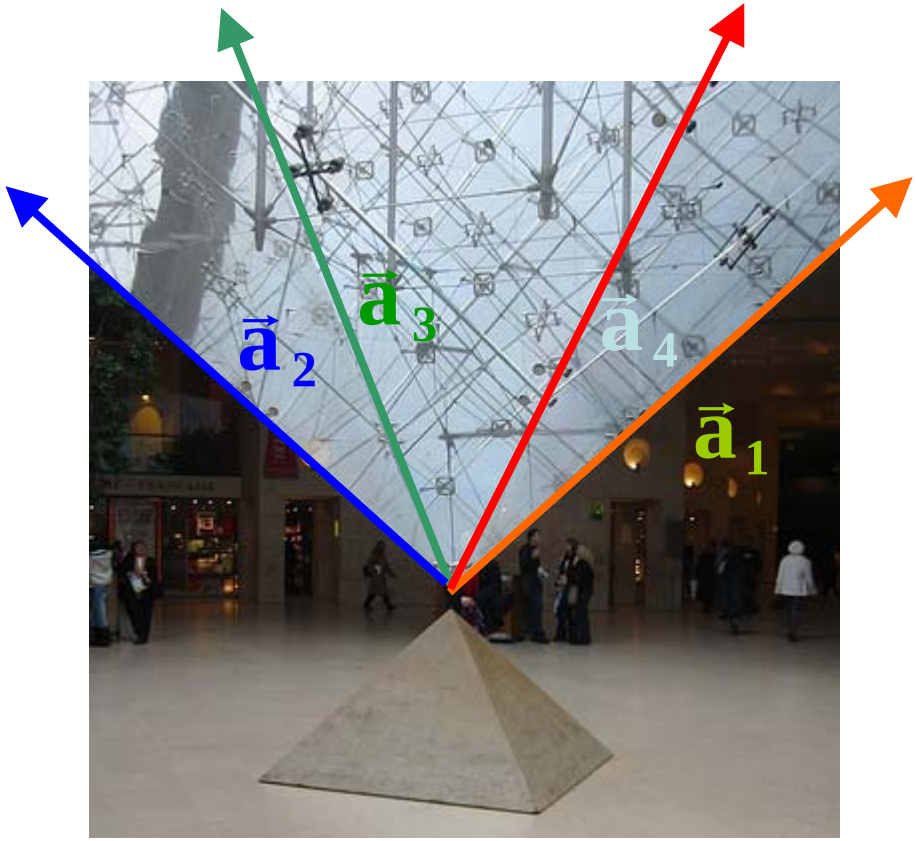
Function of 3-axis sensing element



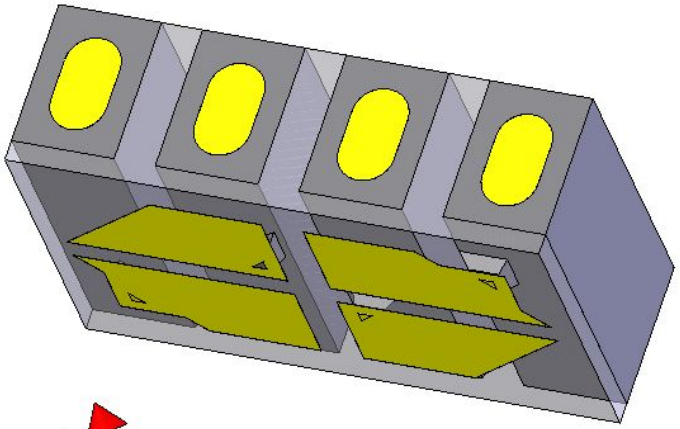


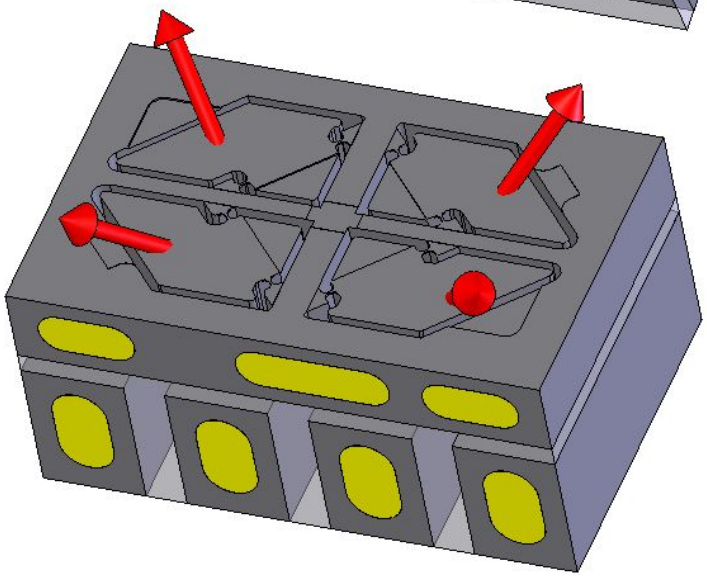
Principle of Operation Multi Axis

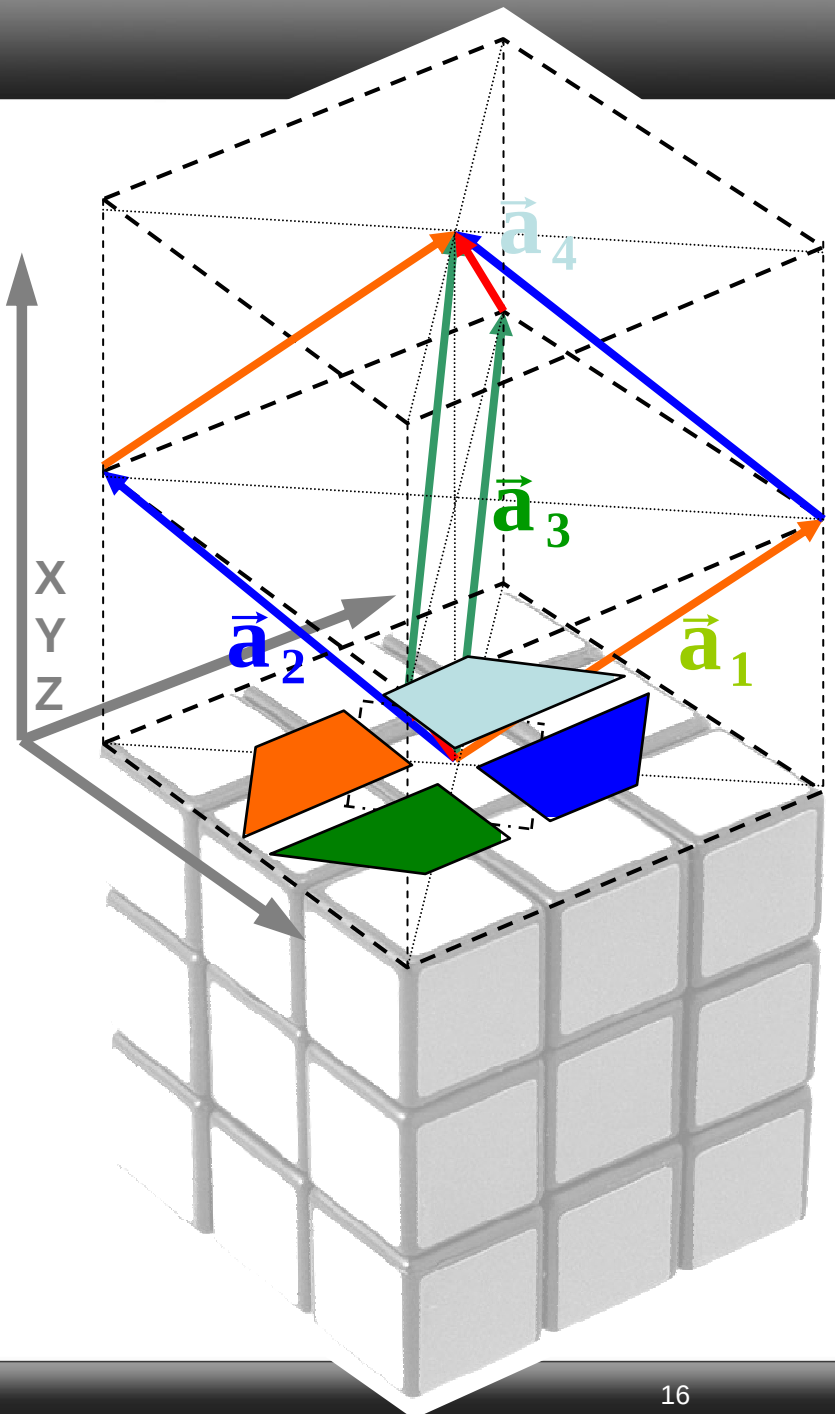




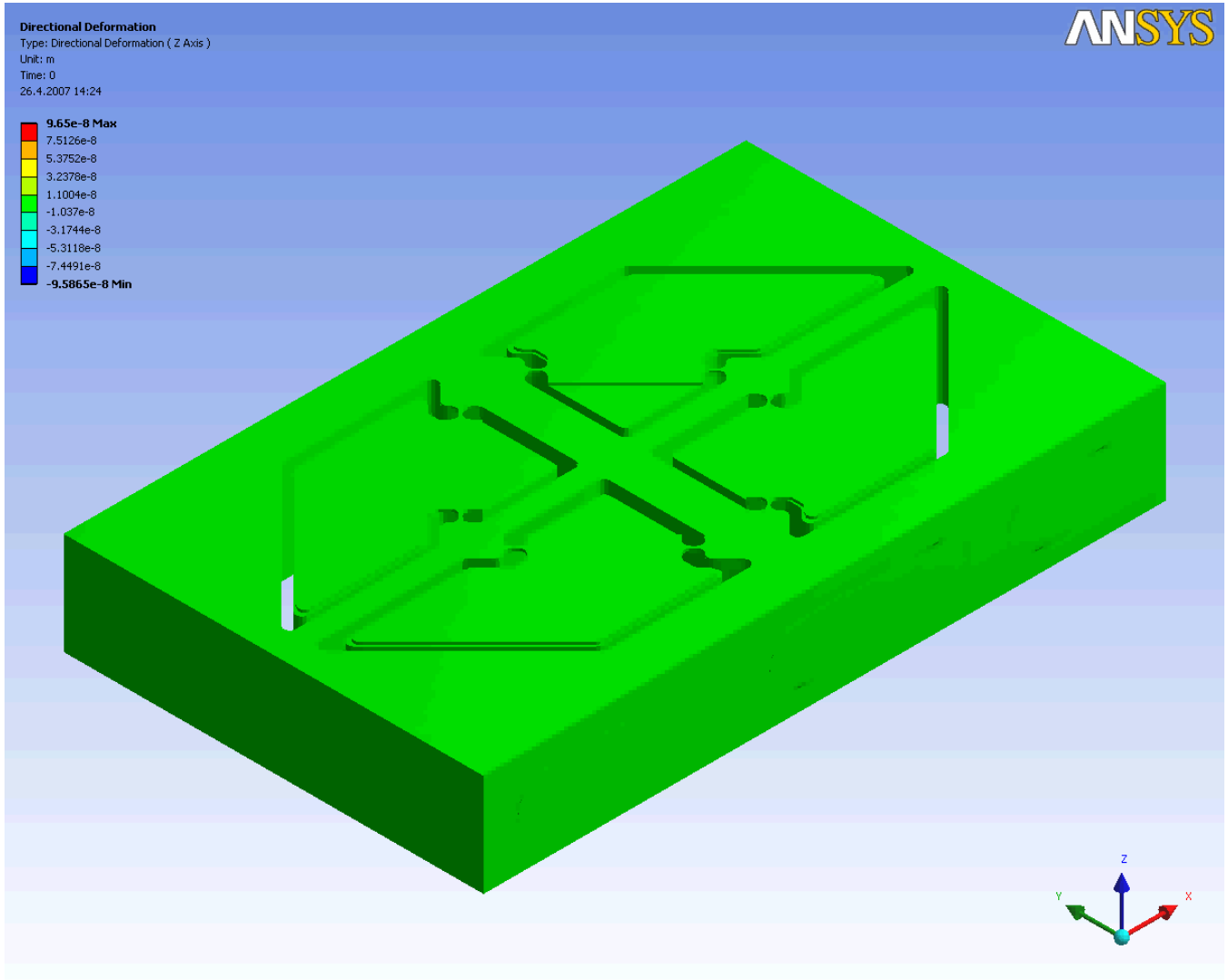
Principle of Operation Multi Axis





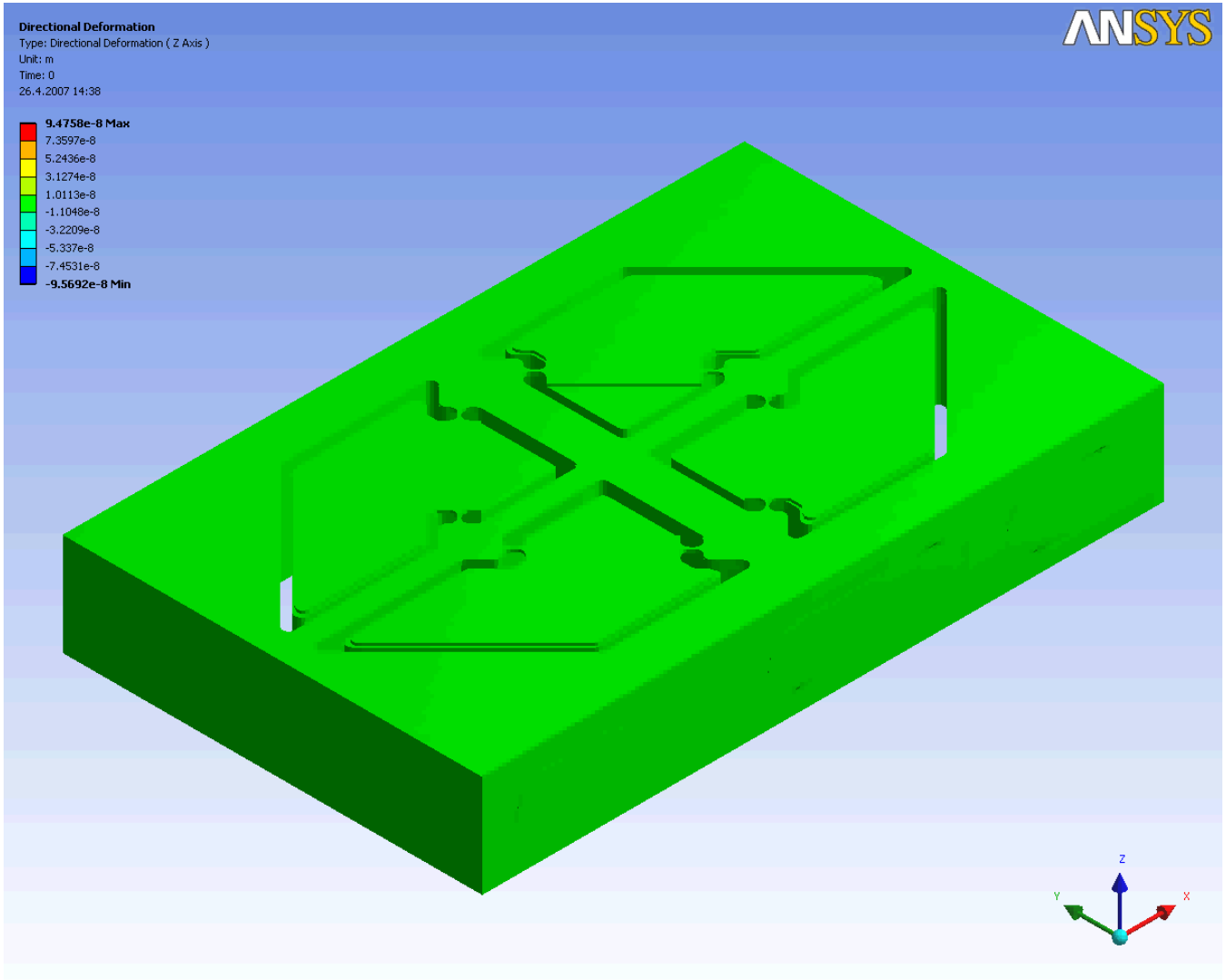


X acceleration



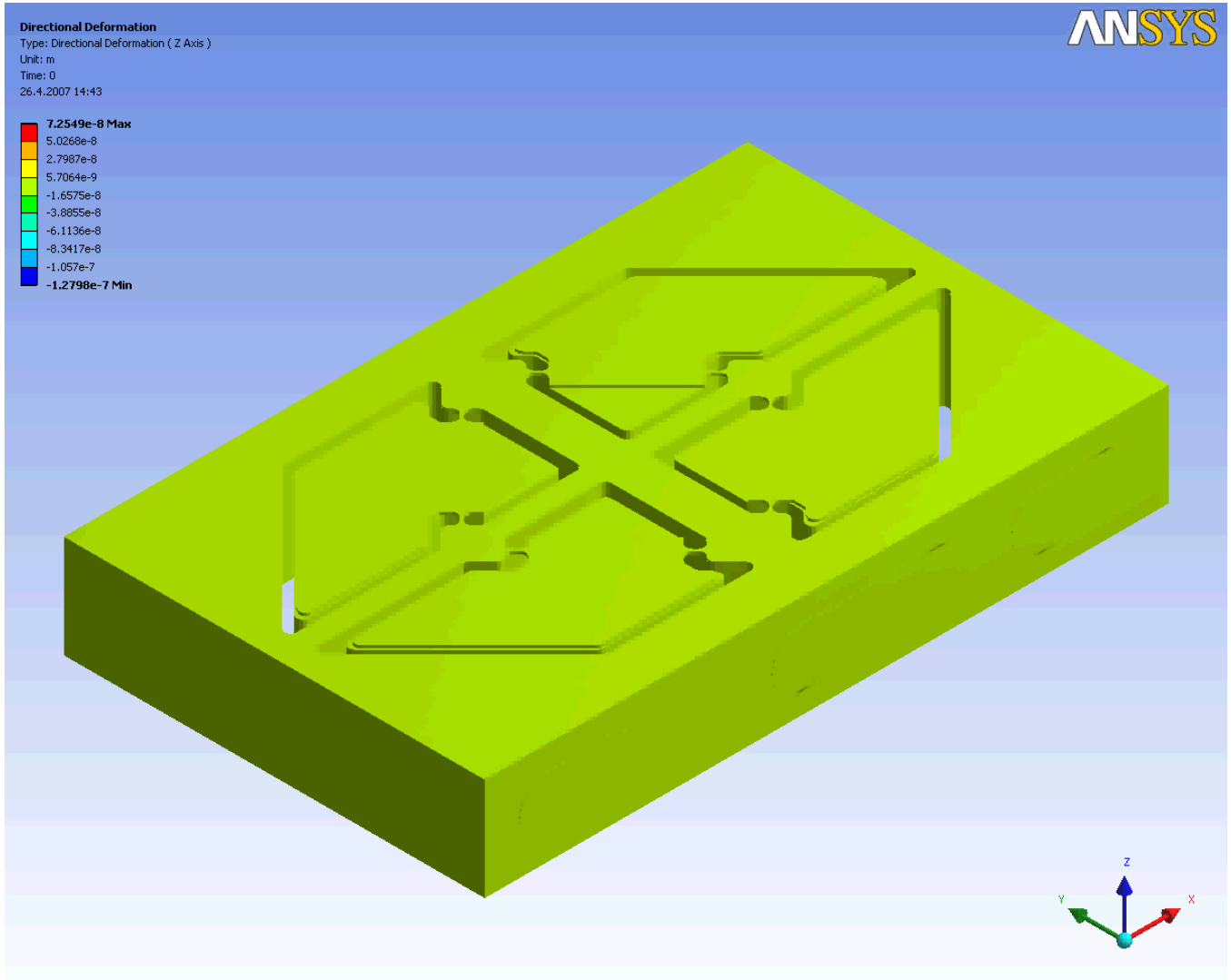
Click the picture to start the animation.

Y acceleration



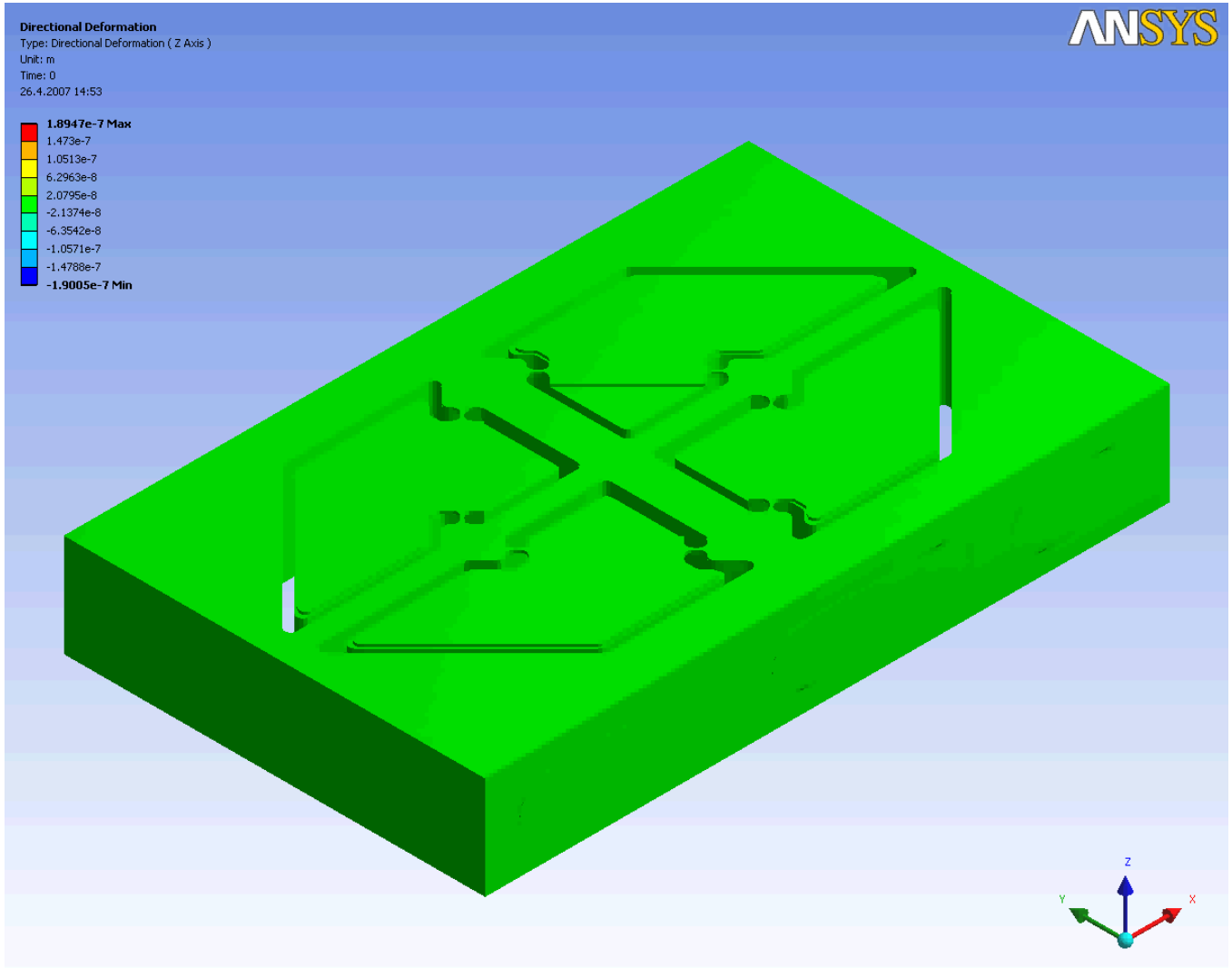
Click the picture to start the animation.

Z acceleration



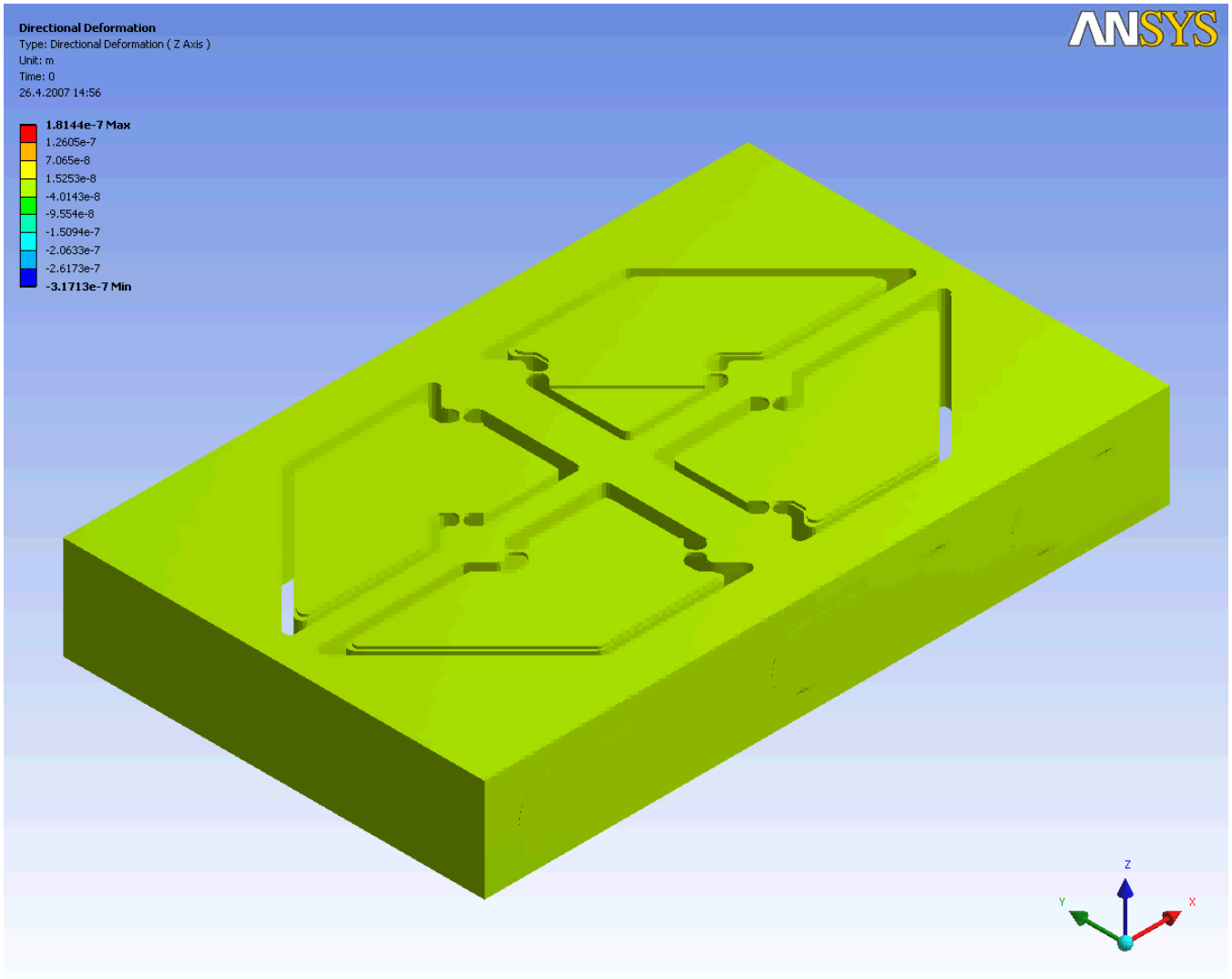
Click the picture to start the animation.

X and Y acceleration



Click the picture to start the animation.

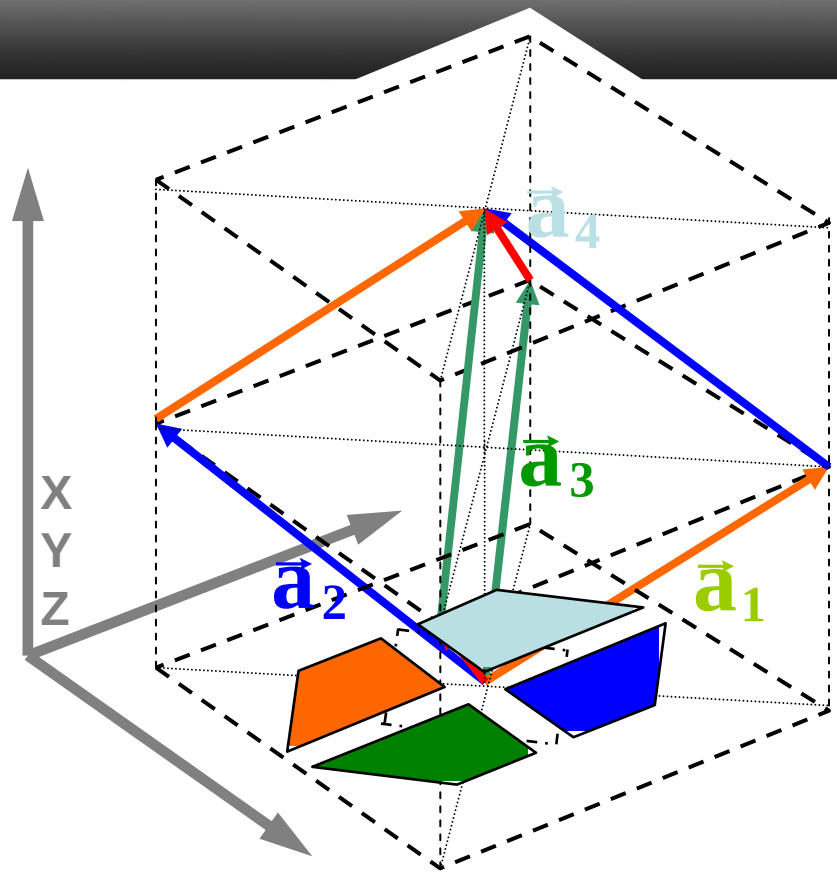
X, Y and Z acceleration



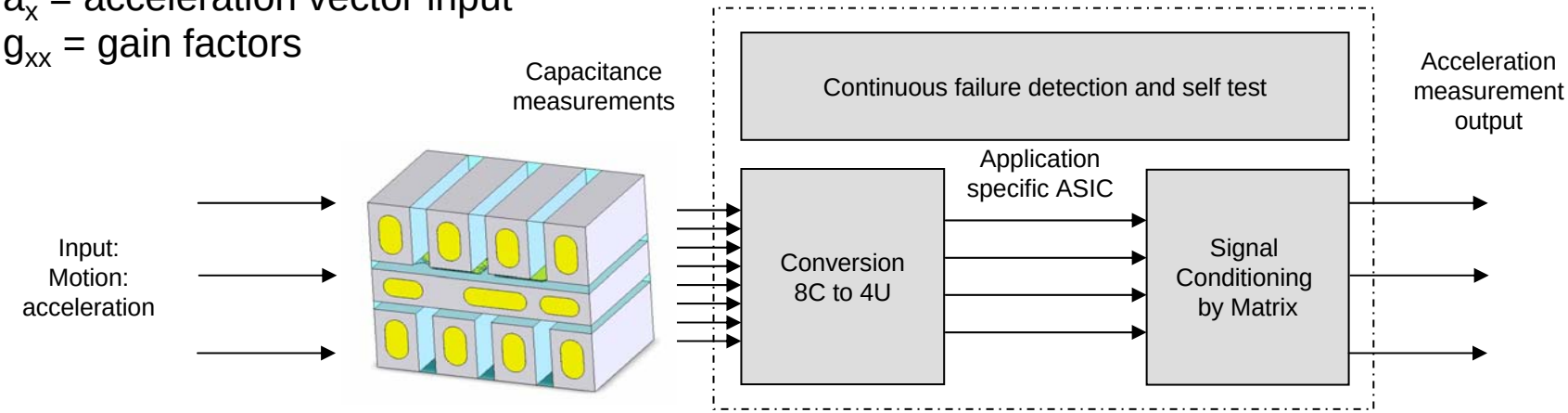
Click the picture to start the animation.

Multi Axis Signal Conditioning

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



X, Y, Z measurement vectors
d = diagnostics = continuous self test
a_x = acceleration vector input
g_{xx} = gain factors



VTI TECHNOLOGIES

Fail Safe Features

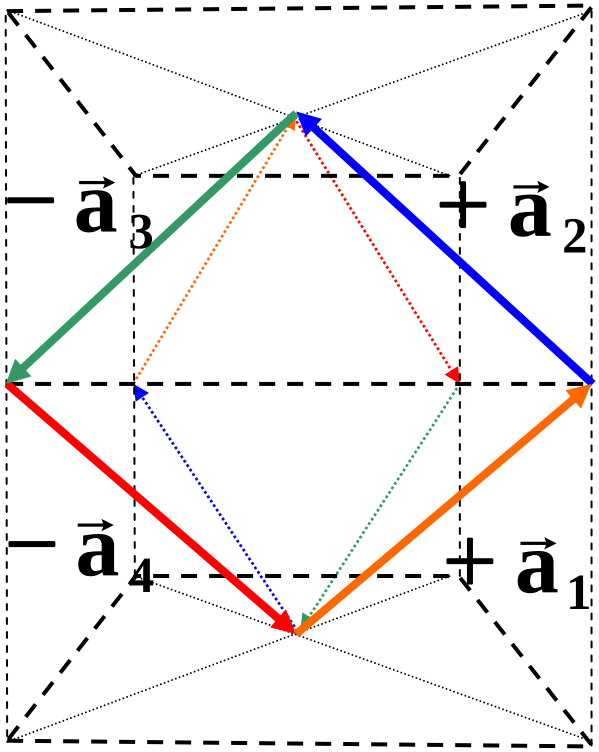
"Self Diagnostics"

Digital Accelerometer Fail Safe Features

ASIC & communication	SCA8x0	SCA21x0	SCA31x0
Memory self test	✔	✔	✔
Under voltage detection	✔	✔	✔
Parity bits	✔	✔	✔
SPI Frame error	✔	✔	✔
SPI Frame fixed bits	✔	✔	✔

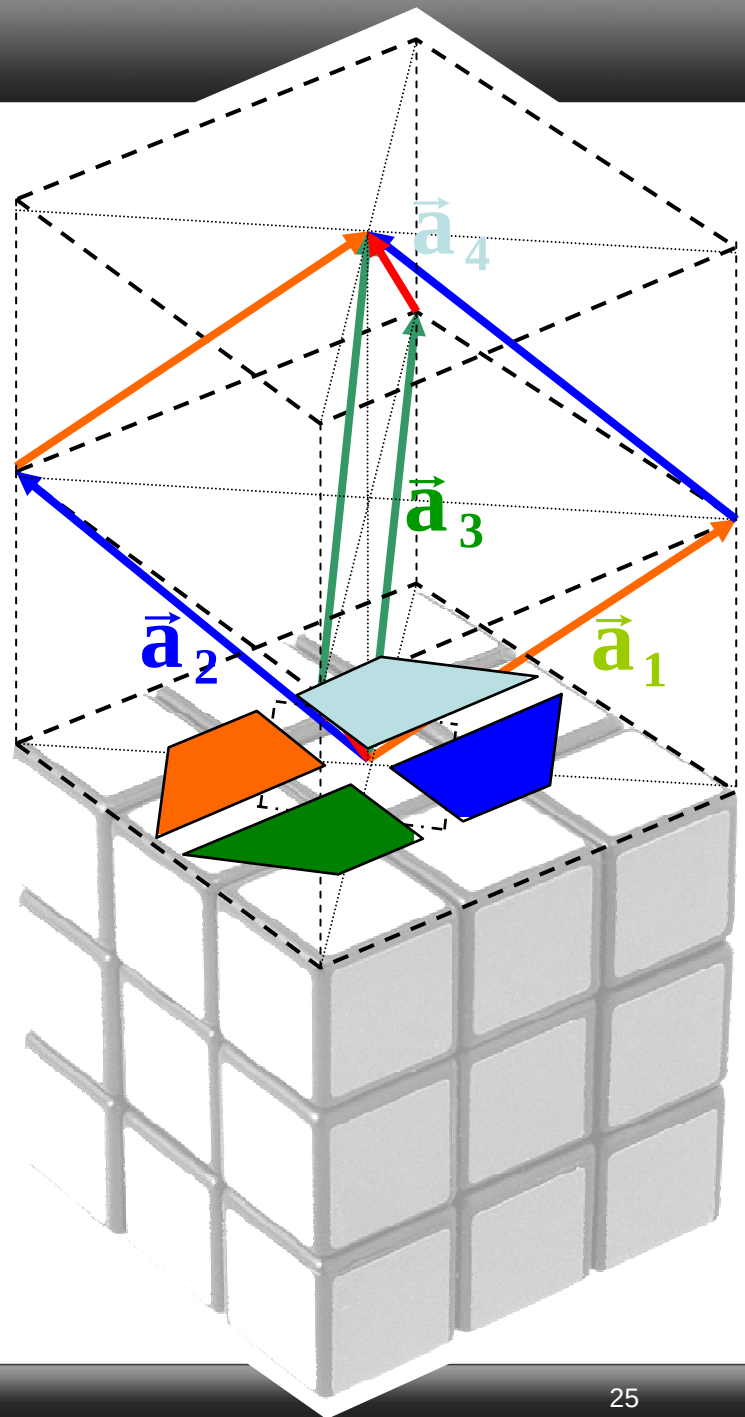
MEMS integrity	SCA8x0	SCA21x0	SCA31x0
Mass deflection self test	✔		
Continuous self test		✔	✔
Static start up self test		✔	✔
SAT saturation warning		✔	✔

3-axis acceleration vector addition



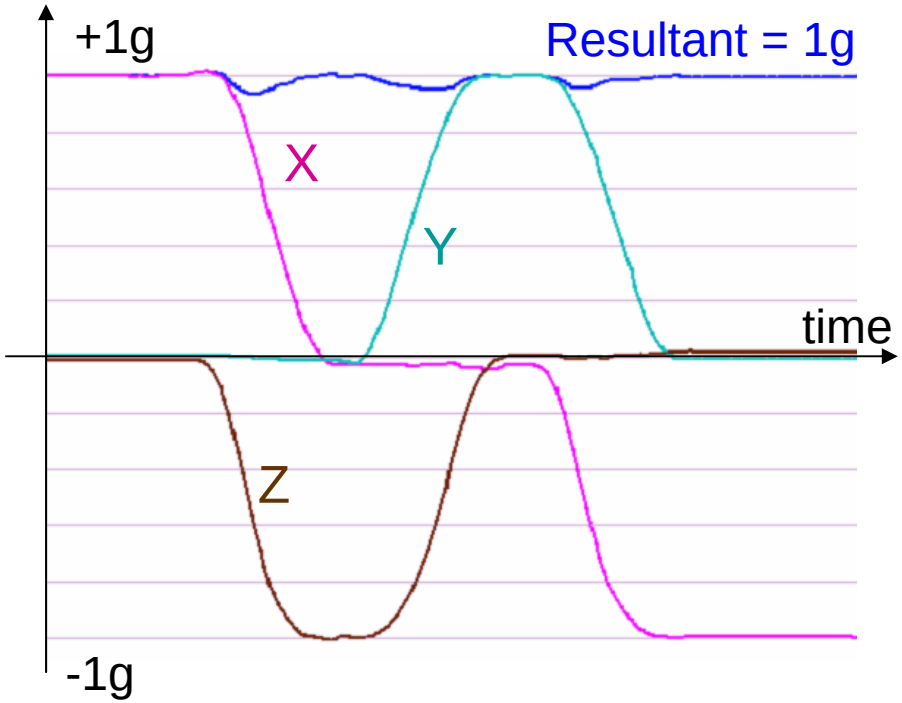
$$+\vec{a}_1 + \vec{a}_2 - \vec{a}_3 - \vec{a}_4 \equiv 0$$

Continuous Self Test ≡ 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.

$$STS\,(a_x, a_y, a_z) =$$

$$a_x^2 + a_y^2 + a_z^2 \equiv 1^2$$

$$= earth\ gravity$$

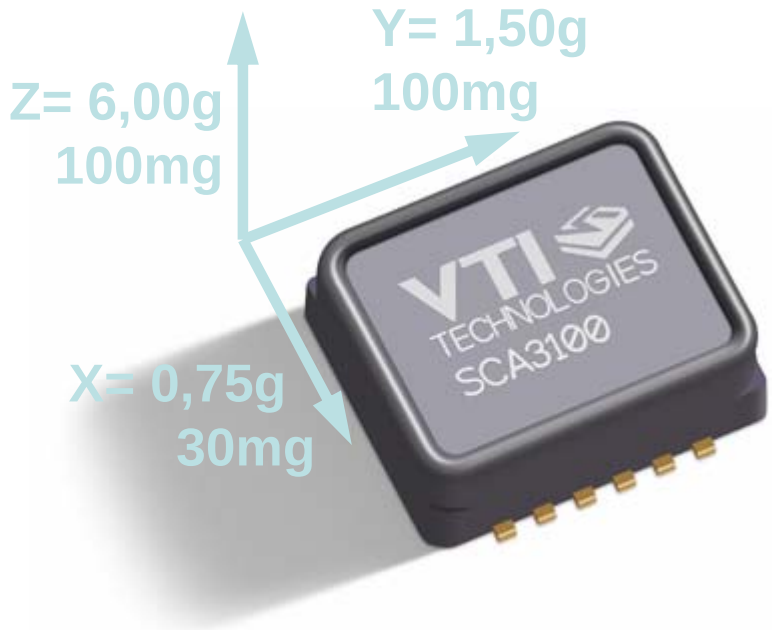
SAT saturation warning

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

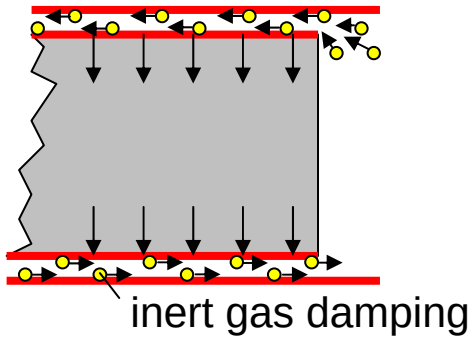
Combination ESC and Rollover

- 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:



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

	ESC (+/- 2g)		ESC +more (+/- 6g)		inclination
	standard performance	high performance	standard performance	high performance	high performance
1-axis	**+/-2g**	**+/-2g**	**+/-6g**	-	-
				-	-
				-	**+/-1g**
2-axis	**ESC** Standard	ESC + **better**	**ESC** Standard	**+/-6g** ESC + **better**	Inclination
3-axis					

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

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Thank you!