Freescale MEMS Sensors for Automotive Safety Applications

November 2009

Freescale Semiconductor China

Abstract

This session will explore Freescale's vision of automotive safety market and how its sensors can be implemented to meet the challenge of active and passive safety systems. It will also provide a update for Freescale entire automotive MEMS sensor product line including airbags, ESC, parking brakes, suspension, as well as advanced sensor technology and general solutions. Merging safety systems in the vehicle is discussed as a trend in future.

This presentation may contain forward looking considerations based on current expectations, forecasts and assumptions of Freescale that involve risks and uncertainties. Forward looking considerations are subject to risks and uncertainties associated with Freescale's business that could cause actual results to vary materially from those stated or implied by this materials and/or its presenter.

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Summary

- Automotive Safety Market Forces
- Airbag and Electronic Stability Control System Explaination
- Freescale Automotive MEMS Technology Capabilities
- Freescale Airbag, ESC and Active Suspension Sensor Solutions
- Long Term Vision
- Conclusion

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Automotive Market Forces

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Automotive Safety Market Forces

More than

1.2 Million people

are killed on the world's roads every year !

Safety

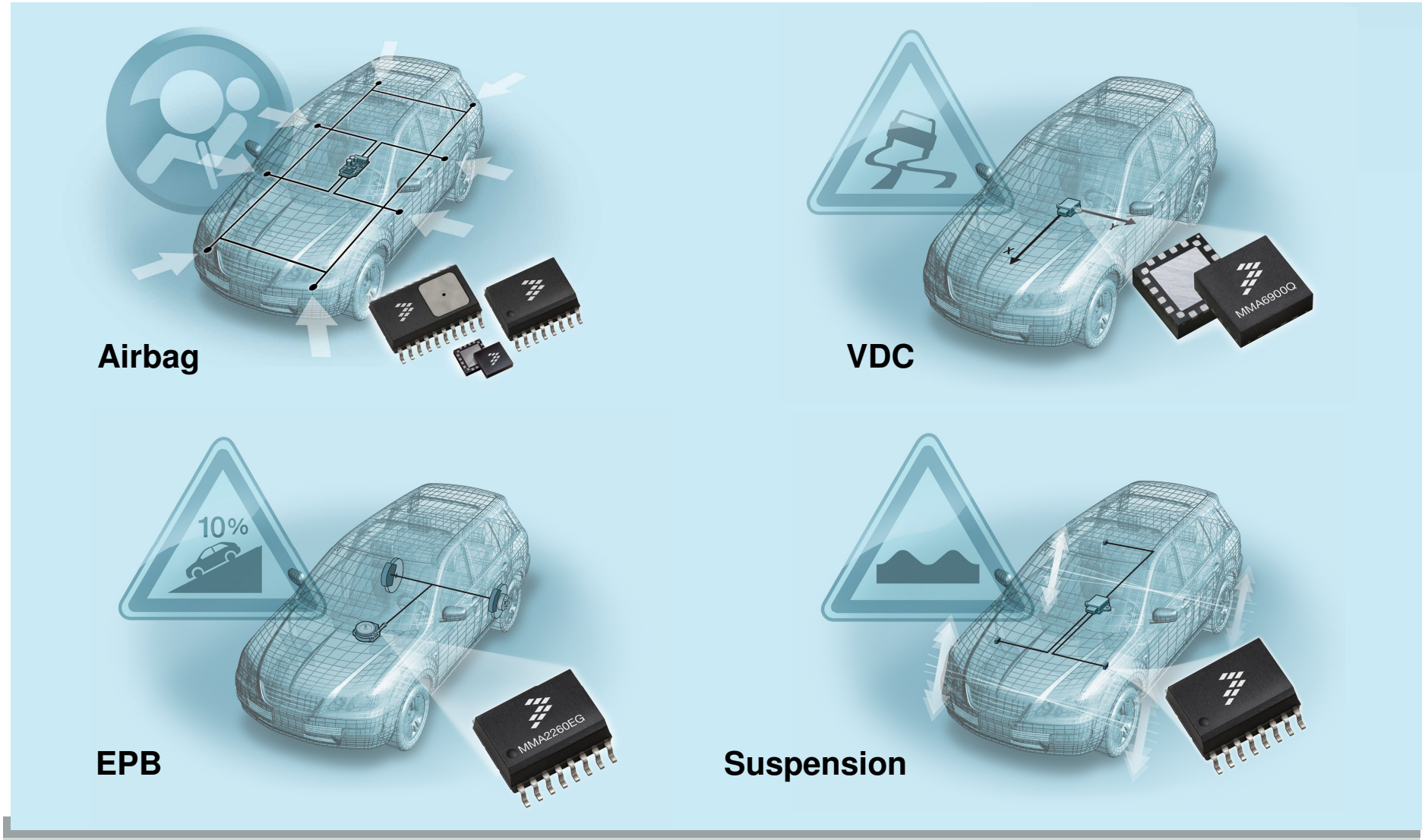
Regulation key to mass penetration

US legislation requiring front and passenger airbag, crash data retention, smart occupant sensing
No specific airbag legislation in Europe, Japan and Asia Pacific
China is introducing front and side airbag legislation
European pedestrian impact legislation may drive pedestrian airbag, although other solutions can be used
ESP mandatory for all passenger cars sold in Europe by Nov 2011 and the US by 2012 (US NHTSA)

Consumer demand driving the most advanced systems

According to Chinese CCID consulting agency, Airbag fit rate in 2006 reached 80% on homemade cars
2005 survey by European NCAP showed that "safety" was the most important aspect influencing car choice
Severe crash testing in Europe (front and side) is forcing a 100% fit rate

FSL Sensors in Automotive Applications



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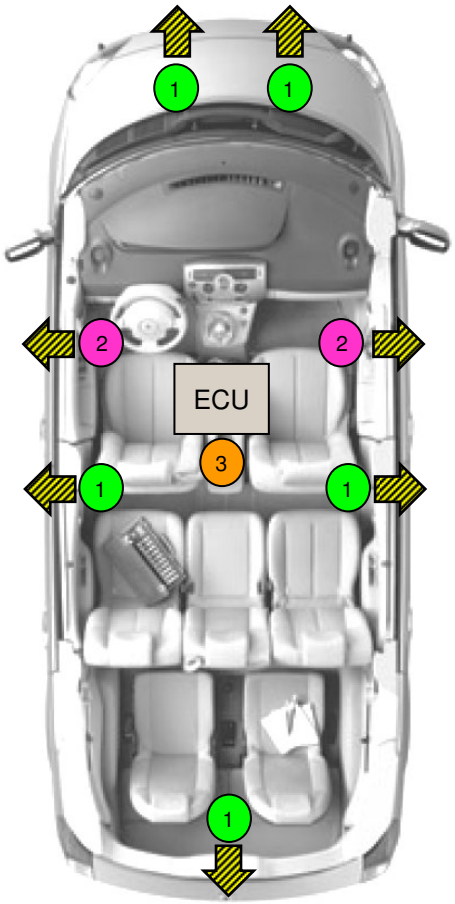
Airbag Application: Where are Sensors located?



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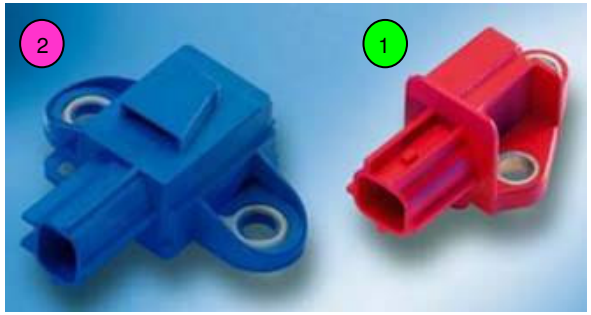

Pressure Satellite

Accelerometer Satellite

Pressure and Accelerometer Satellites.

Located in the bumpers (Front crash detection) or in the B pillar (Side crash detection) for accelerometer.
In the door cavity for pressure satellite.

Contains:
- Integrated Inertial sensor + few passive components
- Integrated Pressure sensor + few passive components

Airbag ECU

Located in the cabin (central tunnel)

Contains:
- Master MCU (16 or 32bits)
- Safing MCU (8 bits)
- Analog components with various level of integration (Power supply, satellite interface, squibs drivers, physical layers, ...)
- Main Inertial Sensors (Usually 2-axis XY)

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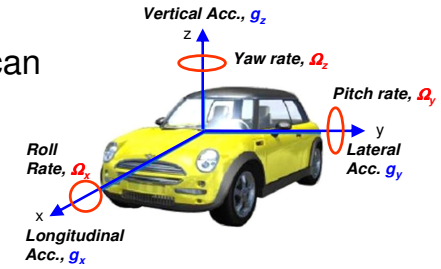
How does ESC Work ?

▸ How does it work ?

- Electronic Stability Control (ESC) assist the driver in critical driving situations.
- ESC compares a driver's intended course with the vehicle's actual movement.
- When instability is detected, ESC automatically applies brakes to individual wheels and can also reduce engine torque to help keep you on track.

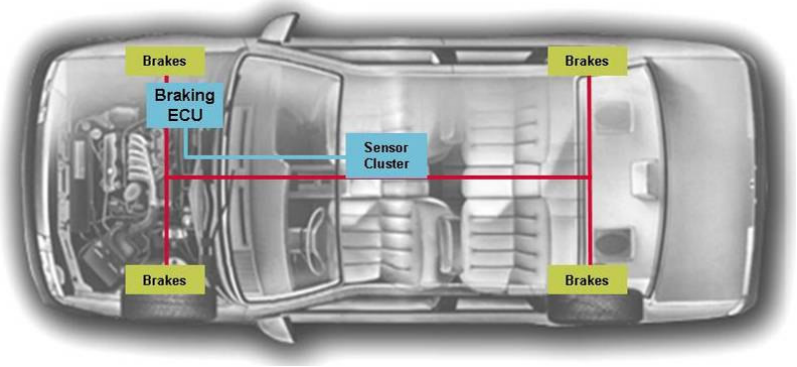


▸ The ESC system relies on sensing inputs from:

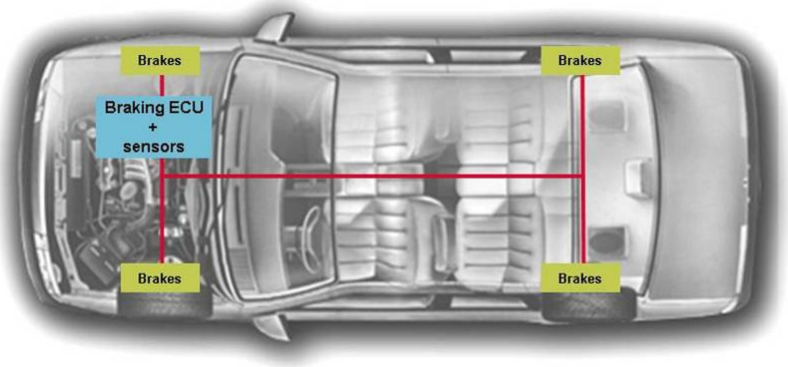
- Steering wheel angle sensor
- Wheel speed sensors
- Pressure Sensors
- **Yaw rate Sensor**
- **Acceleration sensor**

Various Sensors orientations are needed depending on the position in the car:
- In-plane Gyro + Z axis low-g (Embedded)
- Out-of-plane Gyro + Y low-g (Remote)

ESC Remote sensor cluster architecture



ESC Embedded sensor cluster architecture



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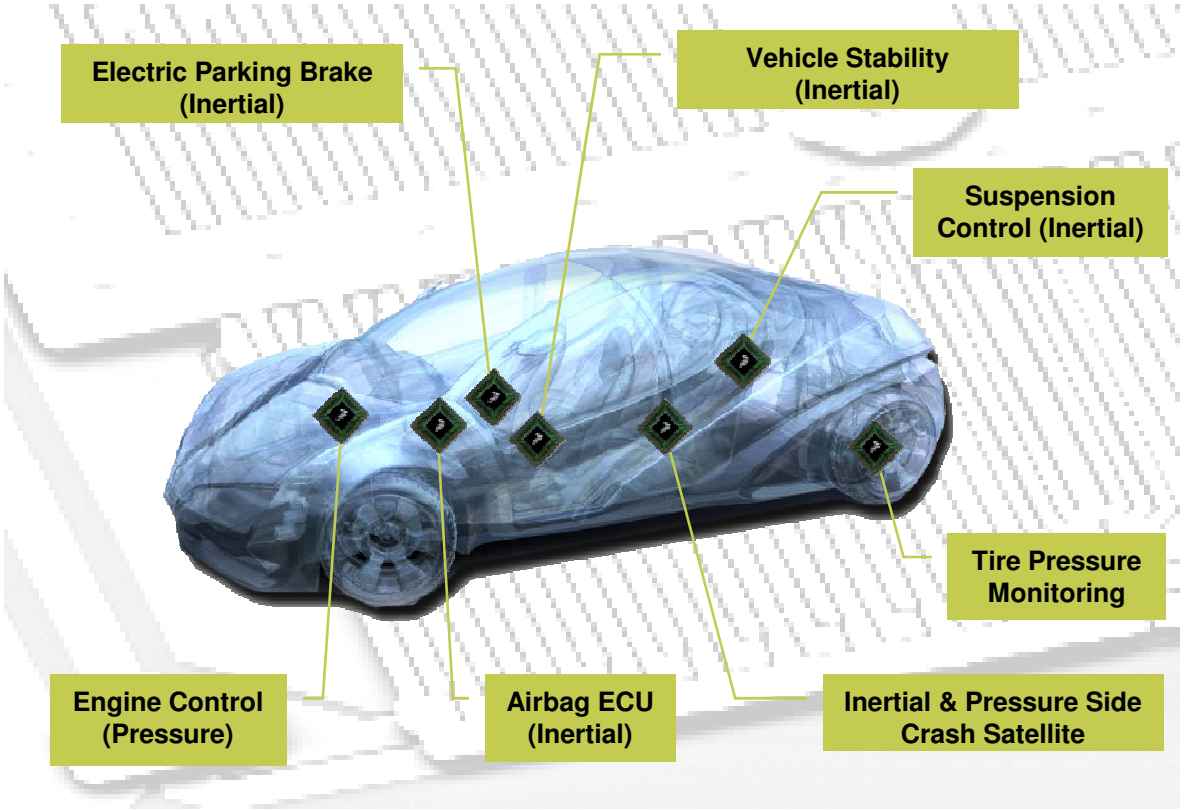
Freescale commitment to Automotive and MEMS



Market Leader

- **FSL is the No. 2 supplier in the Automotive MEMS Sensors market**
- **Broad Standard portfolio**





Business Facts

- **1 Billion** MEMS sensor shippment till June, 2009
- Since 1997, **400 million units acceleration sensors** shipped in custom safety automotive applications
- Among the largest supplier of **barometric pressure sensors for engine management**

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One Billion MEMS Milestone just passed...

One Billion and Counting

From 1980 to 2009 Freescale has designed, produced and shipped innovative sensor products to global customers

1980
We manufacture our first uncompensated pressure sensor

1991
Bipolar integrated pressure sensor production begins

1982
Pressure sensors are supplied for manifold absolute pressure (MAP) to significantly reduce exhaust emissions and fuel consumption

1985
Sensor products release a temperature compensated pressure sensor

Late 1980s
Freescale* begins developing the first surface micromachined inertial sensors for the automotive airbag market

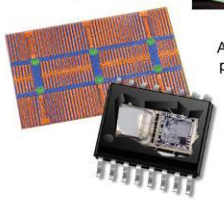
1992 to present
Dedicated supplier to the critical care medical market through shipment of over 60 million units for the invasive blood pressure market

2002
Began providing pressure sensors for respiratory medical equipment

100 MILLION

1996
Inertial sensors start volume production

Late 1990s
A new wingback/PDIP package is developed for the Z-axis inertial sensor



200 MILLION

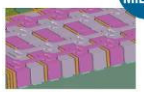
2003
The pressure sensor portfolio expands with the tire pressure monitoring system, utilizing capacitive technology to save power

Early 2000s
Inertial sensor portfolio expands with X-, XY- and Z-axis low-g products for the consumer market

2003
Satellite accelerometers introduced for airbags provide smarter, faster response time deployment

June 2007
Spalding uses the ZSTAR wireless sensing triple axis reference design for an intelligent basketball that tracks trajectory

May 2005
Freescale introduces its first 3-axis MMA7260Q low-g inertial sensor, alleviating the need for multiple devices

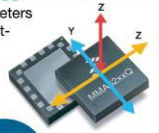


July 2006
First HARMEMS technology MMA62xxEG products are shipped for airbags with robust accuracy

400 MILLION

November 2008
Synerject announces its ongoing use of Freescale pressure sensors for robust, cost-effective ECUs for two- and four-stroke engine management

December 2008
3-axis accelerometers offer reliable, cost-effective freefall detection to help protect data stored on laptop hard disks



800 MILLION

February 2008
Motion-sensing accelerometer enables interactivity of Guitar Hero® and other popular video games

2008
TPMS MPXY8300 highly integrated single-package low-power solution:

- Pressure sensor
- 8-bit MCU
- RF transmitter
- 2-axis X- and Z-axis accelerometer

June 2009
MPL115A first digital barometric pressure sensor with easy-to-use digital interface, small package and low power

April 2009
MMA7660 intelligent 3-axis digital accelerometer introduced for advanced mobile phone interfaces

Energy Efficient Solutions by Freescale

* The Semiconductor Products Sector of Motorola, Inc. became Freescale Semiconductor, Inc. in 2004.

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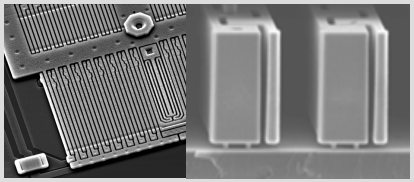
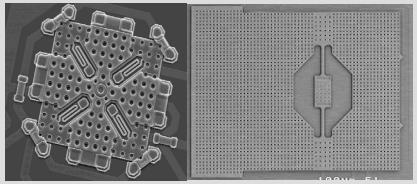
Freescale Sensor Technologies

Transducer Components

Inertial Sensors

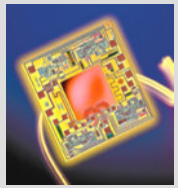


X-axis Sensor element

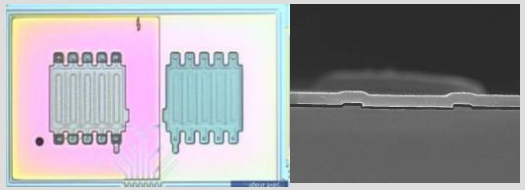


Z-axis Sensor element

Pressure Sensors

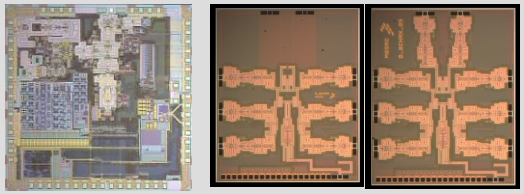


Piezoresistive Bipolar



Capacitive Surface Micromachining

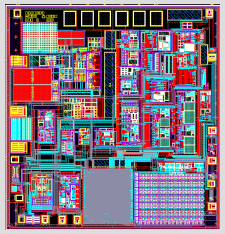
Radar



Embedded Systems

Mixed-Signal Technologies

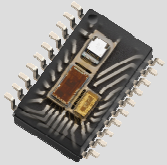
- Advanced Signal Conditioning
- High-Voltage Capable
- Two-Wire Connectivity
- Wireless Connectivity
- Embedded OTP
- Full Design Kits, including MEMS



System in Package

- Dual Die: Side-by-Side, Stacked
- Leadframe or LGA Packages
- Stress Relieved
- Resonance Modeled
- Media Compatible Pressure Sensor

MCU, Memory/Flash, and Embedded Firmware



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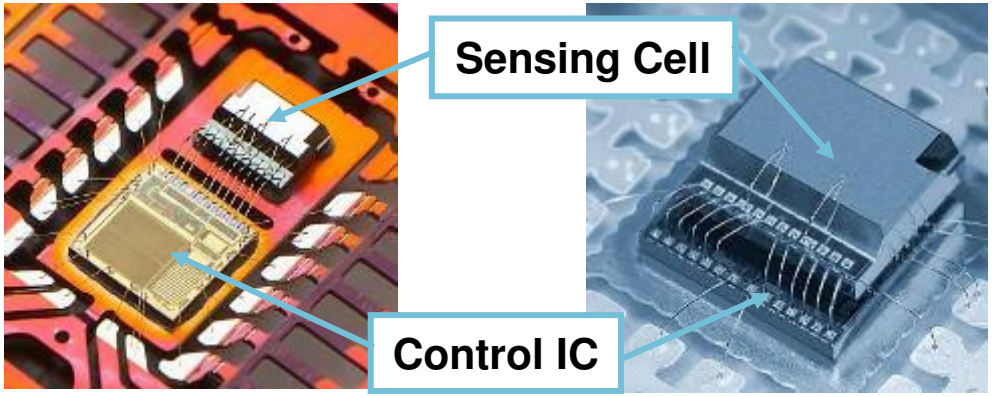
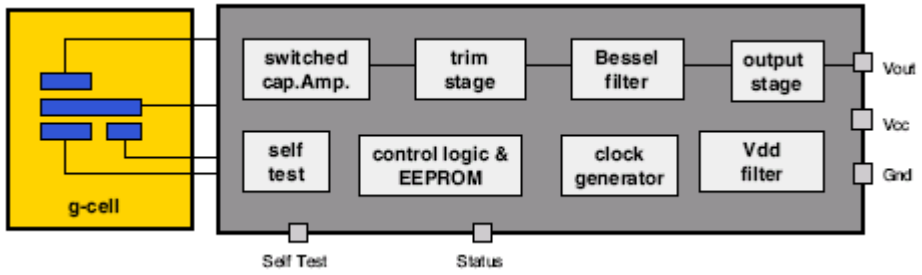
Acceleration Sensor Common Features

Two-Chip Solution



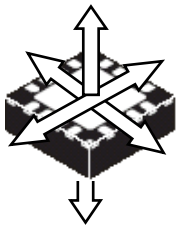


SOIC package

QFN package

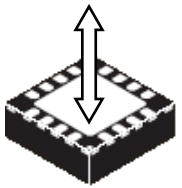
Sensing Axis

XYZ axis
Not automotive

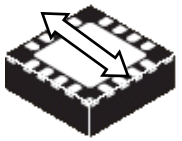


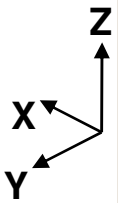
XY axis

Z axis



X axis





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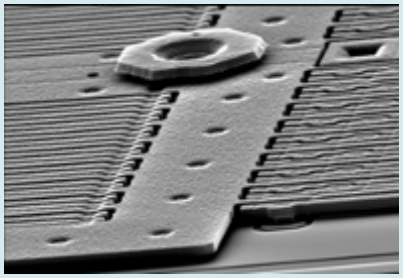
FSL MEMS Technologies for Inertial Sensors

Poly Silicon MEMS

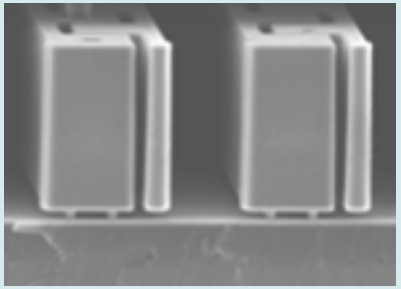
- 3 µm movable structure
- Underdamped response
- Products: All axis accelerometers
- Markets: 1) Consumer 2) Automotive
- Volume production

In combination with lead less package solutions, Freescale developed overdamped transducers to create solutions more robust to external parasitic vibrations (Airbag, ESC)



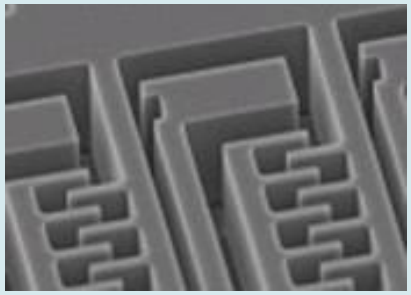
High Aspect Ratio MEMS (HARMEMS)

- 25 µm movable structure
- **Overdamped response**
- Products: Lateral accelerometers (X & XY)
- Markets: Automotive
- Volume production



Enhanced HARMEMS (e-HARMEMS)

- 25 µm movable structure
- Top and bottom sensing electrodes
- Products: Gyro and combined sensors
- Markets: Automotive
- In development



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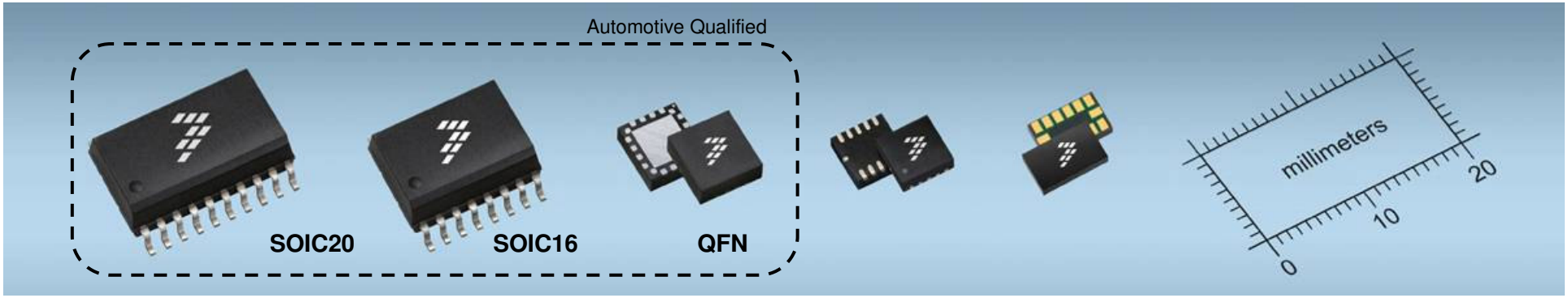
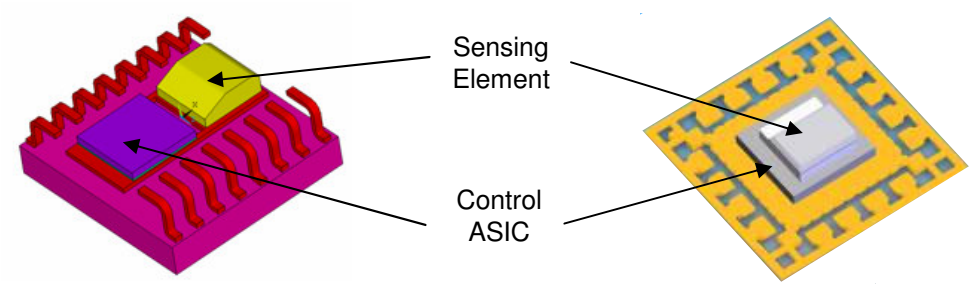
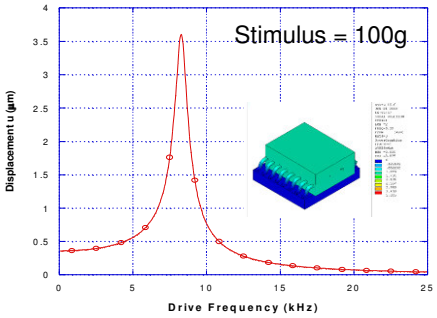
Freescale Inertial Sensors Packaging

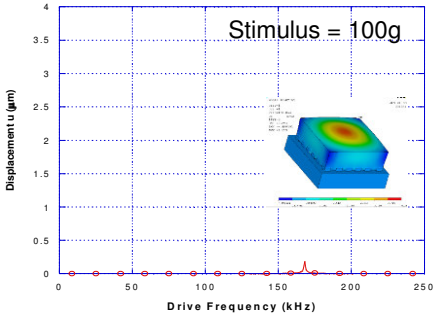




► 2 Resonance Modes, X & Y both at 8.3 kHz

► **Resonance in the band of interest for car vibration**





► First resonance mode at 168 KHz

► **Resonance out of the band of interest for car vibration**

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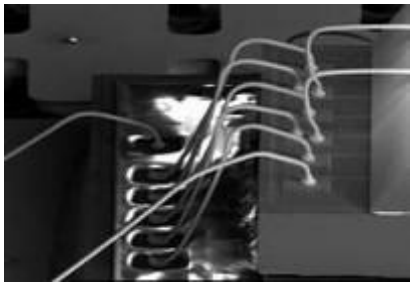
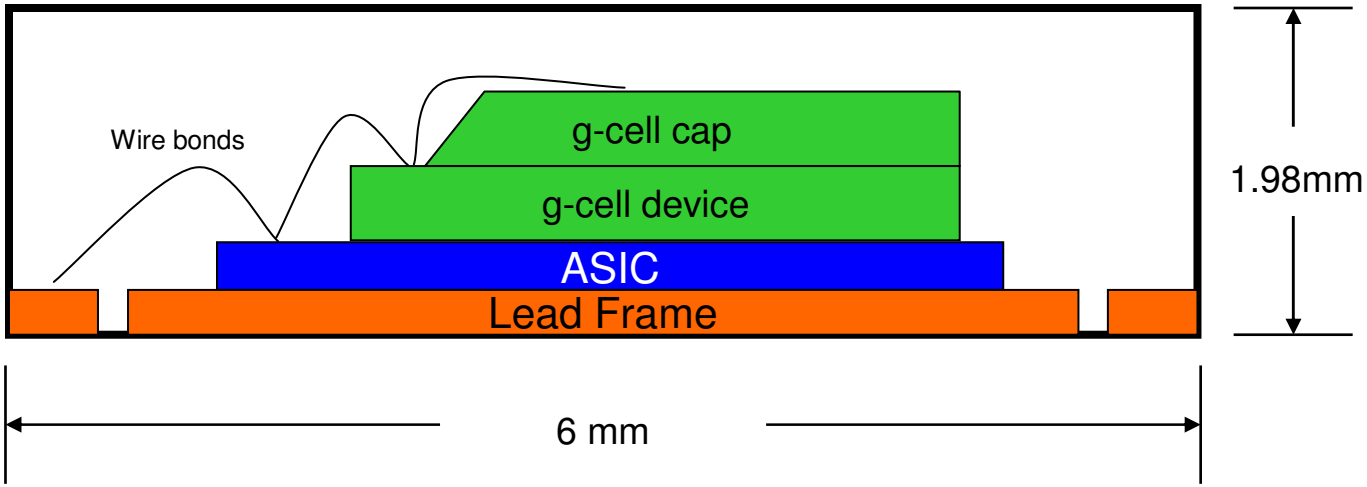
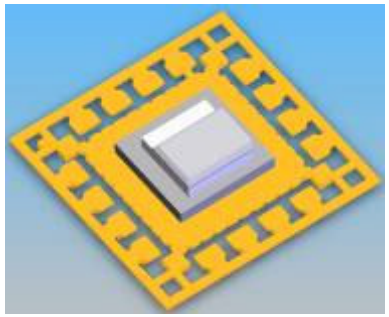
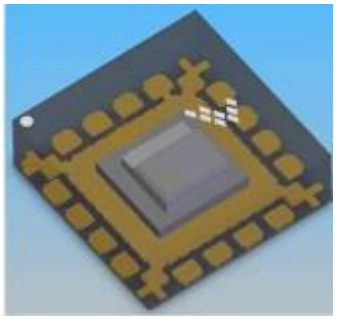
QFN Package Cross Section

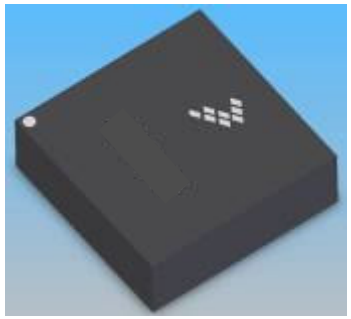


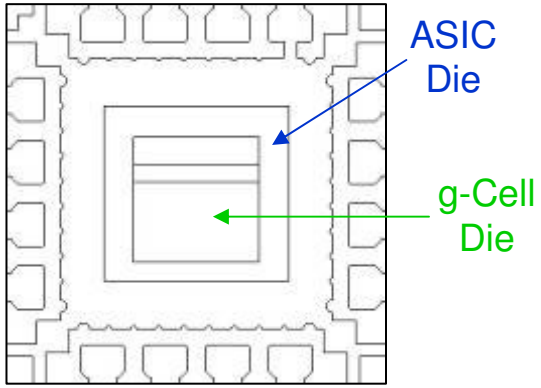


Automotive Qualified Package:
In production since 2006









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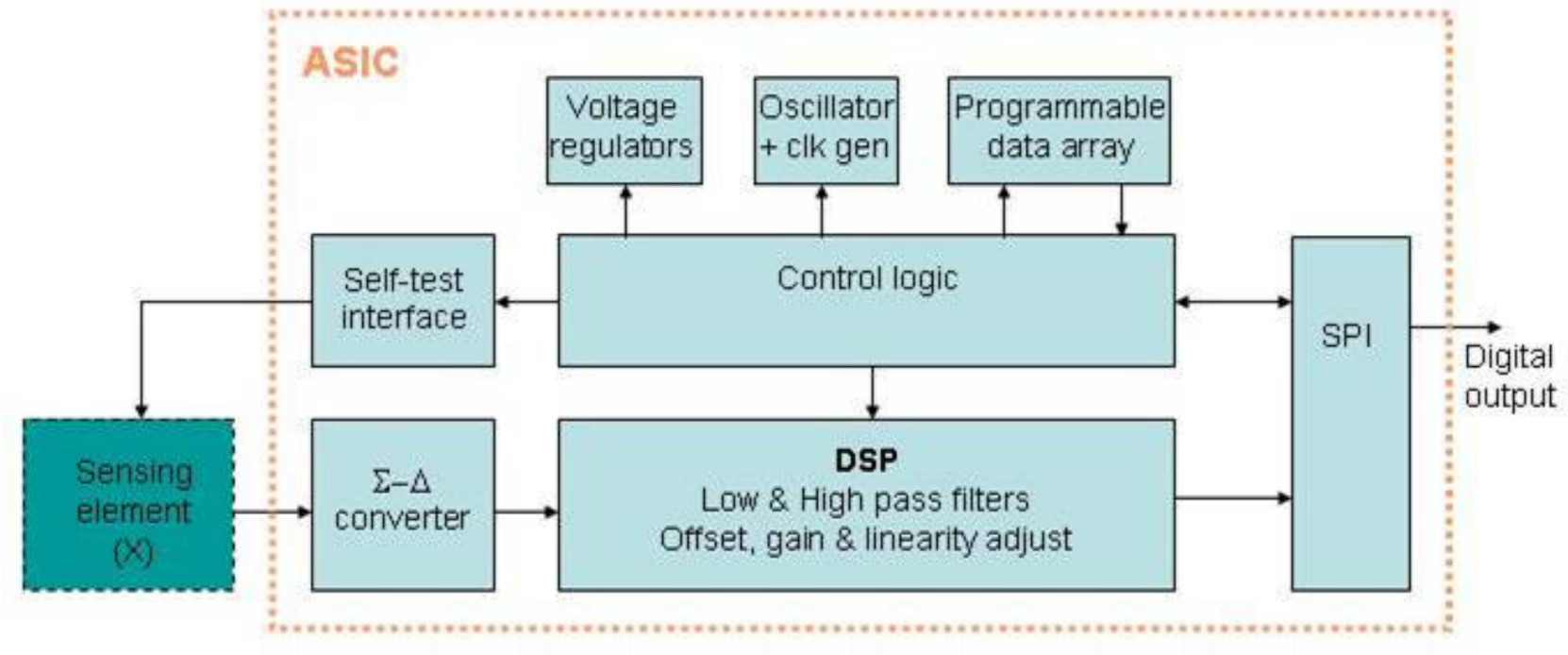
Next Generation ASIC Architecture



- **Flexible design allows to implement more channels like XY or XYZ inertial sensors and/or pressure sensors.**
- **Analog output can be provided by adding a DAC at the DSP output**

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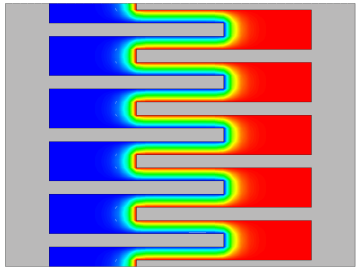
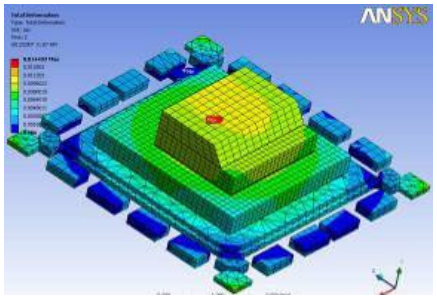
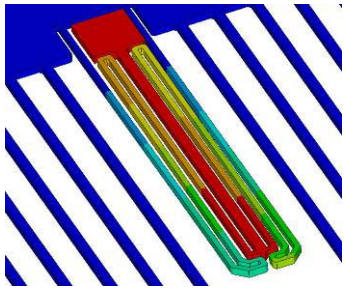
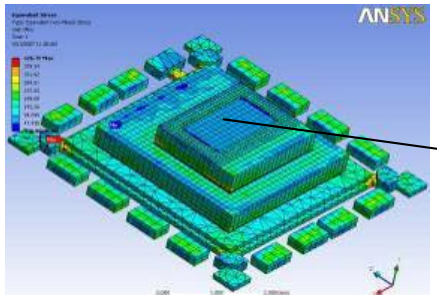
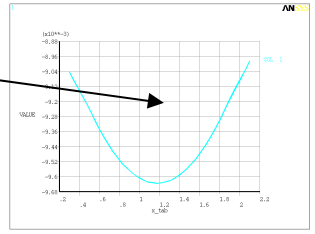
Strong Simulation and Modeling Capabilities











- Use FEA (Finite Element Analysis) to respond to the “Multiphysics” challenge of MEMS design: Mechanics, Electrostatics and Fluidics.
- Use analysis to study TCO (Temp Coefficient Offset) behavior in various package.
- Use analysis to study vertical and lateral deformation of the g-cell
- Model package deformations over temperature and extract surface curvature where transducer sits.

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Special Automotive Tests Capabilities

Mechanical Drop Tower

Ball Drop Test

- **Mechanical drop tower mounted along orthogonal sensing axes.**
- **The drop tower could apply shock pulses predicted to elicit a failure mechanism (Like stiction)**

- **Ball drop test can produce high g amplitudes at high frequencies assumed comparable to those seen during crash test.**
- **If the output reproduces itself during several ball drop test runs, this means the device is performing in a controlled manner.**

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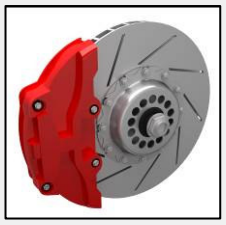
Automotive Inertial Sensor Applications

1 to 20g - X, Z axis

ABS - ESP:
1 to 2g



Electrical Parking Brake: 1 to 2 g

Roll over:
1 to 5 g

Navigation:
1 to 5 g

Tilt monitoring:
1 to 5 g

Suspension Control:
10 to 15 g

20 to 480g - X, Z, XY axis

Crash detection:
20 - 100 g

Side crash detection and motorcycle airbag:
100 - 480 g

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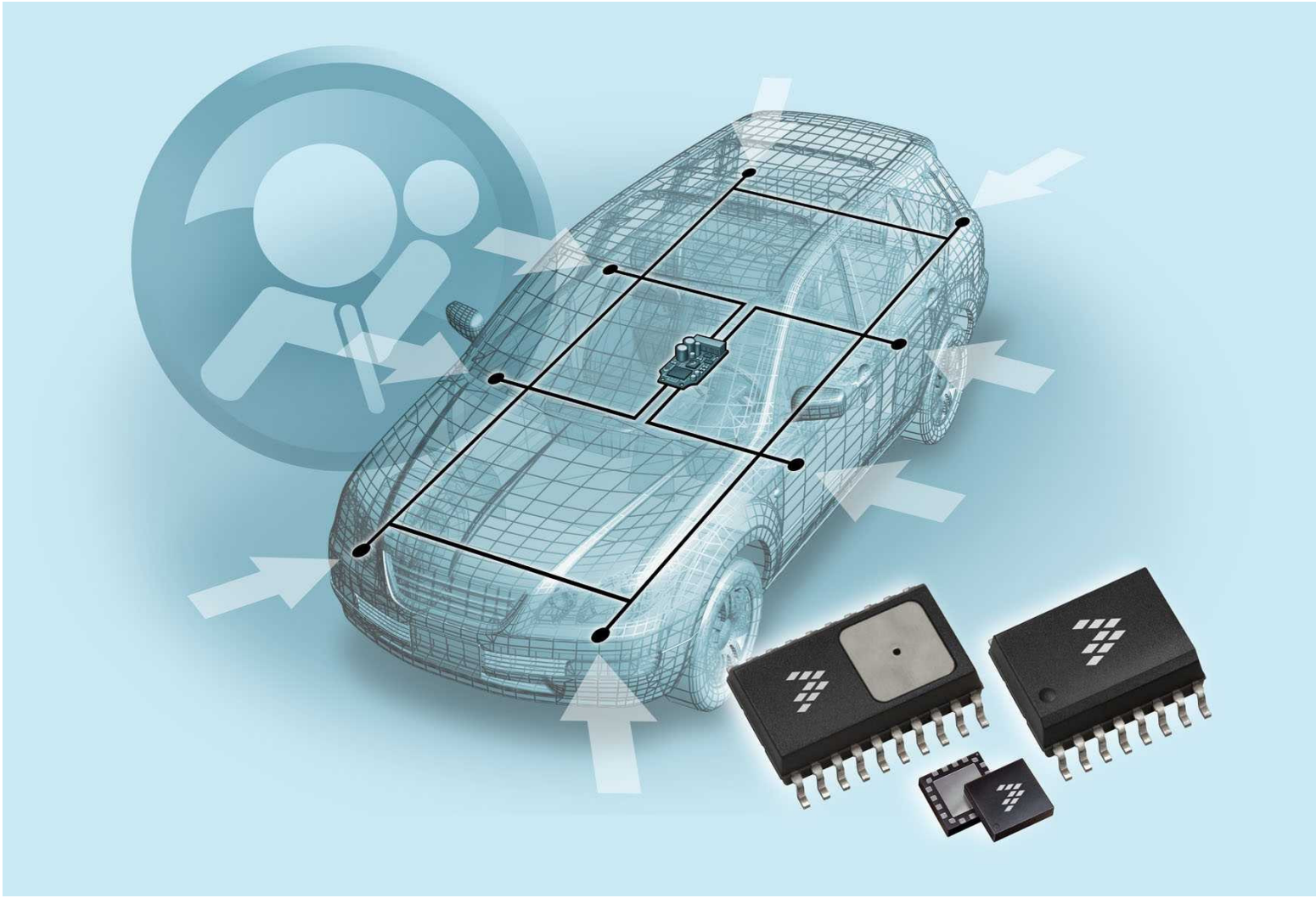
FSL Sensors in Airbag Application



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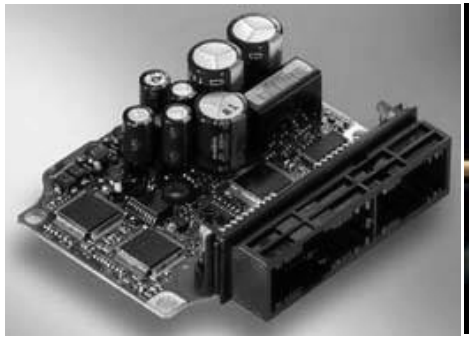
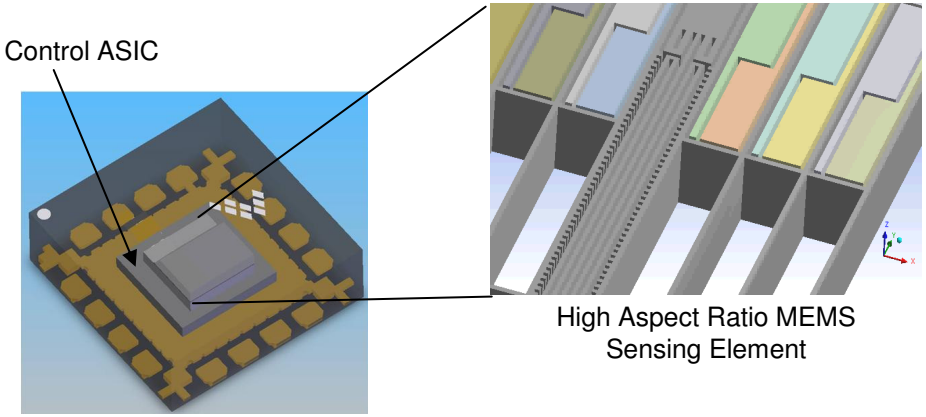
New Main ECU Airbag Sensors

- Dual XY axis Sensors with fully digital signal processing:
  - Overdamped Inertial sensing element
  - Digital output (10 bits)
  - 3.3V or 5V Power Supply
  - Bi-directional Self-test
  - Arming pins (Programmable threshold)
  - Programmability (filters, ...)



Airbag Central Module

Front Airbags



QFN Package

High Aspect Ratio MEMS Sensing Element

XY - Axis		X - Axis	
MMA6801QR2	20g/20g	MMA6851QR2	20g
MMA6802QR2	20g/35g	MMA6852QR2	35g
MMA6805QR2	20g/100g	MMA6853QR2	50g
MMA6809QR2	35g/75g	MMA6854QR2	75g
MMA6813QR2	50g/50g	MMA6855QR2	100g

SOP: Q1 2010

AEC-Q100 Qualified

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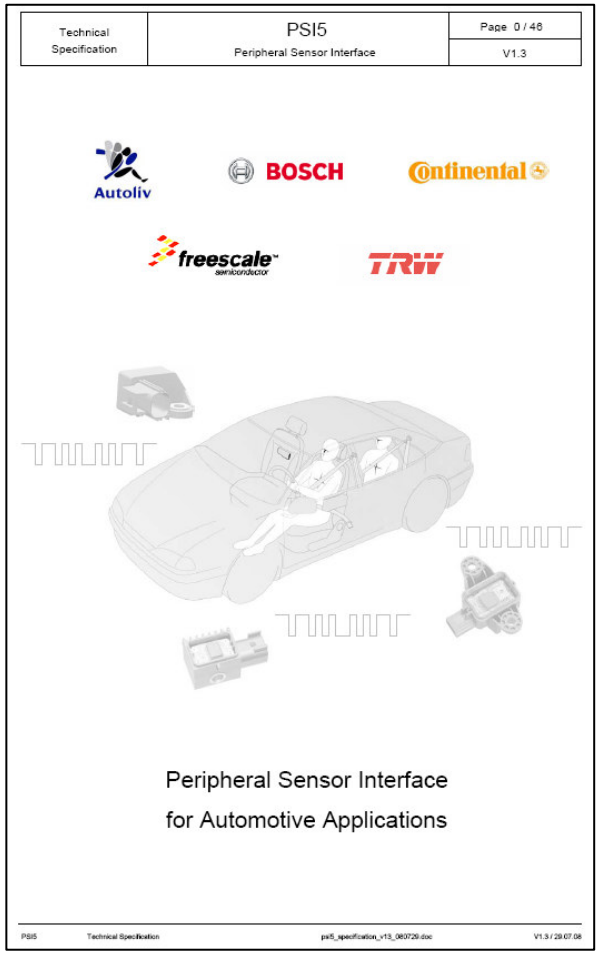
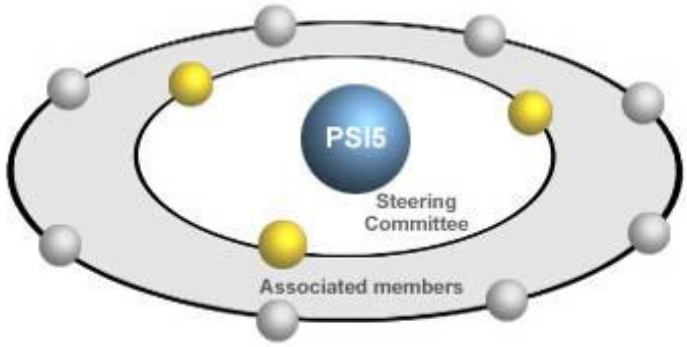
FSL Commitment to PSI5 Standard



Extracted from www.PSI5.org page



- Freescale is PSI5 Associated member since 2006
- As such, Freescale participes actively to the PSI5 consortium meetings with one representant.
- Tasks include:
  - Standard Specification Definition & Review
  - Development of Conformance Test
  - Implementation and promotion of PSI5 protocol

Integrated Airbag Satellite Sensors

- System-in-Package (SiP) solution integrates board-level functionality in a single package:
  - Inertial sensing element
  - State Machine
  - Power supply
  - Communication protocols (PSI5 or DSI)

Airbag Satellite Module

Side Airbag Curtains

		DSI 2.02 Protocole	
		X-Axis	Z-Axis
SOIC16 Package	40g	MMA8204EG	MMA8104EG
	50g	MMA8205EG	MMA8105EG
	100g	MMA8210EG	MMA8110EG
	250g	MMA8225EG	MMA8125EG

In Production

		PSI5 Rev1.3 Protocole	
		X-Axis	Z-Axis
QFN Package	60g	**MMA5206Q**	**MMA5106Q**
	100g	**MMA5212Q**	**MMA5112Q**
	240g	**MMA5224Q**	**MMA5124Q**
	480g	**MMA5248Q**	**MMA5148Q**

SOP: Q3 2010

AEC-Q100 Qualified

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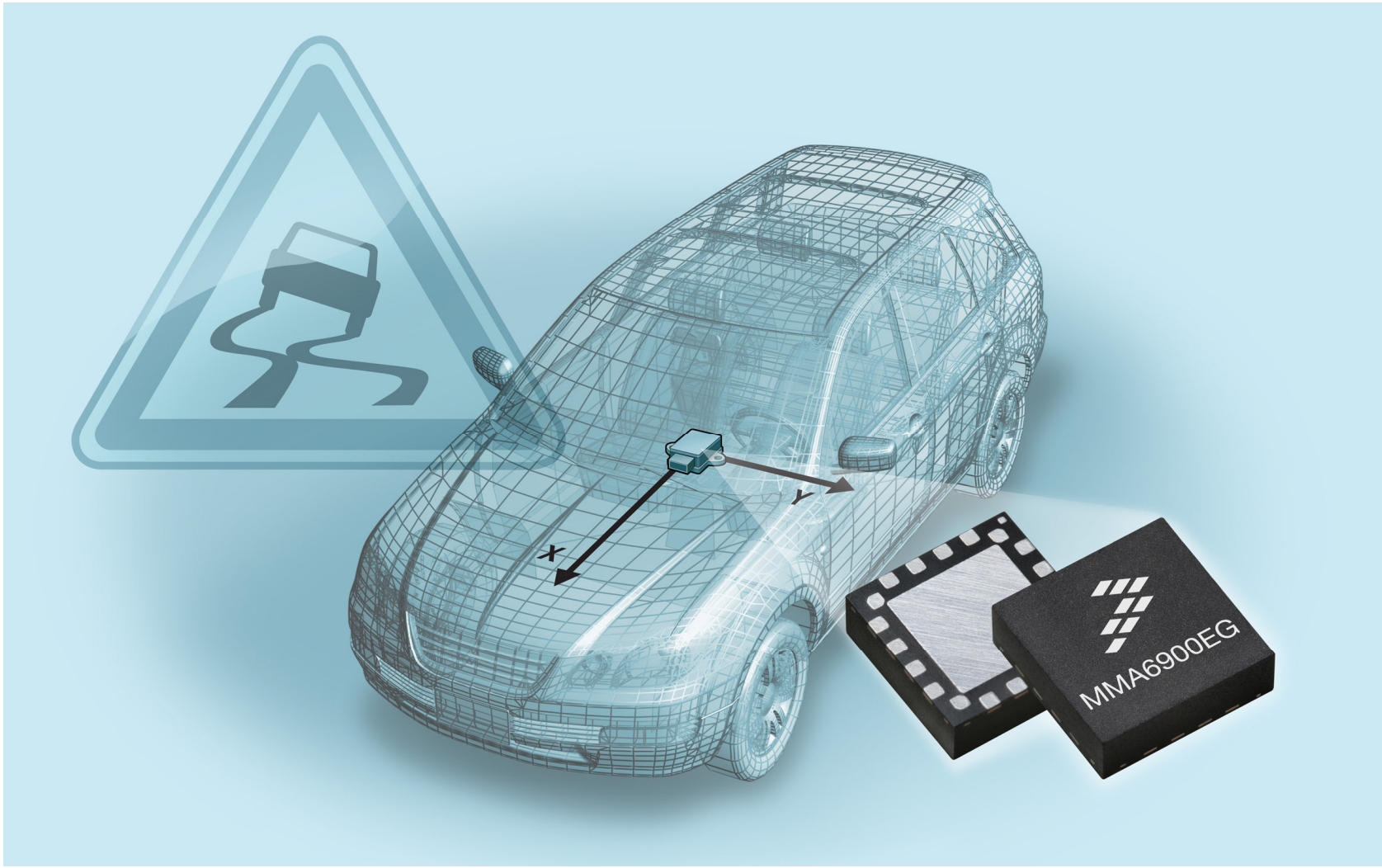
FSL Sensors in Vehicle Dynamic Control Application



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Vehicle Stability Control: Inertial Sensors

- Dual XY axis Sensors with fully digital signal processing:
  - Overdamped Inertial sensing element
  - Digital output (10 or 11 Bits)
  - Low offset drift over temperature (50mg)
  - 3.3V or 5V Power Supply
  - Bi-directional Self-test
  - Programmability (filters, ...)

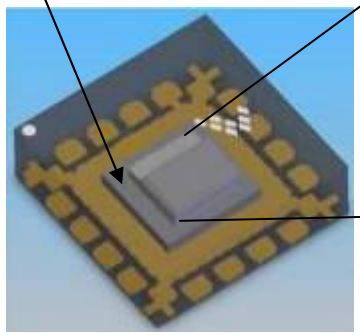
VSC Module

Car with and without VSC

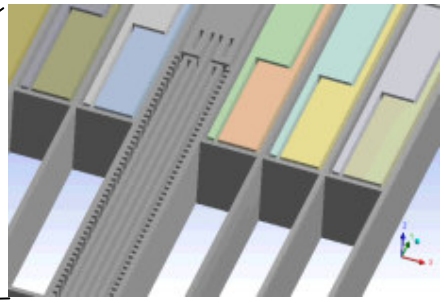
Part Number:

MMA6900Q ± 3.5g

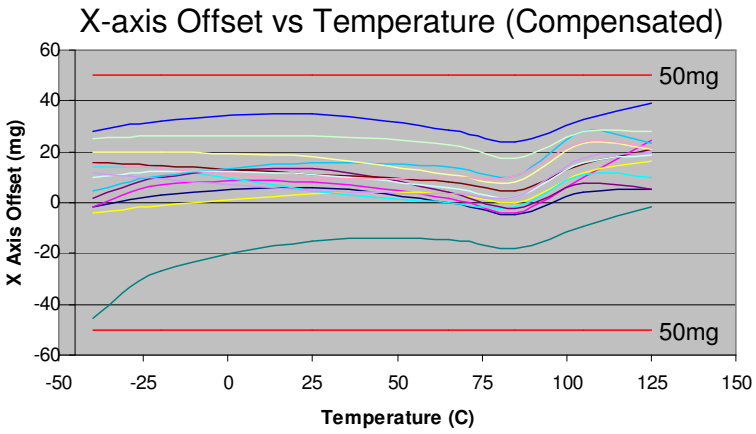
SOP: Q2 2010



QFN Package



High Aspect Ratio MEMS Sensing Element



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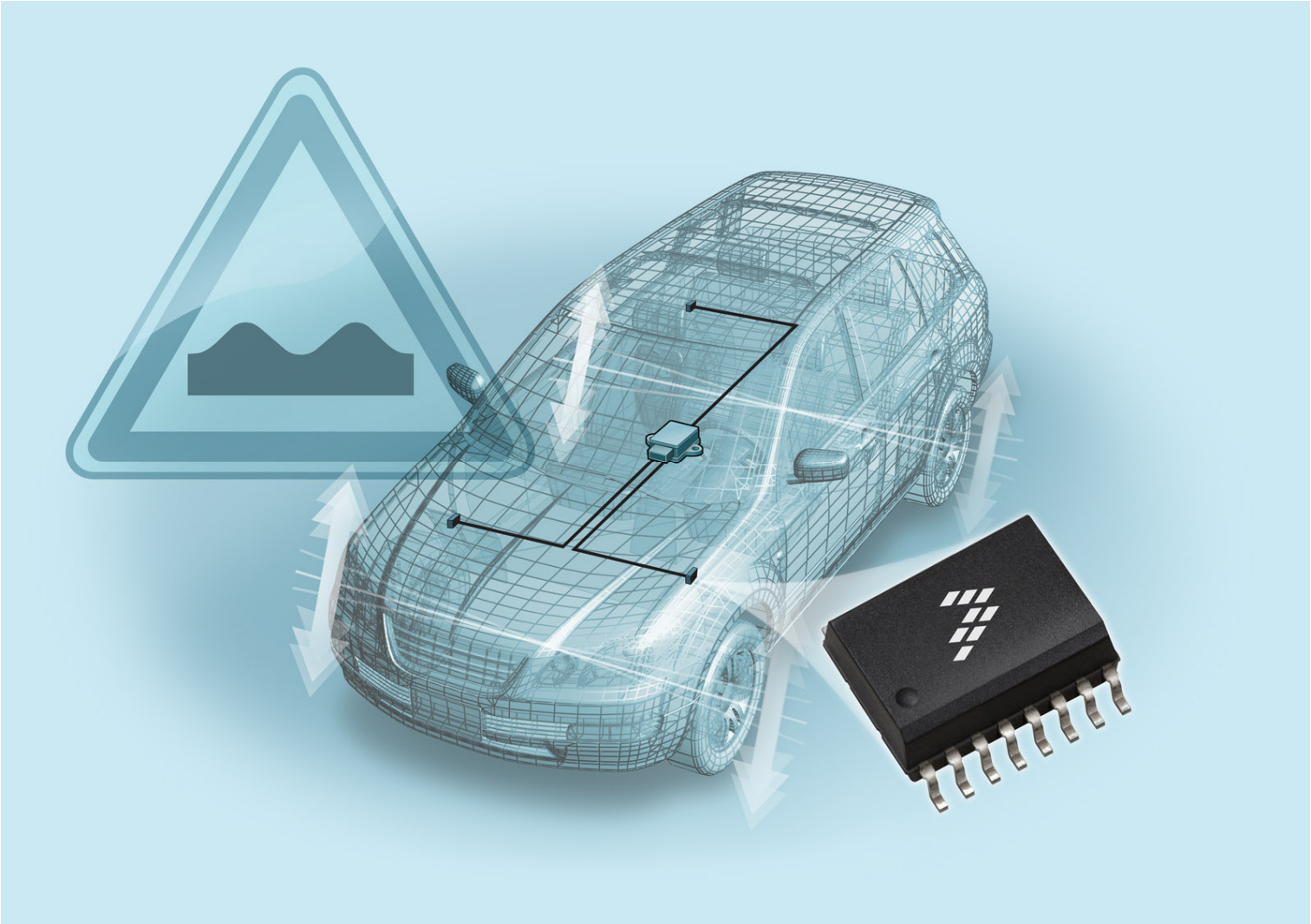
FSL Sensors in Vehicle Dynamic Control Application



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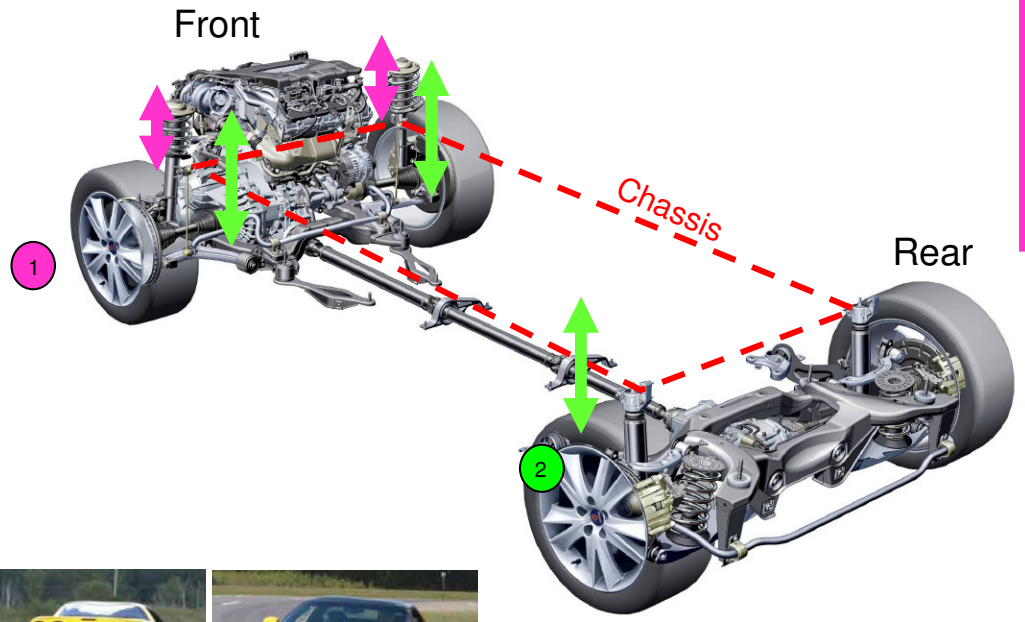
Inertial Sensors for Electronic Controlled Suspension

Key function is to keep the car body stable through :
- **Chassis movement measurement and / or**
- **Wheel/damper movement measurement**



Without Active Damping System

With Active Damping System

1

Vertical wheel movement:
Located on damper directly

2 x Low g sensors
Cut off frequency around 300Hz to 400Hz
-14g … +16g absolute or -15g … +15g if compensated
Sensitivity error: 5% target

FSL product offering: **MMA2240/41/42EG**

2

Vertical body movement:
Located on chassis

3 x Low g sensors
-1g … +3g absolute or -2g … +2g if compensated
Cut off frequency around 100Hz
Sensitivity error: 5% target

FSL product offering: **MMA2260EG**

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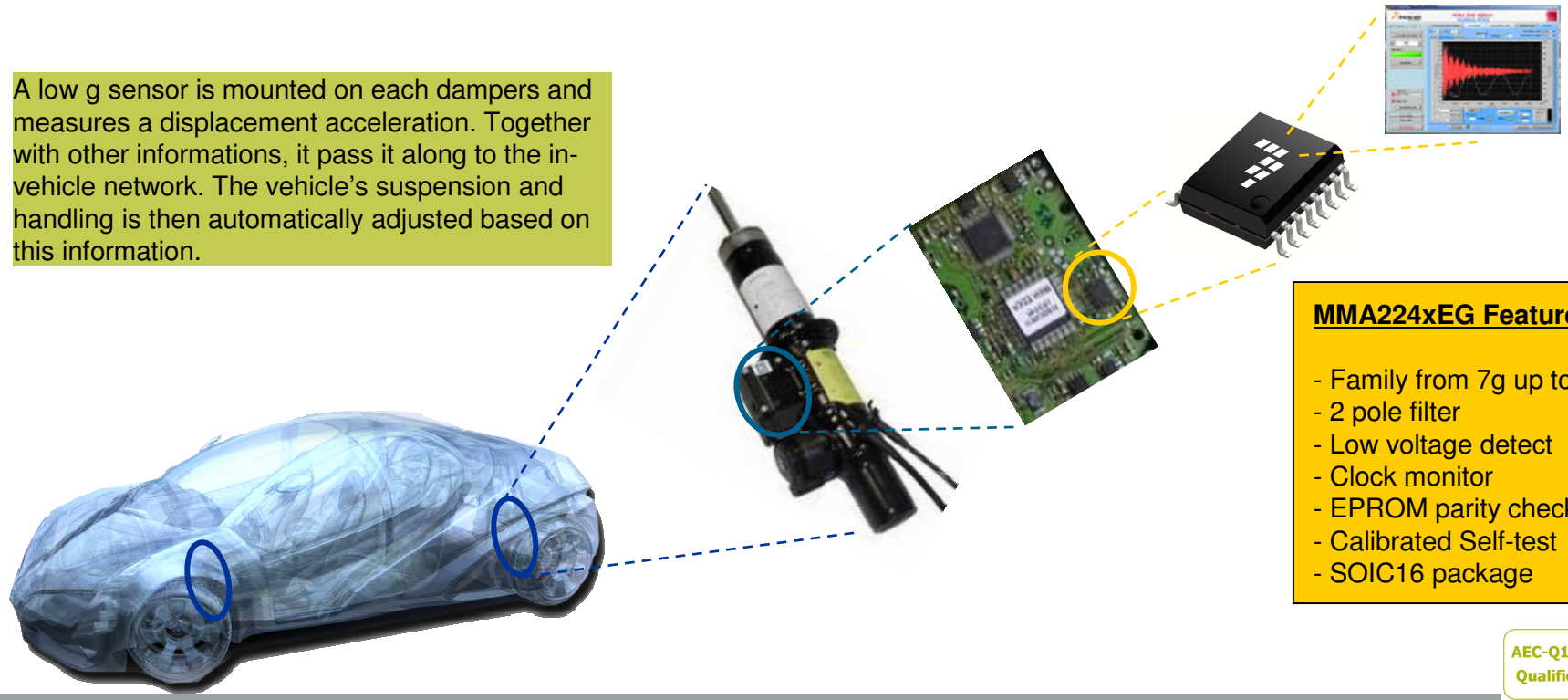
MMA224xEG: Low g Sensors for Active Suspension

- **Electronic Damper Control**
- Resolving the conflict between high ride comfort and high driving safety and agility.
- Minimization of wheel load variation and chassis oscillation.

A low g sensor is mounted on each dampers and measures a displacement acceleration. Together with other informations, it pass it along to the in-vehicle network. The vehicle's suspension and handling is then automatically adjusted based on this information.



MMA224xEG Features:

- Family from 7g up to 15g
- 2 pole filter
- Low voltage detect
- Clock monitor
- EPROM parity check status
- Calibrated Self-test
- SOIC16 package

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Automotive Inertial Sensor Portfolio

Inertial Sensors Automotive parts

	Part number	Axis	g Range capability		Technology		Package	Temp Range	Status	EV Samples (*)	SOP (*)	Comments
			Min	Max	g-cell	ASIC						
Low g	**MMA1220/50/60/70EG**	Z	1.5	8	Poly-Si overdamped	CMOS	SOIC16 WB	-40°C / +105°C	In production			Analog output
	MMA2260EG	X	1.5	1.5	Poly-Si	CMOS	SOIC16 WB	-40°C / +105°C	In production			Analog output
	MMA2240/41/42EG	X	7	15	Poly-Si	CMOS	SOIC16 WB	-40°C / +125°C	In production			Analog output
	MMA6900Q, MMA6901Q	*XY*	*2*	*5*	*HARMEMS Overdamped*	*Smartmos8MV*	*QFN 6*6*	-40°C / +105°C	*In development*	*August-09*	*March-10*	Digital output
Medium g	**MMA2201/02/04/44EG**	X	20	100	Poly-Si	CMOS	SOIC16 WB	-40°C / +105°C	In production			Analog output
	MMA3201/02/22/24EG	XY	20	100	Poly-Si	CMOS	SOIC20 WB	-40°C / +125°C	In production			Analog output
	MMA62xxEG, MMA62xxAEG	XY	20	100	HARMEMS Overdamped	Smartmos8MV	SOIC20 WB	-40°C / +105°C	In production			Digital/Analog output
	MMA68xxQ	*XY*	*20*	*100*	*HARMEMS Overdamped*	*Smartmos8MV*	*QFN 6*6*	*-40°C / +125°C*	*In development*	Now	*February-10*	Digital output
High g	**MMA1200/11/12EG**	Z	20	250	Poly-Si overdamped	CMOS	SOIC16 WB	-40°C / +125°C	In production			Analog output
	MMA2300EG	X	100	400	Poly-Si	CMOS	SOIC16 WB	-40°C / +125°C	In production			Analog output
Integrated Satellites	**MMA82xxEG**	X or Z	100	250	Poly-Si	Smartmos8MV	SOIC16 WB	-40°C / +125°C	In production			DSI Protocol
	MMA5xxxQ	*X or Z*	*60*	*480*	*HARMEMS or Tetter Totter*	*Smartmos8MV*	*QFN 6*6*	*-40°C / +125°C*	*In development*	*Now*	*April-10*	*PSI5 1.3 Protocol*

(*) Dates provided for Information purpose only, can be modified without any further notice

Passenger detection / Roll-over mitigation / Active suspension
Electronic Stabilty Control (ESC) applications / Accurate tilt monitoring
Airbag Main ECU crash detection / Safing / Active suspension
Airbag Satellite Modules

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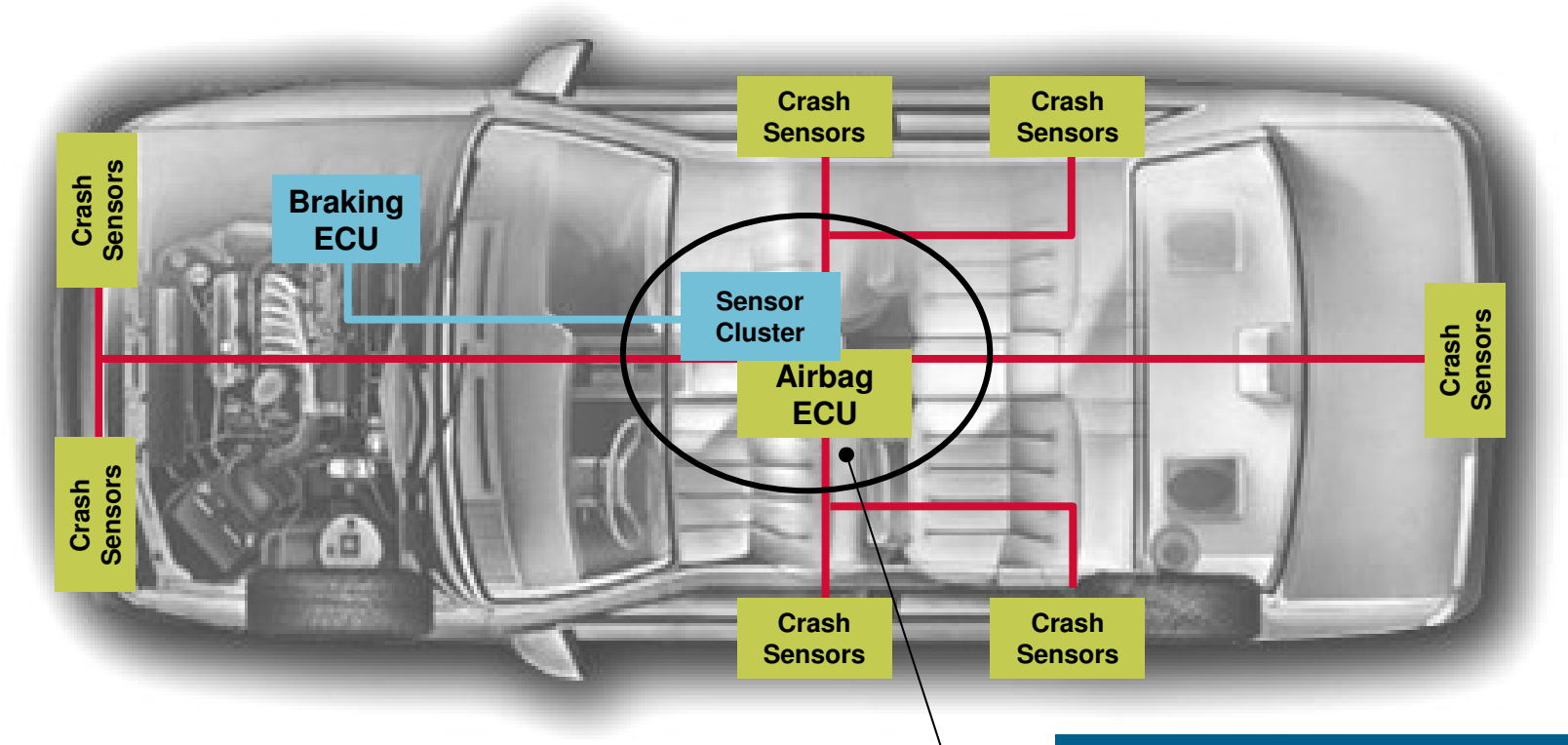
Next Trend: Passive and Active Sensors Merge



Multiple modules sharing the same spot!
Possibility for optimization and cost reductions

CAN bus

Dedicated Airbag bus (DSI or PSI5)

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Conclusion

- Automotive trend is towards more Safety: with Airbag and now Vehicle Dynamic Control (VDC)
- Freescale is a key player in MEMS market and offer solutions for VDC
- Simulation & Modelling tools are key to develop the next generation of devices
- Airbag and VDC modules are merging together
- Long term Vision: Complete System Integration like VDC and/or airbag

Thank you !

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