ESSCIRC/ESSDERC 2020 Presentation

Pushing the limits of MEMS

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Outline

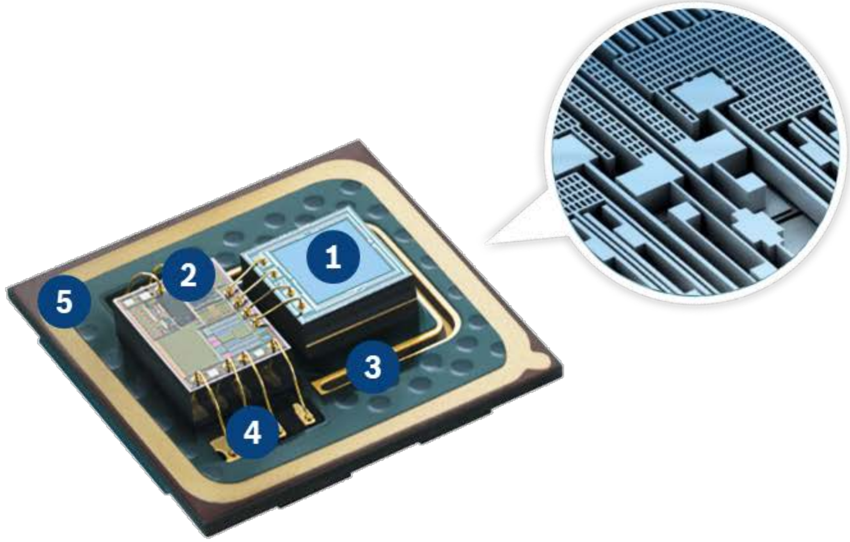
1. MEMS markets
2. Challenges with designing MEMS
3. Model Based Systems Engineering

   Three examples
4. Summary

A Silicon based sensor technology

Micro-Electro-Mechanical Systems

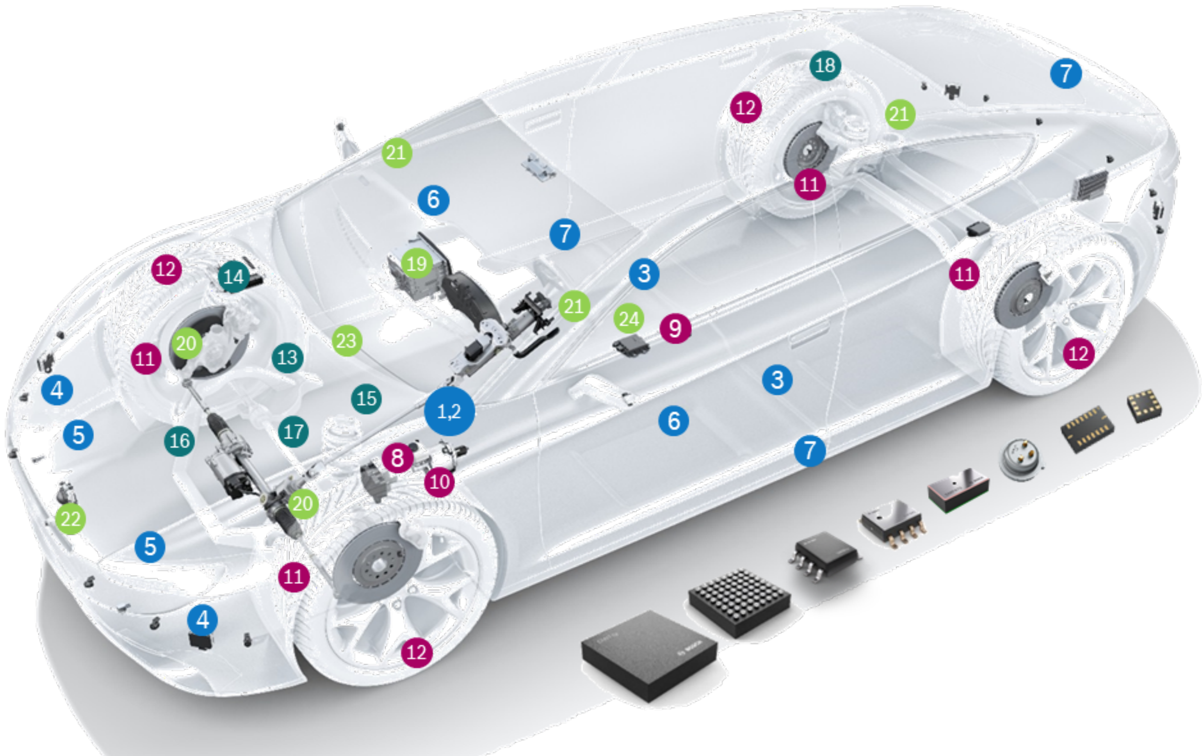
- MEMS are miniature systems that combine tiny mechanical structures with electronic circuits. Typical individual structures have a size of a few µm.
- The MEMS sensor element is usually packaged together with an ASIC and made into one unit, e.g. into an LGA package.



1. MEMS
2. ASIC
3. Decoupling unit
4. Bonding wires
5. Printed circuit board (PCB)

Automotive MEMS applications

More than 50 MEMS sensors per car

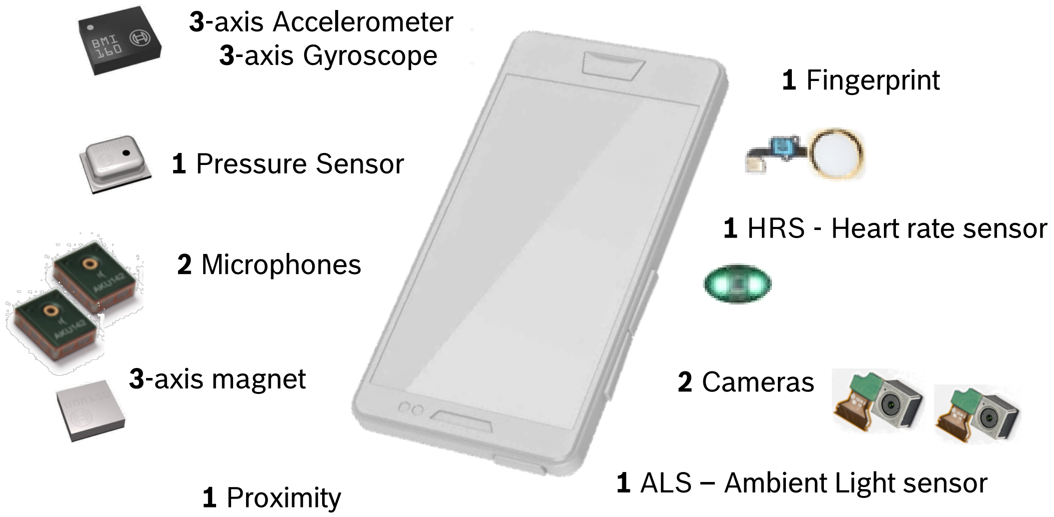


Passive Safety	
1	High G acceleration sensor for AB-ECU and eCall
2	Rollover sensor for Airbag ECU
3	Occupant weight senor or pressure sensor
4	PTS – Pedestrian tube sensor
5	UFS - Upfront sensor
6	PPS - Peripheral pressure sensor
7	PAS - Peripheral acceleration sensor
Active Safety	
8	Inertial sensor für ESP, RSC, RoSe
9	MM – Sensor cluster for ESP (accel + gyro)
10	High pressure sensor for ESP
11	Low G acceleration sensor for active suspension
12	TPMS- Tire pressure monitoring system
Power Train	
13	MAP – Manifold air pressure
14	BAP – Barometric air pressure
15	Medium Pressure for transmission
16	Mass flow sensor
17	High pressure sensor for fuel injection
18	Tank pressure sensor
Comfort Functions	
19	Inertial sensor for navigation
20	Motor damping / noise cancellation
21	Microphone
22	Night vision
23	Gas / air quality
24	Alarm

MEMS sensors improve our mobility – safe, comfortable and economically

Automotive MEMS applications

2015
< 18 Sensors



2020
< 25 Sensors

Sensors open up new degrees of freedom for innovative features and APPs

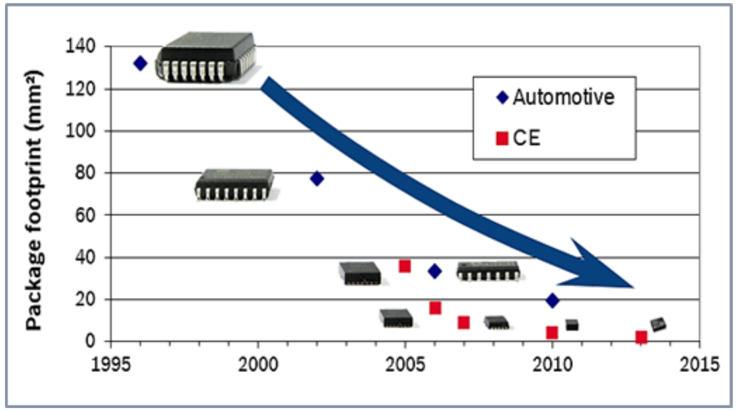
Global MEMS market forecast 2023*

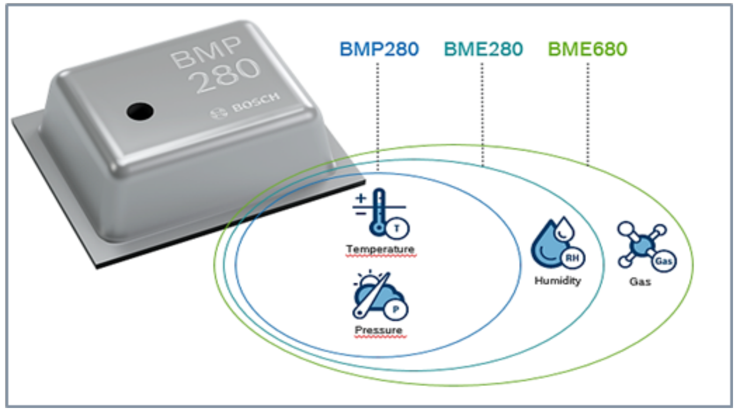
*) Source: Yole Status of the MEMS Industry Report 2018

88 billion sensors – The heart of multiple applications world-wide!

MEMS technology innovation

Size / power	Integration / µC + software	New measurants
Continuing shrinking of sensor size and power consumption (e.g. accelerometer)	**Multi-axis sensors + µC + SW in single combo packages** (e.g. motion / orientation)	**Rise / emergence of novel sensor clusters (T, p, H, …)** (e.g. environmental cluster)





MEMS technology is ready for IoT

Market drivers

Smaller
- Size causes cost
- Size limits design

Smarter
- Integrated data processing
- Embedded software / algorithms
- Functionality for use cases

Ultra low power
- Allways-on applications
- Power management

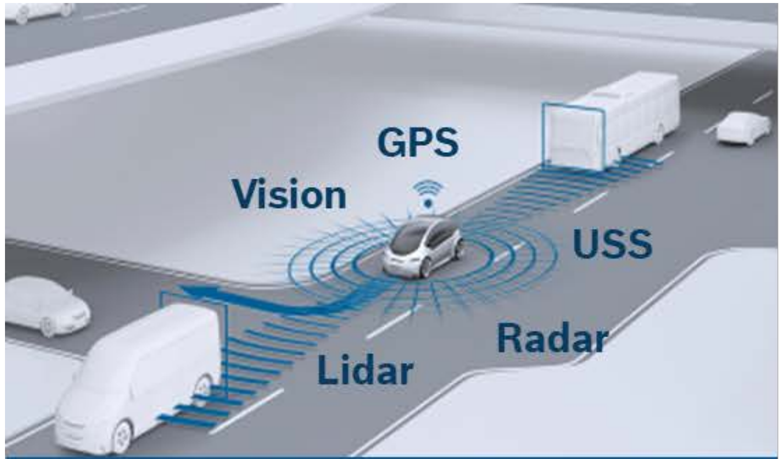
New measurants
- Environmental data
- Imaging

Performance
- Higher accuracy
- Lower noise

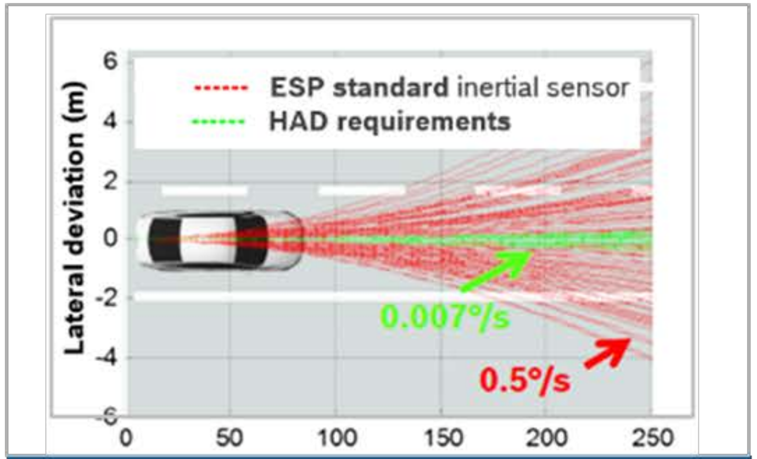
Connectivity
- SPI, I²C, MIPI I3C, GPIO
- BTLE, WiFi, LoRa for IoT, I4.0, ...

Motivation: Highly automated driving

- Localization based on satellite and sensor data fusion – Cam, USS, Radar, Lidar
- Secure safe-stop requires relative **short term localization with high precision**
- Localization can be realized with high performance inertial sensors
- **Key features for inertial navigation: high offset stability and low noise**



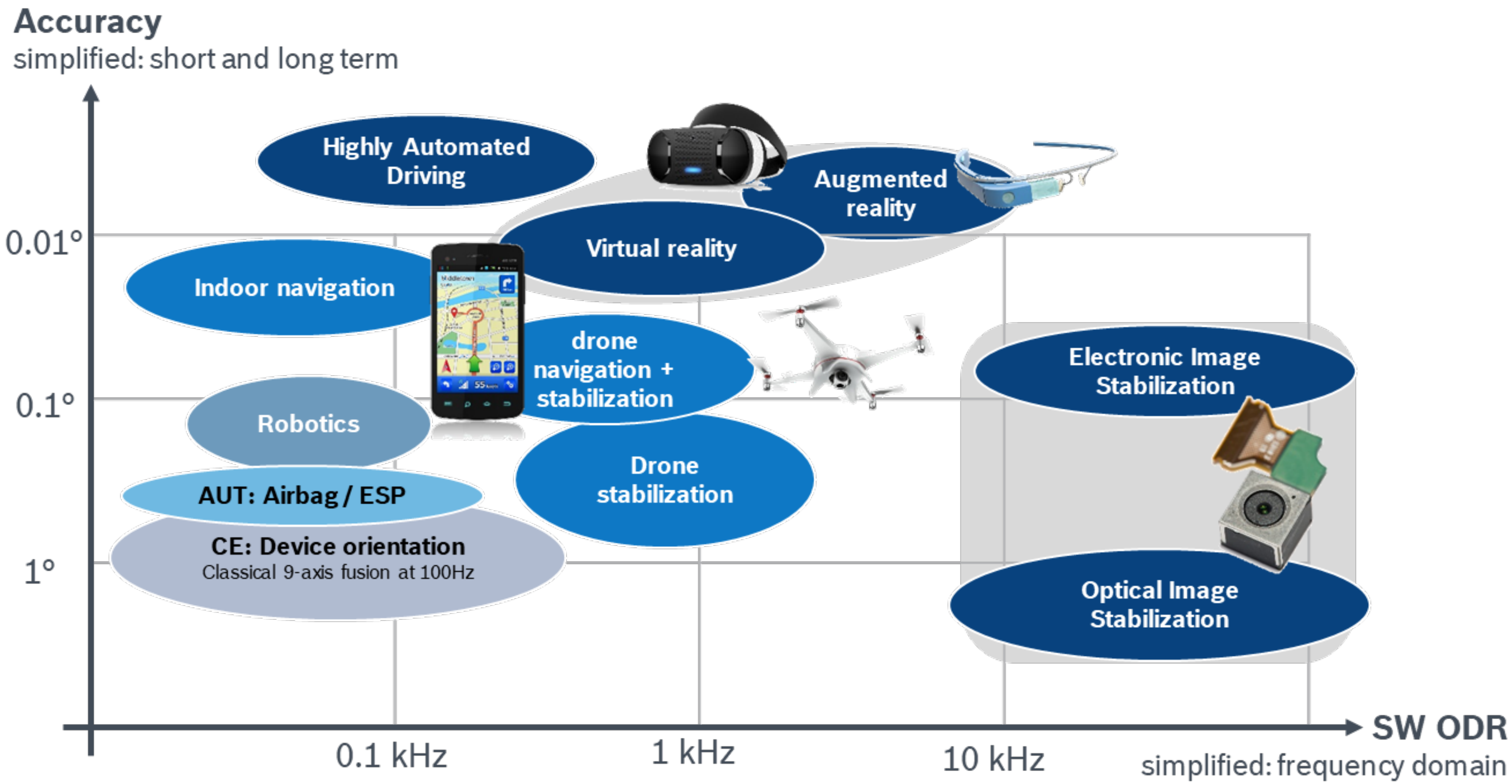
Sensor fusion for HAD



@ 100km/h: up to 4m error / 9s


Navigation error (offet drifts)

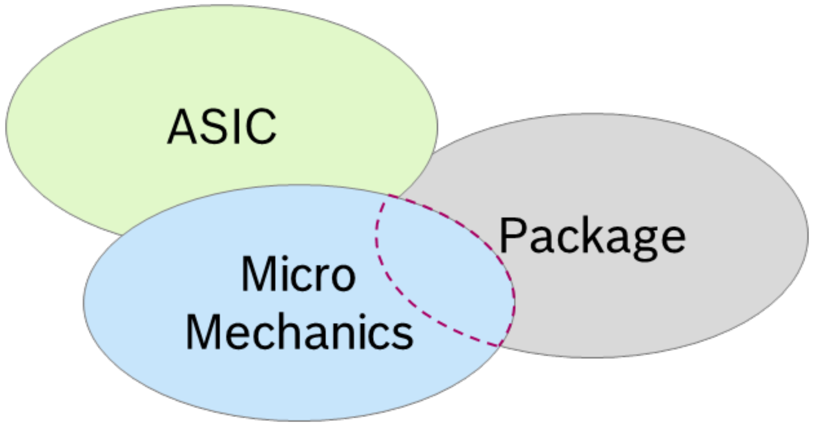
Motivation: High-performance

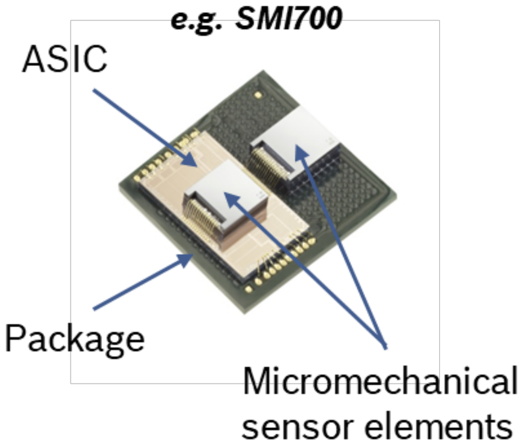


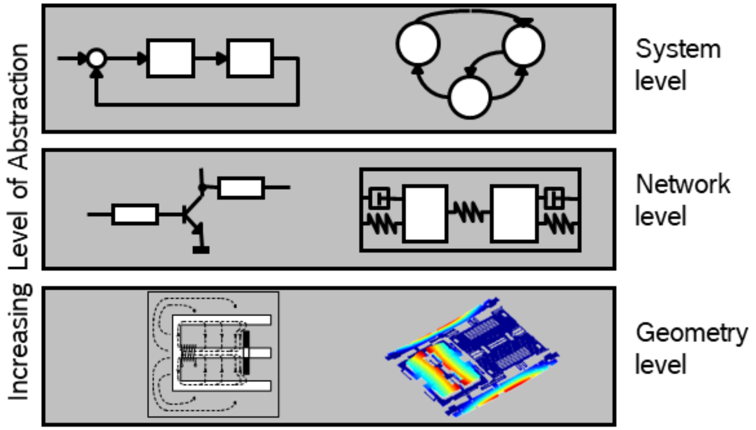
Challenges in MEMS development

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Strong interactions of the different domains:







A reliable system model on a suitable abstraction level considering all relevant domain interactions is the key

Challenges in MEMS development

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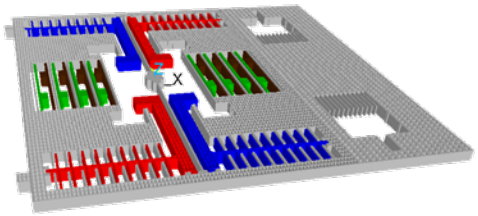
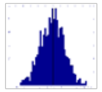
Cause effect chains for basic MEMS sensor parameters:

MEMS

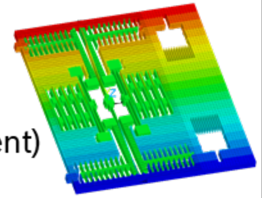


MEMS Model

fnc(process)



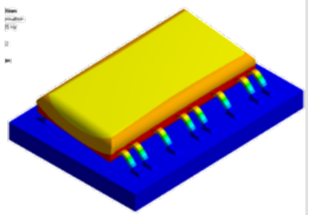
fnc(material parameter)
fnc(temp. / temp. gradient)
fnc(...)



→ FEM simulation time

→ **Reduced order model**

Package



FEM Model

fnc(process)
fnc(temp)
fnc(bending)
fnc(...)

→ e.g. mech. stress

→ e.g. parasites

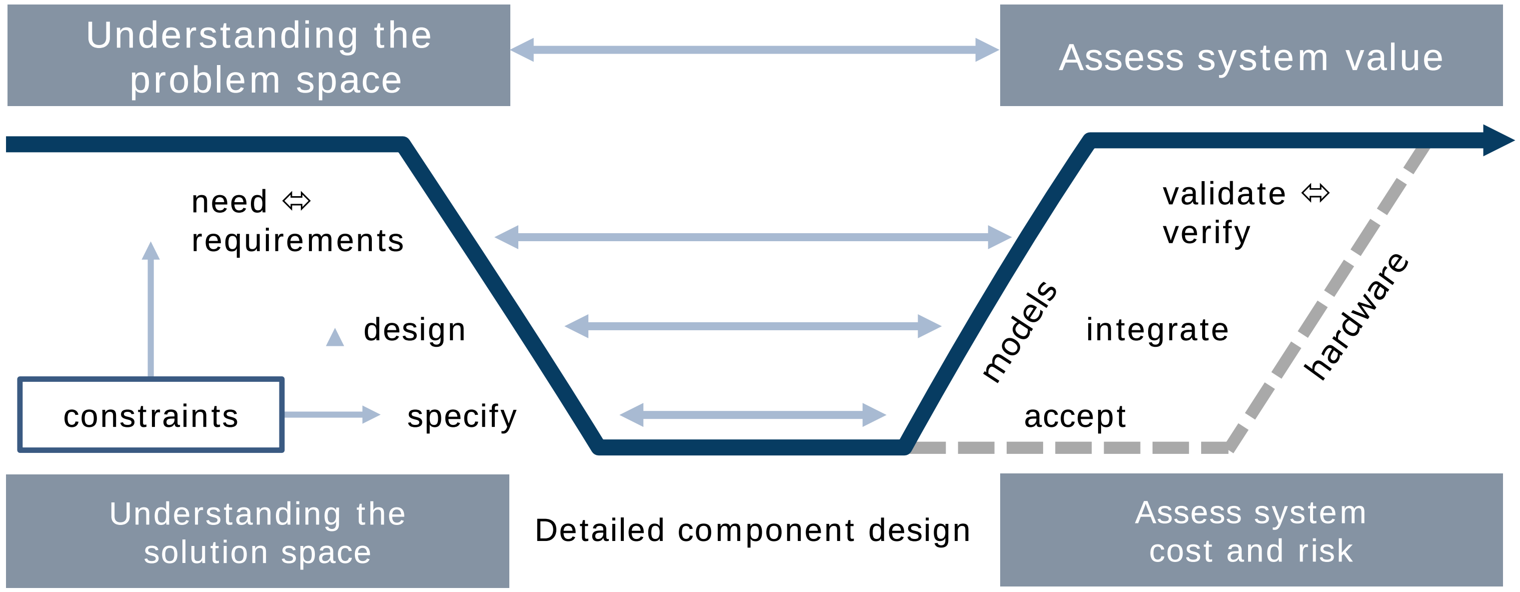
System model

ASIC

ASIC Model

fnc(process)
fnc(material parameter)
fnc(temp. / temp. gradient)
fnc(...)

Model based systems engineering



Systems engineering

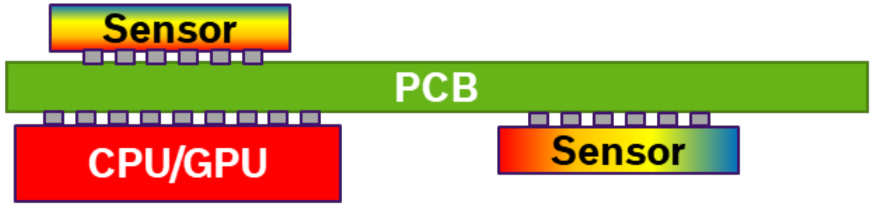
- Big picture thinking
- Divide and conquer

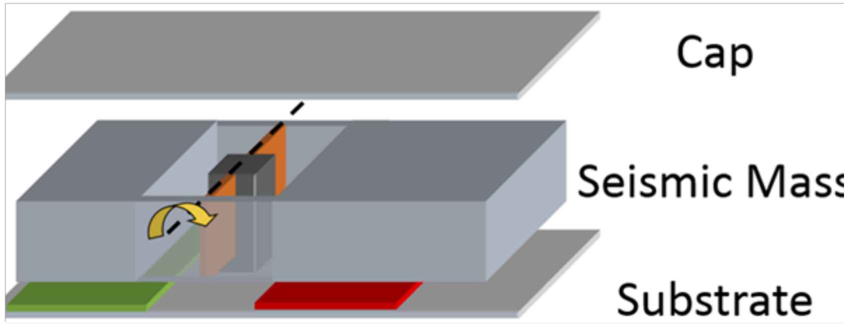
Model based design

- Validate assumptions or theories
- Acceptance criteria for verification

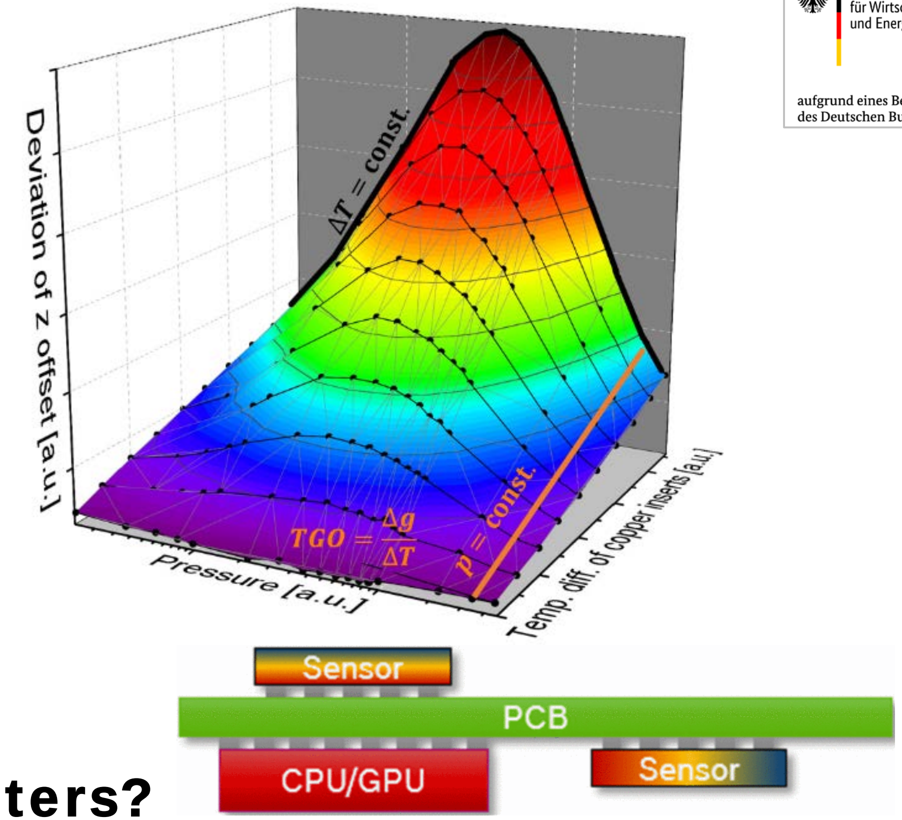
Model based systems engineering (MBSE)
allows to design the right system for the customer

Example 1: Radiometric effects





Standard process with asymmetric teeter totter



What are radiometric effects in MEMS accelerometers?

- Heat sources lead to **temperature gradients**
- Temperature gradient over the accel core leads to a **differential artificial offset signal**

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Example 1: Radiometric effects

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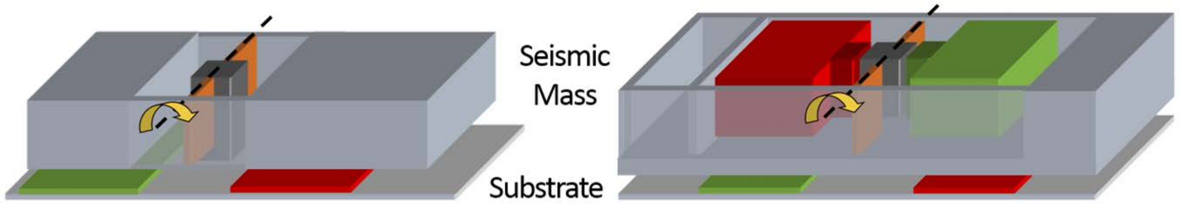
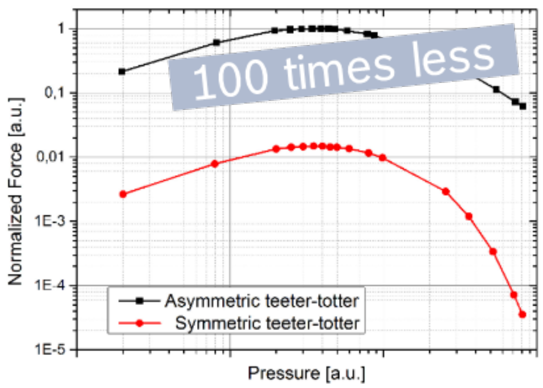
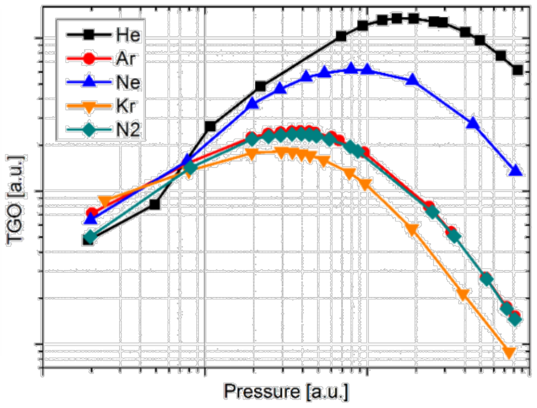


Standard process with **asymmetric** teeter totter

Enhanced process allowing **symmetric** teeter totter structure



Ratiometric effects
(asym. vs. sym. structure)



Gas influence on TGO

- **Symmetrized teeter totter structure**
  - Reduces radiometric effect
  - Possible with new Bosch PSO7 process
- **Correct selection of gases also reduces the TGO effect**

Enhanced MEMS processes enable new design approaches to reduce offset drifts in out of plane accelerometers due to radiometric effects

Example 2: Bending robustness

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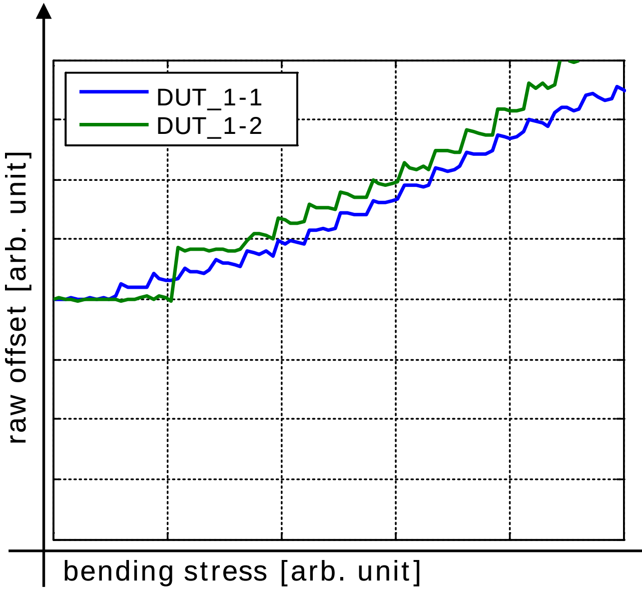

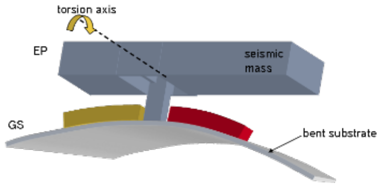

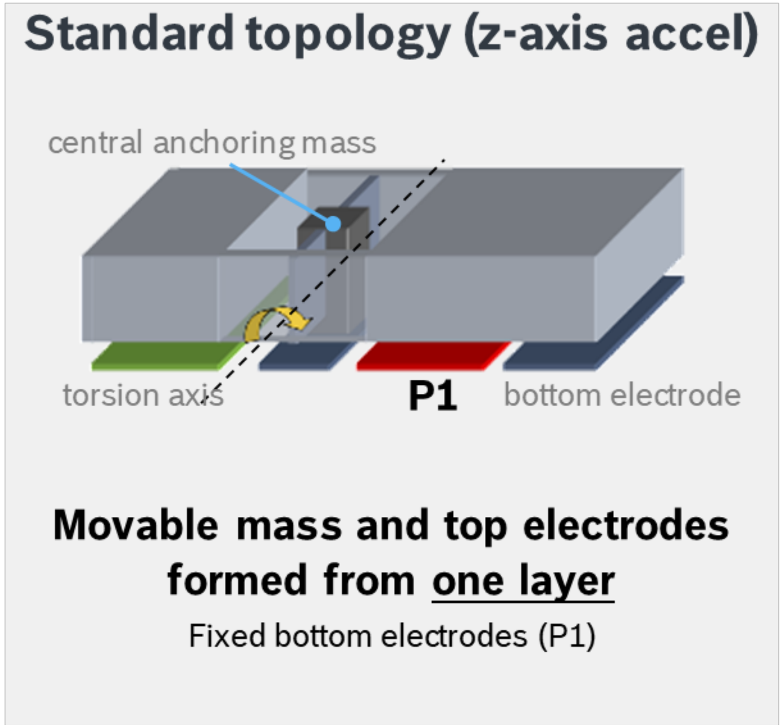

What is stress sensitivity in MEMS?

- Bending & stress leads to, e.g., **change of gap**
- Change of the gap leads to a **change of the raw offset**

Example 2: Bending robustness

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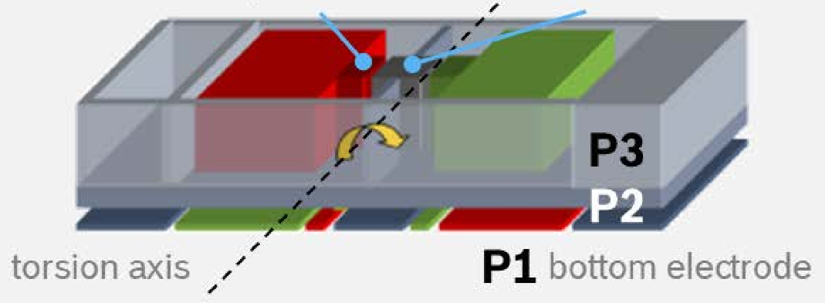
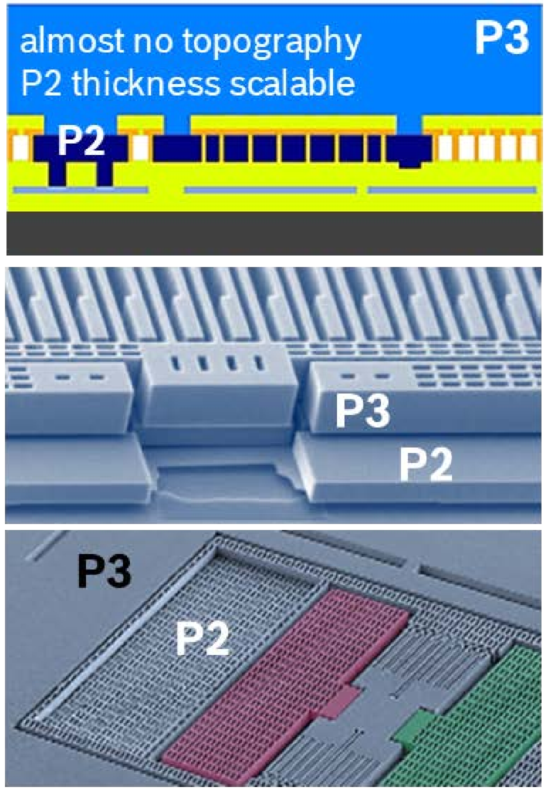
New topology (z-axis accel)

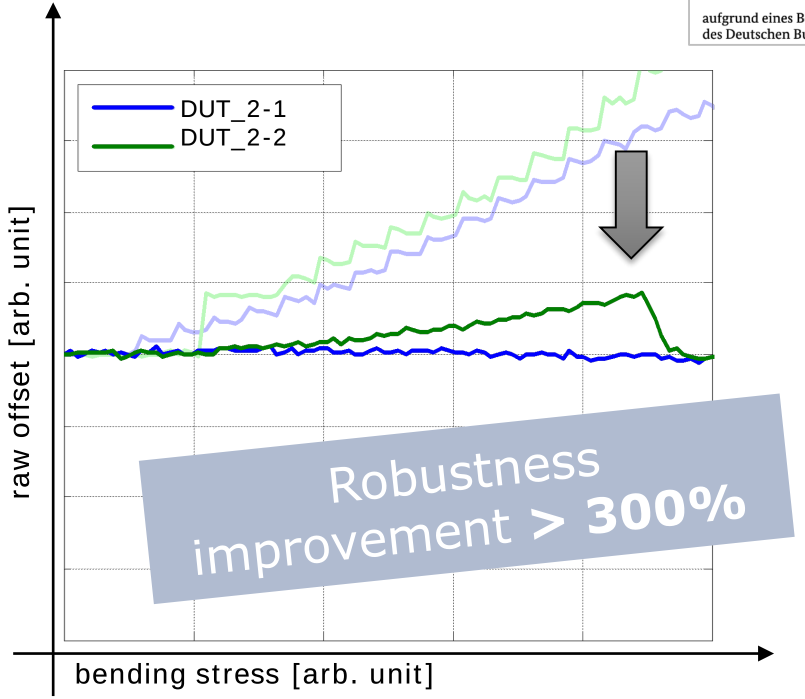


Movable mass and top electrodes formed from dual layers

Movable mass (P2, P3) and electrodes (P2)

Fixed bottom and top electrodes (P1, P3)





Significantly improved sensor performance (stress robustness, solder drift, TCO)

P2 layer thickness can be scaled → higher flexibility due to lack of topography

IPCEI on Microelectronics

Example 3: Low bias instability

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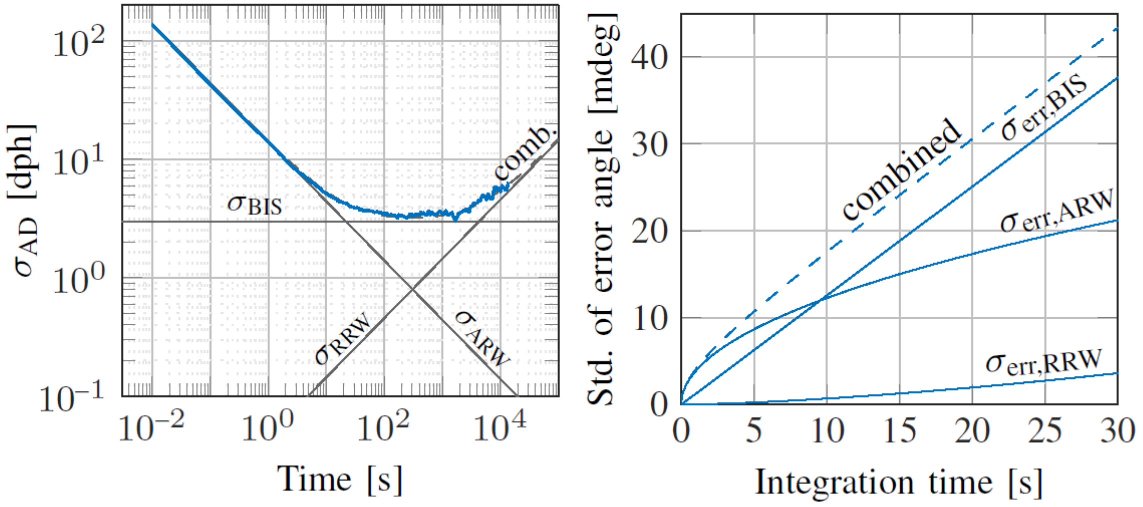


Allan variance and angle error (std.) of integrated rate signal. "State of the Art".

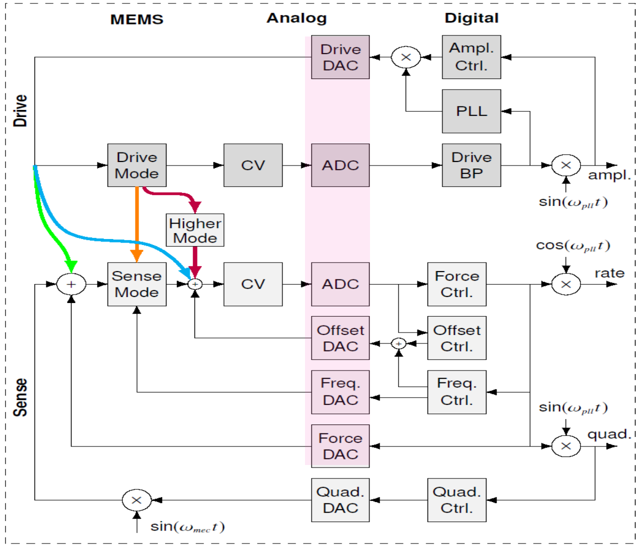
Normal vs. high performance IMU

What is bias instability (BIS)?

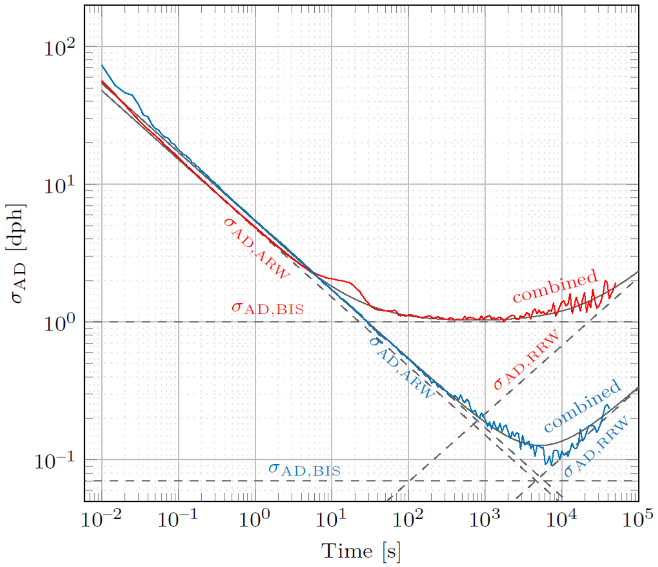
- A measure of slow fluctuations in sensor signal without external stimulus
- Fluctuations are integrated and lead to orientation errors
- Quantified by Allan variance: Has a 1/f or "pink" noise characteristic in power spectrum density

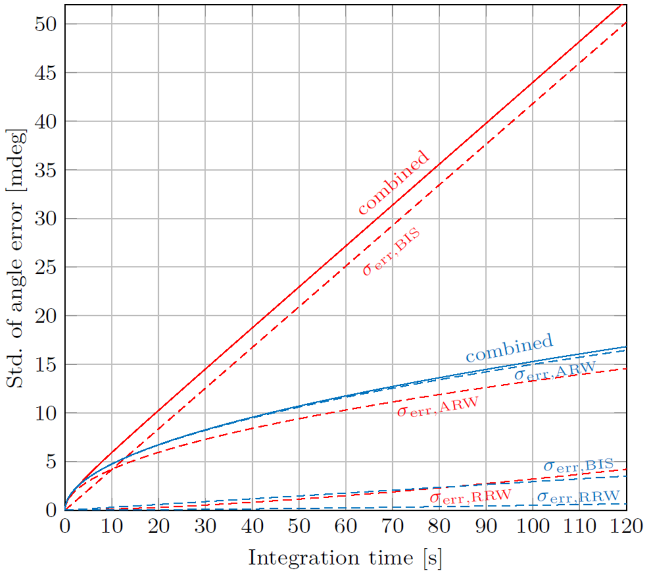
IEEE SSCS Electron Devices Society BOSCH

Example 3: Low bias instability



"Long-Term System Simulation" – Schematic.





Allan variance and angle error (std.) of integrated rate signal.

- BIS root cause: **Flicker noise** on tuning voltage + a **mechanical cross-coupling** offset
- Verified through comparison between measurements and simulation
- Control of **frequency** split by e.g. pilot tones reduces effect

More than 10x improvement → sub 0.1 deg / h possible

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Bosch Semiconductor locations

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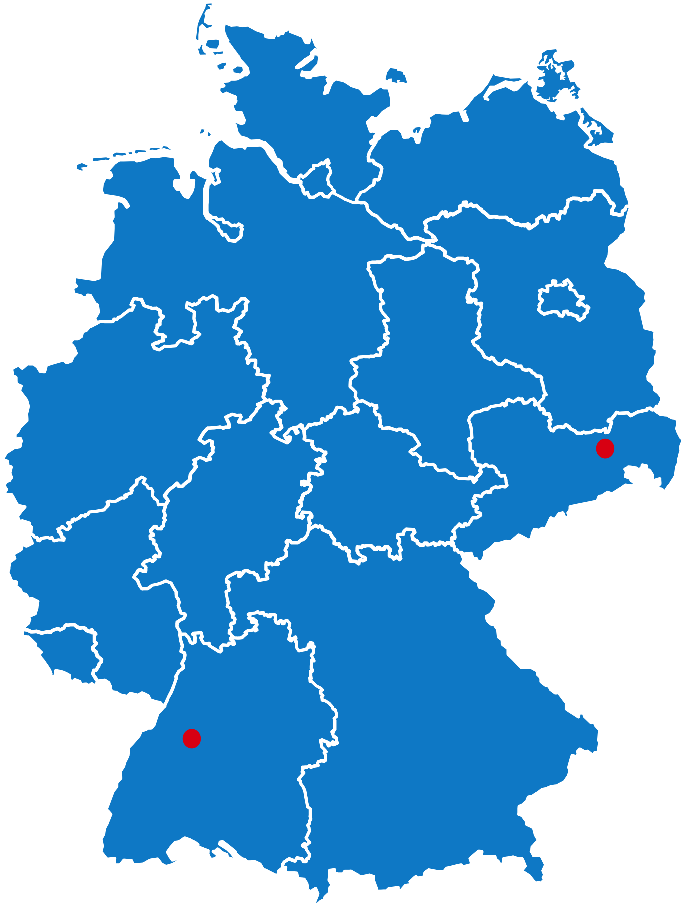
REUTLINGEN

Wafer size 150 mm, 200 mm
Floor space 12 000 m²
Nodes 1 µm … 180 nm
Technologies: Mixed signal, Power MOS, **MEMS**



DRESDEN

Wafer size **300 mm**
Floor space 10 000 m²
Nodes 180 … 65 nm
Start technology: **Mixed signal, Power MOS**

The SC ecosystem in Dresden

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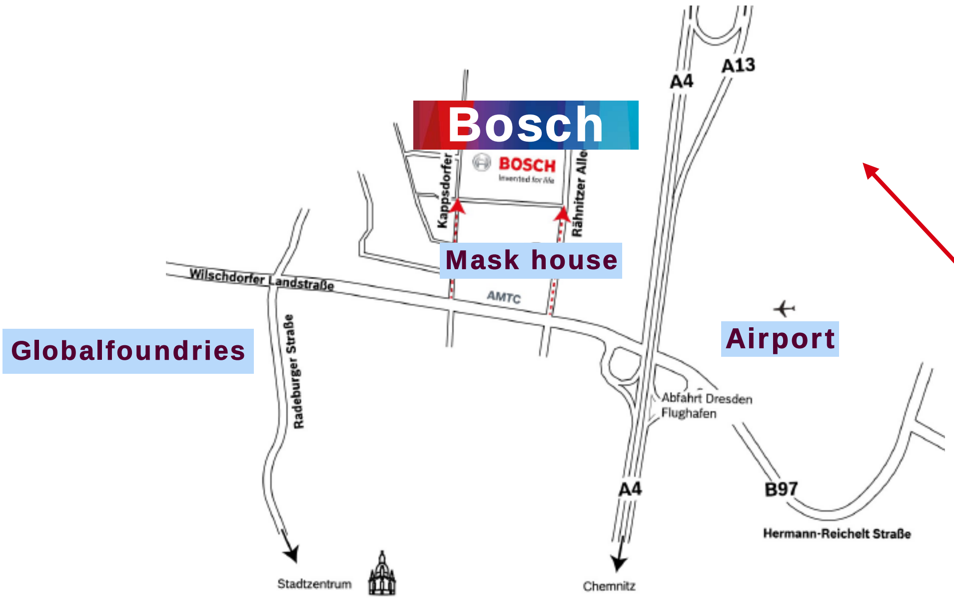
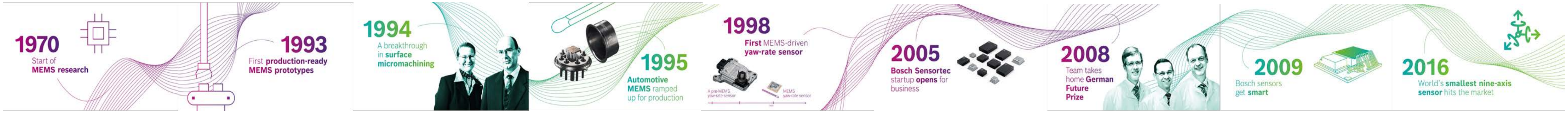
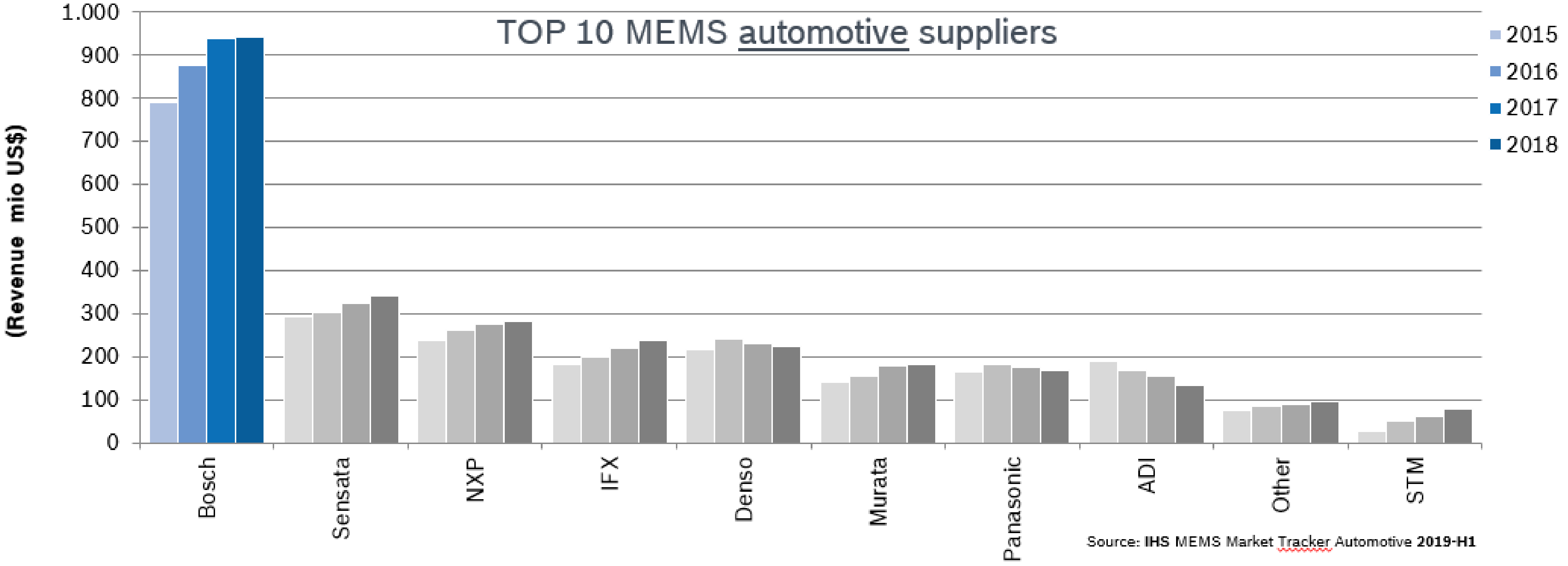


MEMS – enabling technology

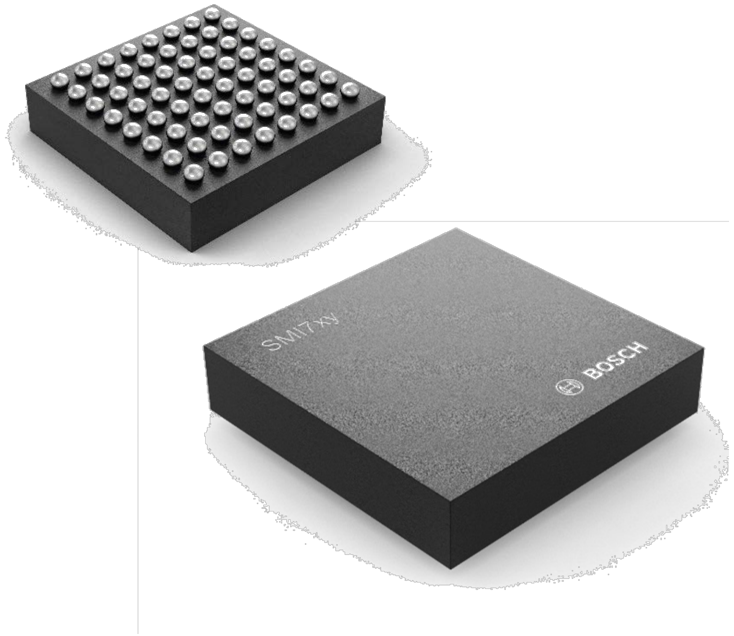




Source: IHS MEMS Market Tracker Automotive 2019-H1

Summary

- MEMS devices are a huge and still growing market
- Designing of MEMS devices is very challenging
  - Complex interaction of micromechanics, ASIC and packaging
- Model based system engineering allows to design the right system based on customer needs



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