Challenges in the development of MEMS sensor ASICs for consumer and automotive market

Dr. Dirk Droste, Bosch Sensortec

Agenda

- Bosch
- Bosch Sensortec
- Market and Applications
- Technical Challenges
  - MEMS-IC Design
  - Integration
  - Miniaturization
- Conclusion

2013 key figures

Bosch Group	→ 46,1 billion euros in sales → 281,000 associates		
Automotive Technology	→ World's largest supplier of cutting-edge automotive technology	66 % share of sales	
Industrial Technology	→ Leading in drive and control technology, packaging and process technology		
Energy and Building Technology	→ Leading manufacturer of thermo-, solar- and building security technology → World's largest supplier of heat pumps	34 % share of sales	
Consumer Goods	→ World's largest power tool manufacturer → Leading the field in household appliances		

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Bosch – the MEMS supplier

Out of one hand MEMS sensors, actuators and solutions

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CE

- Accelerometers
- Geomagnetic sensors
- Gyroscopes
- Pressure sensors
- Humidity sensors
- Combo sensors
- ASSNs

Akustica

CE

- MEMS microphones

Bosch Connected Devices & Solutions

CE & Industrial

- Smart sensor/ actuator nodes
- Embedded SW & Algorithms
- Customized IoTS sensor & actuator solutions

Automotive Electronics

Automotive

- Accelerometers
- Angular rate sensors
- Pressure sensors
- Mass flow sensors

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Consumer MEMS success story

2005
First triaxial acceleration sensor

2006
World's smallest digital pressure sensor

2007
World's smallest digital acceleration sensor

2008
Full portfolio of acceleration and pressure sensors

2009
Strongest growing consumer acceleration company

2010
First 2x2 mm² acceleration sensor

2011
6-axis eCompass in 3x3 mm²

2012
World's smallest triaxial gyroscope in 3x3 mm²

Complete 6-14 bit acceleration sensor portfolio in 2x2 mm²

2013
Smallest triaxial acceleration sensor in 1.2x1.5 mm²

9-axis system (incl. µController) in 5.2x3.8 mm²

2014
World's first Integrated Environmental Unit

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Consumer MEMS success story

2007: SMB380 is E&E's "Best Product of the Year"

2008: German Innovation and Advanced Technology Prize

2009

2010: SMB380 is "Product of the Year 2008"

2011: Acceleration Sensor BMA220 is "Product of the Year 2011"

2012: Global Frost & Sullivan Award for Product Innovation

2013: 9-axis Sensor BMX055 is "Product of the Year 2013"

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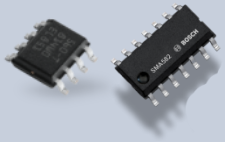
Today's state-of-the-art portfolio automotive

Acceleration sensors

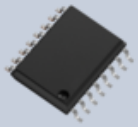
Central/peripheral acceleration sensor
for occupant protection



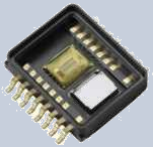
Low-g acceleration sensors
for VDC, RoSe and active suspension

Angular rate sensors

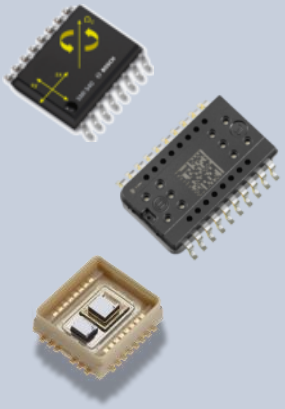
Rollover sensor
for occupant protection



Yaw rate sensor
for VDC



Combined inertial sensors



Pressure sensors

Low pressure sensor
for engine control

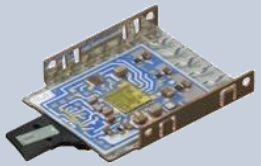
Mid-pressure sensor
for transmission control

Pressure sensor
for occupant protection

High pressure sensor
for engine and brake systems

Mass flow sensors

Mass flow sensor
for engine management



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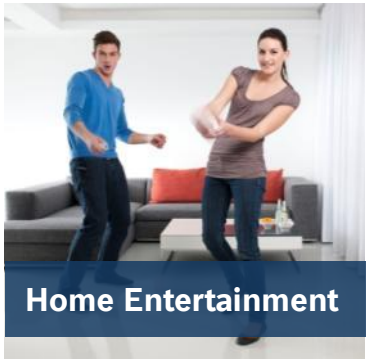
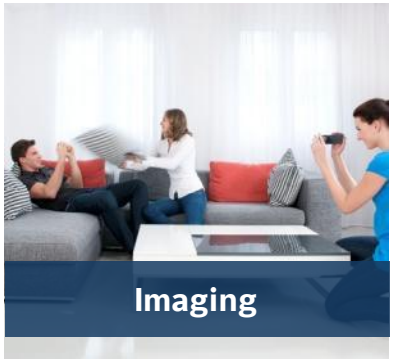
Today's state-of-the-art portfolio consumer

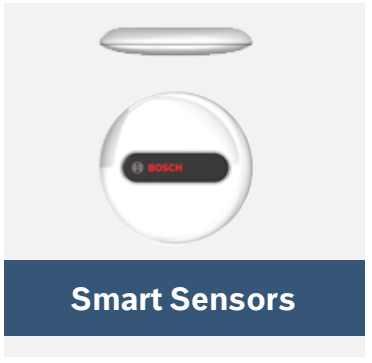
3-axis sensors	6-axis sensors	9-axis sensors	environmental	microphones
				
▪ Accelerometer ▪ Gyroscope ▪ Magnetometer	▪ eCompass ▪ IMU	▪ Absolute Orientation Sensor ▪ Application Specific Sensor Nodes (ASSNs, incl. µC)	▪ Barometric Pressure Sensor ▪ Integrated Environmental Unit	▪ Analog and digital MEMS microphones (Akustica) ▪ High quality voice input for mobile devices

Sensor data-fusion software ties everything together

MEMS sensors – a multitude of markets



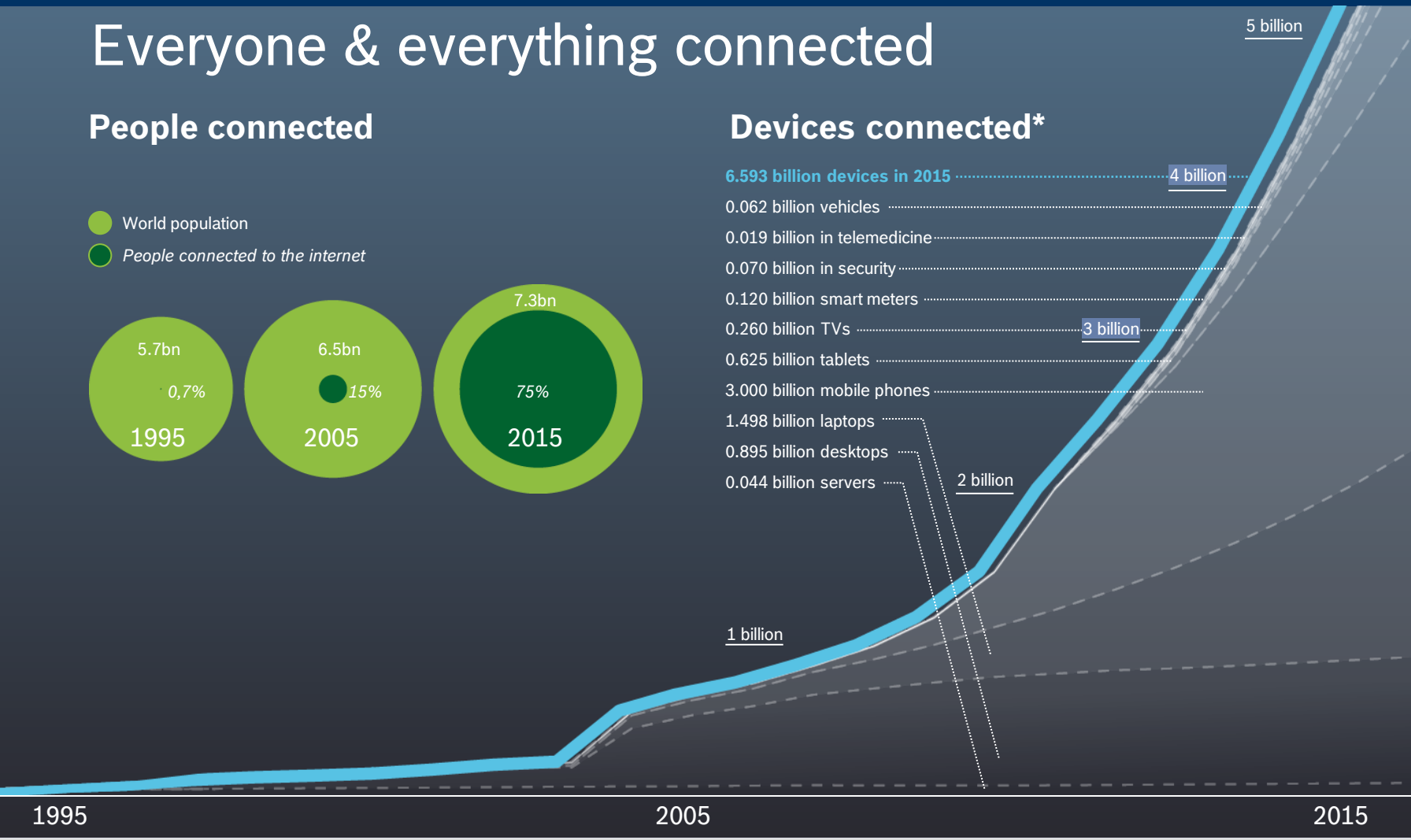




Everyone & everything connected

People connected

Devices connected*



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** Conservative bottom-up estimation*

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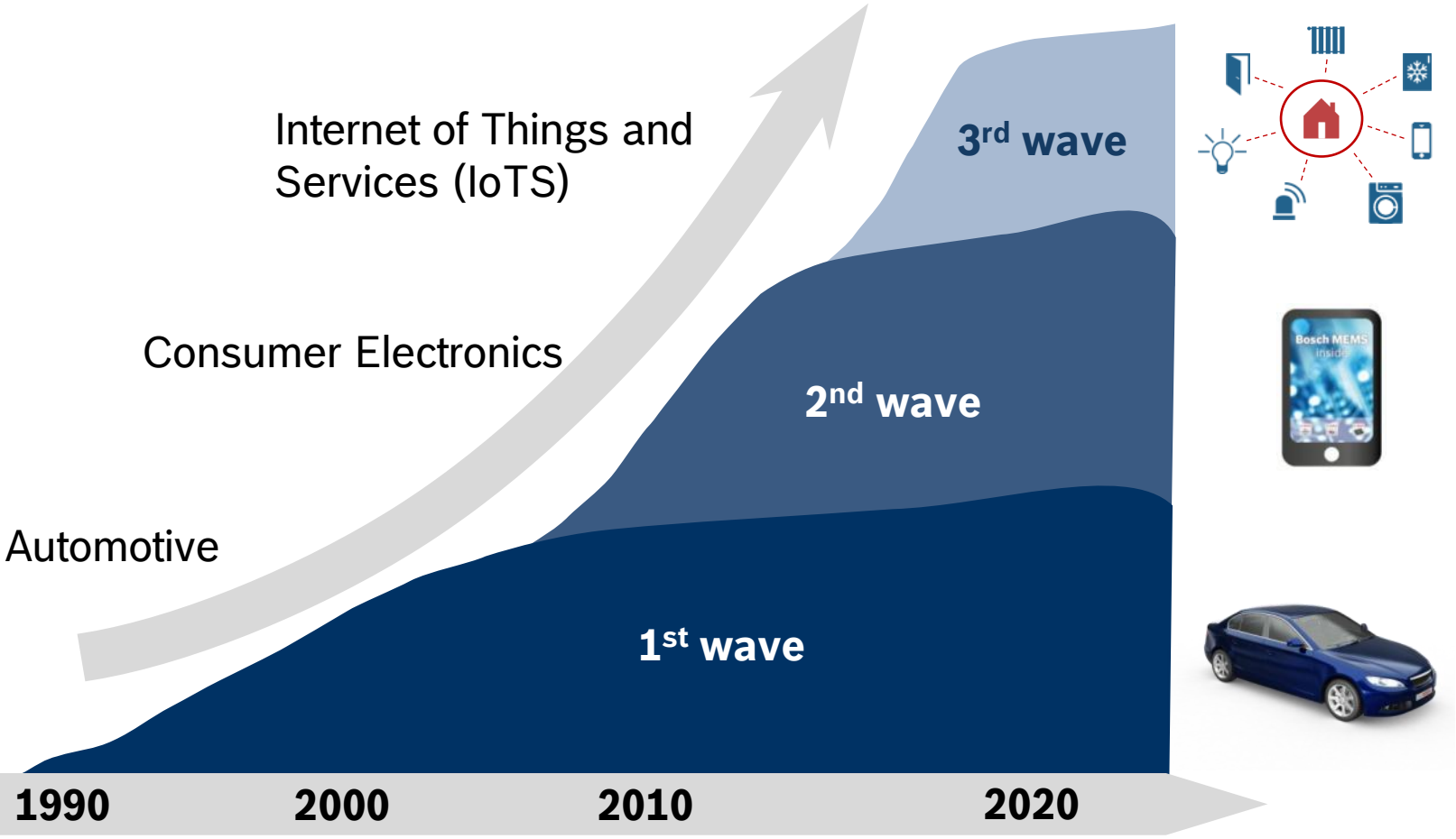
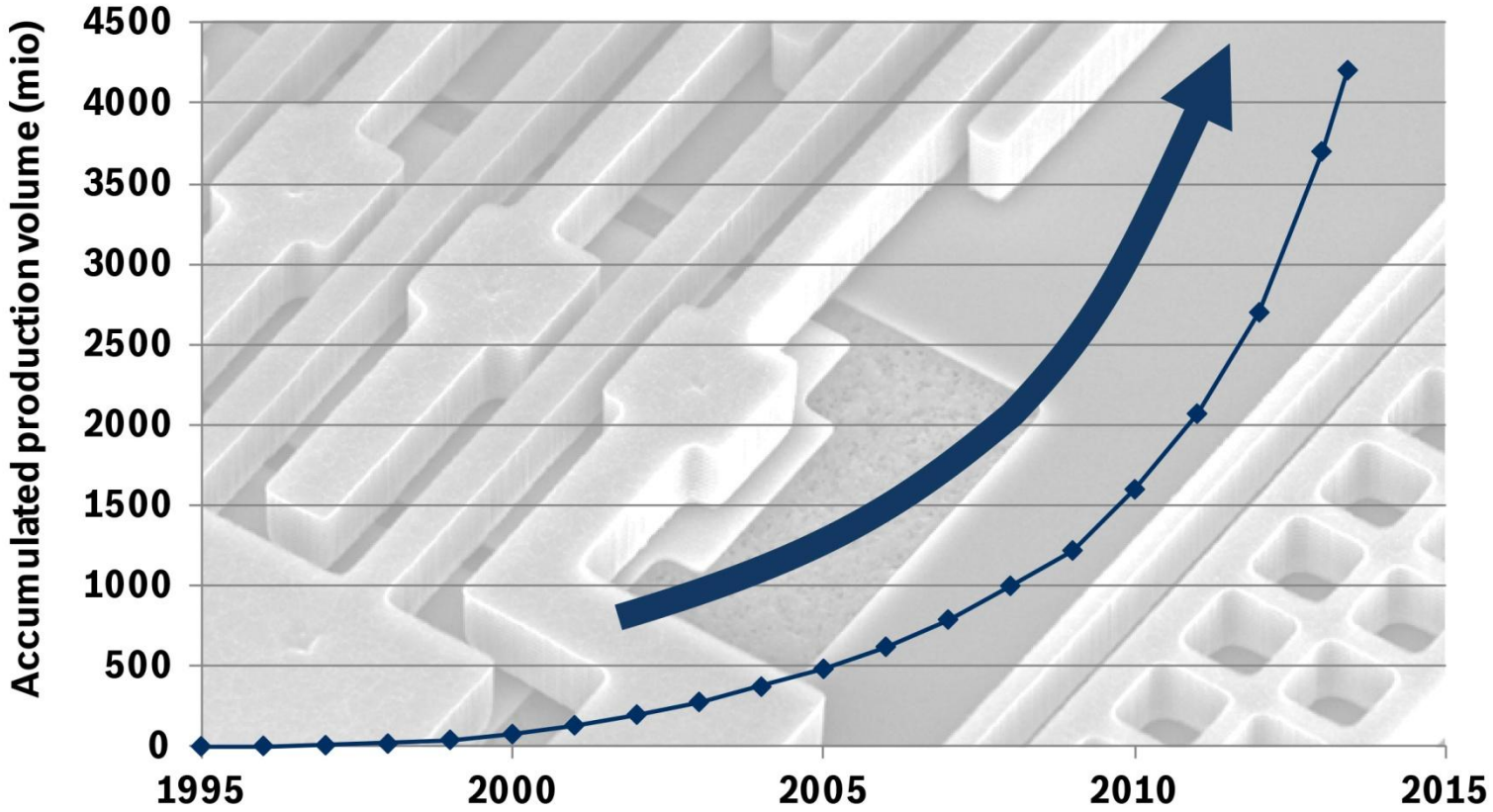
Waves of MEMS sensor proliferation



Volume of MEMS-Production



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Challenges for automotive sensor ASICs

- System Issues
  - Technology Choice
  - Partitioning
  - Interfacing
  - Functional Safety
  - Area / Box size
- Performance Issues
  - Overload robustness
  - Sensitivity stability
  - Offset stability
  - Linearity
  - SNR
  - Power Consumption
- Robustness Issues
  - EMC / active ESD
  - PSRR
  - Supply voltage and impedance variation
  - Temperature stability
  - 50.000h work life cycle
  - ...

Push the limits!

Challenges for consumer sensor ASICs

- Market
  - Extreme TTM requirements
  - Fierce price competition
- Technical Challenges
  - MEMS-IC-design: low-power, low-noise, high accuracy
  - Miniaturization
  - Integration
  - Features
  - Verification
- Application
  - Wide variety of customers
  - Wide variety of application scenarios
  - Non-ideal application environment

Push the limits!

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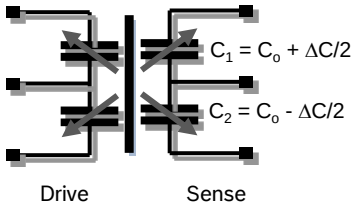
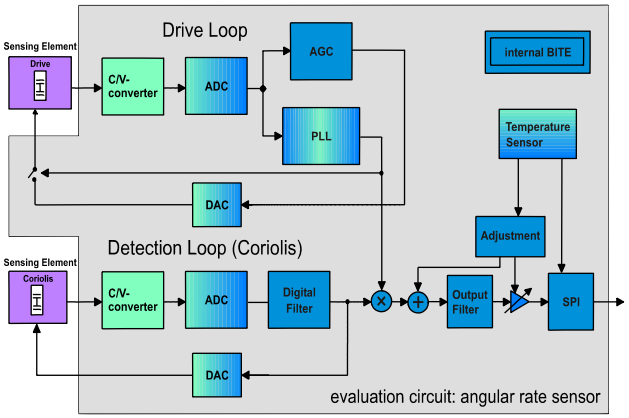
Yawerate Sensing: all the best…

- Noise <0.1°/s
- Overload >1000°/s
- Low offset
- High linearity
- High longterm stability
- High robustness



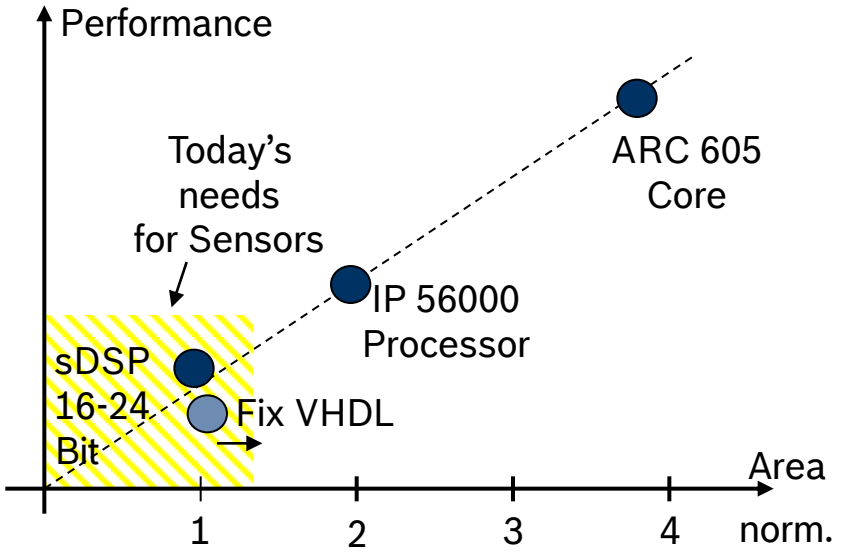


(Circuit schematic removed)

Counting few electrons with high SNR and high robustness (EMI, PSRR, T-Range, …)

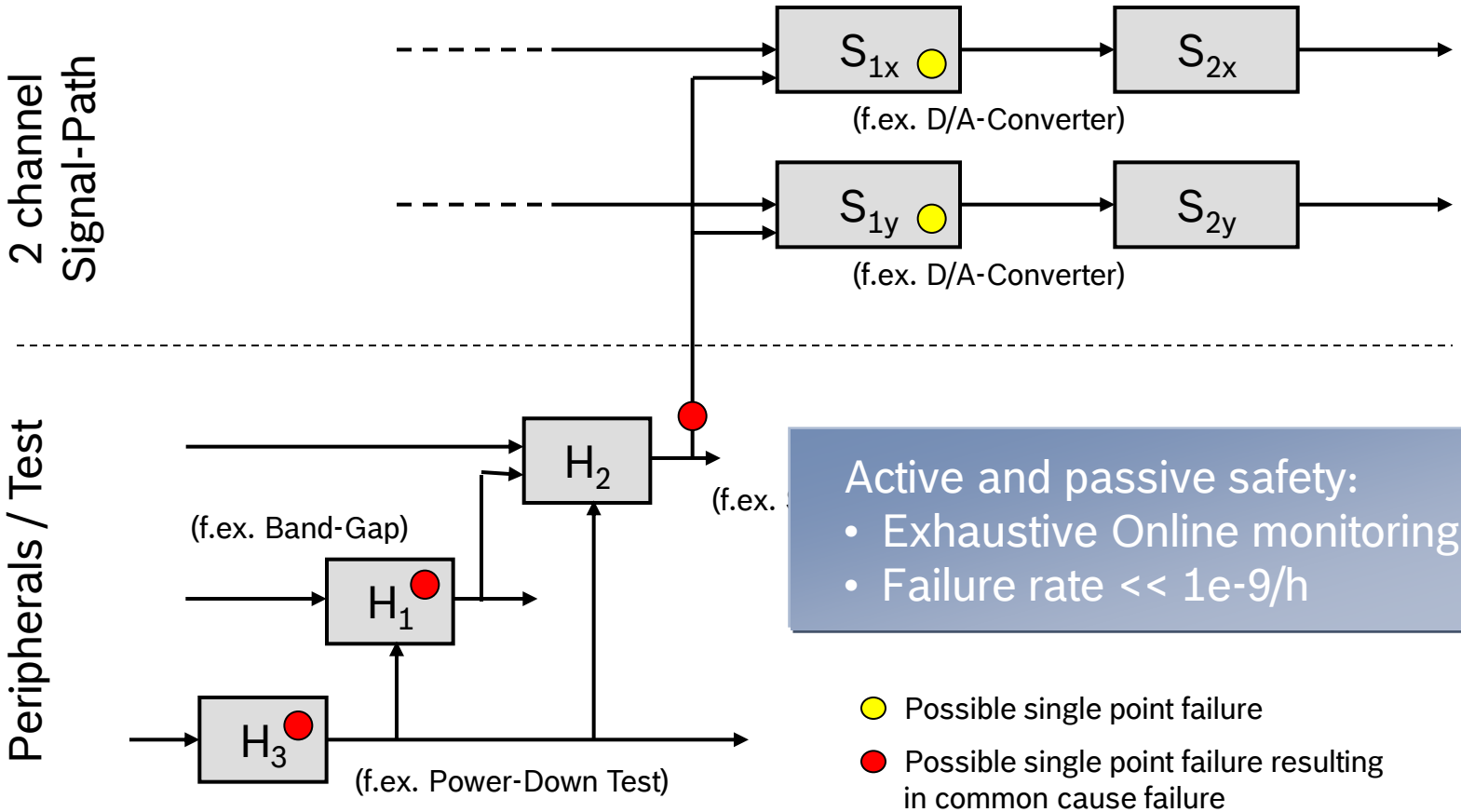
DSPs: smart, modular and scalable approach

- Performance is adapted to signal processing requirements at Bosch automotive or consumer applications
- Enhanced design efficiency
- Seamless verification from system to hardware Level
- Safety features (ISO26262)
- Flexibility (e.g. new functionality by means of ROM-metal fix)



- Performance tailored to application
- Cost-effective solution
- Flexible solution

ISO26262 automotive functional safety



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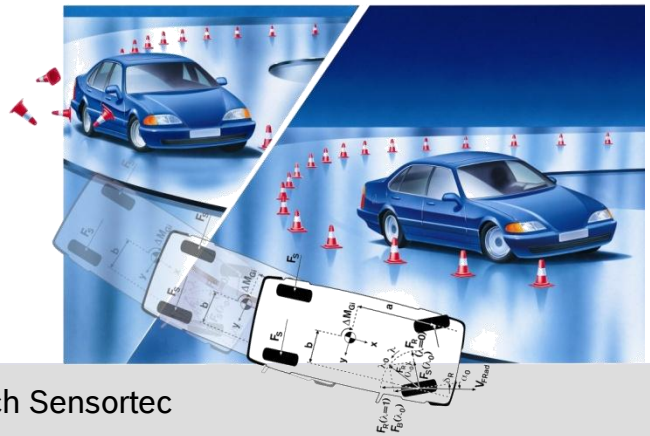
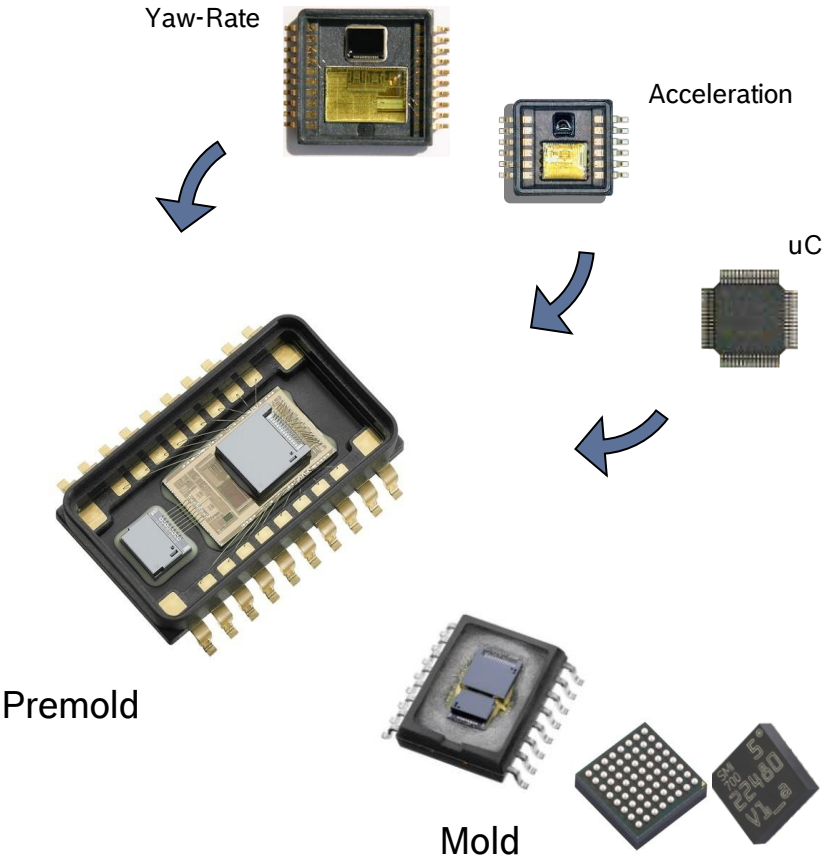
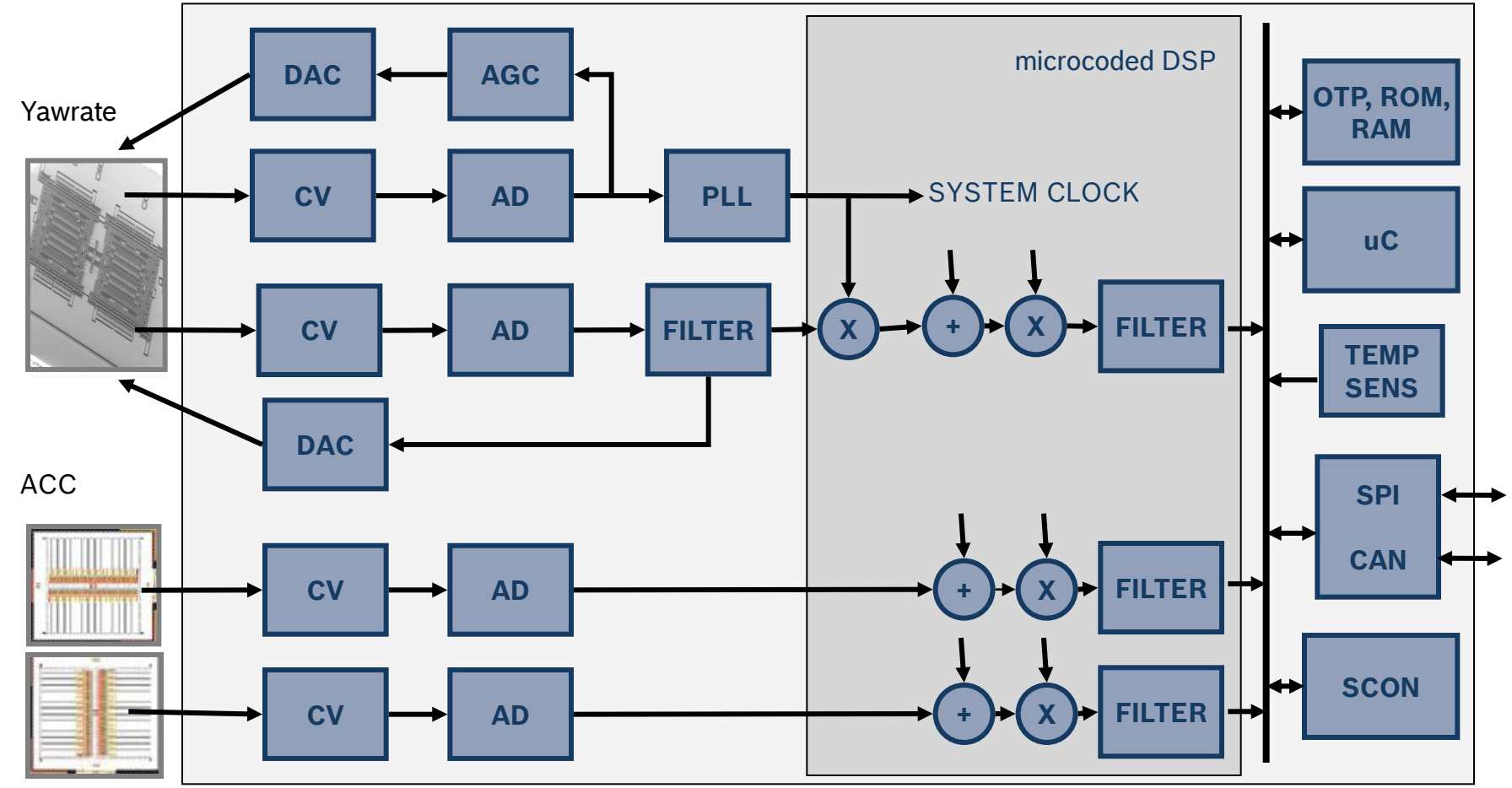
ESP Sensor-ASIC - high integration level, SoC

- Functional Modules on ASIC
  - 2 channel acceleration FE
  - 1 channel yaw-rate FE
  - sDSP for signal processing
  - Internal Bus-System
  - Embedded µC
  - NVM
  - CAN-, PSI and SPI-Interface
  - Full Monitoring & Safety-Control

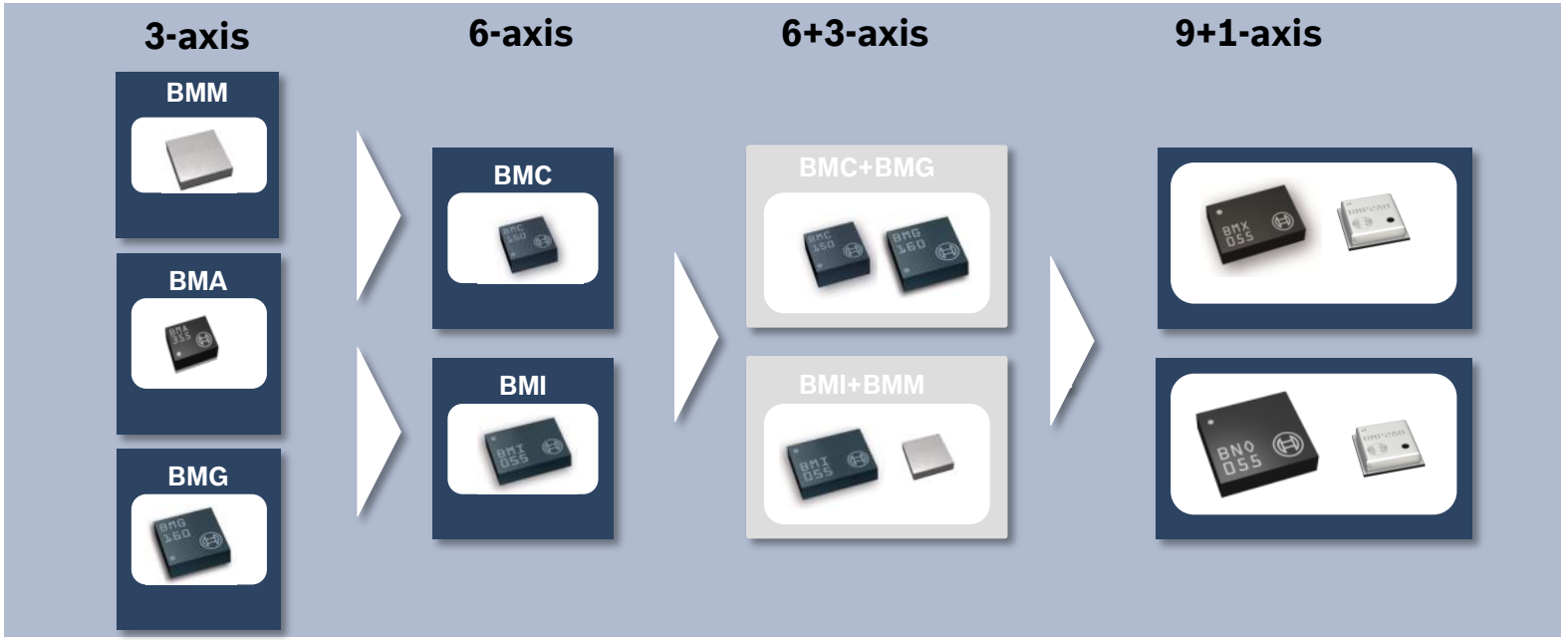




ESP Sensor-ASIC – Functional Block Diagram



MEMS sensor integration/ smart sensors



Different applications require different solutions

*Bosch Sensortec Sensor Data Fusion
**Application Specific Sensor Node

Intelligent absolute orientation sensor - BNO055

First 9-axis sensor with µC + BSF fusion SW

- 3-axis accelerometer (12 Bit)
- 3-axis gyroscope (16 Bit)
- 3-axis geomagnetic sensor
- ARM Cortex µC (32 Bit)
- Bosch Sensortec Sensor Data Fusion with fast magnetic calibration (optimally integrated & tuned)
- 5.2 x 3.8 mm² footprint
- **High performance** (high accuracy, low latency, low calibration time, immune to magnetic distortions)

Augmented Reality | Gaming | Activity monitoring | Navigation | Context awareness | Power management | Home automation | Logistics

BNO055 plus RF interface (WiFi, BT*, etc.) is a key block of IoT based sensing

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* Bluetooth

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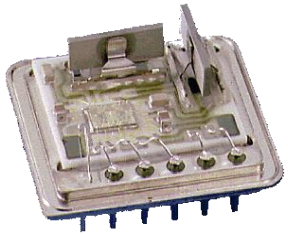
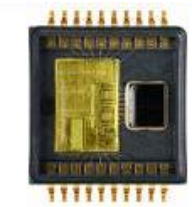
Main challenges for MEMS packages





Cost

- ➔ Metal can
  - Niche product
  - Low stress
  - Very robust package
- ➔ Premold
  - Low stress
  - Robust package
  - Media access
- ➔ Leaded Mold Package
  - Standard
  - Intrinsic stress
- ➔ Leadless Mold Packages
  - Standard
  - Intrinsic stress
  - Stress from PCB - BLR

Mechanical Stress

Automotive ↔ Consumer

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Milestones in packaging technology

➔ Yaw rate sensors automotive

DRS50/100
Precision-mechanics metal housing (Electro-mechanical)

MM1
BMM
- Silicon bulk micromachining metal can
(1st gen.)

SMG06x
SMM – Silicon surface micromachining PLCC44

MM3
Silicon surface micromachining (2nd gen) PM20

MM3R
SMM PM16

SMG10x
SOIC16w

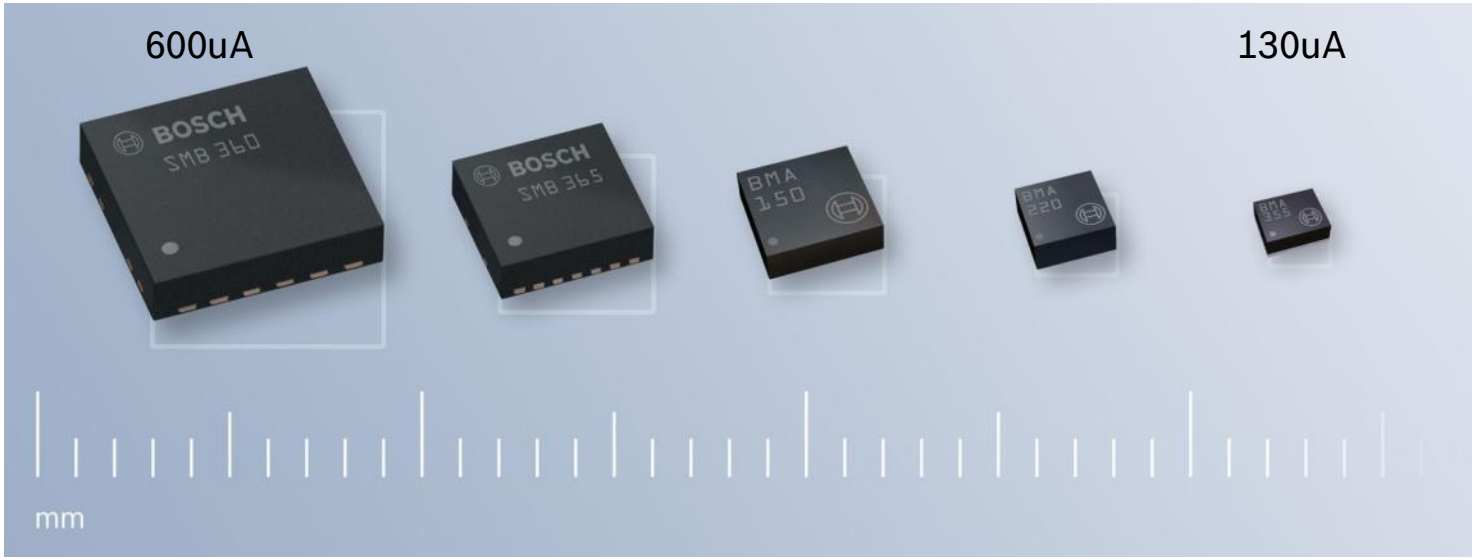
MM4
SMM First ESPi sensor

SMI540
SMM Combo-inertial sensor for ESP in mold-package

SMI7x0
SMM Combo-inertial sensor for ESP in BGA

1995 1998 2001 2005 2009 2013

Consumer miniaturization of accelerometers



Bosch Sensortec 1st with 3x3 mm²

Bosch Sensortec 1st with 1.2 x 1.5 mm²

2005 2006 2007 2010 2013

Bosch Sensortec 1st with 2x2 mm²

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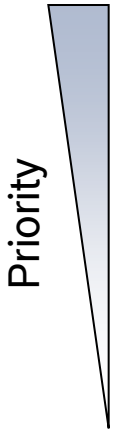
Automotive vs. Consumer Sensor ASICs

	Automotive	Consumer
	→ Overload robustness → Noise → EMC robustness → PSRR robustness → Offset drift → Sensitivity drift → Area → Power	→ Power → Area → Noise → Offset drift → Sensitivity drift → Overload robustness
Spec	→ 4-6 sigma	→ “typical”
Q (field)	→ <<1ppm	→ 10..100ppm

Bosch sensors can be found in every

second

smartphone worldwide.

- height differences of < 1m
- tilt angles of < 1°
- heading accuracy of 3°
- track movement of hour hand in a clock

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