Prospects for sensors in the new automotive economy

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Agenda

• Market drivers
• Emissions aftertreatment and sensing
• Electrification and impact on powertrain
• Advanced safety and automated driving
• Sensor supply ecosystem
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Four main drivers affect sensing going forward

- **ADAS**
  - Advanced safety features, NCAP ratings
  - Harmonization of emissions laws: EURO 6C, CN6, LEVIII
  - Harmonization of testing regimes: WLTP, RDE...

- **L4/L5**
  - New driving paradigms

- **Electrification**

- **Exhaust emission control**

2017 2023 2030
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Near term opportunity for sensors - exhausts

- Exhaust sensor modules market worth more than $3.3 billion last year
  - Air-fuel ratio, lambda, exhaust gas temperature and pressure sensors are staple devices....
  - Mature markets need new sensors such as NOx, PM, and devices for SCR
    - Accelerate market past $500 M in 2022, up from $220 million in 2015
  - Gasoline engines fitted with particle filters
  - Emerging markets like China, India need basic exhaust monitors like pressure sensor

Source: Powertrain Sensor Report

Growth rates for powertrain sensors (CAGR = 2015–22)

Source: IHS Markit © 2017 IHS Markit
What does a Euro 6c compliant diesel look like?

- Sensors are added for OBD of catalysts blocks
  - Diesel oxygen catalyst – oxygen sensor
  - Particle filter – delta pressure + temperature
  - SCR filter - NOx sensor + temperature, temperature + level + quality of AdBlue

- What’s new
  - Particle mass sensors adopted in US market (LEVIII) since MY2014 to monitor DP filter
  - More PM sensors in European market (although legislation is focused on particle number)
Gasoline direct injection engine treated like diesel under Euro 6c

- Gasoline multi-port injection (MPI) engines designed to combust with stoichiometric air-fuel mixes
  - Temperature sensors not required for TWC, air-fuel ratio and OBD oxygen sensors suffice
- GDI use non-stoichiometric air-fuel mixes
  - TWC + gasoline particle filter starting in 2017
  - GPF is (mostly) passively regenerating, but ΔP and temperature deployed for OBD monitoring and characterization
  - May also impact MPI engines
- Huge new market for pressure (+ temperature)

Source: IHS Markit

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Regional variations in powertrain sensor adoption

• Harmonization of emission standards worldwide
• Drives increasing sensor penetration in different regions
  • European GDI C-class car with Euro Standard 6 has 15+ sensors
  • By comparison Chinese C-class gasoline powered car with China 4 standard has 10 powertrain sensors, and Indian cars have fewer than 10
• China and India adopt tighter standards, and sensor adoption also accelerates
• India jumps Bharat 4 to Bharat 6, accelerating exhaust catalyst sensors
Aftertreatment sensors: who makes these devices?

Oxygen sensors: Bosch, Denso, NTK…

SCR urea quality: SSI Technologies, AB Elektronik, Continental…

SCR temperature, level: SSI Technologies, Eltek, Elobau, Meder-Standex

NOx: Continental – NTK, Bosch, Denso (prototype)

PM: Bosch, Stoneridge, Continental (2017)

Exhaust temperature: Sensata, NTK, Denso

Bosch

Continental

Bosch

Continental

Bosch

IHS Markit
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From Internal Combustion Engine to Electric Car – threat to sensors?

All values first level package = sensor + ASIC + 1LP

**MEMS: $9 value / engine on average**
- 4 pressure sensors
- 1 flow sensor

**Silicon magnetic: $5 / engine**
- 6 position, speed devices

**Non silicon sensors: $35 / engine**
- Up to 7 gas sensors, temperature

**Internal combustion engine: around $50 for sensors**

**Electric motor: around $8 to $12 for sensors**

**Silicon magnetic: $1 - 2 per traction motor**
- 3 – 6 position and current sensors for motor position control

**Other sensor for battery: $5-10**
(temperature, voltage, current humidity)
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Safety sensors today… and tomorrow

Anti-blocking system
Electronic stability control
Tire pressure monitor
Roll over detection
Front airbag
Side airbags
Pedestrian occupation detection
Passenger occupation detection
Automatic Emergency Braking
Advanced Cruise Control
Accident sensor (Telematics)
Black box sensor (insurance)
Ultrasonic distance
Camera
Radar

LIDAR
Navigation (dead reckon)
Sensor fusion ECU
Intelligent tires (in tire sensor)
Advanced seat (heart rate)
Occupant drowsiness
CO₂ cabin monitor
Cabin particulate sensor
Active suspension
Adaptive lighting
Laser lighting
…
MEMS & Sensor technologies for autonomous driving

**Automation level**
- Only driver assistance
- Partial Automation
- Conditional Automation
- High Automation
- Full Automation

**System capability**
- Some driving modes
- Some driving modes
- Some driving modes
- Some driving modes
- All driving modes

**Driving environment monitoring**
- Human Driver
- Human Driver
- System
- System
- System

**Fallback responsibility of driving task**
- Human Driver
- Human Driver
- Human Driver
- Human Driver
- System

**Evolution of established sensor technologies**
- Radar: from 1D to 2D detection
- Camera: towards higher resolution (Up to 7MP); increasing frame rate (30 to 60 frames/sec)
- Infrared Camera: essential for **driver monitoring** in L3
- Ultrasonic: No big change

**Emerging sensor technologies**
- Lidar: from macro-mechanical to **solid-state**
- High-performance IMU: **Dead reckoning** sensors for L4 and L5
- Adaptive Lighting: based on **MEMS scanners and/or DLP**
Lidar: the technology fight

Based on solid-state technology

**Mechanical Scanning LIDAR**
- Valeo/Ibeo
- Ibeo
- Velodyne
- Quanergy

**Non scanning Flash LIDAR**
- System Suppliers:
  - Continental
  - Continental (ASC)
  - Valeo
  - Invisage Technologies
  - Strobe*
- Solution suppliers:
  - LeddarCore
  - Phantom Intelligence

**Phase array LIDAR**
- Quanergy
- MIT + Darpa

**MEMS based scanning LIDAR**
- Microvision
- Innoluce (Infineon)
- Innoviz Technologies
- Lemoptix (Intel)
- Bosch
- STMicro
- ...

**Other**
- VCSEL based:
  - Trilumina
  - Xenomatix
- Electro-optic scanner:
  - Princeton Lightwave
- Optical Antenna:
  - OryxVision

Source: Valeo/Ibeo
Source: Continental
Source: Quanergy
Source: Innoluce

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Inertial navigation assumes 100x better performance than today

- Autonomous driving requires high performance dead reckoning

Global positioning of point cloud images for high resolution maps with LIDAR

High-performance IMU can be inside LIDAR, e.g. Quanergy using ADI

Positioning for yaw rate sensor autonomous driving

- Gyroscope
  - Bias drift °/h
  - < 0.01 inertial grade
  - 0.01 to 10 tactical grade
  - 10 – 1000 rate grade

Price per gyroscope axis

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Source: Quanergy
Adaptive lighting: full beam all the time

- Replaces night vision systems
- Competes with microbolometer (expensive) and sensitive CMOS sensors

Source: Bosch

Adaptive laser light based on MEMS

Source: Hella
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Automotive supports many suppliers....

**Safety modules**
- Autoliv
- Bosch
- Continental
- CTS Automotive
- Delphi
- Denso
- EFI Automotive
- Hella
- Hitachi Automotive
- Kefico
- Mando
- Sensata (Schrader)
- TE Connectivity
- Valeo

**Powertrain modules**
- Aisin
- Borg Warner
- Bosch
- Bourns
- Continental
- CTS Automotive
- Delphi
- Denso
- EFI Automotive
- Hella
- Hirschmann
- Hitachi Automotive
- Honeywell
- Kefico
- KSPG
- LEM
- Magneti Marelli
- Mando
- Melco
- NGK
- Sensata (Schrader)
- TE Connectivity
- TT-Electronics
- Valeo
- Visteon...

**Sensors suppliers (die and 1LP):**
- ADI, Allegro, AKM, ALPS, Amphenol, ams, Bosch, Delphi, Denso, ELMOS, Epson, FLIR, Freescale, Fuji Elec., Infineon, Kavlico, Kionix, Melexis, Micronas, MEMSIC, Microstaq, Murata, NXP, Osram, Panasonic, Samyoung, Sensata, Sensirion, SGX, SMI, STMicroelectronics, TI, ULIS...
Automotive MEMS & Sensors Ecosystem (simplified)

Tier 3

MEMS & sensors foundries: Xfab, Teledyne, APM, SMI, TSMC…

Tier 2

Vertically integrated Tier 1 (with own MEMS design and fabs)
Bosch, Denso, Sensata, (Delphi, Conti)

Merchant MEMS & Sensor chip suppliers:
NXP/Freescale, ADI, On Semi, Infineon, Allegro, Melexis, ST…

Tier 1

Tier 1

Conti, Bosch, Delphi, Denso, ZF TRW, Autoliv, ...

OEMs

Traditional OEMs:
Toyota, VW, GM, Ford…
Automotive MEMS & Sensors Ecosystem (simplified)

Historical suppliers of consumer MEMS devices make inroads into automotive applications like ESC, airbags…

Tier 3  Tier 2  Tier 1  OEMs

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ST, InvenSense. Rohm/Kionix?

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Autonomous driving impacts the ecosystem

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Melexis, ST…

Tier 2

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ST, InvenSense. Rohm/Kionix?

MEMS & sensors foundries: Xfab, Teledyne, APM, SMI, TSMC…

Start-ups: Quanergy, Microvision, Innoviz, InnoLuce, Lemoptix, Lumedyne…

SoC for sensor fusion:
Mobileye, nVidia, NXP, ST, Intel…

New mobility players: Google, Uber, Apple…

Tier 3

Tier 1

Tier 2

OEMs
Autonomous driving impacts the ecosystem

Start-ups develop critical sensor technologies for autonomous driving

Tier 3 ➔ Tier 2 ➔ Tier 1 ➔ OEMs

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M&As

Investment
Autonomous driving impacts the ecosystem

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Tier 2
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Autonomous driving impacts the ecosystem

Shift of weight towards SoC to power Sensor Fusion ECU at expense of tier 1

Tier 3
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OEMs
Conclusions

• 2017 – 2022 dominated by need to make exhaust even cleaner
  • Aftertreatment no longer just an issue for diesels, also gasoline engines
  • General harmonization of emissions standards and testing regimes worldwide stimulates sensor backfilling in China, India....

• New European legislation targeting lower CO₂ levels force electrification strategies, i.e. hybrids
  • Aftertreatment depends on duty cycle of ICE, sensors needed for e-motor, sub-systems and batteries

• Autonomous driving will drive new sensing applications
  • Sensors enabling for new systems, e.g. LIDAR, adaptive lighting, performance navigation
  • Startups invigorate supply chain, e.g. for sensor fusion chips, working directly with OEMs

• Future looks great for sensors
Thank you for your attention!

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