

# Sensors in the new automotive economy

Impact of automated driving and electrification in the new infrastructure



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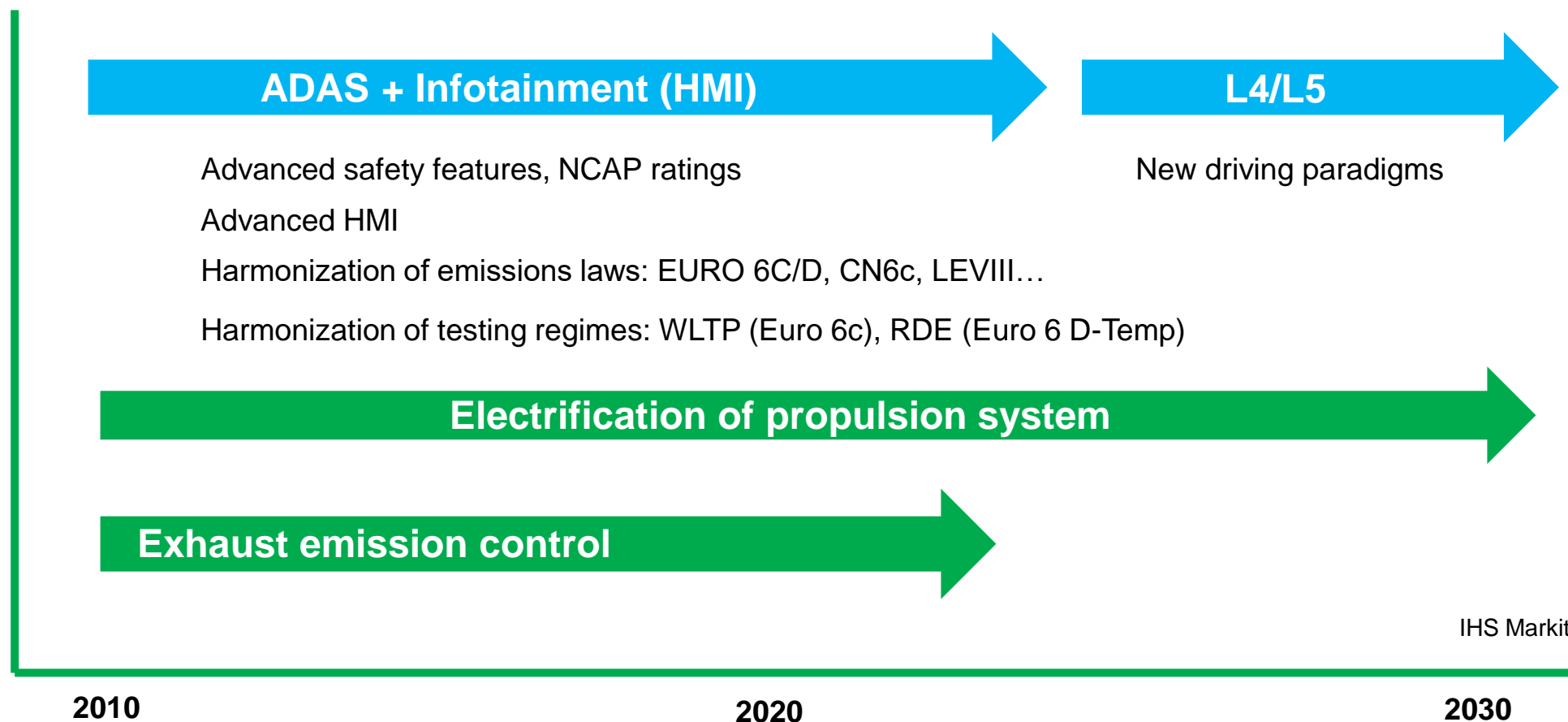
## Agenda

- Market overview
- New market impulses, with examples
  - Aftertreatment
  - Electrification
- ADAS and automated driving
  - Safety applications
  - Cabin applications

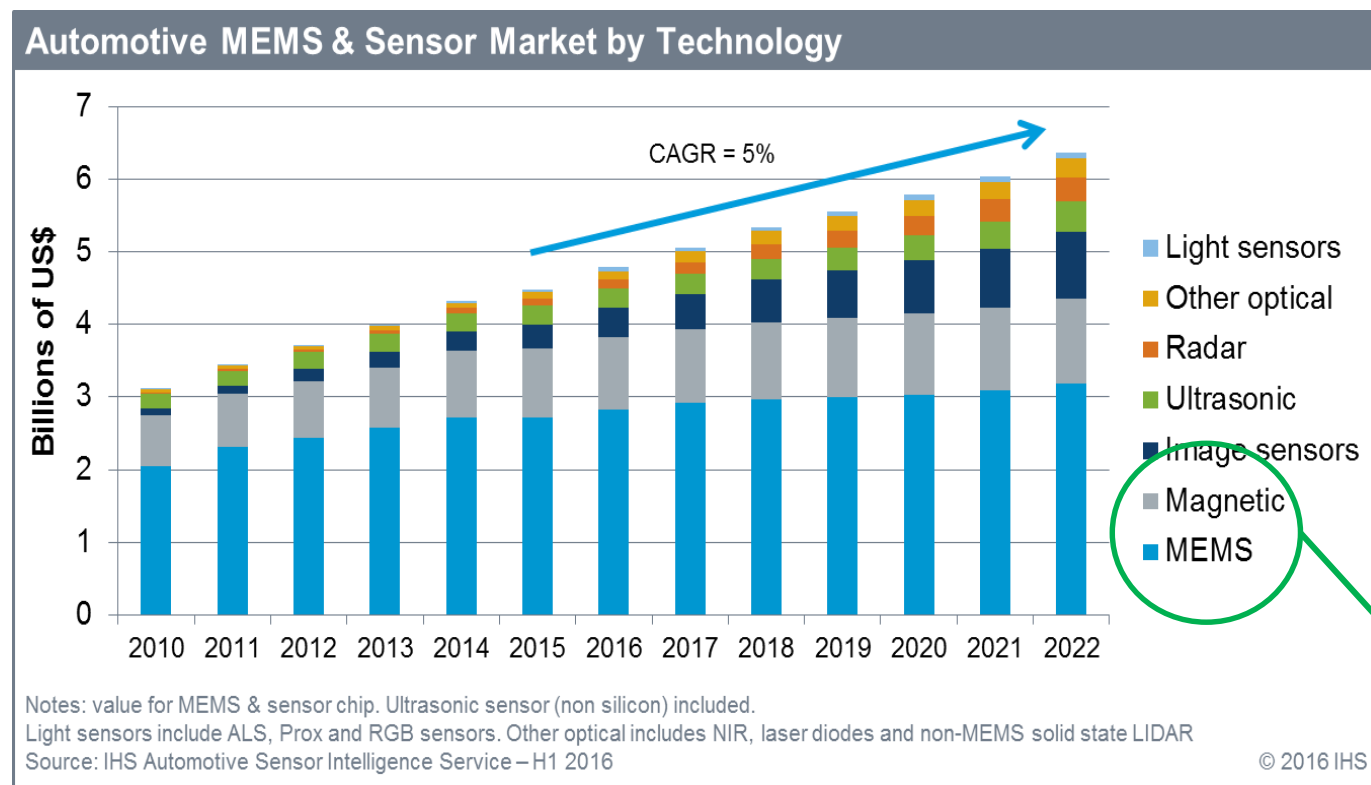
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## Main trends affecting sensing

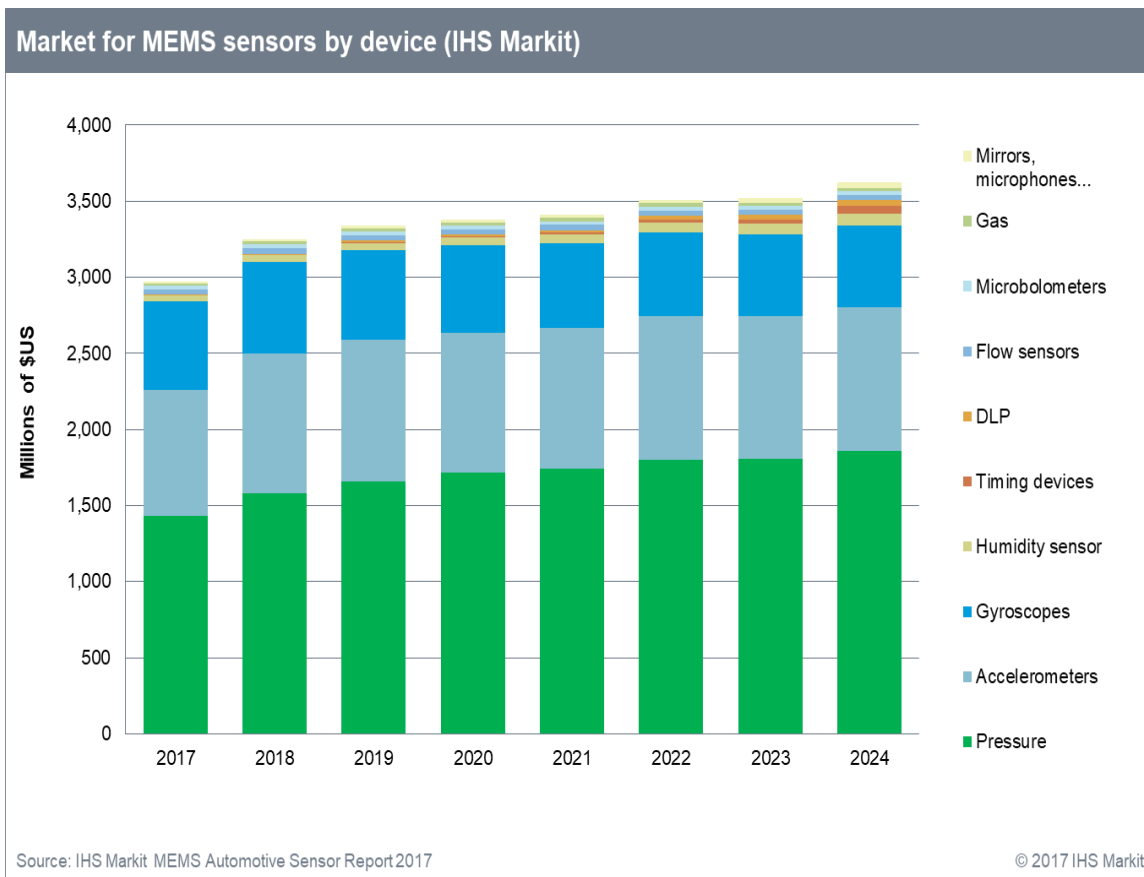


## Markets for automotive sensors



- Market
  - 2017 = \$5 billion
  - 2022 = \$6.3 billion
  - CAGR = 5%
- Growth of sensors driven by ADAS in form of Image (camera sensor, radar and light (mostly LIDAR, but also adaptive lighting))
- MEMS stagnating, some small benefit from ADAS
- Magnetic, strong benefit from electrification
- Light, optical, radar, image driven by ADAS

## MEMS market summary



### • MEMS market maturing

- 90% of \$\$ for 3 main device types, very established
- Many applications commoditized (sub \$1 for airbags accelerometers, BAP, etc.)
- Some niche applications, e.g. RH (\$70M in 2024)

### • Electrification

- Will not stimulate MEMS (rather magnetic)

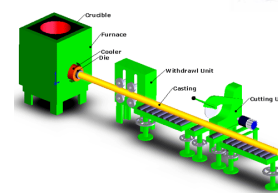
### • Automated driving, ADAS

- Redundancy helps market ..gyroscopes for ESC
- Performance IMUs for navigation
- MEMS timing, driven by ADAS worth close to \$50M
- DLP mirrors, e.g. Adaptive lighting = \$44M in 2014 (Night vision will not realize promise)
- Chance for OIS type applications in ADAS cameras but using cheap 3-axis consumer devices



## Magnetic market overview – auto is strongest sector

- Total for industry is \$2.7B in 2023 (6% CAGR)
- Automotive is most important market!
  - Stable market, low dynamics, steady growth
  - 52% in 2010 grows to 60% in 2023
- Mobile phone, tablet markets
  - High growth, along with commoditization
  - 20% market share in 2010 to just 10% in 2023
- Other markets small, fragmented
  - 10 sectors make up just around 30%
  - Consumer appliances and electronics together 9%



Bosch



VW



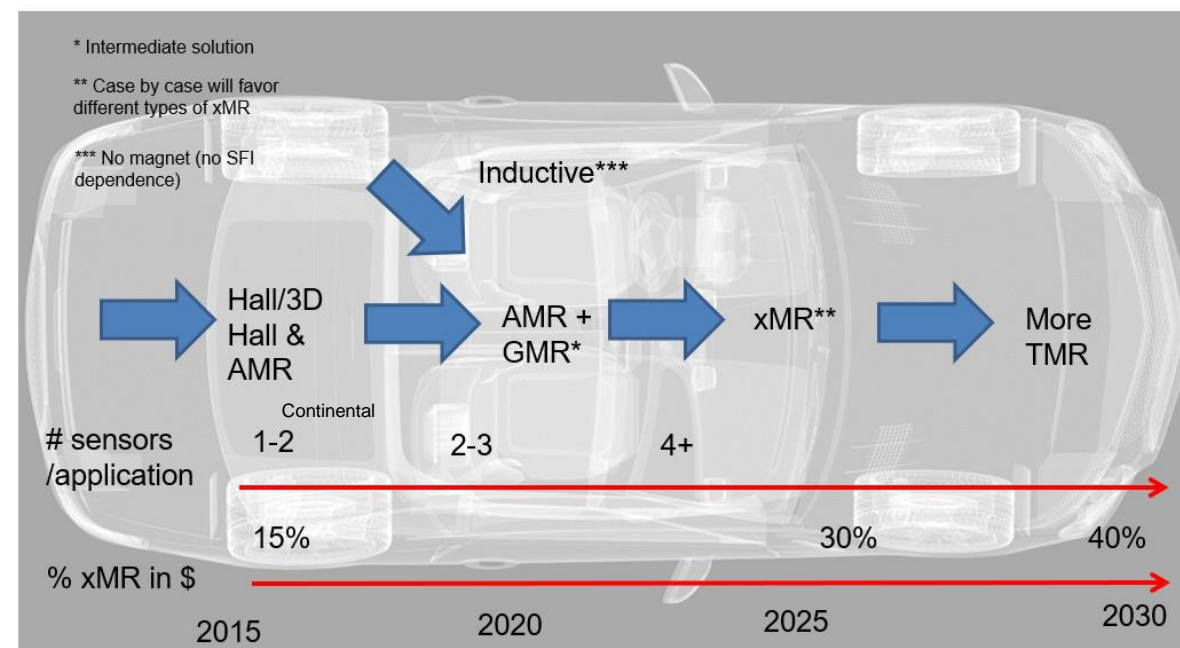
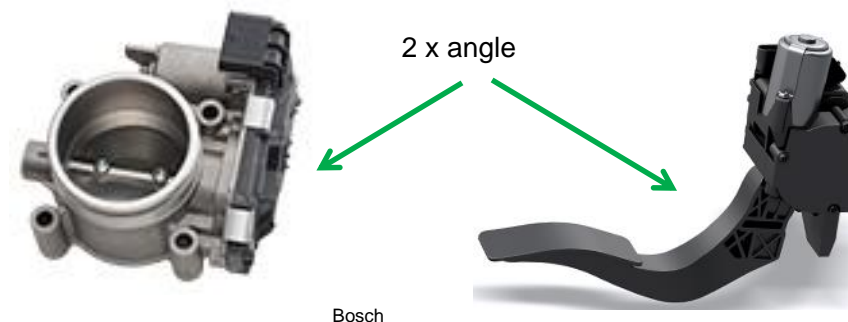
SMEG



Apple

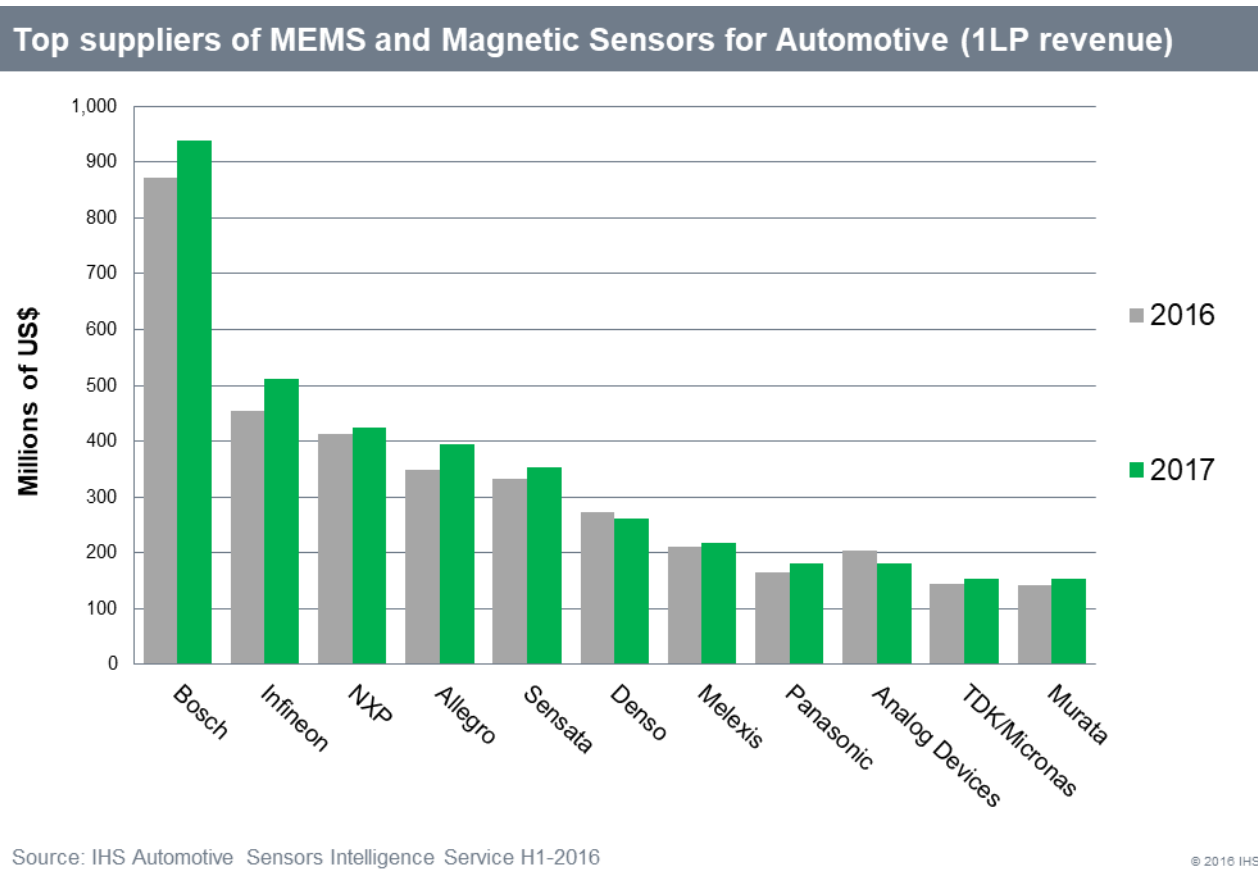
## Magnetic sensor benefits from safety

- \$1.2B in 2018, \$1.8B in 2023, CAGR = 8%
  - 4.7B devices (speed, current, field, position...) in 2023
  - Devices costing from \$0.20 to \$1.50
- Diverse technology base
  - Hall, 2D Hall, inductive, AMR, GMR, and now TMR
  - Angle / torque sensors for steering
  - Suspension, throttle, exhaust valve position....
- Functional safety impact
  - More diagnostics, self check, health monitoring, new communication interfaces, security
  - Redundancy, higher ASIL ratings (xMR + Hall), e.g. steering, throttle and acceleration pedal
  - 2 or 3 dies in same package offset price erosion...





## Who makes it? Top MEMS, magnetic suppliers last year



- Suppliers (tier 2)
  - #1 Bosch dominates in MEMS (tier 1 customer) but merchant market grows
  - #2 Infineon has wide magnetic sensor portfolio position + MEMS pressure
  - #3 NXP with MEMS (airbags, TPMS) + magnetic (wheel speed, steering)
  - #5 Allegro #1 magnetic supplier (speed sensors, switches, well positioned for growth in current...)
  - #6 Sensata top TPMS supplier, high pressure
- Trends
  - Consumer sensors slowly push into auto market
    - Bosch Sensortec (navigation), STMicroelectronics (airbag, eventually ESC)
  - New mag technology entering market – TMR
  - Functional safety, automated driving

## Agenda

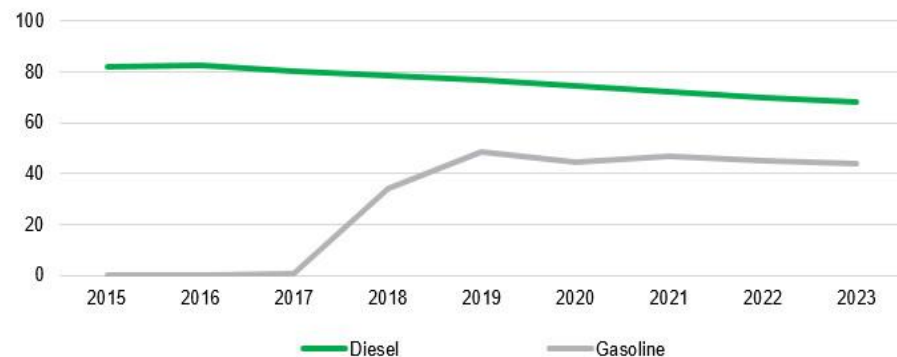
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## Aftertreatment

- Pressure
  - DPF saturated, GPF takes up mantle of growth
- Humidity
  - On intake to improve NOx measurements (on MAF)
  - Occasional humidity sensor to control urea dosing in SCR system (Ad Blue) in diesels

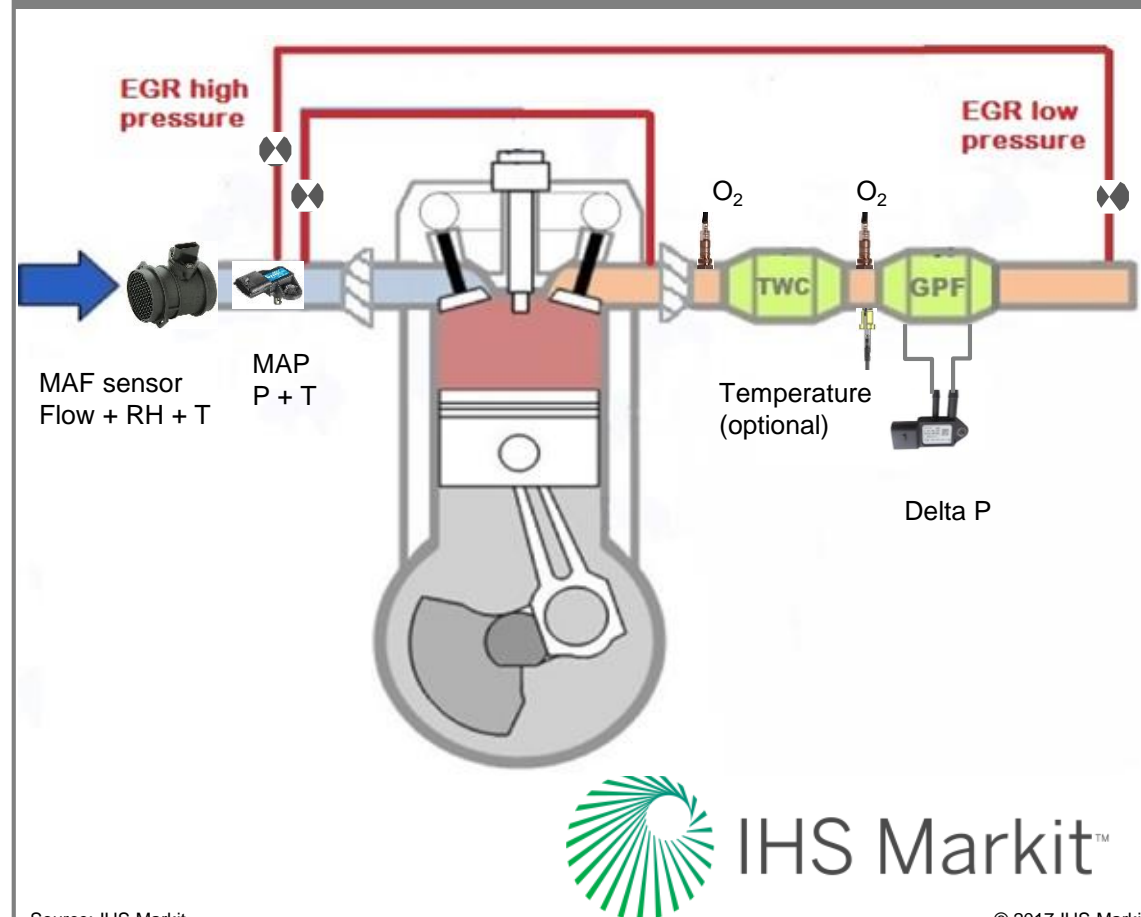
Global revenue of MEMS pressures sensors for gasoline particle filters (US\$ millions)



Source: IHS Markit

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Gasoline upstream and aftertreatment (direct injection)



Source: IHS Markit

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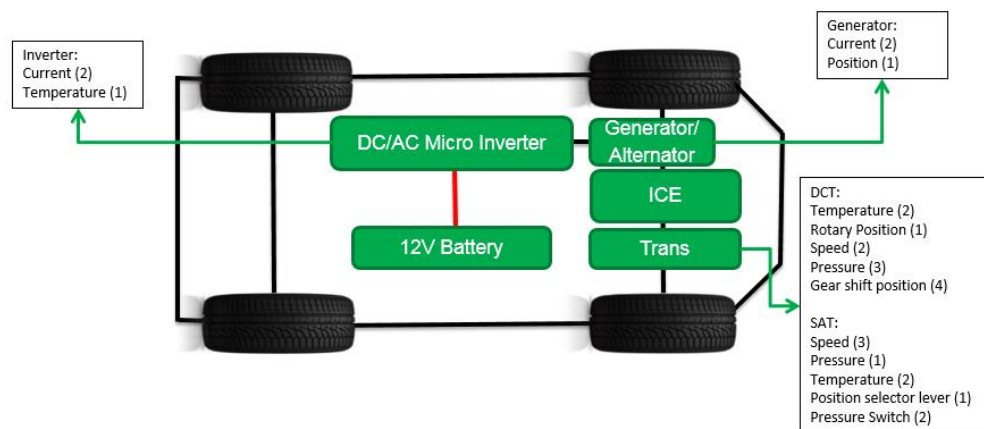
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# Electrification is very significant for sensors



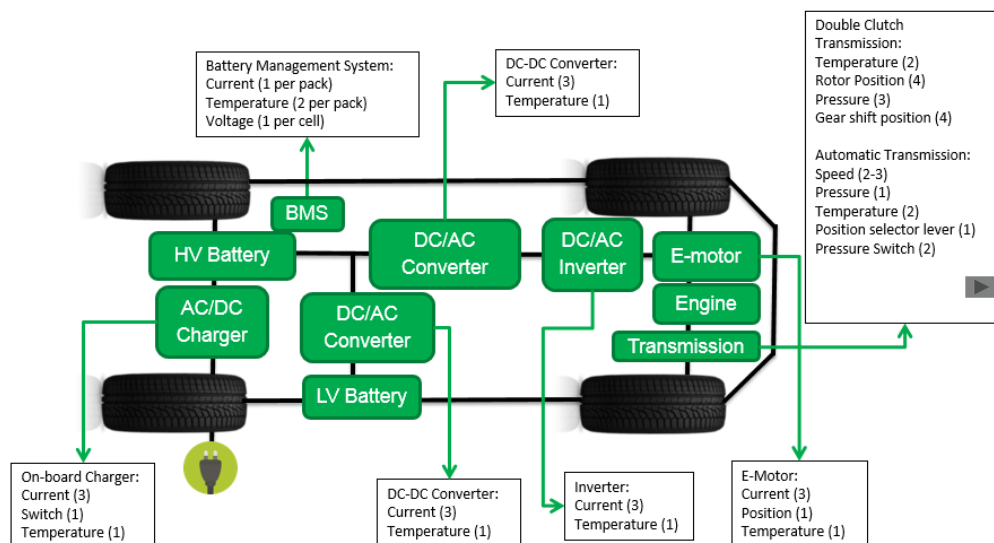
## Micro Hybrid



6 extra sensors:  
current, temp,  
position



## Plug-in Hybrid Electric Vehicle



35+ extra  
sensors:  
BMS alone = 20  
temp, 10+  
current devices

- Rapid uptake of current and temperature
- Battery monitoring, pump and auxiliaries, regenerative braking on-board charger....
- Shunts, open loop- or Hall-IC sensors, fluxgate depending on application
- 3 current sensors per motor generator (MG) inverter



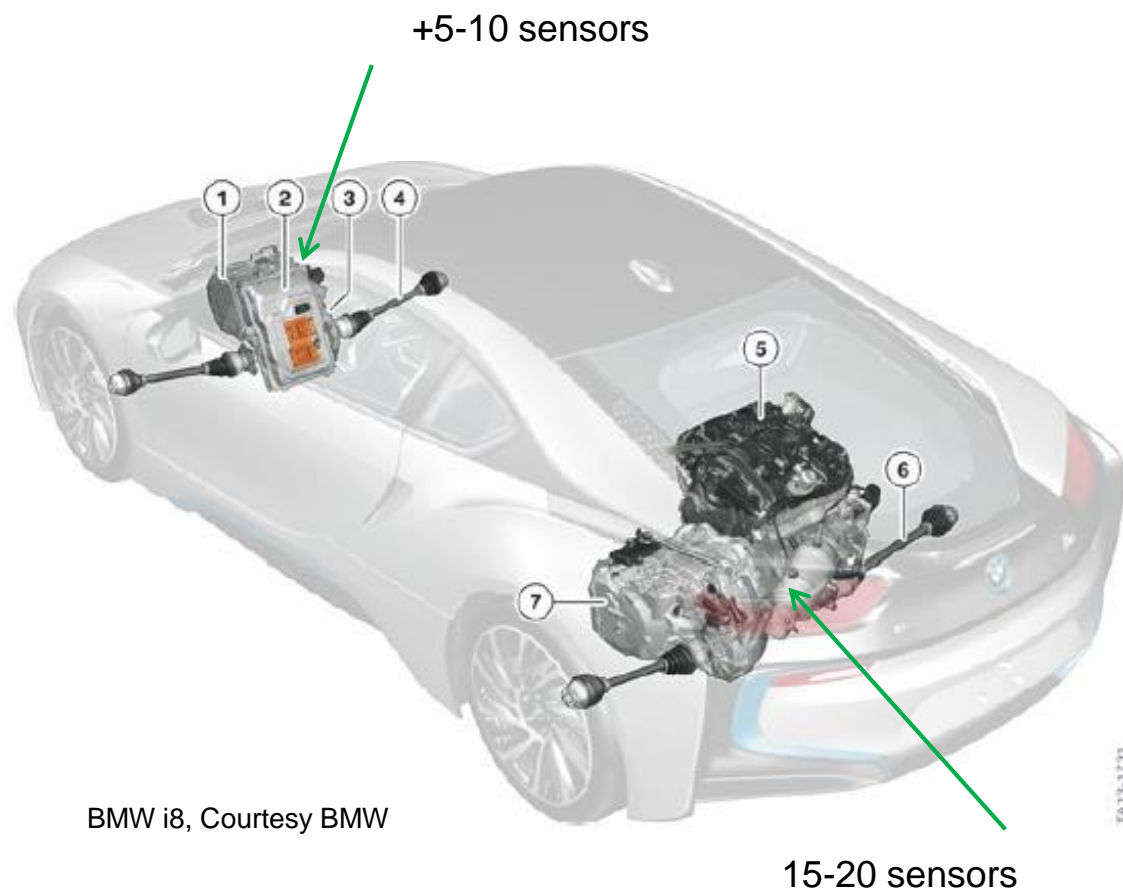
Open loop Hall current sensor for Nissan Leaf (Nippon Ceramic)

## Battery monitoring system

- Simple battery monitor
  - Small BM IC (voltage, temp, current) from Analog Devices, Inc. and shunt resistor for 12V battery
  - Supports micro-hybrid, general high electrical loads
- EV / HEV: state of charge for range, state of health for aging
  - 2 temperature sensors / battery module x 8-10 modules = 20 sensors
  - Voltage measurement in each cell and on top of module = typ. 80 voltage ICs
  - Current sensors on each string of modules (1-2) = 10-20
- Strong focus on safety with increasing energy density
  - Accurate lifetime / condition monitoring
- Implication for MEMS
- Research focus
  - Condition monitoring via distortion of battery indicative of aging / condition but multiple technologies, e.g. strain gages for distortion but MEMS for „burst pressure“
  - Embedded FO sensors, e.g. color change of electrodes for accurate SOC, SOH (research at BMW)
- Accident accelerometer
  - Cut off high voltage EV in event
  - Probably existing sensors



## Best of both worlds: hybridization / transmissions

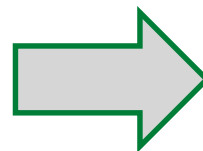


- 1. Electrical motor
- 2. Control electronics
- 3. Two-speed gearbox (2 Hall for selection, 1 inductive PLCD sensor for input speed)
- 4. Output shaft
- 5. 3-cyl gasoline combustion engine
- 6. Output shaft
- 7. Six-speed automatic DCT with 4 position, 2 speed sensors, 1 Hall TRS position...BLDC gear change motor

## Most extreme case: Battery Electric Car –add or replace?



**\$150 in  
modules\***



**\$70-80**



Courtesy BMW

### **Pressure, temperature, position, gas...**

- Up to 15 pressure sensors\*
- 6+ position and speed devices
- 2-3 electrochemical gas sensors, 3-4 high temperature sensors
- Knock, temp, flow sensors, etc.

### **Position, current sensors**

- E-motor position resolver
- 10-12 current sensors for battery, MG inverters, auxiliary pump control, plug in charger...
- 20 temperature sensors

\* engine, transmission, exhaust, depending on region

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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

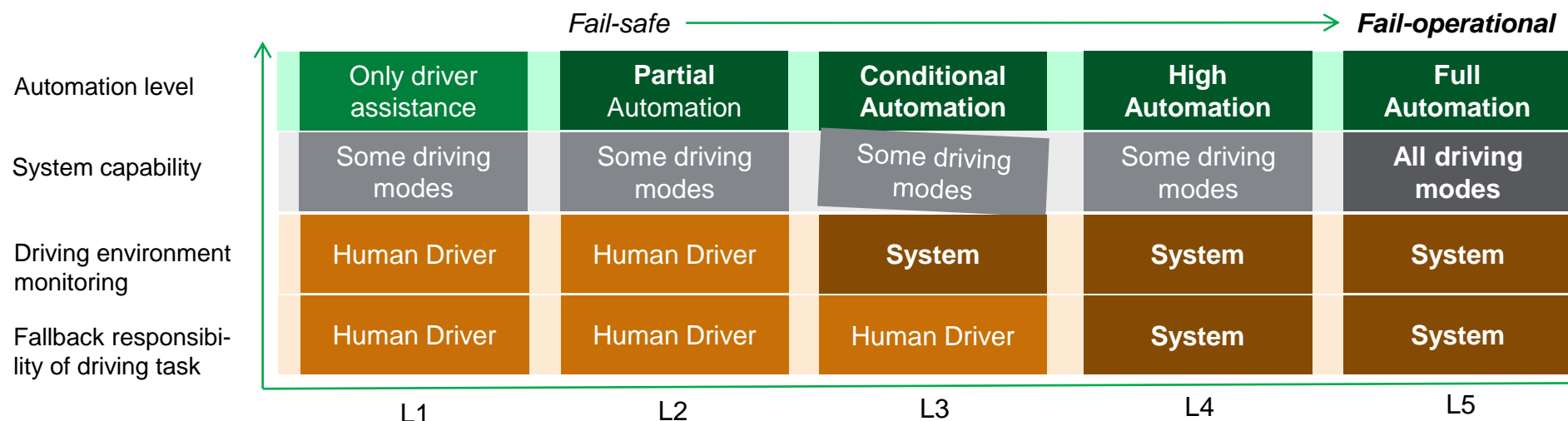


IHS Markit

**LIDAR**  
**Performance Navigation**  
Intelligent tires (in tire sensor)  
Advanced seat (heart rate)  
Occupant drowsiness  
**CO<sub>2</sub> cabin monitor**  
Cabin particulate sensor  
Active suspension  
**Adaptive lighting**  
Laser lighting  
...



# MEMS & Sensor technologies for autonomous driving



## 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


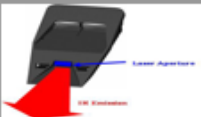
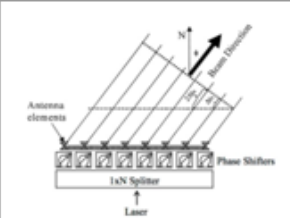

Lidar: from macro-mechanical to **solid-state**

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

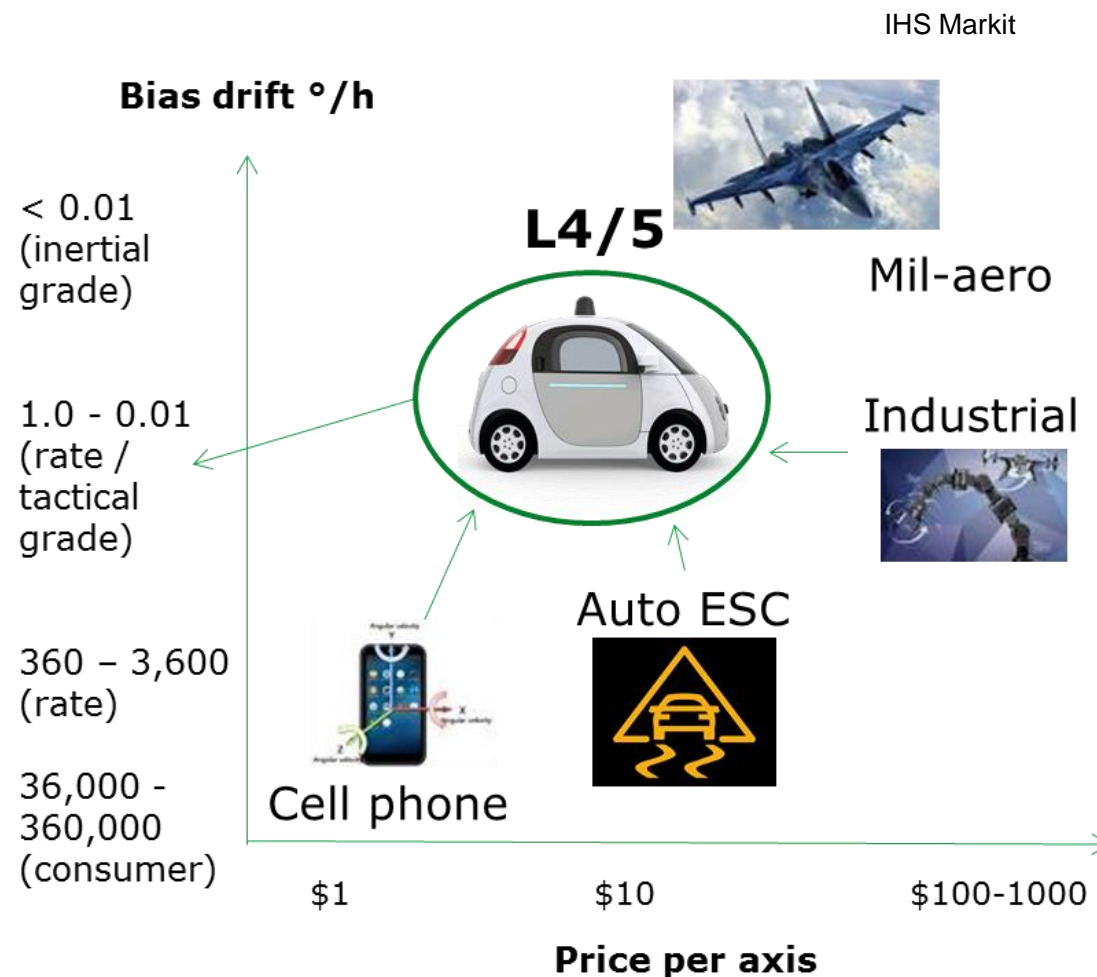
Mechanical Scanning LIDAR	Non scanning Flash LIDAR	Phase array LIDAR	MEMS based scanning LIDAR	Other
<ul style="list-style-type: none"><li>• <a href="#">Valeo/Ibeo</a></li><li>• <a href="#">Ibeo</a></li><li>• Velodyne</li><li>• Quanergy</li></ul>	<p>System Suppliers:</p> <ul style="list-style-type: none"><li>• Continental</li><li>• Continental (ASC)</li><li>• Valeo</li><li>• <a href="#">Invisage Technologies</a></li><li>• Strobe*</li></ul> <p>Solution suppliers:</p> <ul style="list-style-type: none"><li>• <a href="#">LeddarCore</a></li><li>• Phantom Intelligence</li></ul>	<ul style="list-style-type: none"><li>• <a href="#">Quanergy</a></li><li>• MIT + <a href="#">Darpa</a></li></ul>	<ul style="list-style-type: none"><li>• <a href="#">Microvision</a></li><li>• <a href="#">Innoluce</a> (Infineon)</li><li>• <a href="#">Innoviz Technologies</a></li><li>• <a href="#">Lemoptix</a> (Intel)</li><li>• Bosch</li><li>• <a href="#">STMicro</a></li><li>• ...</li></ul>	<p>VCSEL based:</p> <ul style="list-style-type: none"><li>• <a href="#">Trilumina</a></li><li>• <a href="#">Xenomatrix</a></li></ul> <p>Electro-optic scanner:</p> <ul style="list-style-type: none"><li>• Princeton Lightwave</li></ul> <p>Optical Antenna:</p> <ul style="list-style-type: none"><li>• <a href="#">OryxVision</a></li></ul>
 <p>Source: <a href="#">Valeo/Ibeo</a></p>	 <p>Source: Continental</p>	 <p>Source: Quanergy</p>	 <p>Source: <a href="#">Innoluce</a></p>	

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## Instrumentation for ESC and navigation

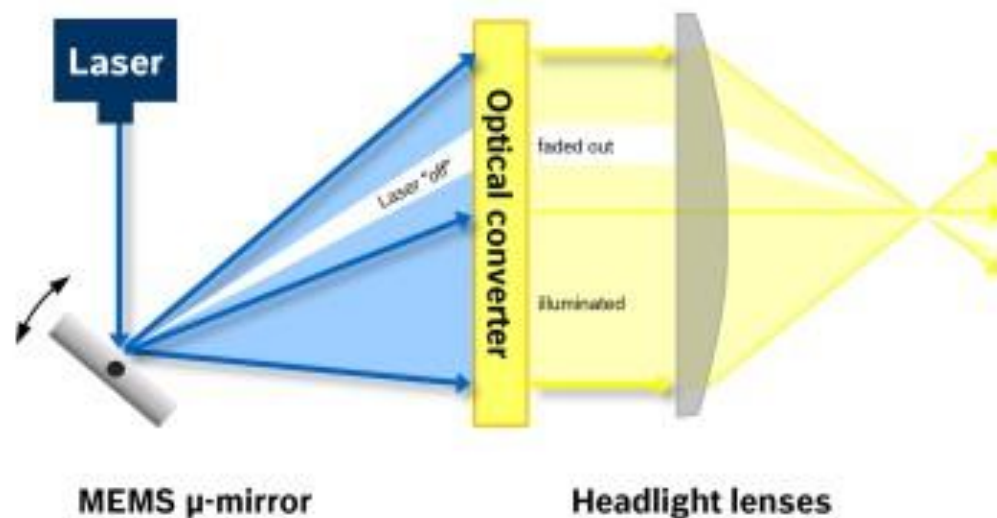
- Vehicle dynamics testing
  - OEMs today using MEMS gyro with 1°/h BS for ESC road testing, and FOG for precision autonomous driving (AD) navigation
- Lost GPS during automated driving
  - Fail safe if other sensors fail
  - L4/L5 driving locational accuracy 2-3 cm (compared to 30-40 cm over 200m tunnel)
  - For AD, MEMS gyro at 1°/h will still be too expensive due to low volume
  - On-board gyros will rely on lower performance specs + sensor fusion but depends on OEM use case (really dead reckoning?)



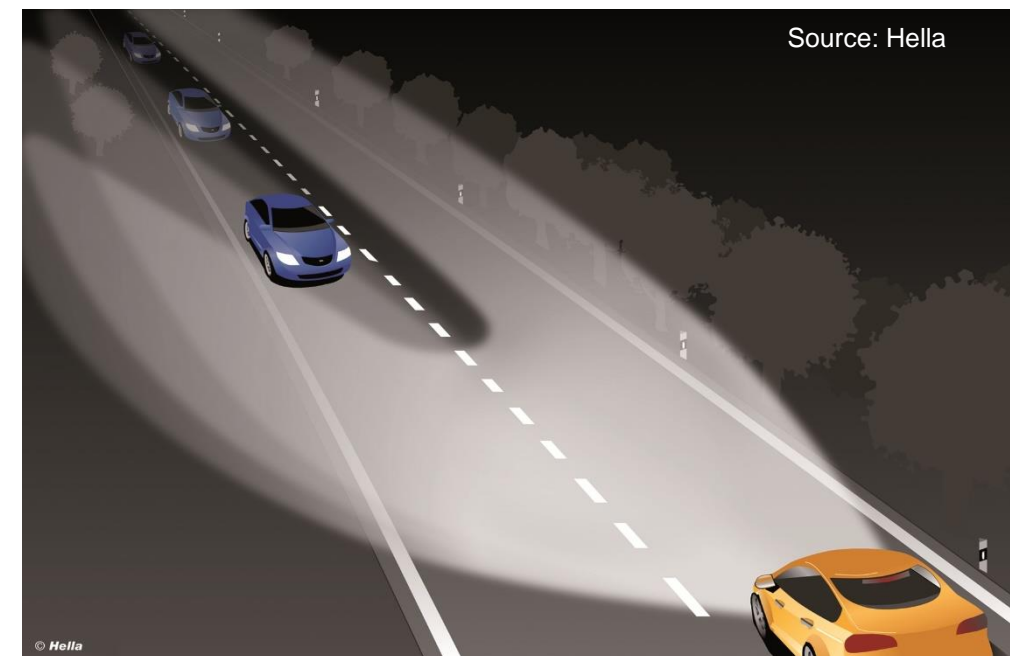
## Adaptive lighting: full beam all the time



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



Source: Bosch



Adaptive laser light based on MEMS

## Other possible passive safety and ADAS applications

### ADAS

- Repositioning of LIDAR, radar using gyroscope...not active control, correction if sensor shifted (rotated) as result of bump, knock
- OIS applications for gyroscope in interior-looking camera (image stabilization)
- Functional safety / redundancy
  - Not really airbags - multiple sensors already used on vehicle for cross-check, plausibility measurements
  - Pedal, steering angle, throttle (safety critical)
  - MEMS such as doubling of ESC gyroscopes
- Direct TPMS + indirect TPMS as complementary systems in redundancy scenario
- Active suspension using position sensors and accelerometers, so far not used much (better with 48V)
  - Some market for chassis position (magnetic sensors) to adjust for headlight position in adjustable headlights
- Other applications
  - Key fobs (anti-hacking) with 30% penetration of cars in 2-3 years using low cost 3-axis motion sensor
  - Accelerometers for active engine mounts, chassis comfort (piezoelectric?)

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## Smart cockpit

- Sensors today
  - Force sensors for dual-stage airbag
  - Pressure sensors for “lumbar” support
  - Infra-red sensor for passenger detection
  - Microphone
    - Hands-free calling
    - Local noise cancellation in region of headrests
    - Noise noise reduction in EVs
- Automated driving focus on intelligent cockpit / seats
  - Driver monitoring for L3-L4 applications
  - Seat sensors for motion, position, and heart rate
    - Measure state of driver awareness for manual control after longer period of self-driving
  - Vital signs following an accident



“Cockpit of the future,” CES 2018 (Faurecia)

## Air quality and HMI

- Cabin air quality
  - Outside CO, NOx to control intake flaps (not growing)
  - Cabin CO<sub>2</sub> + VOC in development for drowsiness monitoring
    - Need for low cost CO<sub>2</sub>
    - UST, SGX, ams, Sensirion....sell to integrator Paragon (30M)
    - Potential for gas monitoring of EV batteries or H<sub>2</sub> fuel cells
  - 2.5 µm particulate matter sensors in development for China market (Paragon, Prodrive, Samyoung)
- HMI applications
  - Distance measurement like proximity or TOF for menu control
    - Elmos, ams, STM, Melexis, Hamamatsu...
    - Basic awareness using gestures and eye movement correlation (BMW)
  - IHSM believes voice activated control is more compelling



Indoor (CO<sub>2</sub>)



2.5 µm particle sensor (Paragon)

Courtesy Paragon



Sensing element CO+NOx



Module CO+NOx, including plastic casing and connector)



## E-call and other transportation applications

- E-call (Telematics...)
  - Low cost 3-axis consumer device with low power consumption but depends on market
    - Russian E-call needed as ECUs can be turned off in case of roll-over, so use dedicated sensor (NXP)
    - European E-call use existing ESC or airbag sensors, or microphone (e.g. STM) but 2-axis low cost accelerometer could be used for redundancy
- Motorcycles
  - Fuel injection
    - Cut-off fuel if leaning over via inclination measurements using low-cost accelerometer (India market)
  - ESC type applications for luxury motorcycles
- Bicycles
  - E-bike Hall or TMR sensor for position sensing of pedal/motor and handlebar grip
  - Replace expensive BLDC encoder

# Thank you for your attention!

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