AUTOMOTIVE

Contents

Executive Summary 1
Introduction 2
Market Potential 2
Applications 9
Advanced Driver Assistance Systems (ADAS) 9
connectivity 12
Lidar 14
Sensors 17
Automotive requirements 18
Key Challenges 19

EXECUTIVE SUMMARY

The automotive industry is going through unprecedented changes. In 2019 the COVID-19 pandemic hit the industry hard, with an expected decline of car sales of >17% in 2020.
But also before the pandemic the industry was facing tremendeous change. The pressure on emission reduction from combustion engines is increasing globally. And the industry is facing 3 Megatrends which occur simultaneously, making it very complex to predict how this will eventually change the market place
These trends are

- Electrification of the drive train, driven by CO2 reduction , and pushing out combustion engines
- ADAS and Autonomous driving
- Change in Mobility patterns, from reducing traffic in dense city centers, to multimode transport and new individual electric transport options like bikes, steps, etc.

Still it is expected that revenue will increase in the coming decade after the pandemic based on global market growth and introduction of the new technologies.
For the electronics industry even faster growth is foreseen, as the electrification of the drive train will drive huge growth of power electronics and sensors and control systems and the same holds for the introduction of ADAS systems and autonomous driving.
Sensors play a big role here and there you will see big changes for sensors related to the drive train. The type of sensors used in combustion engines (pressure, temperature, flow etc) will decline but instead sensors used in EV will show fast growth. Examples are sensors for battery management systems (current, temperature, strain,pressure), electric motors (current, temperature etc)
For photonic systems these trends are generally beneficial as there will be more applications for sensors , communication and lighting compared to traditional vehicles. Especially LIDAR is getting a lot of attention

Increasing density is important for these applications because of cost, size, and weight reductions.. Automotive applications are cost sensitive, and therefore they require cost targets similar to those of a Consumer Product Emulator . The challenge for the Automotive Product Sector Emulator is to adapt other emulators' technologies to meet the high temperature, environmental, and reliability requirements cost effectively.
The harsh environment and the high temperature requirements force development improvements in components and materials.

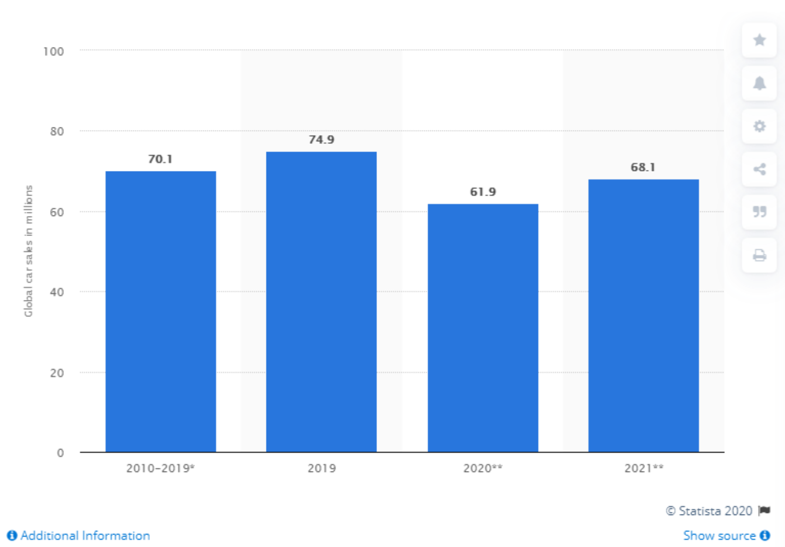


Fig 1. Global Passenger Car sales (vehicles) strongly influenced by COVID-19 pandemic

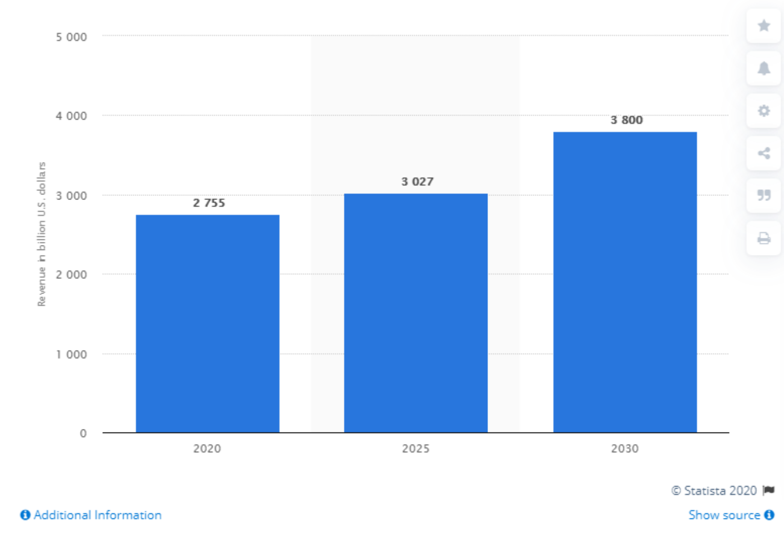


Fig 2 . Global passenger car sales revenue still expected to grow until 2030

Introduction

The IPSR-I Automotive Product Emulator identifies those automotive application needs that may best be met with Integrated Photonics. The applications considered in this emulator are:

1. Advanced Driver Assistance Systems (ADAS) utilizing integrated photonic technology in lidar systems
2. Photonic Sensors for a wide range of applications
3. Optical Local Area Networks (LAN)

The harsh environment for automotive electronics dictates operating conditions: high and low temperature extremes, vibration, shock, drop, exposure to dirt and contaminants, moisture, chemicals, radiation, and gasses. EMI/RFI (Electro Magnetic Interference /Radio Frequency Interference) shielding from internal and external noise, and ESD (Electro Static Discharge) are also critical factors.. Harsh Environment products require high reliability for safety, liability, and warranty concerns (i.e., engine / transmission controllers, brakes, airbags, and steering) with failure targets often well below 1 ppm.

Product volumes are generally below Consumer products but still range from 100,000 to tens of million of units per year. Car makers generally demand full traceability across the supply chain for quality and safety reasons and to be able to respond quickly in case of quality or safety issues (like recalls) so information systems are important. Products that are safety critical have to fullfill special standards as laid out in ASIL levels.

Product life cycles for most electronic systems are three or more years. The design cycle in Automotive is different from Consumer products . Reliabilty and supply reliability are of utmost importanc, nobody wants a delayed car launche or a recall. Typically discussions on product design start 3-5 years before launch, depending on how new the technology is. A multi generation roadmap is expected and often the necessary production capacity has to be in place 6-12 months before launch, which puts a heave burden on investments and release cycles as a.o laid down in the APQP process.

MARKET POTENTIAL

The Automotive market will undergo tremendeous change in ther coming decade but certainly appears to be a healthy segment for the growth of electronics and semiconductor components.. We first give an overview of the automotive electronics market before focusing on the three possible photonic applications.

Electronic modules addressing these issues, as well as other automotive electronics systems, segment into six major categories:

1) *Powertrain Electronics* such as engine controllers, transmission controllers, battery management systems, and any other systems that control the engine or driveline of the vehicle;
2) *Entertainment and infotainment Electronics* ranging from standard AM/FM radios to on-board video entertainment systems, satellite radio receivers, telematics, internet etc.
3) *Safety and Convenience Systems* such as advanced driver assistance systems (ADAS), airbag sensors, climate controls, security and access controls, and anti-lock braking systems;
4) *Vehicle and Body Controls* that manage specific vehicle functions, such as suspension, traction, power steering;
5) *Connectivity and Networking* such as in car networks (CAN, LIN, Flexray, Ethernet, optical , WiFi, 4g/5G, vehicle to vehicle and infrastructure communication (V2V/V2I)
6) *Non-Embedded Sensors* such as speed sensors, temperature sensors, fluid level sensors, and many others.

Market trends show fast developments in the following areas

<u>Electrification</u>

Market forecasts vary from analyst to analyst , which is logical given the effects of the impact of COVD-19 and the large changes in the market. Nevertheless some general trends are visible which will be driven by the Megatrends. The effect of COVID-19 for 2020 is a steep drop in car sales (more than-17% estimated).
For the years after a rebound is expected, however this is not going back to the situation before 2019.
The effects of climate change measures will continue to impact the industry. For combustion engines in Europe the Euro 6 standard is in place with similar standards in China (China 6a/b) and India (Bharat 6). In the USA California has the most stringent standards (LEV III). This will continue to put pressure on carmakers. In order to meet requirements for their total CO2 emissions they are now introducing hybrid vehicles and speeding up introduction of EV. As the new EV require new platforms which are very costly to develop, several carmakers a reducing their investments in combustion engines or even announcing to stop althogether.
VW has stated it will spend >60B$ on electrification and digitalization until 2024 and Daimler has announced it will stop developing new generations of combustion engines. With Tesla still leading the EV pack it is becoming harder and harder for OEM to keep up investments in new development, including ADAS and autonomous driving. So cooperation, and mergers can be expected (e.g. Peugeat-Opel) and not all carmakers might make it, while in China new players step up.
The total effect will be likely a faster change towards new drive trains. The differerences per region are large because of government policies.

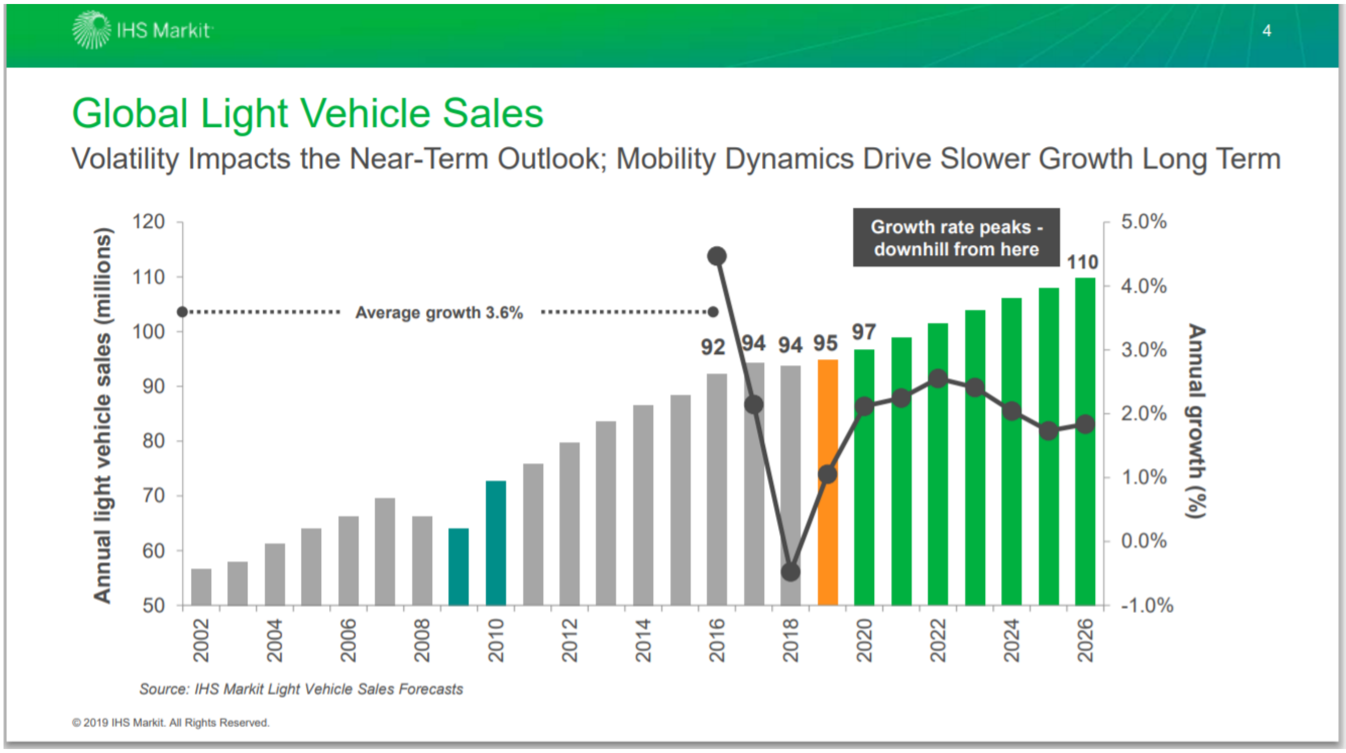


Fig 3 global light vehicle sales, before impact COVID-19

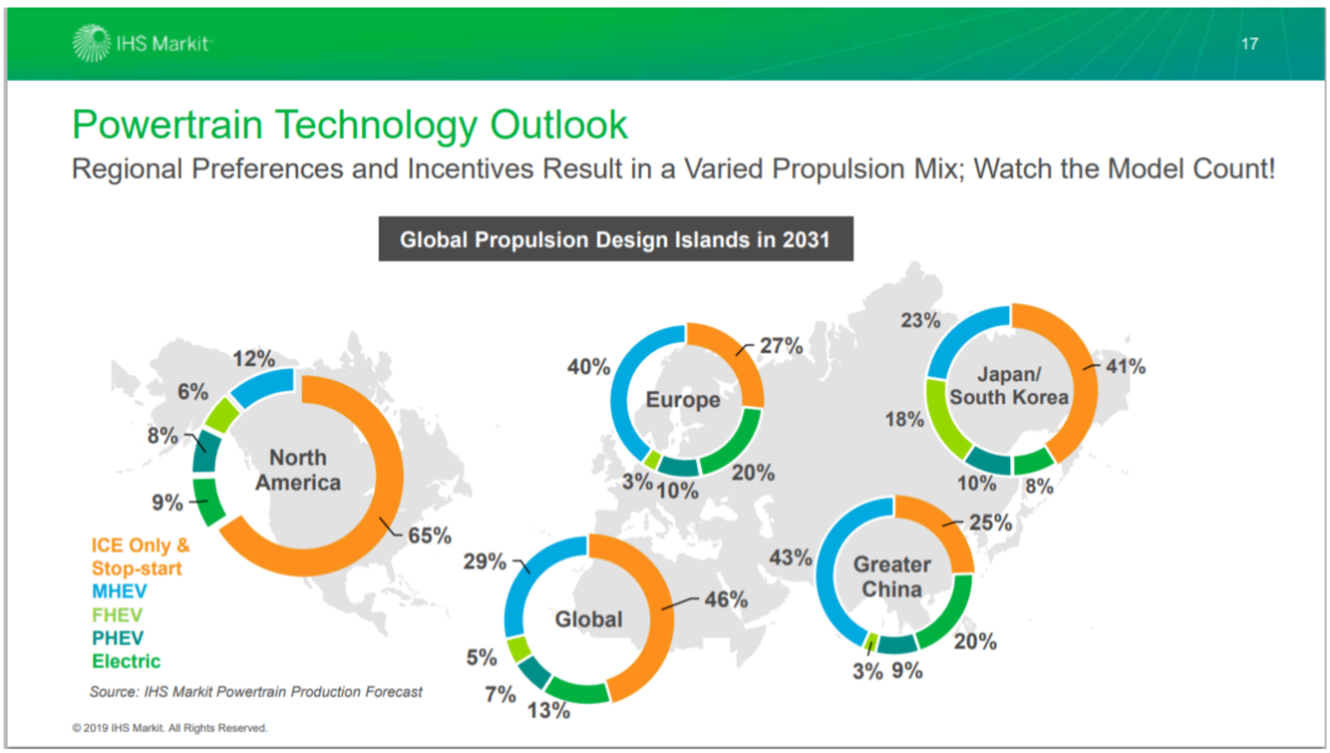
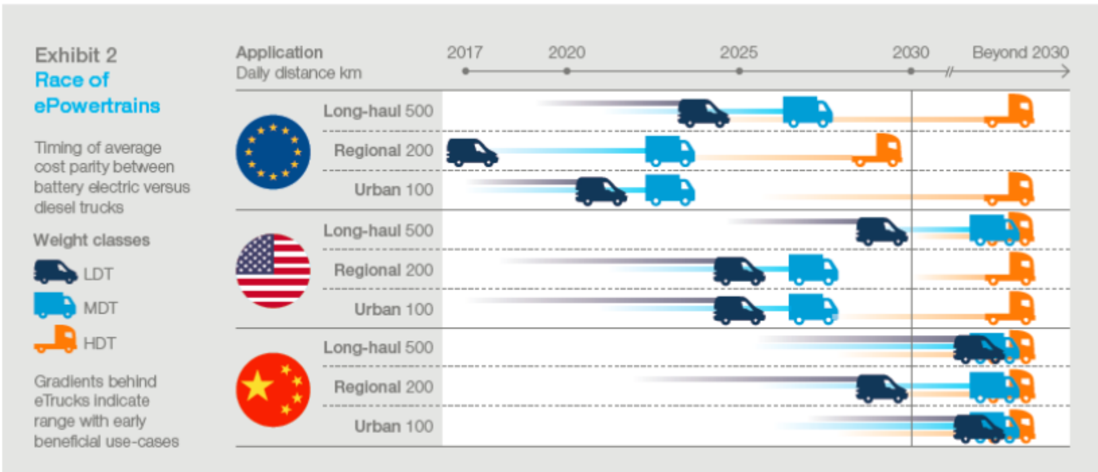


Fig 4 . Powertrain changes towards electrification vary per region.

Although the situation for trucks is different especially for long haul transport also here the effects of electrification become visible. There is already a clear trend towards EV for package delivery (e.g Amazon) but globally this is also visible for short and medium range transport. Whereas it is expected that those vehicles will

be BEV (battery electric vehicles) the situation for long haul is less clear. For the moment batteries are too heavy and do not offer enough range. Alternatives investigated are Biofuels and Hydrogen (combined with Fuel cells). For both the necessary infrastructure to supply either the fuel or the hydrogen is the biggest hurdle
For buses a similar argument can be given . City buses are getting electrified rapidly,but long haul transport is not yet clear.

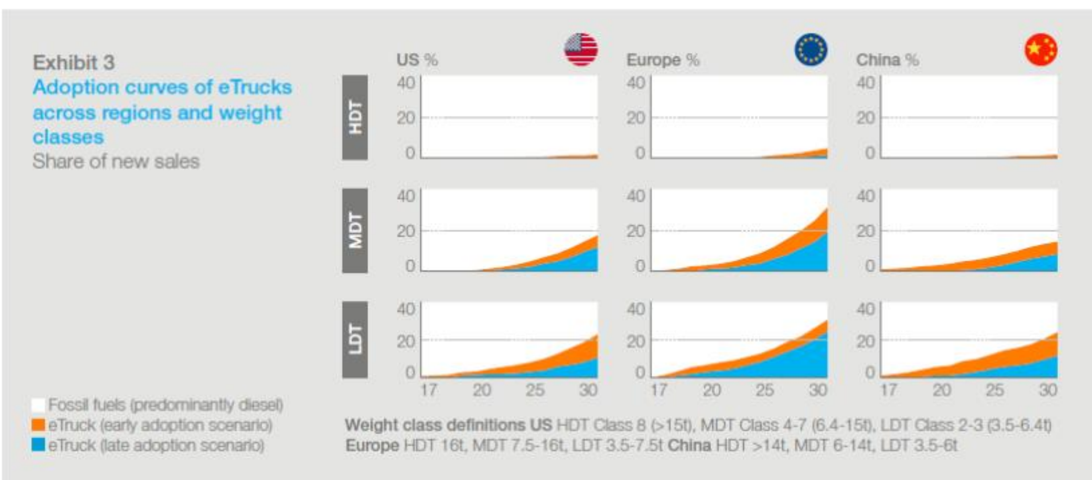
Exhibit 2: Race of ePowertrains



Source: McKinsey Energy Insights, McKinsey Center for Future Mobility

Fig 5 Different adoption per region for different transport classes until parity EV-Diesel

Exhibit 3: Adoption curves of eTrucks across regions and weight classes



Source: McKinsey Energy Insights, McKinsey Center for Future Mobility

Fig 6. Adoption curve of E-trucks across regions and weight classes

For the electronics in a vehicle the adoption rate is of key importance. For the drive train the cost of the batteries is the key driver as it both determines the range of an EV (through the installed capacity) as well as the vehicle cost. In recent years the cost reduction of batteries has accelerated and also there is a huge increase in factory capacity. It is now predicted that prices/kWh can be as low as 62 $ in 2030 which only a few years ago was seen as impossible. The expectation is now that cost parity on TCO (total cost of ownership) will be reached in the 2022-2024 timeframe, as the vehicles are more expensive but maintenance and fuel cost are less

For the electronics this means a huge increase in volume both in power electronics as well as sensing. To keep the battery in a healthy and safe state with long operating life each battery in the pack needs to be monitored and balanced, while cell temperature needs to be monitored as well and also sensor need to be added to maintain a safe state and avoid runaway. This BMS (battery management systems) are for this reason complex and expensive.

ADAS systems are being adopted for all tpyes of vehicles, but autonomous vehicles will so far be all EV. Obviously for powertrain electronics EV have far more content. The situation for Autonomous vehicles is even more interesting as the amount of sensors goes up rapidly with the autonomy level. This is even more the case with so called robotaxis's or robotransporters. The business case here is the big saving as no driver is needed.This warrants the cost of a huge amount of additional electronics and SW.

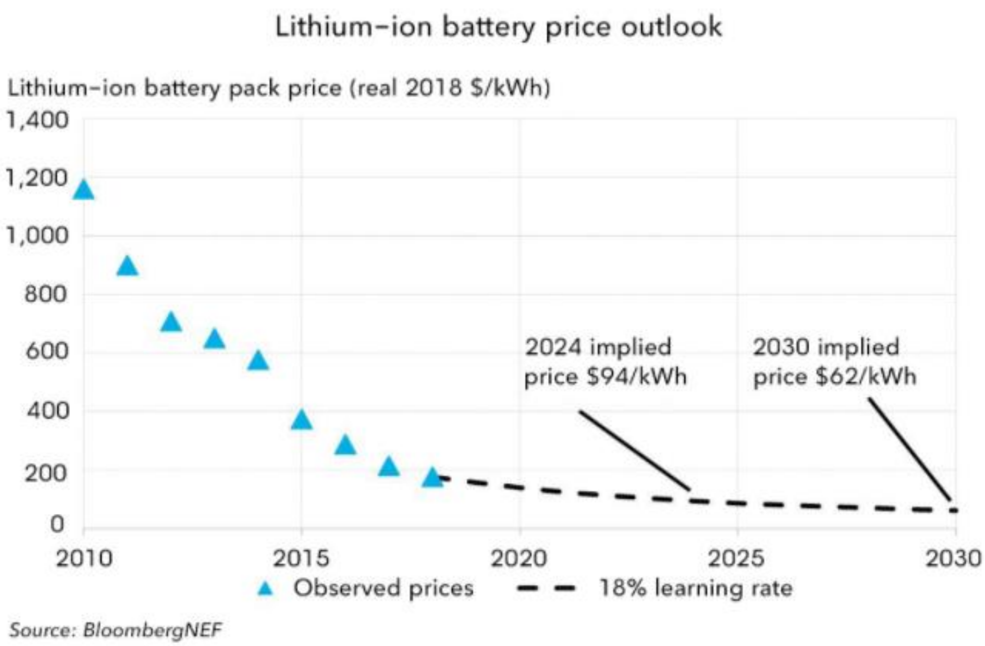


Fig 7. Lithium battery pack price outlook, driving adoption of EV

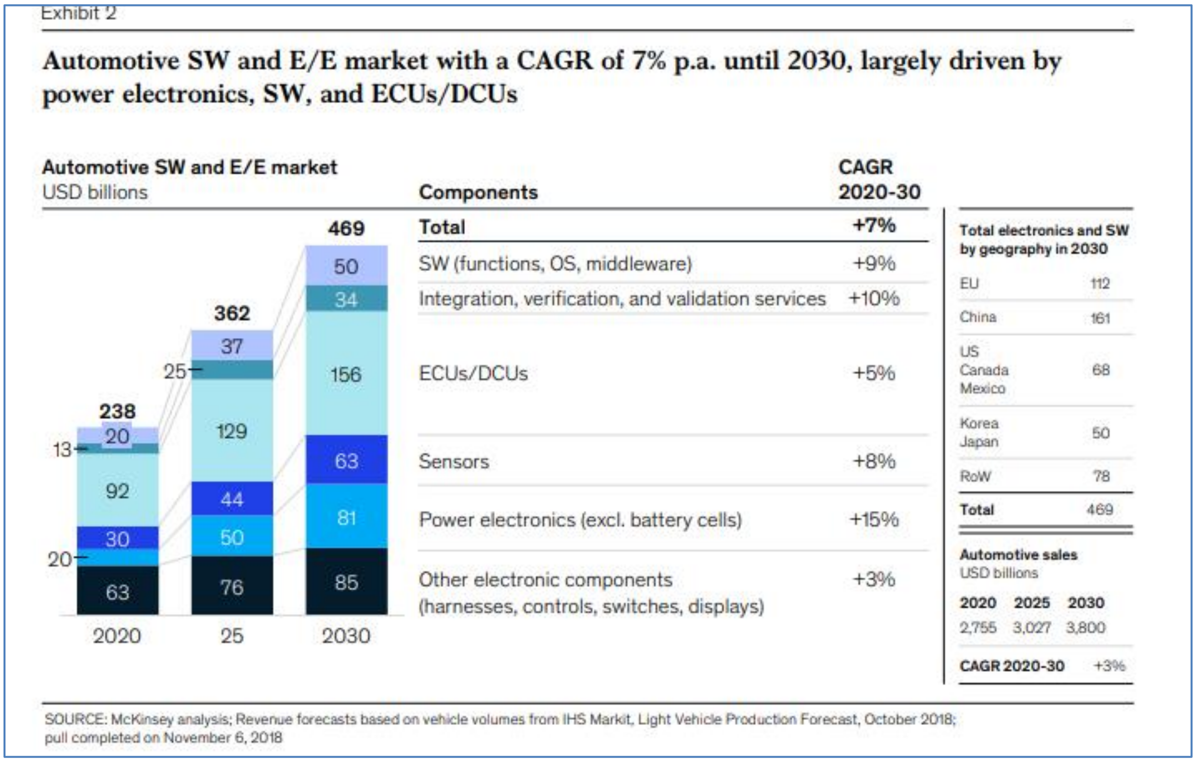


Fig 8. Automotive electronics and SW growth . For Sensors this is a combination of new sensors in EV replacing different sensors in ICE

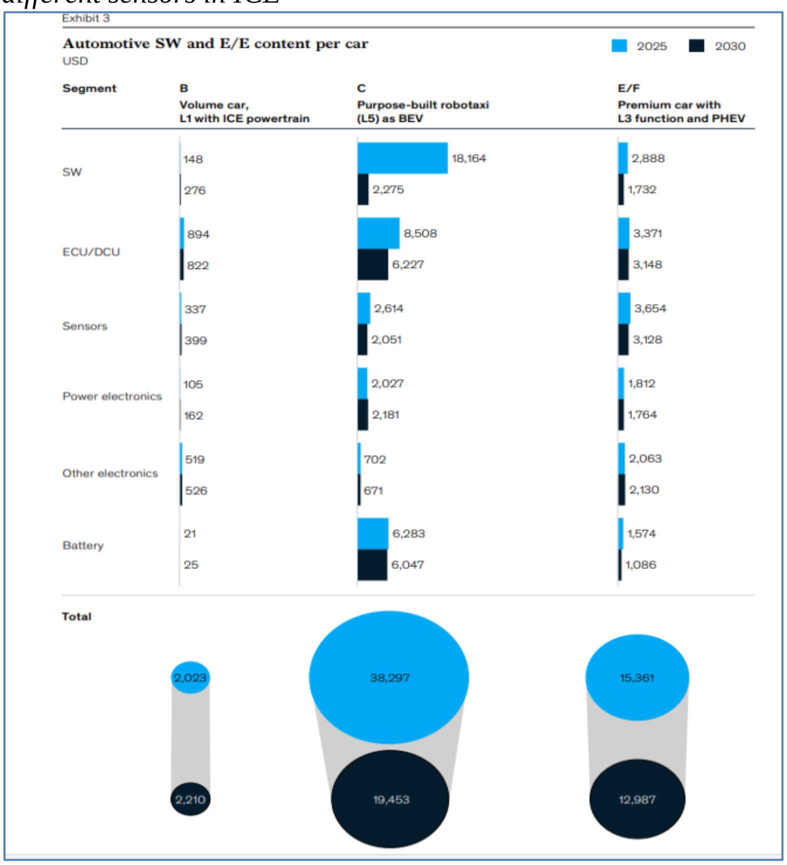


Fig 9 Value of electronics in vehicles is strongly driven by drive train ans autonomy level. Robotaxis can afford very high levels of electronics and still have a good business case

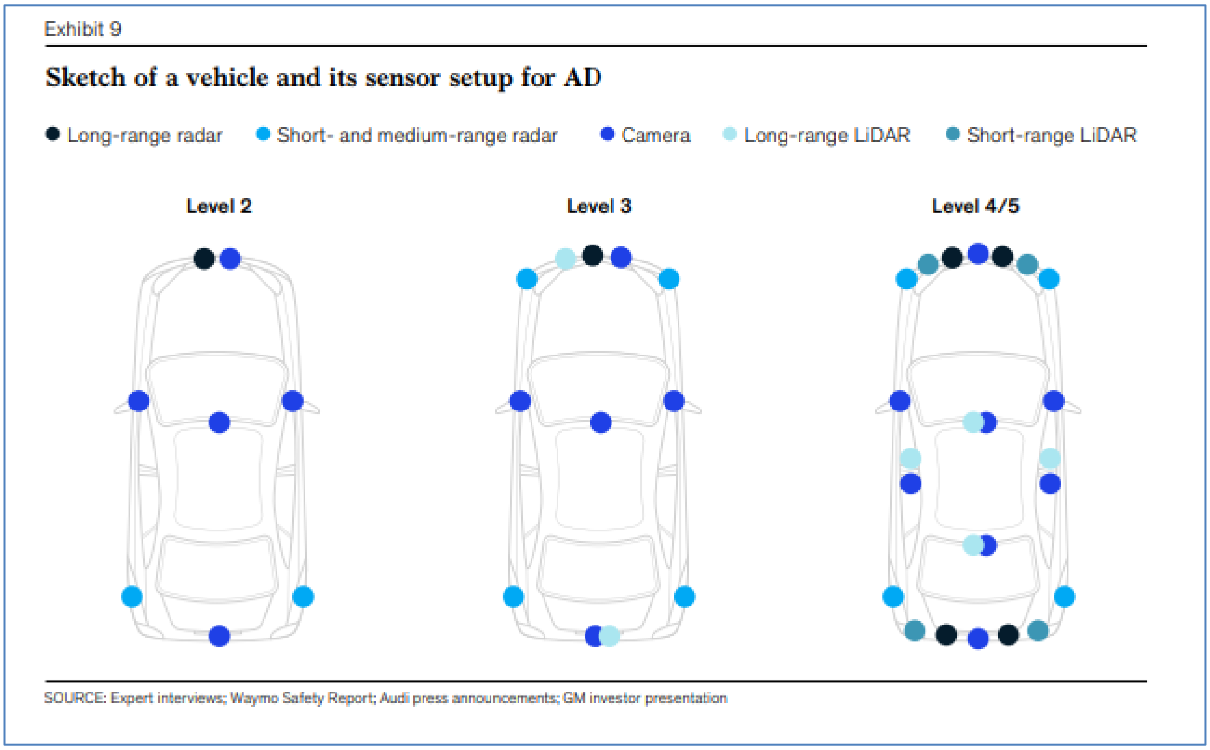


Fig 10. The amount of ADAS sensors is expected to increase strongly with autonomy level

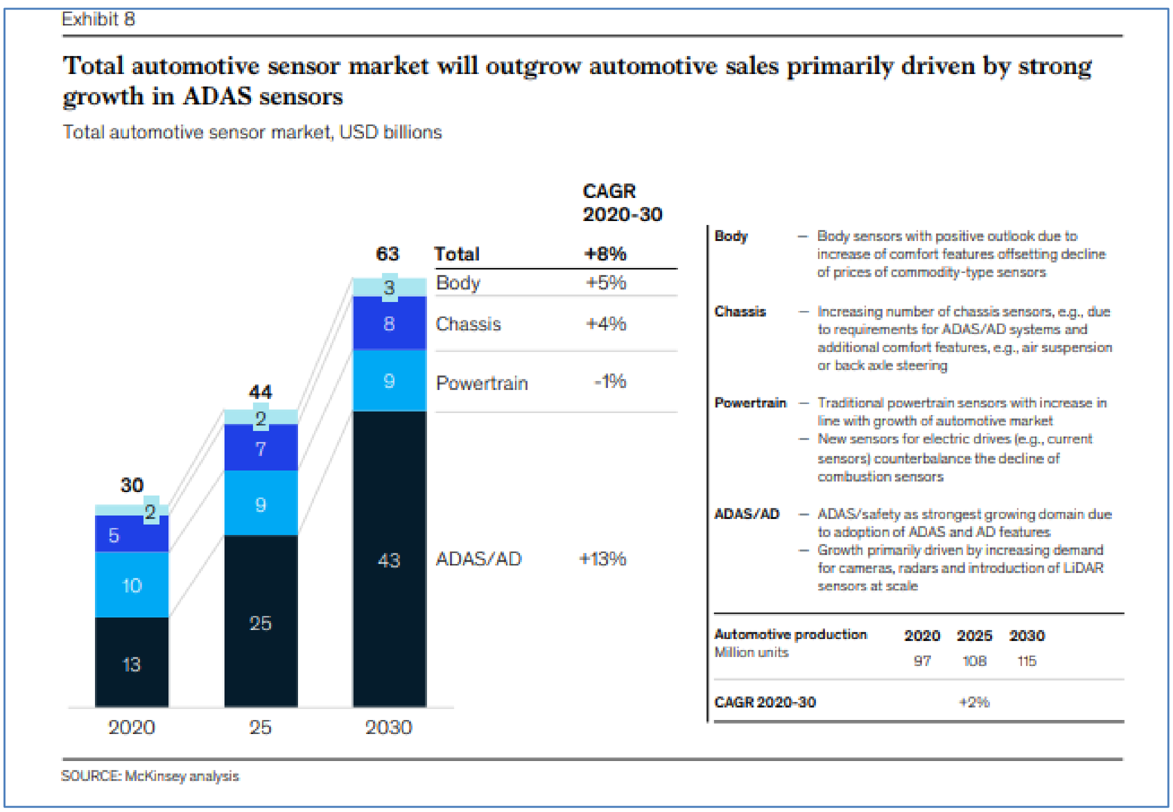


Fig 11 Strong growth in ADAS implementation will drive fost growth in ADAS sensors

ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)

Autonomous Driving is a key application for remote sensing and it represents a major technological advancement influencing the future of mobility. The main arguments for autonomous traffic infrastructure and higher level of automations are:

- Reduction of accidents
- Increase of transport systems efficiency as vehicle to vehicle communication eliminates bottlenecks in urban areas
- Augmented comfort for passengers as attention can be dedicated to alternative tasks
- Novel ride-sharing concepts to further enhance mobility-on-demand

In order to reach these targets, the automotive industry is continuously integrating novel sensors into the vehicle, complementing already established devices for ABS, ESP and ADAS. Therefore autonomous functionality will scale progressively as more sensing and communication functions are integrated. Figure 12 provides an overview of sensors employed in a car with early autonomous driving capability. As can be seen, there are a large number of components, ranging from imaging sensors, radar sensors, gesture sensors and a centralized multi-domain controller for processing this information. For photonics Lidar is of interest and this function has gotten a lot of attention recently.

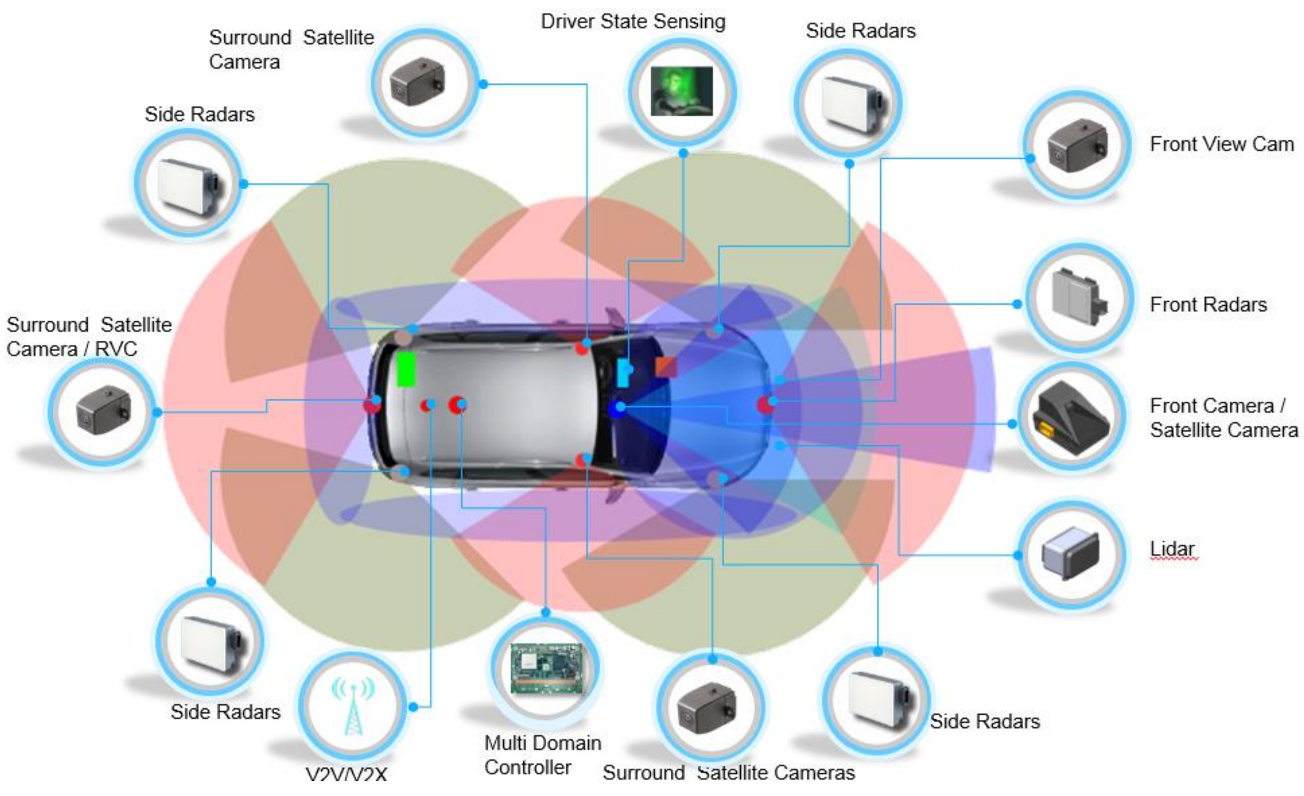


Figure 12. Subset of sensors used for autonomous vehicles

For maximization of safety the perception sensors are positioned to allow for a 360° redundant coverage. While the image depicts this situation for radar and cameras, the number of LiDAR units will increase as unit price drops.

Capability Type	Frontal Requirements	Corner Requirements
Azimuth FoV	120°	120°
Elevation FoV	30°	45°
Range (@10% reflectivity)	80m (+/- 60°) 120 m (+/- 30°) 200m (+/- 10°)	80m
Resolution	<0.1°(azimuth) <0.1°(elevation)	<0.1°(azimuth) <0.1°(elevevation)

Figure 13. LiDAR sensor placement and required performance

The industry expectation is that there will be different LiDAR sensors which trade of range and field-of-view coverage, to optimally to fulfill specific functions. The result of the assessment is summarized in the table below. Frost and Sullivan have noted that lidar can cover all SAE levels of ADAS systems as shown in Figure 7.

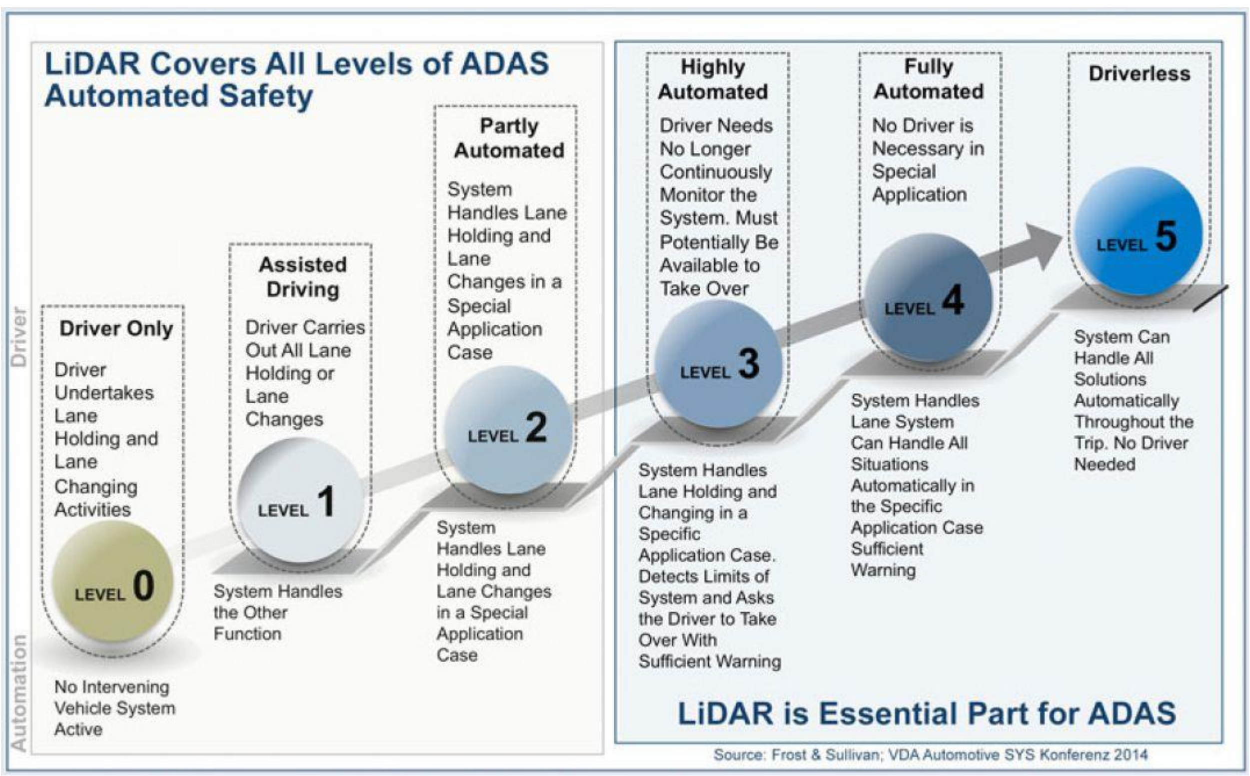


Figure 14. Lidar Covers All Levels of ADAS Automated Safety

The increasing application rate of connectivity, telematics, and navigation systems, together with several technology improvements, continue to maintain high attention and the growth confidence for the next-generation systems in the automotive infotainment segment.

Autonomous driving has attracted a lot of attention in the last years with many demonstrators and almost every car maker making bold statements on implementation. It was even predicted that level 5 cars could be on the road by 2023. The huge complexity of autonomous driving in city environments, several accidents and the rapid increase in development cost has toned down these expectations. With the notable exception of Tesla most carmakers now have chosen a more evolutionary approach and are implementing functions in ADAS systems with level 2 and 3 enabled cars bing announced. The interest in Lidar and other sensors remains high. The first Lidars are implemented in passenger cars (e.g. Audi) . Whereas use on open roads can still take a number of years ,the implementation in controlled environments (logistics , airports , factories) and robot applications is seen as a more short term opportunity. Overall the market is expected to grow rapidly.

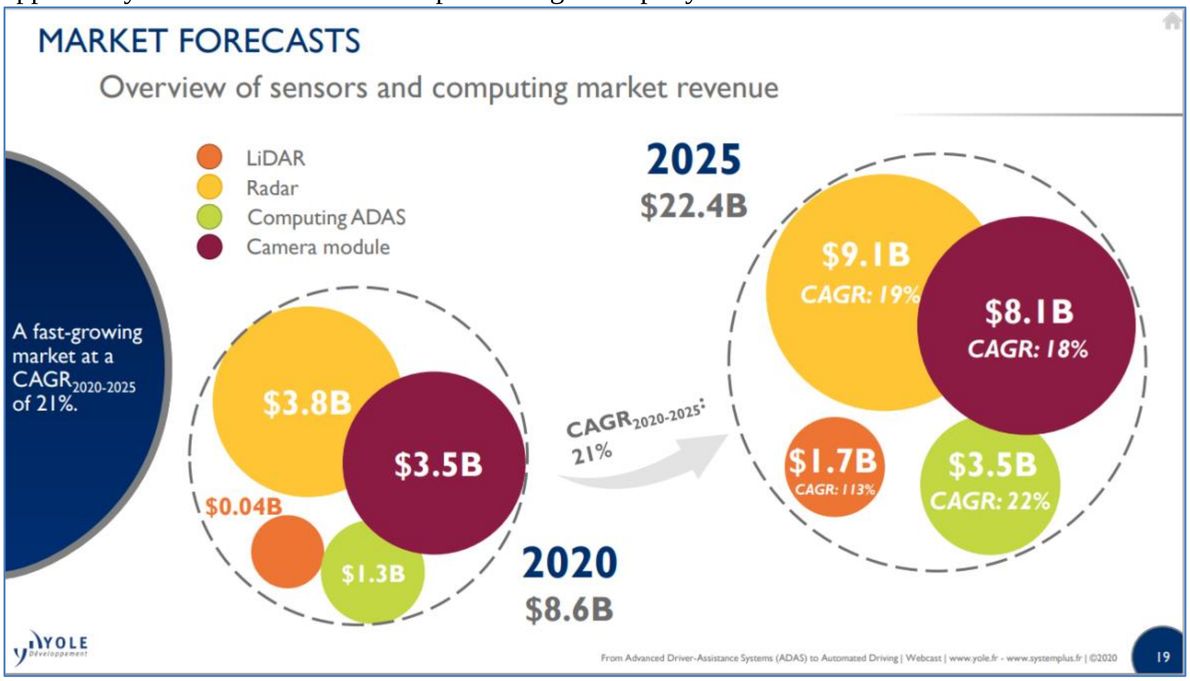


Fig 15 Market forecasts show fast growtg ADAS sensors, with Lidar coming up strongly

System complexity in the various automotive segments continues growing at a rapid rate. It is not simply related to the amount of semiconductors that will be integrated in an average car. In fact, there are some key elements challenging the development of in-vehicle electronics systems including:

1. Interconnection among different control units; i.e., networking;
2. System integrity when opening the vehicle to the external world, via telematics links;
3. Integration of multiple heterogeneous functions in a single system (e.g. Infotainment + ADAS);
4. Human Machine Interface (HMI) needs to be shared between entertainment and safety critical functions;
5. Sharing and exchanging larger amounts of data;
6. Higher computational power to elaborate such data and deliver an appropriate message or action; and
7. Increasing role that software has in in-vehicle systems.

Another aspect that appears more and more evident is the closer relationship occurring in the early development stages between semiconductor suppliers and vehicle manufacturers. A tighter relationship between vehicle manufacturers and suppliers is expected to optimize system development and quality, as well as ensure long-term support and adequate roadmaps for future developments.

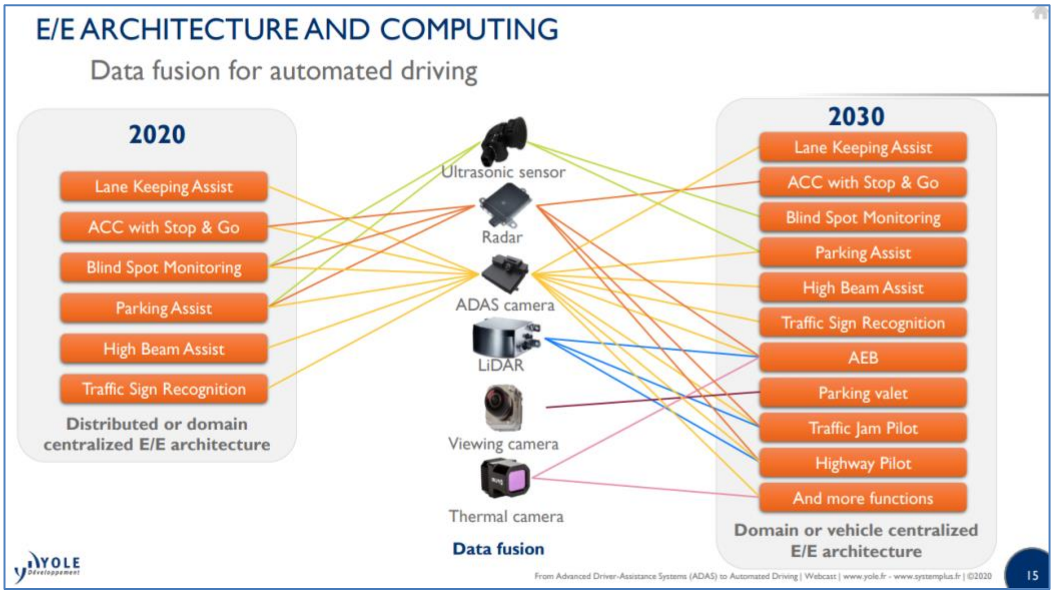


fig 16. Data fusion for ADAS systems showing fast growth and increasing complexity

Looking beyond the horizon, infotainment will focus more on safety, rather than entertainment, in the effort to limit a driver´s distraction., Natural voice and natural gesture recognition are expected to be in the next generation Human Machine Interface (HMI) that will allow interacting with the car Also driver well being systems are increasingly being implemented. This can range from monitoring driver distraction to functions that monitor passenger vital functions. In car “lidar” type of functions now also seen in mobile phones, camera’s and a range of other sensors are used, often combining functionality.

Scalable Solutions

In a scalable solution approach, a number of ADAS multi-functions are implemented by two or more ECU's. A primary ECU is responsible for detecting the surroundings around a car along with implementing the primary set of ADAS functions. An additional data processing module is used for implementing the rest of ADAS functions. This additional data processing module makes use of the data from the primary ECU and would process the information according to the requirements of the ADAS application. Another approach is to do only a limited amount of processing per sensor and feed the preprocessed data to a central system to do the sensor fusion processing. This obviously leads to very high data rates as well as huge computing power requirements.

Important considerations to be made while designing such architectures are:

- Power consumption by individual ECUs when using high-performance processing units.
- Thermal dissipation in the sensor module considering the sensitivity of sensors to high temperatures.
- Communication bandwidth between the primary ECU/sensor and the additional data processing module for transmitting required number of image frames per second
- The limited attach rate in vehicles of more advanced features that would not allow over-engineering the basic hardware, to accomplish the features that will be just “optionally” sold.
- Decouple highly safety critical functions (ASIL D (Automotive Safety Integrity Level D requirements) from non-safety critical ones.

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Connectivity

In the longer run, ADAS functionalities will be driven by integration of V2X technologies and further steps toward more advanced and reliable autonomous-driving vehicles,.

"Vehicle to Vehicle" and "Vehicle to Infrastructure" systems, although with different flavors and technologies, will be essential to go one step further in the reduction of road fatalities and in efficient traffic regulation. There are different implementations based on "a Wifi P"approach or on 5G functionality. Some carmakers have made announcements (e..g VW) but overall the situation is not clear yet

Within the vehicle there has been a rapid deployment of car networks over the last decades. CAN and LIN based networks are the workhorses of the industry and there are now dozens of nodes in cars . However for autonomous functions these are not fast nor reliable enough, Flexray has been developed for that. But for ADAS functions the data rates will not be not high enough, so Ethernet networks adapted for Automotive are now deployed. For infotainment in the past the fiber optic MOST bus has been developed. This has never become popular because of high cost, limited vendors and reliability issues. Wifi implementations in vehicles as well as Bluetooth links are now becoming commonplace

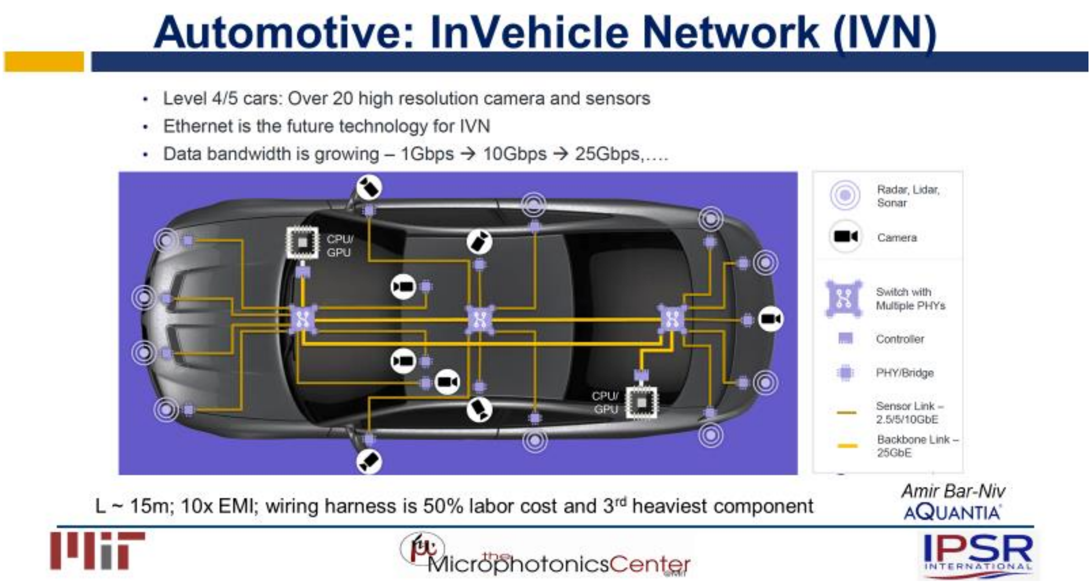


Fig 17. In vehicle networking needs for future demand

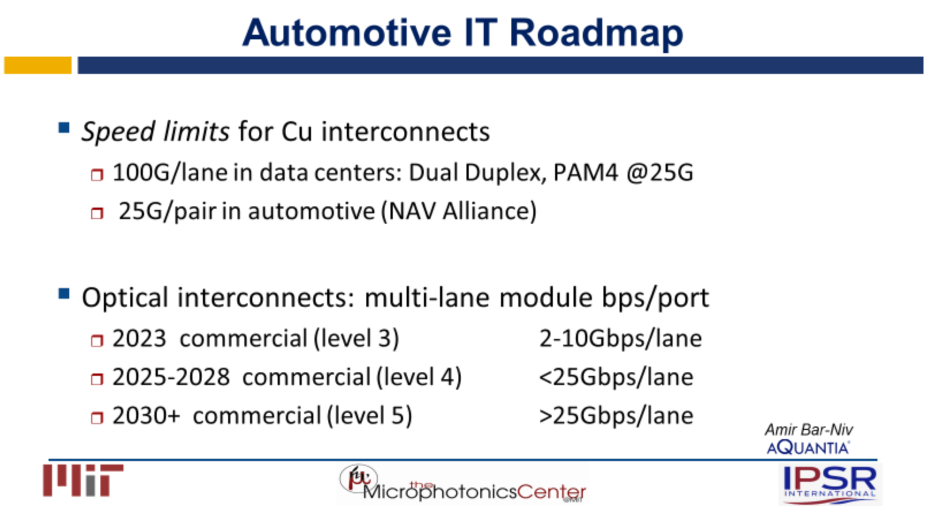


Fig 18 automotive connectivity roadmap far ADAS

Going forward with advanced ADAS systems which require huge computing power combined with sensor bitstreams which can go up to Tb/s the current solutions will fall short and this will create opportunities for photonic solutions

Lidar

There are several implementations of Lidar (Light Detection and Ranging), both in the detection principle as well as the implementation.

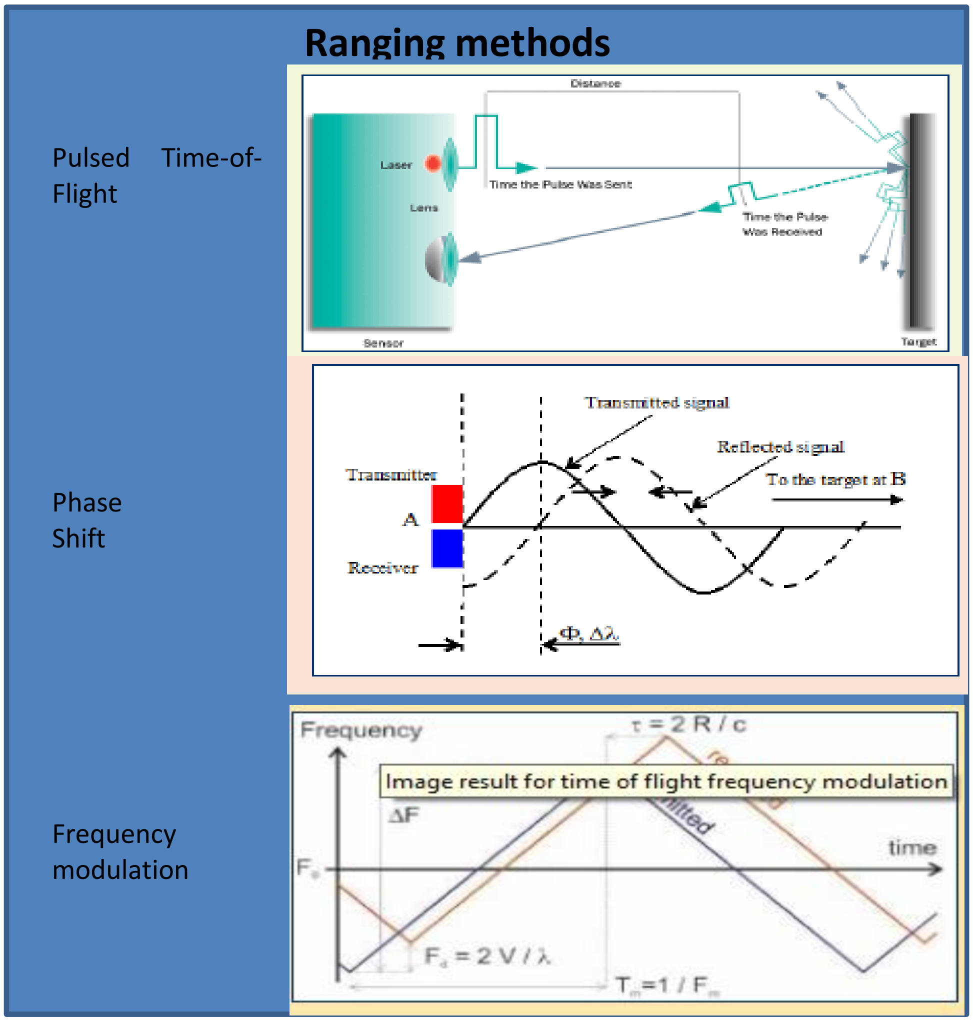


Fig 19, different ranging methods for Lidar (source: Yole)

The most well known is based on Time of Flight, but FMCW (Frequency Modulated Coherent Wave) which is often used in RADAR is also gaining popularity. Besides these main systems there are also variants being developed.
The most widespread LiDAR approach to measure a target distance is based the round-trip delay of a light pulse. As summarized in Figure 17 top. These systems consist of a pulsed light source, a beam-steering section, a detector and the electronic read-out [2]. A challenge for low-cost scanning LiDARs is the requirement of achieving a 2D deflection mechanism for spatial mapping with high resolution and a large coverage of the scene. Furthermore, scaling range resolution of these systems requires the measurement of the round-trip delay with increased accuracy. Inherently for long range detection the round trip time limits the scan frequency, requiring additional actions to create higher resolutions.

At the expense of additional optical signal processing, the method described above can be improved by using a frequency-modulated continuous-wave (FMCW) laser, while also enabling the measurements of the target's velocity. The FMCW approach requires a tunable laser and a coherent receiver. As the laser is tuned in frequency, the reflected signal can be evaluated in the frequency domain to retrieve the target range with a resolution determined by the tuning range of the laser. As this method is based on an interferometric measurement, the coherence length of the laser should be larger than the measurement range.

At the moment most implementations are based on ToF principles. Historically they were using mechanical scanning for beam steering. This however leads to relatively large constructions with price levels in the range of thousands of $. (e.g Velodyne) A good example of this implementation could beseen on the Google car. For mass market implementation high volume ready products are needed with price levels ultimately in the 100$ range. This will take several generations, but for that reason the industry has been investigating "full solid state" solutions.

State of the Art

Current solutions currently available on the market mainly rely on system integration of discrete components. More precisely, lasers and detectors are integrated with an electro-mechanical rotating mirror that serves as actuator for the beam deflection.Valeo has a unit in production implemented in the Audi A8.

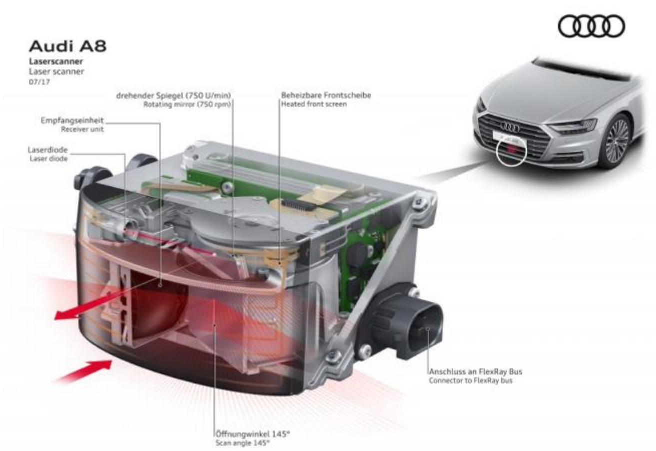


Fig 20, Lidar based on rotating mirror from Valeo , implemented in Audi A8

These types of sensors are used in automotive mainly for research and learning purposes, development, as the, size and temperature range pricing and expected lifetime do not fulfill the requirements of the automotive market. However, within the coming years new approaches based on hybrid-integration of various discrete semiconductor components will emerge. There are several approaches, the most well known are;

- Flash lidar where the full scene is illuminated by a laser pulse. As this requires a lot of power and raises eye safety issues, this is so far mostly used in non automotive short range implementations
- MEMS mirror; here a powerful laser (bar) is used to create ns pulses which are deflected by a MEMS mirror to scan the scene. Depending on the implementation a SPAD detector array is used to read out the return signal. This is solid state, but the MEMS mirror is a complex moving device, which is sensitive to the harsh automotive conditions.

- VCSEL array. This solution is using a 2D array of about 10K VCSELs which are used to create scanning patterns of ns laser pulses. This is combined with a 2D SPAD array. This is a true solid state solution that has become more popular in recent years enabled by the rapid development of powerful VCSEL arrays. An example is IBEO which is developing this with AMS.

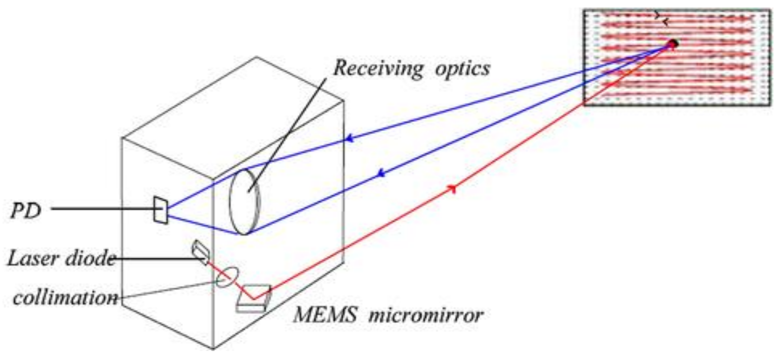
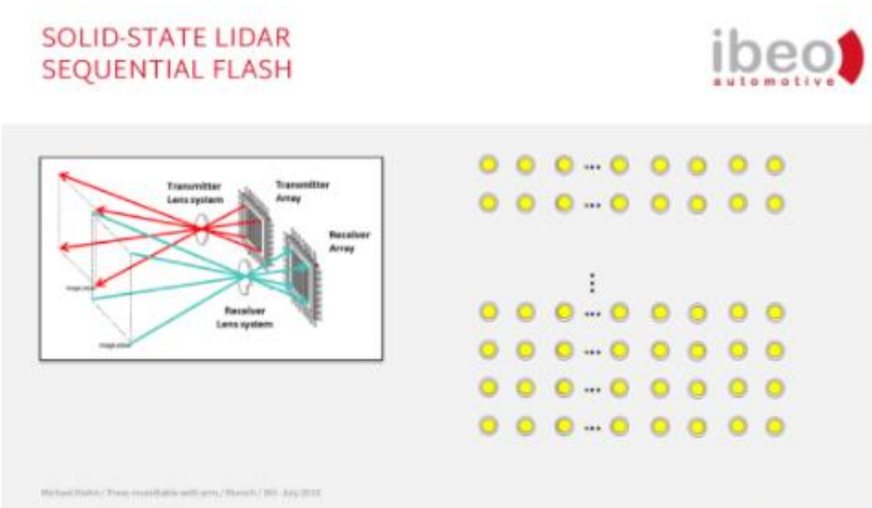


Figure 21. MEMs based LiDAR unit



The Ibeo laser scans the environment column by column. In specific cases, the sequence can be altered or randomized. (C) Ibeo

fig 22, VCSEL based Lidar unit

An issue for all ToF systems is that most affordable detectors are having a low detection efficiency in the IR range while there are very stringent eye safety requirements that have to be met. For that reason most solutions use lasers in the 850-904 nm range which limits the amount of power that can be used.

FMCW Lidar concepts are being developed by a large number of companies. Quite a few startups are active in this area. (e.g. Blackmore,Scantinel, Insight,SilC)

From a photonics point of view this is a very interesting field as it in principle could be achieved by an integrated photonic solution. It requires a tunable laser and coherent detector. Beam steering could be done by an Optical Phase array and a grating. This solution is still some time away, most companies use a subset of this in combination with existing technologies

An advantage that these solution have is that they can use frequencies around 1550 nm , which is well known in the communication area and has much less stringent eye safety requirements.

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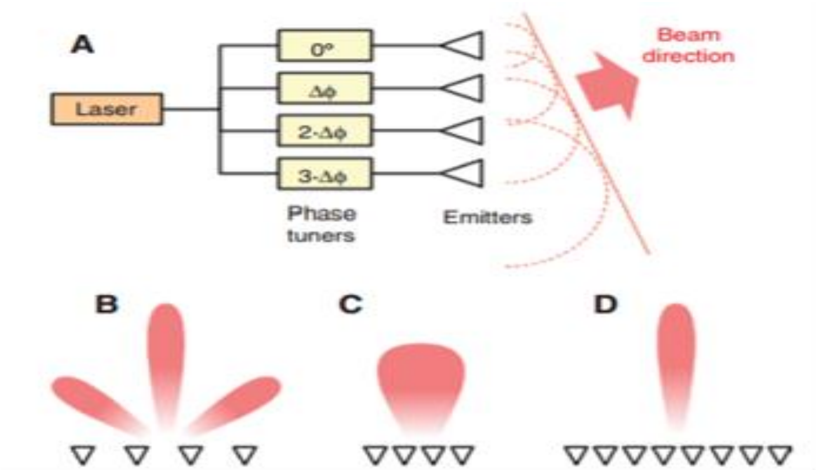

fig 23 Principle of Optical Phase Array for beam steering.

SENSORS

Sensors have become ubiquitous and increasingly critical in the automotive sector to monitor systems, driving performance or safety . ADAS sensors have already been discussed but a short overview of the rest is given here. For the most they are not Photonic in nature now but there could be opportunies in the future in e.g. gas sensors, gyroscopes , temperature and strain:

1. Integrated sensors for pressure (MAP, Fuel, Occupant Detection, Tire, Air Bags), acceleration, non-contact temperature, airflow, fuel flow, angular rate (Electronic Stability Control, Roll Over) sensors;
2. Gas/Chemical sensors for in-cabin air quality, monitoring exhaust gas composition and oil quality; Optical/Infra-Red sensors, Occupant Sensing, Night-Vision and in-vehicle displays;
3. Polymer based sensors for humidity detection; and
4. Ultrasound sensors fore back up aid.

With the advent of the EV the multitude of sensors used in Combustion engines will slowly decline while the sensors uses for Battery management will increase, as well as sensors aimed at driver well being and Autonomous driving

AUTOM OTIVE REQUIREMENTS AND ENVIRONMENTAL CONSIDERATIONS

The environment in vehicles is harsh and dependent on mounting position; components need to be able to sustain a large range of ambient temperatures (-40° C to 85/105 or even 150C°), high humidity levels and mechanical impacts with high G shocks over a lifetime of 15 years. Car makers are very stringent on quality for obvious reasons .For that reason quite a number of quality standards have been developed (a.o AEC-Q100) and it is normal to agree on tough qualification tests for new parts.. Failure rate is expected to reach <1 ppm long-term, for solid-state devices .For complex sensors often compensation mechanisms and internal tests are built in.

Safety .Depending on the use of the system different safety requirements have to be met (e.g the airco is less critical than the Brakes). This protects the passengers against failing parts by creating a safe situation if this happens. The procedures for this are in ISO26262. And ASIL levels have been defined (automotive safety integrety levels. This has a big impact on the design and development cycle of critical; components

Quality is a key metric that all automotive suppliers are measured on by using Assembly Plant Returns (APR). This metric is kept in parts per million (ppm). Assembly Plant Returns are returned to the supplier for root causes and corrective action.

Reliability is measured in warranty returns from the field. Warranty rates are calculated for 30, 60, 90, 180, and 360 days of exposure in the field. This metric is measured in Incidents per Thousand Vehicles (IPTV). Warranty units are returned to the supplier for root cause and corrective action. Automotive suppliers must also successfully pass validation in order to put the products into a production vehicle. Future business can be won or lost by past performance on reliability.

Developing reliable products needs a strict development process, defined with many deliverable and milestones, know as APQP. Being able to meet this is critical to success in Automotive
Once in production certification and strict change management is required

- Production (facility) needs and milestones (ASAP)
- Qualification of components according to AEC-Q100 (BIST, HTOL etc.)
- Certification of production sites according to automotive standards (e.g. IATF 16949)

Key Challenges

Needs 2020-2025

- Tuneable laser with >100mW output power around 1550 nm
- Laser operation uncooled to >100C
- Optical phase arrays with >200 channels
- High density interconnect of photonics and electronics
- Integrated solution with multiple laser sources

Needs 2025-2030

- Integration of tuneable laser , coherent detection and OPA
- Co packaging of electronics and photonics
- OPA with >500 channels
- Integrated electronics photonics package
- Lidar module with BOM <100$
- Full interrogator solution for EV
- Full automotive qualification

Needs > 2030-2040

- Lidar range increase to >300m in daylight
- Fully integrated module with OPA and grating for 2D scanning
- Lidar module with BOM <50$
- Full optical TB/s ADAS in car communication network
- Additonal photonic solutions in production , like Optical communication, Driver wellbeing monitor or optical gyroscope

With the megatrends in mobility changing the automotive landscape there are many new opportunities for integrated Photonics. The key challenges summarise the most important needs to play a significant role.

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