
Driving Assistance and Advanced Lighting Systems Synergy and Challenges

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Executive Summary

The current convergence of vision, safety and other systems in the automobile presents the entire industry with challenges on a never-before-seen scale. The size, complexity and interaction of these converging systems require paradigm-changing approaches, tools and talent to successfully undertake their development, testing and homologation.

The ever-increasing synergy of Lighting and ADAS, (Advanced Driving Assistance Systems), and V2X connectivity is significant, but this resulting integration will only be a part of the more daunting automotive “mega- architecture” required for semi-autonomous/autonomous driving.

In this update report about ADAS and Lighting technologies, DVN has limited the scope to the automotive Lighting/ADAS/ community faces now and in the near future. The enormously wide range Automated and Connected driving and their ramifications are subjects only dealt with here as how they can effect automotive Lighting.

After having described the current state of art and the need for an integrated systems approach for car-embedded hardware and software, this reports defines the various ADAS functions available on premium car segments and briefly traces their history.

In a next chapter, the two main categories, Advanced Front Lighting Systems with their five features and Adaptive Lighting Systems with their four functions are described followed by the panel of the different global players analyzed.

Sensors are the subject of the 5th chapter with their related image and information processing needs.

Finally the last chapter tries to outline what the outlook of combined Lighting and ADAS systems could be in the next future and which are the main challenges the automobile industry is facing in this context.

About the authors



John Cooper earned a degree in mechanical engineering from Carnegie-Mellon University and a master's degree in international business strategy from The Fletcher School of Law and Diplomacy at Tufts University.

He started with Faurecia in the US, Japan, France, and Germany. Then for 12 years, he worked in various positions at Valeo Group, including as General Manager of the China Sensor division. Previously, he had been based in Paris and responsible for global sales and business development for the Sensors and Switches Business Unit.

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He joined IAV Automotive Engineering last year as Business Development Director of Vehicle Systems.

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Daniel Stern, DVN's General Editor based in Vancouver, BC, Canada and Seattle, Washington, USA, is the chief author of this report. He is one of the five greatest lighting experts in North America. He is an appointed member of the US transportation Research Board Visibility Committee, which steers North America research on matters related to automotive conspicuity, lighting performance and regulation. He attends and participates in the world's automotive lighting symposia.

Salomon Berner, a senior Management Consultant and Coach, is based in Paris. He first graduated as a polytechnic and aeronautical engineer, and then successfully took over managing responsibilities in medium sized industrial and service companies.. His business experience was very helpful in setting up the DVN business model.

Introduction

The world automotive market is presently in the midst of a massive revolution, one which is making personal transportation safer than ever. Distinct domains of technology are evolving rapidly toward converging paths. ADAS, using cameras, radar, lidar and ultrasonics as sensors, are now emerging from more than a decade as mostly low volume curiosities to soon become the standard equipment on most vehicles in Europe, NA, and Japan.

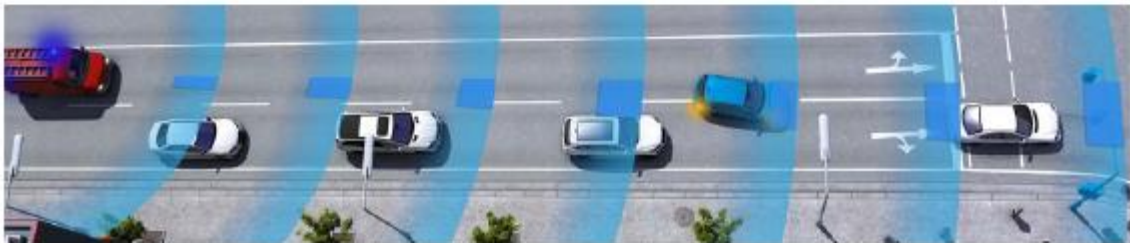
New lighting systems are advancing with Adaptive Driving Beam which tailor its profile to allow full power while avoiding the dazzling of oncoming drivers.

In addition, the communication between the vehicles, with infrastructure, and with “the cloud” (V2V vehicle to vehicle, V2I vehicle to infrastructure, V2X vehicle to anything) will complement the ADAS and Lighting systems.

The race towards autonomous vehicles will eventually make use of both onboard sensors as well as information gathered received through V2X systems in Europe and the US using the IEEE 802.11p in the 5.9 Ghz frequency range, a derivative of the wireless LAN used in many homes. These systems will have a range of 300 to 1000m and a high data rate of 6 to 27Mbps

Government regulations requiring such capability are expected first in the US in 2016 where the aggressive policies are taking advantage of the benefits of a single, homogenous jurisdiction.

Toyota, due to its market strength in Japan is even further ahead in deployment having developed similar V2X functions using another frequency i.e. 760Mhz. Already in 2015 some of Toyota’s new models sold in Japan will receive information by V2X that cannot be obtained by onboard sensors. At intersections with poor visibility, information about oncoming vehicles and pedestrians will be communicated to the driver with audio and visual alerts when necessary. Even a Toyota Communicating Radar Cruise Control feature uses V2V to keep leading and trailing vehicles at safe distances.



Bilder Car2CarCommunicationConsortium

In the next few years, all new vehicles in the US, Europe and Japan will almost surely be equipped with such OBU (onboard units) allowing DSRC (Digital Short Range Radio Communication) with infrastructure RSUs (roadside units). Such V2X communication will allow vehicles to exchange standardized and anonymous information with each other and with infrastructure

It is expected that the addition of V2X capability should not change the overall electronic architecture. Data input from sources outside the vehicle, e.g. nearby vehicle speed, location or traffic signal phase and timing (SPaT) should be treated in the same way as onboard sensors in order to facilitate fusion of data from both onboard sensors. Such complementary and sometimes redundant data will provide the reliability needed for autonomous driving.

This enormous and complex constellation of information and control systems within and outside the vehicle will be necessary to significantly reduce traffic fatalities towards the goal of semi-autonomous/autonomous driving.

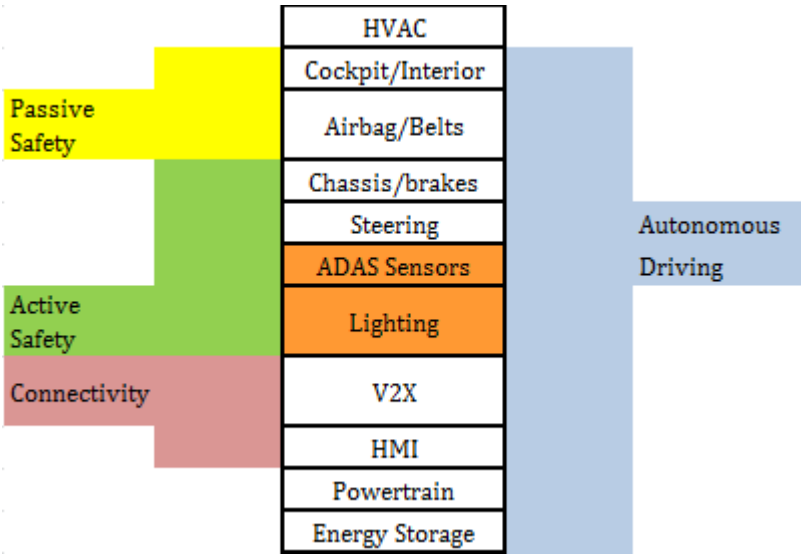
All of the constituent elements of such systems already exist today in the lab if not in production. The remaining obstacle up this mountain of development will be the enormous effort to master the complexity of what will be the ADAS/Lighting/V2X constellation.

Although many of the Lighting and ADAS systems already exist in high level luxury cars, the goals of fatality-free driving can only be approached through wide spread application of these technologies.

Although there has been intensive media coverage of Google and its autonomous and connected driving vehicles since the first edition of this paper in January 2013, DVN foresees that the corresponding effect of potentially driverless vehicles on automotive lighting will be negligible if any. Although futurists might extrapolate to eventual non-illuminated roadways traveled by lightless vehicles, for the imaginable future, all vehicles will require lighting systems to allow the onboard cameras and corresponding image processing (object/pedestrian detection, traffic sign recognition, etc) to function. Even a driverless car will still need to see and be seen. The autonomous and connected driving revolution now underway will not have a significant effect in the foreseeable future on the interaction of Driving Assistance, Lighting, and V2X already underway.

Status/Context

As can be seen from figure below, the conjunction of ADAS and Lighting systems is only a fraction of the challenge presented by semi-autonomous/autonomous driving. This survey therefore is intentionally limited to examining the intersection of ADAS + Lighting + Connectivity. As is often the case with electronic integration, additional features increase complexity by a multiplicative if not exponential factor.



ADAS and Lighting in the Vehicle Systems Context

ADAS and Connectivity definitions

Since the objective of this discussion is to examine how ADAS sensors will augment night visibility, let us define some terms:

Sensor/Connectivity hardware	Associated features
FCS - Front Camera System	Monocular and binocular LDW (Lane Departure Warning) ---- > LKA (Lane Keep Assist) FCW (Front Collision warning) PED (Pedestrian detection) IHC (Intelligent Head light control) ADB (Adaptive driving beam) TSR (Traffic sign Recognition) Drowsiness detection Night Vision
Rear/side cameras	Surround View (Image stitching) Object detection during forward driving Object detection during low speed maneuver Pedestrian detection Impending impact Automatic Parallel Parking Automatic Perpendicular Parking Blind Spot detection ARS, Adaptive rear light systems
Radar (77-79 Ghz and 24 Ghz)	ACC - (Automatic Cruise Control)

	FCW – (Front Collision Warning)
	Urban environment sensing
	Lane Change Assist
	Cross Traffic
	Impending impact
Lidar	Object detection
	Medium range environment
	Long range environment
Ultrasonic	Proximity Warning front and rear i.e. traditional assist
	Automatic Parallel Parking
	Automatic Perpendicular Parking
	Blind Spot detection
V2X communication device	Red Light Violation Warning
	Curve Speed Warning
	Spot Weather Impact Warning
	Reduced Speed/Work Zone Warning
	Pedestrian in Signalized Crosswalk Warning
	Emergency Electronic Brake Lights
	Forward Collision Warning
	Cooperative Adaptive Cruise Control
	Left Turn Assist and many more!

History

The history of the separate developments of early discrete driving assistance systems demonstrate a convergence which is now accelerating.

The first optical and radar ADAS systems appeared in low volume production the Japanese market in the 1990's i.e. the first ACC in the 1997 Toyota Celsior, the first LDW 1999 Mitsubishi Praudia. Neither vehicles were exported outside of Japan to the more legally-demanding European and NA markets.

In 1999, Mercedes-Benz introduced a first ACC system, Distronic in their S Class. In 2004 Nissan debuted the first LDW system outside Japan in the Infiniti FX with a camera product from Valeo using Iteris technology. Soon after, in 2005 an alternative LDW technology was launched with PSA in C4, and C5 vehicles using infrared emitters and sensors on underbody of the vehicle to detect road markings. This system eventually became extinct after PSA replaced it with their multi-function front camera to do LDW as well as other front camera functions like FCW, TSR, AHC etc.

Now in 2015, we are well into the explosion of ADAS applications, driven by the following factors:



The inclusion by NCAP/EuroNCAP of ADAS systems is having the effect of forcing even non-premium brands toward the application of at least a front camera system (with or without complementary lidar or radar) even in their B and A segment vehicles.

The strategy consultants Roland Berger estimate that by 2030 an additional revenue pool for automated driving hardware will increase at a rate of 39% CAGR to around €30-40 billion. Additional revenues from corresponding software €10-20 billion.

As in most product life cycles, the cost reductions are being driven by large volumes. Having fewer suppliers of the key aspects of this technology is allowing standardization as well as high reliability in their application.

Of course, there remain obstacles, of which a primary one is the cost-effective integration of such systems into vehicles' electronic architecture. The necessary technical expertise on the part of the OEM as well as the supplier is very substantial, especially when considering the need to implement ISO 26262.

The rapid improvement and the standardization of ADAS have convinced observers of this market to believe that the question is no longer "WHETHER autonomous vehicles will be common on the roads?" but rather WHEN will it take place.

All major OEMs have announced plans for “Automated Driving” however such a term require clarification. Using the NHTSA definitions there are four levels of driving automation:

- Level One: The vehicle can control minor functions like automatic braking, parallel parking assistance, advanced cruise control, active lane keep assist, and even electronic stability control.
- Level Two: Includes features, such as adaptive cruise control and active lane keep assist working in unison, are performed by vehicles when the feature is engaged, but drivers must always be in control of the vehicle.
- Level Three: Vehicles can function completely on their own in limited capacities, equivalent to auto-pilot in the aviation industry. Drivers may manually override systems and make adjustments to driving situations.
- Level Four: This is a fully automated vehicle, requiring no driver input whatsoever.

Many of the all OEMs have announced concrete plans for at least level two vehicles to be on the road by 2016-2018, if they are not already (Level 2 vehicles are already sold by VW/Audi, BMW, Daimler). Crossing the threshold to level three however is major challenge for regulatory and infrastructure reasons. Most OEMs forecast to have level three vehicles to be available for sale not before 2020, though Google’s level 4 vehicles could be on sale in 2018.

The end result in the world of autonomous vehicles will most likely be decided by the obstacles represented by the various standards of driving infrastructure in the countless number of jurisdictions around the world. In any case, the vehicles’ future onboard ADAS capabilities are no longer seen as a limiting factor.

Functions

The use of video systems to determine the run and width of the road or the use of navigation systems are other ways of enhancing the potential of AFS and adaptive lighting. If the run of the road is known in advance, the light distribution can be adapted beforehand. The intention is to let the light guide the driver's gaze into a curve. The evaluation of the video images will not only make it possible to predict the further run of the road but also predict the position of other vehicles. More effective lighting under all conditions will also improve ADAS camera performance, especially in the minimization of "false positive" detections.

"The headlamp should be able to detect fog, spray, rain and snow, contamination on the lamp window and even the separation and speed of following traffic," says Dr. Huhn. "Using this data in conjunction with the vehicle data, it will be possible to adapt light output from the rear of the vehicle intelligently."

Two different Lighting functions have developed in conjunction with ADAS.

The first one, AFS, (Advanced Front Lighting Systems) started without ADAS but now increasingly uses GPS and cameras for bending light, motorway light and adverse weather light. The second one, ADB (Adaptive driving beam) needs cameras and possibly GPS and other sensors.

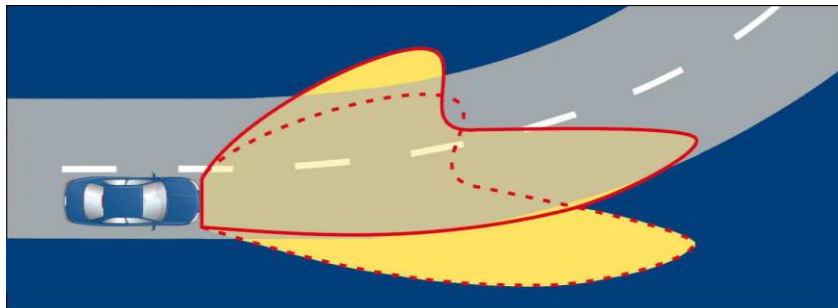
AFS Function

Advanced Front Lighting Systems provide beams with differing characteristics for automatic adaptation of the low and high beam to varying conditions of use i.e. road, weather and speed. It is type-approved to ECE Regulation 123 or in the US, certified to comply with the applicable provisions of FMVSS 108.

The AFS provides five light features with differing characteristics for automatic adaptation to varying conditions of use of the headlamps.

1) Bending Lights

- *Dynamic Bending Light* ensures curves are better illuminated. Depending on speed and steering angle, the movable light module swivels by up to 15 degrees into the curve, so obstacles become more easily visible.





HID headlamps without bending light



HID headlamp with bending light

- *Static Bending Light or Cornering Light* on tight corners helps during maneuvers on dark roadways. At speeds of up to 40 km/h the light comes on when the turn indicator is actuated or the steering wheel turned through about 90 degrees. This function is also very suitable to assist the driver's orientation when parking, the static bending light activates to illuminate the parking area when reversing.



Porsche Cayenne headlamp, first equipped with static bending light

Research by University of Darmstadt shows that AFS provides much better visibility in curves. By measuring driver eye movements, scientists demonstrated that night-time visibility in curves with steering-linked HID headlamps (36 metres) is close to daytime levels (38 metres), while conventional static halogen headlamps allow just 24 metres.

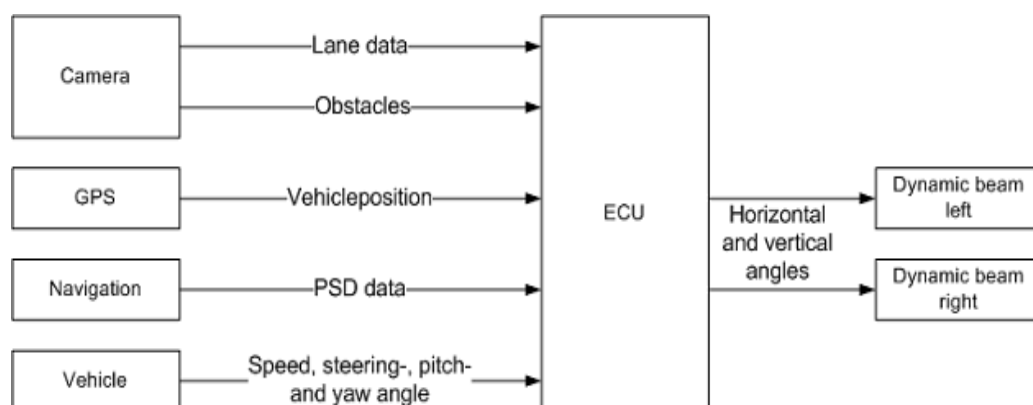
Bending Light systems and then AFS systems strongly introduced lighting in the era of complex systems with the use of multiple sensors, and in parallel with the development of CAN bus communications to channel complex information including speed and steering angle to the lighting system.

2) **Motorway Light**

This system improves vision on highways by illuminating the roadway substantially further ahead while lighting more of the opposite lane. The motorway light switches on automatically at speeds over 100 km/h. Due to the fact that there is no directly oncoming traffic, the viewing distance on one's own side of the motorway is increased. The visibility range can increase from 70m to 140m so that very distant objects can be recognized across the entire width of the road.

3) **Adverse Weather Light :**

This is activated when the rain sensor detects precipitation or fog. The side boundaries of the road are more brightly illuminated for better orientation using the edge lines. The light cone is somewhat shorter on the left-hand side.



Self diagnostic system for fog, rain, snow, windshield occlusion



Visibility distance: 51m



Visibility distance 41m

Additionally the glare of oncoming traffic is reduced by lowering of reverberation on the wet road.

The current state of the art is found in the 2013 E-Class which removes the 15° cut off of the left

headlamp while light is turned to the left.

4) ***Country Light***

This feature illuminates the left and right-hand edges of the road more brightly and widely than the conventional low beam. It is activated at speeds between 50 and 100 km/h.

Country light is relatively similar to the current low-beam but uses the new possibilities to improve the illumination of the road and the side areas when driving in rural areas.

5) ***Town Light***

This provides a wider light distribution at reduced range, helping drivers to better see pedestrians on the edge of the road.

“Adaptive lighting” Function

Adaptive Lighting Systems assemble technologies which automatically and dynamically adapt light in all circumstances of driving: environment, weather, roads, speed, traffic and in the future, drivers (fatigue, alcohol) to allow the optimizing of visibility without increasing glare.

The detection of cars requires cameras from suppliers which are generally from outside the lighting business. This development of a Lighting/ADAS “ecosystem” has resulted from this need for cameras, their associated image processing software and smart actuators. As a result, the arrival of ADAS-driven adaptive lighting has introduced many new players including Autoliv, Continental, Gentex, and Mobileye..

The table below shows the lighting companies with respect to some of the ADAS players

Automotive Lighting*	Infineon
Autoliv	Koito *
Bosch	Knorr-Bremse
Brightway Vision**	Lear
Continental	Mobileye
Delphi	Magna Electronics
DENSO	Micron
Eaton	Mobis *
Federal-Mogul	Takata
Freescale	Toshiba
Gentex	TRW
Hella *	Tyco Electronics
Hitachi	Valeo*
Ibeo Automobile Sensor**	Velodyne**

System/Component Suppliers

* Indicates Lighting supplier

** not a production equipment supplier

Most of car makers do not develop ECUs or image processing. However some car makers like Mercedes-Benz, BMW or VW are involved in them.

The 4 functions of Adaptive Lighting Systems

1) High Beam Assistant

High Beam Assistant is the function which does the automatic switching between low and high beam for optimal illumination of the roadway, ensuring the maximum use of high beam without glaring oncoming vehicles.

Even when the high beam is warranted by prevailing conditions, drivers generally do not use them. There have long been efforts, particularly in the US, to devise an effective automatic beam selection system to relieve the driver of the need to select and activate the correct beam as traffic, weather, and road conditions change.

Early systems like GM's *Autronic Eye* and Koito's *Safety-eye* respectively appeared in 1952 and 1962, with an electric eye mounted on the dashboard, which was supposed to switch between low and high beam in response to oncoming traffic.



GM's Autronic Eye

Present systems based on CMOS cameras can detect and respond appropriately to leading and oncoming vehicles while disregarding streetlights, road signs, and other spurious signals. Placed behind the windshield close to the rear view mirror, the camera detects the different light sources in the visual field. Image processing software then determines whether the light source is from a moving vehicle or a fixed light source, such as a street light or an information panel.

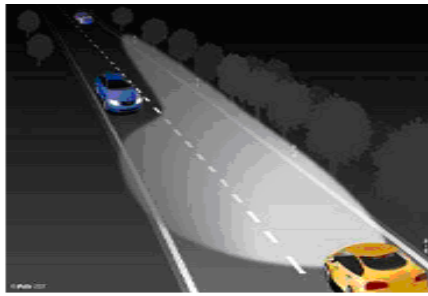
The position of other vehicles is precisely determined in order to avoid glaring the drivers. Automatic high beam assistant not only relieves the driver of the beam selection task, but is expected to alleviate the drastic under-use of high beam headlamps.

Camera-based beam selection was first released in 2005 on the Jeep Grand Cherokee.

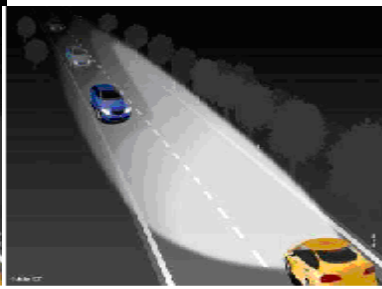
2) Adaptive Cut-off

Adaptive Cut-Off involves an automatic adjustment of the cut-off shape and/or placement within the beam ensuring optimized visibility without glare.

It is a continuous, progressive transition between low beam and high beam, equivalent of a dynamic automatic aiming with the integration of opposite car position and sometimes vertical road geometry (hills and slopes).



Standard low beam



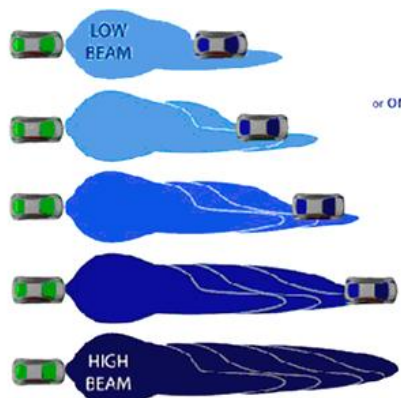
*Adaptive cut-off,
when oncoming*



*Adaptive cut-off,
when heading vehicle*

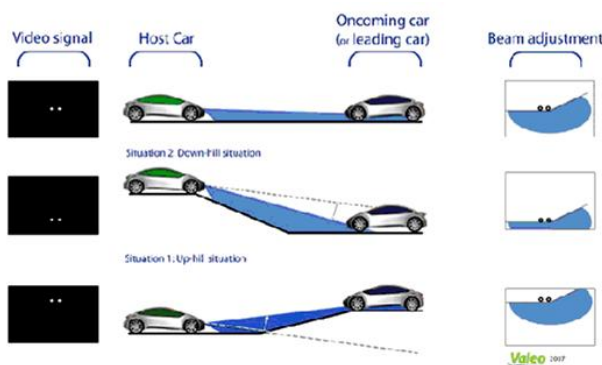
Adaptive Cut-off is the newest headlamp technology, introduced in spring 2009 in Mercedes-Benz E-Class. The system uses the information from a camera mounted behind the windshield to automatically and continuously adapt the headlamp range to the distance of leading or oncoming vehicles.

The same feature is also present in the BMW 7 Series. BMW's application integrates Mobileye HW/SW, to control swiveling headlights that always point in the direction the vehicle is steering so as to better illuminate obstacles and the road ahead.



Cut-off position is optimized regarding opposite and following cars

Adaptive lighting representations considering traffic



An improved technology involving slope variation of the road, is now available in the new Audi A8. Adaptive lighting representations considering slope variation of the road

Adaptive lighting representations considering road:

3) Adaptive driving beam or Glare free high beam

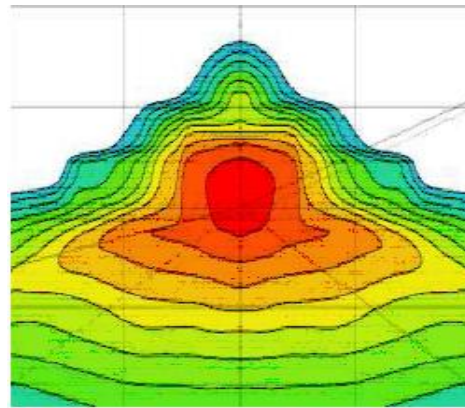
Glare Free High Beam is a high beam permanently illuminated without glaring other drivers; the maximum light is maintained on the road with the exception of the specific zones where other vehicles are located; these are dynamically shadowed out of the beam pattern.

With this technology we can achieve a remarkable gain of safety in night-driving.

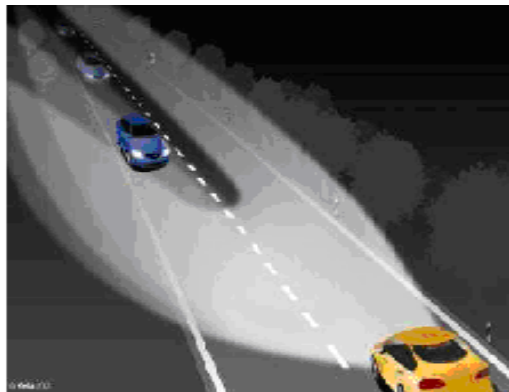
The permanent Xenon and now LED high beam with slices or spots shadowed out dynamically to prevent glare allows the driver to see potential dangers, for example an obstacle or pedestrian on the road, at far greater distance than with any type of low beam.



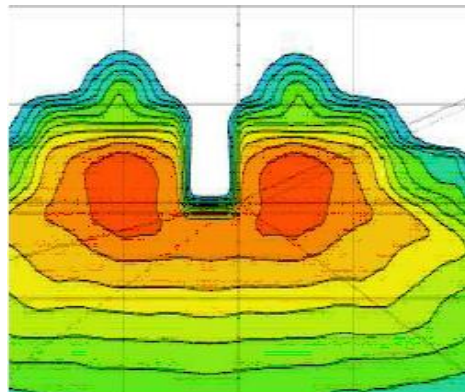
Picture of standard high beam



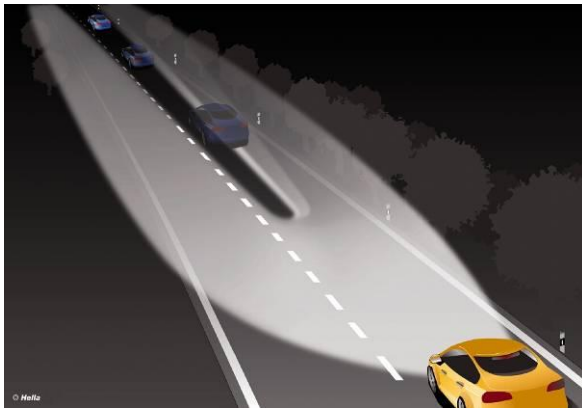
Isolux of standard high beam



Picture Glare free high beam, oncoming vehicle



Isolux Glare free high beam, oncoming vehicle



Traffic ahead



Oncoming traffic



ADB principle

Matrix beam

Another breakthrough came when LEDs and related electronic technology matured to allow much closer control of light within the beam, the first level being matrix beam. Matrix beam provides the glare-free high beam function without moving optical elements. By switching and dimming separate LEDs in different optical units or individual chips of a fixed LED array, the glare-critical areas of the high beam distribution are selectively darkened without need of mechanical actuation or motion within the headlamp.



MXB LED-Chip Reflector Group from Hella



Audi A8, first car equipped with matrix beam

It offers the potential for higher resolution and new capabilities such as sending light between adjacent shadowed-out vehicles.

Audi started the production of the technology on their 2013 A8 and then on their 2014 TT.



CLS matrix module with LED array



Audi TT 2015 equipped with matrix beam

Pixel light

Mercedes-Benz will soon introduce Multibeam LED headlamps with a matrix light source featuring 84 LEDs, which allow an even higher resolution light pattern. This will make

it possible to protect other road users even more precisely against dazzling while providing even better illumination of the roadway. This will make a host of new adaptive lighting functions possible that will make driving at night for the driver and for other road users safer still.

All car makers and set makers, with support from universities and source suppliers, are working towards finding the best reasonable compromise between performance, complexity, design and cost.

In lighting, we are in the beginning phase of pixel light and the future will not just bring more and more LEDs.

Over the medium term, a new type of LED chip with more than 1024 pixels will allow further improvement of night time visibility.

The partners Infineon, Osram, Fraunhofer, IZM, Hella, and Daimler have just achieved a breakthrough in the "μAFS" research project in the form of a new type of LED chip with an extremely fine structure. Monolithically structured pixel LED semiconductor layers are built up on a silicon substrate which, via the integration of circuit parts, allows the selective control of more than 1024 individually addressable pixels per LED chip. This LED technology developed in the project sponsored by the German Federal Ministry for Education and Research (BMBF) is to be installed and tested in a Mercedes-Benz experimental vehicle in 2015.

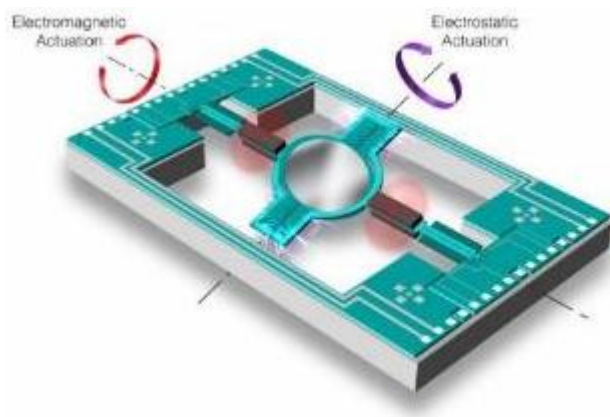
Other Potential Technology for totally variable beams

Due to the highly focused sources like blue laser beams illuminating a phosphor target, the system is devoted to create totally variable light distributions by moving the laser beam on different locations on the phosphor. To create automotive beams, movement of the laser beam on the phosphor has to be done in two dimensions, horizontal and vertical. There are two different versions of mirror systems possible to control such movement.

In the first case two subsequent mirrors deflecting the laser beam one in vertical direction and one in horizontal direction are used. The first system can be realised by two conventional electromechanically moving mirrors (galvanometer technology). Though the one dimensional mirror systems are easy to produce and implement, the technical challenge is to synchronise the relative movement of the two mirrors in time and space. Therefore the application of such system for automotive use will be difficult to realise.

A second alternative is to have a single mirror able to move in both directions. In the following sketches both systems are depicted. The system has a Micro Electronic Mirror System (MEMS) synchronising laser light output and scanning speed to camera-detected vehicles, an arrangement crucial to generating an ADB. Such systems are based on silicon wafer technology.

Sketch of two versions of Laser Systems to create Variable Beams



Schematics of a two dimensional moving MEMS

MEMS technology shows the potential to achieve totally variable beam functionality with fewer light sources than in matrix beam systems, and with more potential. We will see in the future whether LED matrix beams, scanned laser setups, a mix of both, or something else will dominate the world of ADB.

4) Marking Light Function

A Marking Light (or Spot marking light or Marker light) guides the driver's attention to the possible danger of pedestrians or animals beside the road, with an optimal addition of light using information from a camera-based system.

Marking Light is an addition to glare-free high beam systems, and a sort of inversion of them ; instead of shadowing out spots or slices within the beam, the Marking Light system adds spots or fingers of light outside the normal beam area to show the driver detected obstacles of concern not sufficiently illuminated by the ordinary light beam.

In this feature LED technology's ability to variably actuate individual LED elements is brought into play to the benefit of all motorists.

In this manner, the driver's attention is directed to potential dangers, thus affording him more time to respond. The possibility of actuating LED chips individually allows for consistent illumination of a potential danger despite respective movement of vehicle and the object..

Here drivers are able to identify objects in a simple manner without having to take their eyes off the road.

Due to the mandatory aiming of low-beams, the range of the low-beam light distribution is limited to 60 – 100 meters, depending on the height of the headlamps, the specific local aiming regulations, and the quality of the light.

Regarding the time necessary to stop a vehicle, physiological as well as mechanical factors have to be considered.

The physiological components include perception and comprehension of the scenario as well as the activation of the brake pedal. The process can take between 2 seconds, depending on the driver's condition.

Future adaptive lighting could bring a lot to decrease the whole process time.

The picture below at the left, shows the illumination of a pedestrian at 60 m using the low beam function. The picture below at the right, shows an additional marking light spot.



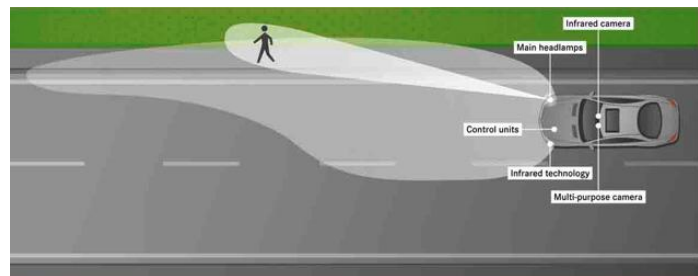
Using the low beam function



Using an additional marking light spot

Illumination of a pedestrian at 60m

An intelligent Marking Light system produces a small spot to highlight only those pedestrians or animals to which in danger or potential danger. The picture below shows an example of Marking Light with LED-array.



Illumination of a pedestrian or animal

Signaling Function

Weather conditions

The rear lamps' signaling appearance automatically adjusts to diverse weather conditions. During bad weather and with the rear fog lamp active, just one of the two brake light zones functions. Adding the rear fog lamp gives the characteristic multi-zone effect visible in adverse weather conditions. This helps the following driver to accurately discern the 7 Series' position.

Multi-level tail lamps

Mercedes-Benz have achieved another world first by developing tail lights with multi-level functionality, meaning that the brake lights and indicators are operated at varying intensities depending on the current driving state and ambient brightness levels (day/night).

If the Mercedes 2013 E-Class driver presses the brake pedal while stopped at traffic lights, for instance, the brightness of the brake lights will be automatically dimmed to avoid dazzling anyone behind. The light distribution is broadened to ensure the lights do not become too dim and continue to fulfill all legal requirements.



2013 Mercedes-Benz E-Class rear lamp

This provides three intensity levels in rear stoplights and rear DI to better be seen in daytime without too much glaring in nighttime conditions.

Daytime driving: High level of light

Nighttime driving: Low level of light

Nighttime stopping: Lower level of glare

Progressive brake light warning system

The traditional brake light circuit consists of an on-off switch that is activated when braking. The brake light has the same intensity, however hard the brake pedal is pressed. A Hazard Warning Flasher is compulsory on all vehicles, but is activated manually. The Progressive Brake Light Warning systems now being introduced are adaptive and are designed to impart a higher level of urgency and clearer warning of hazard, mainly to prevent rear end collisions when braking.

The adaptive brake light introduces technology from the luxury class into the compact segment, which therefore benefits from a further accident prevention system as a standard feature. Under emergency braking from a speed exceeding 50 km/h, the brake lights flash rapidly to warn following traffic, enabling drivers to respond faster and prevent a collision.

Using flashing brake lights as a warning system has come about through extensive practical research covering the braking behavior of drivers.

In European markets, the progressive brake light warning systems have been fitted mainly on premium segment vehicles as standard equipment.



BMW 7 Series rear lamp

The ECE version of the BMW 7 Series is equipped with a multi-stage safety brake light function based on the newly updated ECE regulations 7 and 48. In an emergency-braking situation, the brake lights flash at 5 Hz. It is not known whether this function will be retained in the North American market, where it could be confusing due to the widespread presence of flashing red rear direction indicators. In case of an abrupt stop or crash, the ESS system (emergency stop signal) will be activated. The automatic warning lights indicate the emergency situation.

Audi have demonstrated an interesting scanning-laser rear fog lamp that projects a stop line behind the vehicle to indicate safe following distance and creates a big red warning triangle in foggy conditions. The technology to do the job well is now more accessible than ever, but at the moment adaptive rear lighting seems to be regarded mostly as a luxury frill. Much more effort is being put into adaptive front lights; at the rear, the attention is going into design, styling, and the development of technologies like OLED. Eventually we may see signal functions that deliver different kinds of information to communicate with oncoming, leading, or following road users of all types—drivers, bicyclists, and pedestrians—and even to communicate with other vehicles themselves.



Picture 3.50: Fog active-safety concept Audi

Externally Projected Information – Augmented Reality

With the future application of laser front lighting, the possibility of projecting information within beams onto the road becomes feasible. In a way similar to a heads up display, pertinent information (GPS direction, pedestrian warnings etc) can be displayed on the road surface so as to be within the already-focused field of vision of the driver. Of course, this kind of type of external information display requires input from the front camera and radar sensors so as to know when such a display is appropriate.



Externally projected GPS information

Ultrasonic

The first ADAS sensor technology was the innovative ultrasonic park sensors pioneered by the German SWF (now Valeo) with BMW in 1994. Over the years this technology has been come down in cost and been applied in a larger share of vehicles with the market leaders being, in order, Valeo, Bosch and Denso.

In 2006, Valeo successfully launched an ultrasonically-guided “Park4U” system with Volkswagen which located, and then guided the vehicle into a parallel parking spot in conjunction with the Electric Power Steering System which provided the torque needed to turn the steering wheel at the appropriate time with the only driver’s intervention being control of gas and brake.

Ultrasonic sensors have the advantage of being less costly but are limited by the speed of sound thereby restricting their applications to low speed maneuvering.

An exception to this constraint has been the unique application by Bosch of ultrasonic sensors in 2008 for blind spot detection systems at PSA, as opposed to the typical radar used elsewhere.

In any case, the market demand for ultrasonic parking sensors in the OEM market continues to increase year on year with a penetration over 50% in Europe and approaching 40% in NA.

There is debate in the ADAS community whether ultrasonics will eventually be replaced by cameras and or lidar or whether all the technologies will coexist in varying degrees depending on the level of the vehicle and the market expectations.

Presently the ultrasonic market is dominated by Valeo, Bosch and Denso, in that order, with many advances taking place in the area of semi-automatic/automatic parking. The first such systems were done by Valeo for the VW Touran in 2007 and later for Ford in 2009. Valeo and Bosch have been publically demonstrating their “valet parking technology” for the past few years. It would appear that the first step toward such a system will be equipping the BMW 7 series on sale later in 2015. A remote control parking function will allow a driver to exit the car and then control the vehicle using a new key fob into very tight parking spots.

Radar 77Ghz versus 24 GHz

Many technological advances have been made in the world of automotive radar since the first ACC systems in the late 90’s.. Those initial systems used 77Ghz technology to obtain the long range (200+ meters) required for the first, but most demanding applications, the German autobahn speeds of 200 to 250 kph. Bosch, TRW (Autocruise), Continental, Fujitsu, Denso were among the first players in this area, and still remain strong.

Subsequently a lower cost, shorter range radar was developed for Blind Spot Detection sensors located in the rear side quarters of the vehicle. These 24Ghz blind spot radars (two be per vehicle) were used and applied in the largest numbers by Valeo, Autoliv and Hella, which surpassed the front 77Ghz leaders in raw numbers of units sold due to the rapid acceptance of the BSD feature and its derivative Lane Change Assist (resistive torque on steering wheel if attempting to change lanes into an occupied lane) and having two sensors per vehicle. Since most markets do not require the German Autobahn speed and therefore range and resolution requirements, 24 Ghz radar could be used in the forward mode. More recently significant cost reductions have been made in 77Ghz technology that have allowed wider applications and its use in Blind Spot detection and at short range. It now appears that the contest between the two radar frequencies is tilting in favor of 77Ghz as radar volumes increase to become a significant portion of the global automotive market

Lidar

Lidar (**L**ight **D**etection **A**nd **R**anging,) systems are a more recent arrival onto the ADAS sensor domain. They have the advantage of being able to accurately determine distance of many points in the short to medium range through the projection of laser (usually invisible) light and the analysis of the subsequent reflections. Like radar, lidar is limited by its inability to identify the objects it locates and tracks. As a result, the lidar should usually be used as a complementary sensor medium.

The combination of camera + lidar is appearing to be a choice for the mass market, low cost “sensor suite” since this pair allows enough environmental data to provide the base ADAS functions, plus the ability to reliably execute AEBS (Automatic Emergency Braking System.) The leading players in the lidar market are Valeo (using technology from IBEO, the automotive spinoff of SICK) Bosch, Continental (with Austria microsystem). Although lidar applications have until now been limited to simple traffic jam assist functions, recent demonstrations of autonomous driving vehicles (e.g. Audi’s demo Stanford to Las Vegas demo drive for CES 2015, Delphi’s San Francisco to New York drive in April 2015) included lidar as a key sensor. Audi is rumored to be launching their lidar device in production soon. The Audi demo car used two lidars, one front and one back. The Delphi vehicle uses five of the lidars.

Cameras

The term “Camera” is the commonly used label, though more precisely, these devices are “Sensors of visible and invisible light.” A “camera” is normally a device which captures light and whose output is an image to be viewed. In most of these ADAS applications, the images captured by the “camera” are never viewed by a person, but rather the image is processed and classified as part of algorithm to identify road markings, objects, pedestrians etc.

The more significant portion of camera can be its integrated image processing capability done with microprocessors, FPGAs (field-programmable gate array) or combination of these and other electronic components.

Depending on the architecture of any such camera system, the image processing hardware can be integrated into a “smart camera” or can be located remotely from a “dumb camera” in a central image processing control unit. There are many pros and cons of the two approaches, and the choice between the two is made depending on the philosophy of the system architecture.

Front Camera System

ADAS front camera systems typically are smart sensor packages integrating, in order of appearance, Lane Departure Warning, Automatic Headlight Control, Object detection, Traffic Sign Recognition, Pedestrian Detection, etc.

Since each of these functions requires some portion of the shared processing capacity of the hardware, it is important to maximize processing capability within the cost constraints of the hardware budget. It is through optimization of the software for the desired features, that the cost of hardware can be also kept within the desired limits.

Stereo or Mono FCS

The impressive technology of the Israeli Tier2 Mobileye has proven its ability to satisfy NHTSA Forward Collision Warning requirements and EuroNCAP Emergency Braking using only its mono camera device.

Most of the non-Mobileye-linked Tier1s have already in production or announced their intentions to launch stereo vision cameras which provide better distance measurement to objects using the parallax effect as do the paired human eyes.

Probably the high point of proliferation of ADAS sensors will forever remain the Mercedes S-Class launched in 2013 with a total of 25 sensors of all types:

Three front radars, (one long range, two medium range)

Two rear quarter panel radars (medium range)

One rear radar, (medium range)

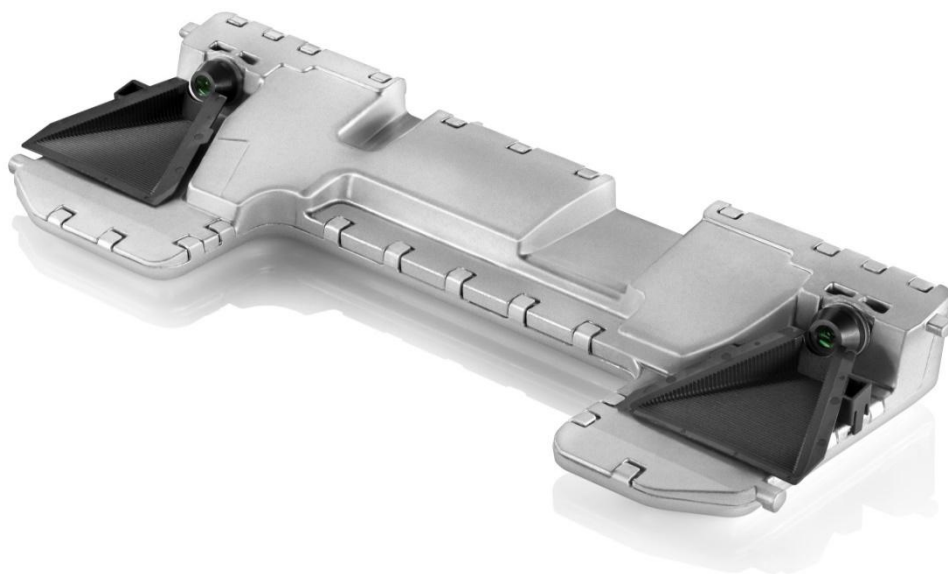
One front stereo camera ,

Two front infrared cameras, (one passive IR, one active IR),

Four wide angle camera for an overhead “bird’s eye view” low speed manouvers

Six front ultrasonic sensors

Six rear ultrasonic sensors



The Continental Stereo Front Camera – Daimler S Class

Camera + Radar or Camera + Lidar ?

In the expected generalization of ADAS sensors to all vehicles, the front camera is considered the heart of any vehicle's "sensor suite" (a common aerospace/military term for the ensemble of sensor technologies in a given vehicle) due to the camera's ability to identify an object. However most Tier1s and OEMs believe that the camera's identification capability is best complemented by a technology better able to more precisely determine distance to target and therefore TTC (time to collision). With the near-perfect reliability needed for AEBS (Automatic Emergency Braking), a safer approach integrates the fusing of data from two different sensor technologies. This dual technology mode is leading toward the implementation of by some OEMs and Tier1s to integrate lidar systems into the FCS package. Those OEMs and Tier1s using Mobileye technology (see section e) below) are able to satisfy EuroNCAP and NCAP requirements using only front cameras.

In addition, the revolutionary technology of ToF (Time of Flight) imagers is being developed by companies like PMD Technologies. Using a modulated optical signal transmitted by the camera and the greatly increased speed in their custom 3D CMOS imagers, a ToF camera is able to measure the time of flight of and thus the distance to the various elements captured in an image. A reliable, cost effective ToF camera would in theory eliminate the need for either radar or lidar to complement the radar. However, no ToFs are yet committed to a production vehicle introduction despite some press releases to the contrary. Thus the jury is still out on this very promising new technology.

Front "camera" or "light sensor"

Two of the pioneers in Automatic Headlight Control, Gentex and archrival Magna Electronics (prior Donnelly) were among the first to develop the SW and HW for intelligent headlight control. Their positions as major global rear view mirror suppliers provided each company with the opportunity enrich the "real estate" surrounding their rear view mirror products. They chose to invest in SW/HW to identify oncoming vehicles' headlights in order to allow signals to be sent to the Lighting control unit for either a simple high/low beam adjustment, and later to provide data to permit Adaptive Driving Beam. A quick search of US patents for intelligent headlight control will reveal more than a hundred patents, most of them registered in the name of Gentex or Magna(Donnelly).

The Mobileye Factor

A useful way to analyze and understand the various Tier1 players in the ADAS sensor market is to examine the evolution of the front camera market over the past several years with respect to the unavoidable predominance of Mobileye.

Mobileye is the global leader in automotive image processing with a dominant position as a Tier2. Their successful business model is quite unique. Mobileye invested heavily in the early 2000s on the basis of their founders' multi-frame 3D mono-camera image processing algorithms which were then coupled with a custom proprietary chipset. Such an approach allowed the symbiotic optimization of the hardware and software combination. Mobileye provides the HW/SW combination product to Tier1s who then integrate and complement the core technology for their OEM customers.

Players in the Front Camera market

The evolution of the players in the Front Camera market is strongly influenced by their relation with respect to Mobileye. Starting in 2007 with three OEMs (Volvo, BMW and GM) by 2015 Mobileye technology will be found on more than ten distinct vehicle manufacturers ((AUDI , BMW, Fiat Chrysler, General Motors/Opel, Ford Motor Company, Honda, Hyundai Kia Motor Company, Jaguar Land Rover, Mitsubishi Motor Company, Peugeot Citroen, Volvo, Yulon Motors, Scania) providing a range of functions for LDW only to AEB and ACC using only a camera.

Tier1s who targeted complete front camera function

2006
Autoliv
Bosch
Continental
Delphi
Denso
Elesys
Hella
Hitachi
Kostal
Magna

Tier1s who target complete front camera function without Mobileye

2015
Autoliv ↔ Autoliv
Bosch
Continental
Delphi
Denso
Elesys (negligible)
exited FCS market
Hitachi
Kostal
Magna

Magneti-M
Mobis
SiemensVDO
Takata
TRW
Valeo
Varroc

Magneti-M
Mobis
See Continental
Takata (negligible)
TRW
Valeo

In March 2015 Valeo, a solo pioneer in the front camera market since 2004, established a technical agreement with Mobileye thus further reducing the list of major players able to do front camera without the Israeli giant to only Bosch, Continental, Denso, and Hitachi.

Another recent partner in 2015 the Mobileye camp is Key Safety Systems, a US supplier of passive safety systems (airbags, seat belts etc). Until now KSS had no product experience in the surrounding sensor area. This move should be seen as a move by KSS to compete with its traditional passive safety competitors, TRW, Autoliv, and Takata. The first two especially have grown significantly due to their active safety activities.

It will be interesting to observe Mobileye's evolution in the front camera market as the low end version product becomes a commodity. There are new entrants into the field which are trying to find a niche, most probably in the low end. Companies with little sensor experience are seen to be jumping on the driving assistance band wagon. Working with Mobileye would be the most likely way of getting into the front camera market, but the cost of that HW/SW would leave little for low level entry. Unless of course, Mobileye is now making a lower level project available to those Tier1s whose hunger is great. One should not underestimate however the great expertise still required to do the integration of the technology.

Although it is difficult currently to estimate FCS market share when volumes can double, triple or more in a year, Mobileye's share of the front camera market is estimated between 70% and 85% in 2015. Though the FCS market is changing at exponential speed, Mobileye's position will surely remain extremely strong.

Rear/Side cameras

From the camera's first installation in production vehicles in Japan in the 1980's, the viewing camera in a rear/side view has come a long way. Later many vehicles incorporated rear view cameras including some data from ultrasonic park assist sensor and/or the trajectory path from steering angle superimposed on the image. In Japan, the small streets and focus on passenger side blind spots (along the front quarter panel) encouraged the use of cameras in front applications and also mounted on side exterior mirrors.

The expected application of a new NHTSA rule in the US will require rear view cameras in new vehicles starting in 2018. This new rule is triggering reflections on the other applications that can be made of this rear camera which all cars in that market will have to have, in any case. One possible development from the obligatory rear camera leads to "surround view" around the entire vehicle.

More recently, cameras around the periphery of the vehicle overcame the difficult challenge of representing their large amount of information to the driver in a simple intuitive manner. By treating the image of the bird's eye lens cameras, the corrected result could be more intuitively understood. Nissan worked introduced a surround view camera in the Infiniti EX in 2009 and BMW included similar system in the BMW 5 series that same year. Valeo's surround view systems in BMW, VW and Audi vehicles are considered by many to be the technical benchmark in the industry. Also active in the surround view field are Continental, Panasonic, Hella, Magna, Autoliv, and Denso.



The BMW X5 Surround View system

Of course, the logical path for development lies in the image processing. If it can be done for surround view to correct distorted bird's eye views, then more sophisticated image processing can be used to detect objects, pedestrians etc. Since these "dumb" peripheral cameras are best designed with limited if any image processing, a central ECU is used for image processing. A possible next step would be to examine if the image processing hardware needs to be specific for each of front and peripheral camera systems. Why not centralize the image processing?

Again the choice of the electronic architecture strategy of the vehicle's ADAS and overall system comes into play. If very large volumes of a standardized Front Camera systems are to be produced, the associated, localized image processing should take place that FCS. However, one

can imagine some vehicles whose peripheral systems also take on the needs of the front view, while sensing the entire surrounding environment at slow and at higher speeds.

Whatever the decision concerning the architecture of the Front camera versus a multi camera approach, it is clear that the interface and data fusion with the Lighting system will be complicated.

Architecture – To centralize or not to centralize?

The architectural challenges of transmitting large amounts of sensor data as well as the strong positions of the ADAS Tier1s listed above have been motivating some of the leading OEMs to approach.

In view of the approaching exponential explosion, NVIDIA, the specialist in high performance video cards for computer gamers decided to jump into the automotive market. Their approach was to centralize the many varied and sophisticated functions currently distributed throughout the vehicles' ADAS sensors. The huge data processing capacity developed for those realistic video games can be used to manage the complexities of driving assistance.

NVIDIA has already been using their providing infotainment systems for Audi, BMW, Tesla, and VW. They have been successful at convincing at least Audi that adopting the ZFAS (zentrale Fahrerassistenzsteuergerät the German acronym for centralized driving assistance system) is the way to future.

Centralizing such functions into one super ECU brings advantages as well as major changes. This would allow or even require the sophisticated sensor software to reside in the ZFAS. From the perspective of the OEM, this would render the sensors less intelligent and therefore allow more interchangeability between suppliers' radars or cameras etc. Such flexibility is not impossible today but if achieved, would greatly weaken the market position of the strong sensors systems suppliers. Thus, we can expect all OEMs to seriously evaluate whether centralized system is right for them.

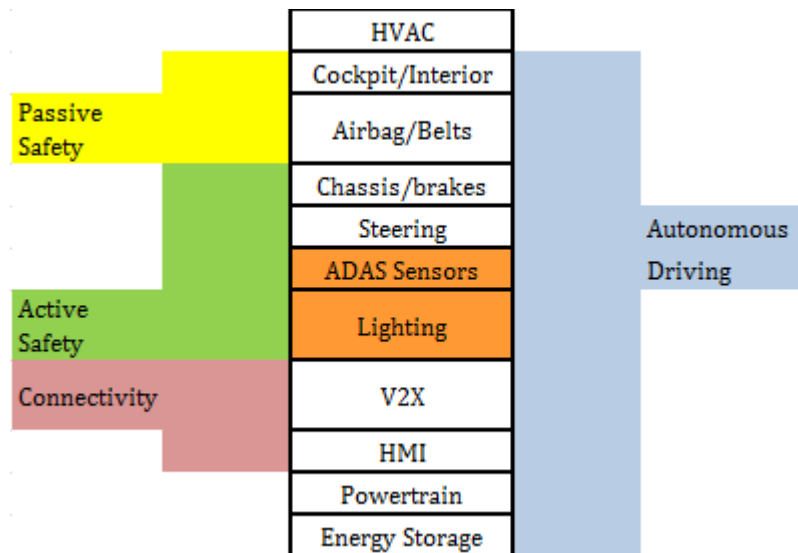
The decision of whether or not to centralize is neither easy nor straightforward. It depends on the expected content of future vehicles but also surprisingly on the organization of the OEM. The biggest obstacle to implementing centralization lies with the development process for such a system. In the current distributed processing architecture, suppliers and their corresponding OEM departments are more or less free to develop their functionalities in parallel. If all functions need to be integrated into the same ADAS centralized mega-ECU, the coordination of 10 or 20 suppliers in the development and validation for dozens of functions would require superhuman organizational skills to respect real launch dates.

The first Audi launch using ZFAS is planned to take place in early 2016. Whether or not Audi is able to launch on time and with high reliability will have much influence on the future of such a centralized architecture. Many automotive traditionalists question whether a consumer electronics philosophy can be valid in an industry where lives can be endangered by any minor SW bug.

There is and will be significant Silicon Valley influence in the evolution of the Automotive Industry in the next decade. It will be fascinating to see where and how much it will be.

Outlook

Recalling the figure below from the beginning of this survey, the automotive industry's momentous move toward semi-autonomous/autonomous driving requires the integration and management of the most of the automotive control systems of the vehicle:



The integration of the various systems (Lighting, ADAS sensors, Steering, Chassis/brakes) required for Active Safety is already problematic. Since the high end automobile today already incorporates more than 10 million lines of code and 2000 functions, (per Manfred Broy, Technische Universität München) Complexity Management becomes the biggest challenge.

Individual features such as object detection, marking light, or airbag deployment are difficult enough separately. If those are integrated with a hundreds of individual functions, each of which can easily have dozens of inputs and outputs, the mastering of this the mountain of tasks of becomes superhuman.



What is the cost of NOT managing this exponentially-growing complexity? In 2010, the recall of Toyota vehicles due to an alleged accelerator pedal software issue has sent a clear message to OEMs. Even if no software bug can be found (as NASA concluded in 2011), such an incident can quickly destroy even the most reputable company's vaunted image of quality.

Despite the absence of any found electronically-linked failure, Toyota has been unable to prove a negative i.e. that there was no failure. But the financial reality is enormous. The cost of the recall, lost sales, and legal bills are estimated to be in the USD billions as confirmed by Toyota's relief

that a US court has just ruled that the settlement ceiling will be in the \$1 to \$2 billion. Some estimates of Toyota's total cost for this unproven "failure" exceed US\$10billion! Clearly, in litigious societies like the US, even an alleged but unfound fault in even a relatively simple electronic control system can be extremely painful.

ISO 26262

The exponential growth of HW/SW complexity in recent years has been the driver for establishment of ISO26262, "Road vehicles -- Functional safety." The norms's mandate is to assure *"the E/E Item is free from unreasonable risks due to hazardous behaviors."* ISO26262 implementation will be a necessary template to use in the momentous HW/SW task of systems integration in the evolution toward semi-autonomous/autonomous driving. The Toyota accelerator episode provided even more motivation for the norm's 2011 adoption.

Lighting technologies - status and trend

In this last decade, a huge number of technologies (light sources and functions) arrived equipping the Premium cars

- In light sources: extension of Xenon 35w, confirmation of LED technologies, Xenon 25w, OLED, laser beam.

- In functions, after AFS starting in beginning 2000's, adaptive lighting with its 4 functions is arriving very fast in Premium cars and now in middle range cars.

The trend will be accentuating but we have to solve some challenges to see all these technologies going in lower range cars.

- 1) Remaining major obstacle up this mountain of development will be the enormous effort to master the complexity of what will be the ADAS/Lighting/V2X constellation around which the principal functions will be centered.
- 2) Regulations in ECE and SAE.
- 3) Standardisation of light sources and parts of functions.
- 4) Lack of communication to end-users and dealers while many new technologies arriving.
- 5) High costs and also high margins.

Which light sources?

LED will be the number one light source in the future thanks better styling differentiation, lower energy consumption, and very soon less expensive than Xenon at equivalent lighting performances.

Xenon has a limited future, Xenon 25w taking more and more market share in a global decreasing market share.

Which sensors will complement lighting?

Front Camera Systems

Due to the high volumes of vehicles which will be required to be fitted with the basic front camera system functions (lane departure, object detection, pedestrian detection,) we can be sure that FCS will be fitted to all but the lowest level cars by 2018.

As for the mono versus stereo battle, Mobileye is leading with a single imager. However the stereo camera still offers strong advantages of parallax advantage plus a possible complementarity of two different imagers which could outweigh the extra cost. But will such imaging eliminate the need for lidar/radar? This will depend on the level of vehicle and the customer expectations.

Lidar or Radar or Camera?

Although front mono-cameras are proven to work well, more precise, complementary information from alternate means of measuring distance/speed of objects (as identified by the front camera) will be required to provide an complementary medium of detection. This dual input provides redundancy before an autonomous decision is made to apply automatic emergency braking.

Conventional simple lidar has the advantage of being able to be combined in a single package with the front camera looking through the windshield, though future lidar will be installed in the front grill area. At the same time, radar's gigahertz frequency range offer significant differentiation from the optical frequencies used by cameras.

It would be an oversimplification to predict "camera+lidar for low end vehicles" and "camera+radar for high end" due to the recent successes in cost reduction of the traditionally more expensive radar. In addition, how will the wild card of Time of Flight (ToF) cameras play in this struggle? As in most technology battles, the market will determine the equation of [cost] vs. [real value] vs. [perception of value] in the eyes of the final consumer.

Which actuators?

Actuators have also a limited future in lighting with the arrival of the matrix beam, pixel or matrix light.

We will see during the next 10 years still actuators in lighting because they are more and more reliable, small, light and inexpensive. Actuators for leveling devices, AFS, or adaptive light as the more recent ones in the Mercedes-Benz E-Class will continue to be used.

Conclusion

The advances in sensor, lighting and electronic technology in general are rapidly driving changes in all aspects of the automotive world. Chris van den Elzen, Magna's global director of machine vision observes, "There is an 'ADAS soup' coming to a boil. V2V, Cameras, Radar, and digital maps are creating a plethora of information in real time within the communication networks of our cars."

Adaptive Driving Beams using LEDs, and in the future lasers, will provide unparalleled visibility for drivers and for the optical sensors.

Manfred Broy of Technische Universität München summarizes very well, "Traditionally quite unrelated and independent functions (such as braking, steering, or controlling the engine) that were freely controlled by the driver get related and start to interact. The car turns from an assembled device into an integrated system. Phenomena like unintentional feature interaction become issues."

Currently being combined into active and passive safety systems, these already sophisticated networks must be integrated into the complexity of the complete vehicle systems required for semi-autonomous/autonomous driving all while satisfying the stringent functional safety requirements of ISO 26262. The automotive Lighting/ADAS community faces unparalleled challenges now and in the near future. These demands are reshaping the work processes of the entire automobile industry as it moves toward the era when the software and hardware systems will represent the majority share of a car development cost.

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25 OEM

Audi, Germany
Bentley, UK
BMW, Germany
Chrysler, USA
Daimler, Germany
Ford, Germany
Geely, China
GM, USA
Great Wall, China
Harley-Davidson, USA
Honda, USA
Hyundai, Korea, Europe
Jaguar-LandRover, UK
Nissan, Japan, Europe, USA
Opel, Germany
Porsche, Germany
PSA, France
Renault, France
SAIC, UK
Seat, Spain
Skoda, Czech Republic
Shanghai Volkswagen, China
Toyota, Japan, Europe, USA
Volkswagen, Germany
Volvo Cars, Sweden

15 Univ., labs, Consultants

Comedd Franhauser, Germany
Darmstadt university, Germany
DEKRA laboratory, Nederland
Fudan university, China
Hannover Leibniz Univ.(HOT), Germ.
Institut d'Optique Graduate School, Fr.
Karlsruhe Lighting Institute, Germany
LAB, France
Light Sight Safety, Belgium
Nuremberg university, Germany
Parma university, Italy
Rensselaer university, USA
UMTRI, USA
University of California, Santa Barbara
Mr Shunxing Wang, China

29Suppliers Tier 1

AL, Germany, USA
Denso, Japan
Farba, Turkey
Flex'N'gate, USA
Grote, USA
HAITEC, Taiwan
Hella, Germany
Hyundai IHL, Korea
Ichikoh, Japan
J.W. Speaker, USA
Koito, Japan, Europe
Lear, USA, Europe
Magna, USA, Austria
Mobis, Korea
Myotek Industries, USA
NAL, USA
Nordic Lights, Finland
Odelo, Germany
Olsa, Italy
SG Co., Korea
SKoito, China
SL Corporation, Korea
Stanley, Japan
Truck-Lite, USA
Valeo, France, China
Varroc, Germany
Xingyu, China
ZKW, Austria
Zodiac, France

45 Suppliers Tier 2

Allio-Groupe, France
AML Systems, France
Astron-Fiamm, France
Bayer, Europe, US, China
Bertrandt, Germany
BicomOptics, China
BrightWay Vision, Israel
Com Corp Industry, USA
DBM Reflex, Canada
Delvis, Germany
Docter Optics, Germany
Elmos, Germany
Enmech-Freudenberg, Germany
Everlight Electronic, Taiwan
General Electric, Europe
Gentex, USA
GXC Coatings, Germany
Hitashi, Japan
IAV, Germany, USA
IDEA Institute, Germany
Innorex Techn., South Korea
Instrument Systems, Germany
Keboda, China
LG Innotek, South Korea
LG Electronics, South Korea
LMT, Germany, China
Mentor Graphics, Europe, USA
Mobileye, Israel
Mitsubishi Electric, Europe
Nalux, Japan
Nichia, Japan
NXP, UK
Optis, France
Optoflux, Germany
Osram, Germany
Panasonic, Japan
Peterson Manufacturing, USA
Philips, Netherlands
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