ADAS and LIGHTING

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ADAS and Lighting

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Executive Summary

The link between lighting and ADAS is recent. It took root a decade ago when AFS—Adaptive Front-lighting Systems—used steering angle sensors to swivel the headlamps into road curves. Then some years later, ADB arrived as a camera-driven evolution of the previous, relatively crude AFS.

After describing the various sensors used by ADAS, this report presents the interaction of these sensors with lighting—how intelligent lighting functions help ADAS sensors to better see obstacles and pedestrians, how front and rear lamps integrate sensors, and how both existing and novel lighting functions need sensors.

The report describes the integration of lidar, camera, radar in the front and rear lamps with descriptive reference to the work of various suppliers who have demonstrated better efficiency of lighting-integrated sensors, because of their optimised position at the front and rear corners of the car.

The author presents the current lighting functions, including the evolution of adaptive lighting systems which automatically and dynamically adjust the light output and direction to optimise visibility and conspicuity in all driving, weather, road, speed, traffic, and driver conditions, as well as new lighting functions to protect vulnerable road users such as pedestrians.

There is emphasis on future safety technologies being progressively improved, and the new lighting functions which can contribute. Future cameras, new lidars and radars, for example, will give a much more precise image, allowing vehicles and drivers to keep better, more accurate track of road users and obstacles. Software developments, too, will dramatically improve the level of recognition. More intensive use of artificial intelligence will further boost this line of evolution. These improvements will be realised by dint of better ADAS sensors and by the evolution of lighting—more high definition systems, using technologies like DMD and μLED.

A variety of technologies are presented in context of road projection functions to support the driver and communicate to others, and of new communication-by-light concepts using sinals and displays.

Finally, the author presents an outlook on the link between sensors and lighting.

1. Introduction

The world automotive market is presently in a massive revolution making personal transport safer than ever. Distinct domains of technology are evolving rapidly on convergent paths, and ADAS using ultrasonics, radar, lidar, cameras, and sensors is becoming standard equipment on increasing percentages of the vehicles sold in Europe, Japan, and North America.

Lighting is improving safety with functions linked to cameras like ADB, and more and more new lighting functions are relying on a variety of sensors now being integrated into vehicle front and rear lamps.

When this trend first took hold, AFS headlamps used cameras and GPS to anticipate road curves and throw light into them. Now, new lighting systems are advancing with ADB (Adaptive Driving Beam, also called Glare Free High Beam) which provides high-beam seeing with low-beam glare by detecting, tracking, and dynamically, selectively shadowing out other road users from the equipped vehicle's otherwise-full high beam headlight pattern. All these functions are strongly linked to ADAS, and cameras are structurally central.

Communication among vehicles, with infrastructure, and with the cloud (V2X) will complement ADAS and lighting systems in a complex constellation of information and control systems within and outside the vehicle to cut traffic fatalities in parallel with progress toward the goal of partly and then completely autonomous driving. The remaining obstacle on the way 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 ADAS and advanced lighting systems already exist in high-level luxury cars, the goals of fatality-free driving can only be approached through widespread application of these technologies. After more than a decade of low-volume ADAS applications, the market is now exploding, driven by NCAP and effective standardisation. The inclusion by European and American NCAPs of ADAS is practically 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 conjunction of ADAS and lighting systems is only a fraction of the challenge presented by autonomous driving. The scope of this report, therefore, is limited to examining the intersection of ADAS and lighting.

2. ADAS Sensors

2.1 Ultrasonic

The first ADAS sensor technology was the ultrasonic parking sensor. Over the years this technology has come down in cost and been applied in an ever-larger share of vehicles with the market leaders being Valeo, Bosch, and Denso. The market demand for OE ultrasonic parking sensors continues to increase year on year with an equipment rate over 50% in Europe and approaching 40% in North America. There is debate in the ADAS community whether ultrasonics will eventually be replaced by cameras and lidars, or whether all the technologies will coexist in varying degrees depending on the level of the vehicle and the market expectations.

2.2 Radar

Many technological advances have been made in the world of automotive radar since the first ACC systems in the late 1990s. The initial systems used 77-Ghz technology to obtain long-range (>200 metres) required for the first and most demanding applications, the German Autobahn speeds above 200 km/h.
Bosch, Continental, Fujitsu, and Denso were among the first radar suppliers, and still remain strong in this field.

Eventually a lower cost, shorter range radar was developed for Blind Spot Detection sensors located in the rear side quarters of the vehicle. These 24-Ghz radars, two per vehicle, were applied in the largest numbers by Valeo and Hella, and surpassed the front 77-Ghz 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 into an occupied lane) and having two sensors per vehicle. Now significant cost reductions have been made in 77-Ghz technology, allowing wider applications and its use in BSD and at short range. The 77- versus 24-Ghz contest will be determined by cost-performance calculus in markets round the world as radar volumes increase.

2.3 Lidar

Lidar systems are a more recent arrival in the ADAS sensor domain. They have the advantage of accurately determining distance of many points in the short- to medium-distance range through the projection of (usually invisible) laser light and analysis of its reflections. Like radar, lidar is limited by its inability to identify the objects it locates and tracks. As a result, the lidar is usually used as a complementary sensor.

The combination of camera + lidar is shaping up as a frequent choice for mass market, low cost sensor suites, as 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 lidar suppliers are Bosch, Continental (with Austria Microsystems), and Delphi. Not far behind are Denso and Valeo (using IBEO technology).

Conventional lidar's reliance on moving mechanical devices, usually rotative ones, to distribute its laser beam is a hindrance to its application. Phased-array lidar, which scans electronically rather than mechanically, has no such constraint.

2.4 Cameras

The term "camera" is commonly used, though more precisely these devices are sensors of visible and invisible light—an electric eye, of sorts. A camera, proper, captures light and outputs 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, and other relevant things. The more significant portion of camera can be its integrated image processing capability done with microprocessors, FPGAs (field-programmable gate array) or combinations of these and other electronic components.

Depending on the architecture of any such camera system, the image processing hardware can be integrated (a "smart" camera) or can be located remotely from a "dumb" camera in a central image processing unit. There are benefits and drawbacks of both approaches, and the choice is based on the philosophy of the system architecture.

ADAS front camera systems typically are smart sensor packages integrating Lane Departure Warning, Automatic Headlight Control, Object detection, Traffic Sign Recognition, Pedestrian Detection, etc.
As each of these functions requires some portion of the shared processing capacity of the hardware, it is important to maximise processing capability within the cost constraints of the hardware budget. By optimising the software for the desired features, the cost of hardware can be also kept within the desired limits.

Front camera as a light sensor
Two of the pioneers in Automatic Headlight Control, Gentex and Magna Electronics, were among the first to develop the software and hardware for intelligent headlight control. Their positions as major global rearview mirror suppliers provided each company with the opportunity to enrich the real estate surrounding their existing products. They chose to invest in software and hardware to identify oncoming vehicles' headlights, then signal the equipped vehicle's lighting control unit for either a simple high/low beam adjustment, or 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).

Mobileye
A useful way to analyse and understand the various tier-1 suppliers in the ADAS sensor market is to examine the evolution of the front camera market over the past several years with respect to the predominance of Mobileye. They're the global leader in automotive image processing, with a dominant position as a tier-2 supplier. Their successful business model is rooted in having 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. This approach allowed the symbiotic optimisation of the hardware and software combination. Mobileye provide their hardware-software package to tier-1 suppliers, who then integrate and complement the core technology for their automaker customers.

BrightWay
BrightWay Vision's technology is an Active Gated Imaging System (AGIS) meant to give improved driving safety at night and in bad weather by enhanced identification of obstacles on the road up to 250 metres away. The system uses gated near infrared, constantly projects a clear picture of the road even in bad weather conditions, analyses the data it collects, and alerts the driver when hazards are present on the road.
AGIS offers a better, more naturalistic image quality for the driver than conventional systems, and provides a better basis for image processing task. The following images show pedestrian recognition in conditions that would make that task difficult or impossible for the unaided human eye:

AGIS Night Vision during Heavy rain

AGIS Night Vision during snow

The front camera industry
The main suppliers of front cameras are Autoliv, Bosch, Continental, Delphi, Denso, Hella, Hitachi, Kostal, Magna, Marelli, Mobis, Takata, and Valeo.
Many vehicles incorporate rearview cameras, integrating data from ultrasonic park assist sensors and the trajectory path from steering angle superimposed on the image. In Japan, with small streets, a focus on passenger side blind spots encourages the use of cameras in front applications and also mounted on sideview mirrors. And three years ago, a new US regulation began requiring reversing cameras in new vehicles.
Cameras around the periphery of the vehicle have overcome the difficult challenge of representing their large amount of information to the driver in a simple intuitive manner. By integrating multiple cameras' images into a bird's-eye view as though the driver were looking down at the car from above, the information can be

intuitively understood. Nissan and BMW were the first to introduce a surround view camera system of this nature.

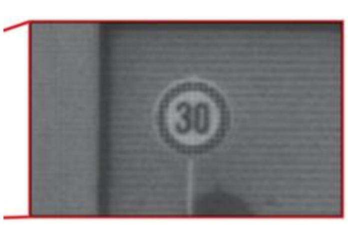
3. Interaction of ADAS Sensors and Lighting

Recent intelligent lighting functions and future ones will systematically need sensors to improve their efficiency. Conversely, some ADAS sensors—cameras, especially—can be strongly helped during nighttime by a linked lighting system.

3.1 Intelligent lighting functions need ADAS sensors
Beginning with High Beam Assistant (selecting high or low beam automatically), and continuing right on up to today's Adaptive Driving Beam and Marking Light, advanced lighting functions need information from the environment to operate effectively. This information is mainly provided by cameras right now.
With High Beam Assistant, relatively simple information was required from the sensors: to know if a vehicle is present in front of the equipped car. So, a relatively basic camera could do the job.
With ADB, very precise information is necessary to avoid blinding other road users and to keep the shadowed safety margin around them as small as possible. The positional accuracy of the information about other vehicles and objects must be on the order of 0.1°. To achieve such a precision, a camera with megapixel resolution is necessary, and a precise alignment of the camera and the lighting system must be realised by software at the end of the car production line. The camera must avoid false detection or false categorisation, which poses challenges in the form of street signs and street lighting, etc. So, the camera and its software must be intelligent and advanced. For the Marking Light function, even more precise information is requested to identify the objects and to clearly define their position to send the appropriate light.

For quite some time, cameras were the main ADAS sensor linked to advanced lighting functions. But with the advent of other kinds of ADAS sensors on the car—radar and lidar, for example—the possibility arose of linking them to the lighting system. DVN is convinced that data fusion with the information from all the sensors will be used for the lighting functions, especially the new ones that will need increasingly precise, accurate, and detailed information. These other sensors are giving complementary information compared to standard cameras, and particularly augment the distance-sensing capabilities. Currently their resolution not at the level of cameras, despite the possibility for some to break into the megapixel level, but combined with cameras for the definition and recognition and lidar and radar for the distance, we could for instance achieve a better marking light with an adapted intensity for each object or VRU.

3.2 ADAS Sensors are helped by a good lighting system
For the foreseeable future, cameras will remain an essential sensor for ADAS, largely on strength of their resolution, which is crucial for good recognition of road users and objects.

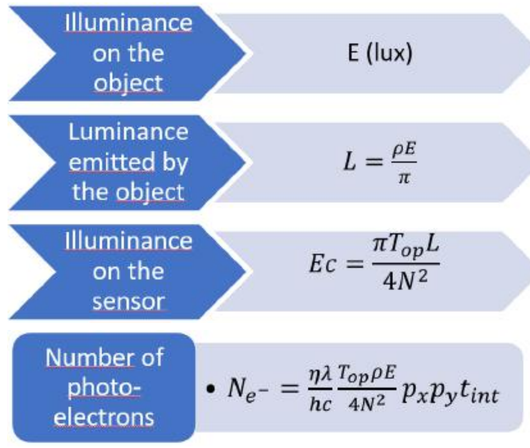


IMX324 (7.42M) magnified image


X224 (1.27M) magnified image

The new generation of cameras can now reach a resolution of 7.4 megapixels—an example is the new Sony IMX 324 sensor shown in comparison to the previous X224. The higher resolution naturally gives much more information to the software for a better identification of objects. But after dark, cameras need a good illumination of the scene to keep their performance. Despite improvement in dynamic range (the new Sony camera boasts 120 db, for instance) more photons received by each pixel of the camera—more light on the scene—still helps separate the useful information from the noise.

And naturally, a good lighting system will send more photons to the objects with a better illuminance, providing better luminance of these objects depending on their albedo. In the end, we have a better illuminance of the camera sensor and more photoelectrons for the image analysis. Going to L3-4-5, with more responsibility for safety placed on the car's systems, will require perfect recognition of objects and their position. Redundancy with several sensors is helping for that, but only if each sensor provides good information. The lighting system can even improve the level of recognition when the system has the electronic equivalent of doubt—for instance by using the high-definition ADB system to send more light to whatever the system isn't quite sure it sees or recognises.



Technology	Standard Camera	LIDAR	TOF, Phase Modulation	Passive LWIR	Active NIR imaging	Active NIR Gated imaging
	CMOS sensor	Pulsed TOF	Modulated TOF	Microbolo-meter Sensor	Continuous Light & HDR Image Sensor	Pulsed Light & Gated Image Sensor
Image (situation awareness)	++	-	-	+	++	++
Day performance, clear weather	+	+ R	+ R	+	++	++
Day performance, harsh weather	-	+	- -	-	-	+
Night performance, clear weather	-	+ R	+ R	++	-	++
Night performance, harsh weather	- -	+	- -	+	- -	++
Resolution	++	-	-	+	++	++

Note: (++) Excellent; (+) Good; (-) Fair; (- -) Poor; (R) Range only
Source: BrightWay Vision™ Research

Characteristics of different ADAS sensors (Brightway)

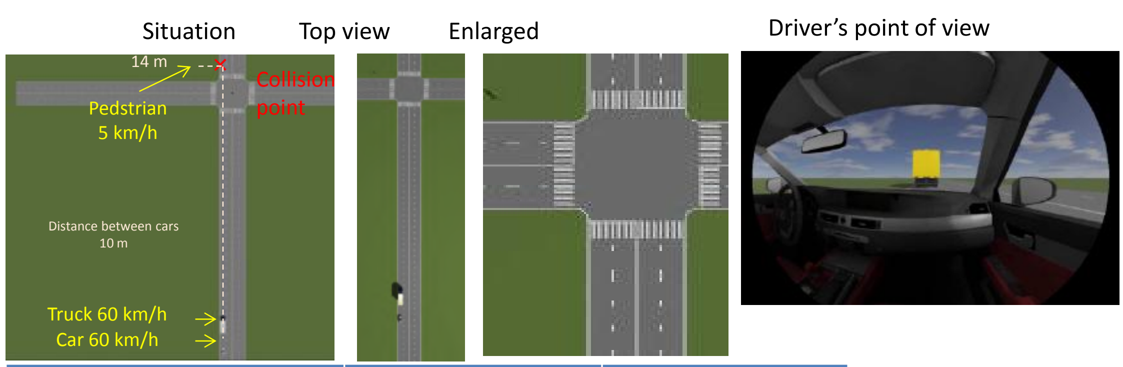
4. Integration of Sensors in Front and Rear Lights

The position of ADAS sensors is defined primarily by their safety role, and secondarily by convenience factors. For instance, the front camera used for many ADAS functions including AEB and LDW and for ADB headlighting must be in a high central position, and where rain will not overly reduce camera efficiency. With this set of requirements, a position behind a wiped portion of the windscreen naturally suggests itself. Similarly, radars for Blind Spot Detection need to be on each side, and a position in or near the rearview mirrors has worked out the best.
Increasingly, ADAS sensor integration in lighting equipment offers attractive benefits. Front and rear lamps have a strong positional advantage, being at the four corners of the car—closer than any other point to potential danger, and with large overlaps between the left and right lamps' field of unobstructed view. Lamp housings also offer protection to sensors against rain and dust, and lamp lenses can transmit many kinds of wavelengths.

However, the size of many sensors is an obstacle to in-lamp integration, especially as current styling trends are moving in the direction of smaller and smaller front and rear lamps. Nevertheless, sensors grow not only better but also smaller with seemingly every iteration and evolution, so integration remains a promising prospect.

Lidar integration:
Lidars are costly, and so for the most part there is still only one on each of a limited number of equipped car. At first, lidars were large, rotating things that had to be installed on the roof with no design integration possible. There were experiments with lidars in the bumper or in the front grille, which revealed difficulties including how to efficiently and effectively keep the lidar clean enough to function properly. So, the idea to install them in headlamps is progressing with the advantages of rain and dust protection and easier cleaning.

Perhaps one of the most important advantage is in relation to the position of the headlamp at the corners, allowing earlier perception of other vehicles—which could translate directly to better crash-avoidance performance from the system and the car as a whole. Koito, for instance, did a study showing that in the case of a car overtaking a truck, a lidar integrated in the headlamp could save roughly 3 seconds versus a roof lidar to see a pedestrian crossing the road ahead.



Position of LiDAR	In the headlamp	On the roof
Time to collision	5.9sec	2.8sec

Lidar-equipped car driving behind truck, pedestrian crossing from the nearside (Koito, DVN Workshop)

Lidar can be integrated singly or dually; one lidar can be in only one headlamp, the other headlamp having some other kind of sensor. Or one lidar can be installed in each headlamp, with the benefits being in redundancy of information and a larger field of view. Some specific short-range lidar dedicated to the front sides can also be integrated. Ideally, four short-range lidars with a 120° field of view, one in each front and rear lamp, and one narrow-view, long-range lidar would be optimum for safety performance.

Obviously, only a compact lidar can practically be integrated into car lights. Current mechanical lidars have dimensions around 80 to 100 mm per side, and solid-state lidar with MEMS about 60 to 80 mm per side. For easy lamp integration there is a size target of 50 mm per side, so it seems reasonable to hope the next generation of solid-state lidars will begin to be practically integrable into front lamps.

		Lower Complexity		Medium Complexity		High Complexity
No.	**LiDAR Location**	**Size Impact**	**FOV Coverage**	**Thermal Management**	**Style Considerations**	**Obscuration**
1	Rooftop	Can be large	Can offer 360° HFOV with single unit	Less complex, can consume and dissipate more heat	Worst option from styling and aerodynamic aspects	Need additional mechanism to keep optical surfaces clear
2	In Cabin	Need low size and weight	Difficult for HFOV coverage	Difficult, need low power unit	Compatible, ensure no acoustic noise	Easier to keep optical surfaces clear
3	Head and Tail Lamps	Need low size and weight	Can get 360° HFOV coverage with multiple units	Higher ambient temperatures	Compatible	Easier to keep optical surfaces clear
4	Behind Grill	Need low size and weight	Difficult for HFOV coverage	Higher ambient temperatures	Compatible	Exposed area for dirt and water
5	On Side View Mirrors	Need low size and weight	Difficult for HFOV coverage	Less complex, can consume and dissipate more heat	Compromises styling to some extent	Need additional mechanism to keep optical surfaces clear
6	Bumpers	Need low size and weight	Can get 360° HFOV coverage with multiple units; VFOV more challenging	Less complex, can consume and dissipate more heat	Compatible	Need additional mechanism to keep optical surfaces clear

Locations for lidar integration—benefits and drawbacks

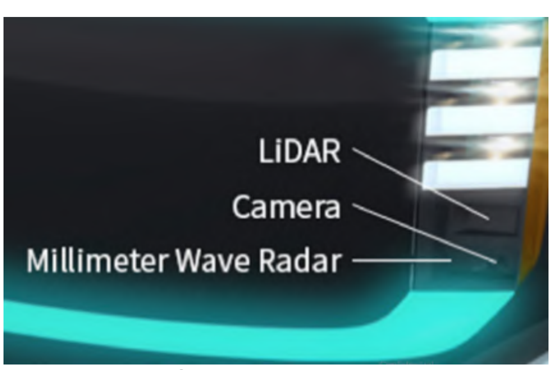
Camera integration

There are more and more cameras on cars; sometimes 10 or more on a single car to have 360° all-around vision. Cameras behind the windscreen, in rearview mirrors, in the roof, and elsewhere, but very few yet in front or rear lamps. This position at each corner is very interesting to anticipate the arrival of other vehicles in difficult situations such as when visibility is reduced by an obstacle or a truck, or when leaving a parking place. With future L4-5 AVs, no risk of accident will be permitted and so more sensors will have to be installed where they are the most efficient—meaning likely at least one camera in each headlamp and rear lamp.

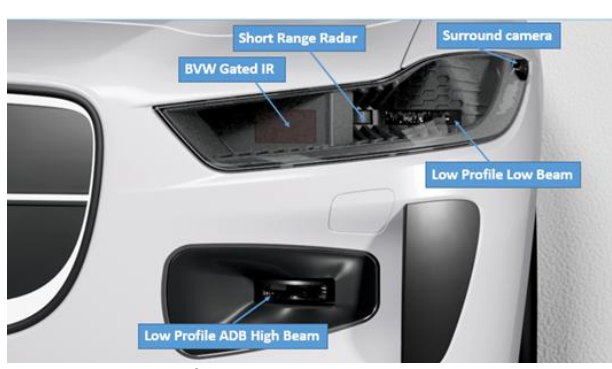
This integration of cameras is much easier than lidar as cameras are already very small and affordable.

Radar integration:

Radar uses millimetre-scale waves and many materials are transparent to this kind of wave. Their positioning is so not as difficult as other sensors and their current favourite position behind bumpers seems good. So, there's little chance of seeing automakers put priority on integrating radars in lighting devices. Nevertheless, we can imagine all kinds of sensors inside headlamps in the future.



Koito concept of sensor integration



Varroc concept of sensor integration

5. Existing Front 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 minimisation of false detections.

Two different lighting functions have developed in conjunction with ADAS. The first one, AFS (Advanced Front-lighting Systems) started without ADAS. Today's systems increasingly use GPS and cameras for bending light, motorway light and adverse weather light. And more advanced adaptive lighting systems assemble technologies which automatically and dynamically adapt light to all circumstances: environment, weather, roads, speed, traffic and in the future, driver condition—fatigued? Impaired?—to optimise visibility without increasing glare.

The detection of cars requires cameras from suppliers who are generally from outside the lighting business. The 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 suppliers to the automotive realm including Autoliv, Continental, Gentex, and Mobileye.

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

Lighting and ADAS suppliers	**ADAS suppliers**	
Marelli AL	Autoliv	Hitachi
Hella	Bosch	Ibeo
Koito	Brightway Vision	Infineon
Hyundai Mobis	Continental	Knorr-Bremse
Valeo	Delphi	Lear
	Denso	Mobileye
	Eaton	Magna
	Federal-Mogul	Electronics
	Freescale	Micron
	Gentex	Takata
		Toshiba

Front lighting functions using ADAS sensors

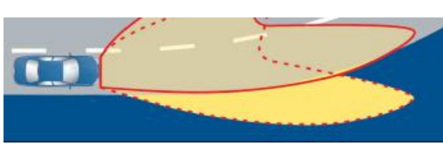
5.1 AFS

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

There are 5 AFS functions.

1) Bending Light

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



Static Bending Light, on tight bend a static cornering light helps during maneuvers in dark access roads. At speeds of up to 40 km/h the light comes on when the turn indicator is actuated, or the steering wheel turned through more than 30° to the right or left. This function is also very suitable to assist the driver's orientation when parking, the static bend light goes on to illuminate the parking area when reversing.

2) Motorway Light

The motorway light switches on automatically at speeds over 100 km/h when the curve radii measured by the steering angle sensor indicate that the road profile does not match that of a country road. It illuminates the roadway substantially further ahead and focuses more on the left edge of the road.

Due to the fact that there is no directly oncoming traffic, the viewing distance on the own side of the motorway has been increased. The visibility range can rise from 70m to 140m so that very distant objects can be recognized across the entire width of the road.

3) Adverse Weather Light

It is activated when the rain sensor detects precipitation or the windscreen wipers are on. The edges of the road are more strongly illuminated for better orientation to the guiding lines. The light cone is somewhat shorter on the left-hand side.

The wide light distribution – slightly swiveled to the outside – enables improved orientation at the edge of the road. Additionally the glare of oncoming traffic is reduced by lowering of reverberation on the wet road.

4) Country Light

It 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 overland.

5) Town Light

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

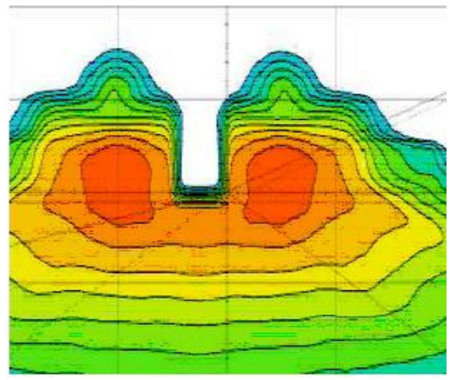
5.2 High Beam Assistant

High Beam Assistant automatically selects and activates low or 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. Present systems based on 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 retro-reflective sign. The position of other vehicles is precisely determined to avoid glaring the drivers. Automatic high beam assistant not only relieves the driver of the beam selection task but is a countermeasure to the drastic under-use of high beam headlamps.

5.3 ADB: Adaptive Driving Beam/ Glare-free high beam

Glare Free High Beam, formally known as Adaptive Driving Beam (ADB), is a camera-driven system wherein the equipped car's headlamps provide a strong high beam, and the camera system detects and keeps track of other traffic participants and road users, providing this information to the lighting control system which selectively and dynamically shadows other people out of the beam. In short: high beam seeing with low beam glare. ADB has been shown to provide 30 metres' more seeing distance than a low beam, with no increase in glare; this stands to provide a remarkable gain of safety in night-driving.

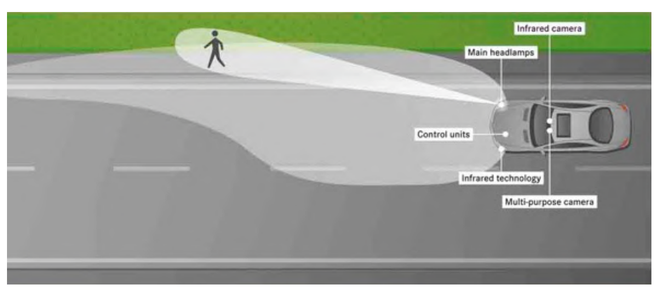
ADB light



ADB isolux

5.4 Spot Marking Light Function

A spot marking light (or just "marking light") is, in a sense, the inverse or opposite of ADB: it shoots a directed, tight spot beam to guide the driver's attention to pedestrians, animals, or other potentially at-risk road users. An optimal addition of light using information from a camera-based system. In this manner, the driver's attention is directed to potential dangers, thus affording more time to respond. The possibility of actuating LED chips individually allows for consistent illumination of a vulnerable road user despite respective movement of vehicle and the object. Drivers are easily able to identify objects to mind and avoid without having to take their eyes off the road. The more advanced systems are precise enough to cut off their illumination of a pedestrian below their eye level, so as to illuminate but not glare.



Illumination of a pedestrian or animal

6. New Front Functions

During the last several decades, lighting functions have been added to automobiles for safety—DRLs, for example, and more recently the functions in relation with ADAS that we have seen in the previous chapter: AFS, ADB and marking light. Safety needs to be continuously improved, and new lighting functions will surely carry on being developed and applied to that end.

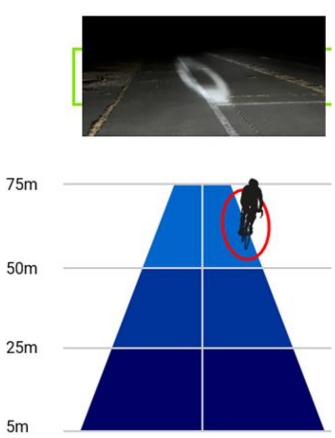
6.1 Improvement of current functions

6.1.1 Introduction

Future high-definition cameras with over 7 megapixels, new lidars with over one megapixel, and new radars will give a much more precise image with a better positional perception and tracking of road users and objects. Software will have to be actively developed in parallel to make use of the sensor data for greater levels of recognitional accuracy. More intensive use of AI (artificial intelligence) will surely augment this evolution.

This continual improvement of software and hardware is illustrated by the recent performance trend of the Mobileye modules:

The current lighting functions using ADAS sensors—AFS, ADB, and marking light, for example—will carry on improving. For instance, false ADB detection from retro-reflective road signs remains to be eliminated. Marker lighting could classify detected road users (pedestrian, animal, bicyclist…?) and send the most appropriate light.



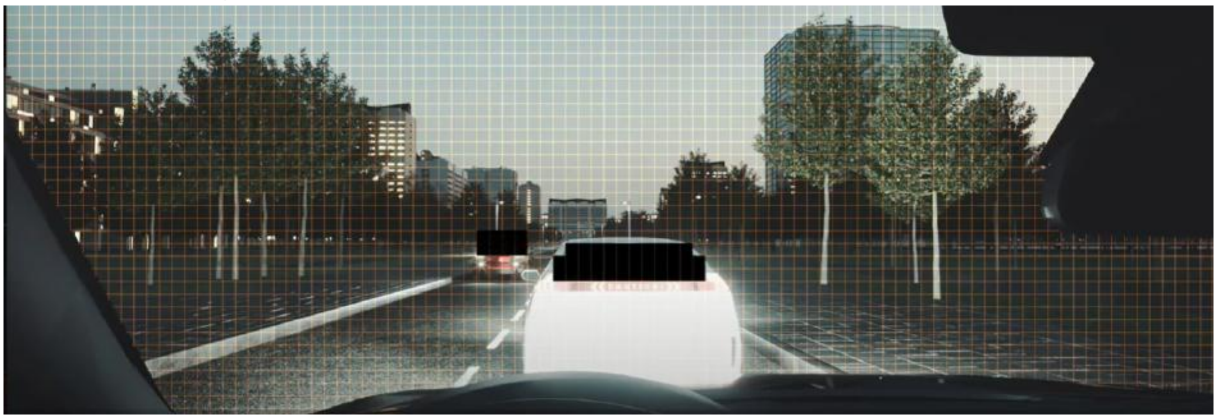
Marking Light for cyclist (Valeo)

These improvements will be permitted as seen before by improved ADAS sensors, but also by the evolution and proliferation of high-definition lighting systems.

6.1.2 High definition systems

ADB is the most recent breakthrough in lighting, providing high-beam seeing for the equipped driver with low-beam glare for other road users. Future high definition systems will be comparably revolutionary. Today, only very few, very costly cars (Mercedes Maybach…) are equipped with HD lighting systems with 1.1-megapixel DMD. But in the next two years, several systems using microLEDs will begin to democratise the advantages of HD lighting. First, they will limit their definition to some thousands of pixels, but this is already enough to give exceptionally good performance—ADB with a much more precise projected light contour around other vehicles, for instance, or highly precise marking light. In parallel, microLED HD lighting systems with resolution on the order of 10s of kilopixels naturally provides for even more precise ADB and marking light—and these systems from this definition level up, will also allow new road-projection lighting functions.

With this level of definition and also thanks to a better image analysis with ADAS sensors, it is possible to hide only the position of cars passengers and not the entire car, allowing more light in the field and being even closer to a real high beam.



25.6-kilopixel Osram Eviyos 2.0 MicroLED HD system (Osram)

6.1 New front communication function by road projection

Road projection will be used both to help the driver and also to communicate to others

6.1.1 Road Projection helping the driver

6.1.1.1 Guidance lines projection

Projected-light lane and waypath guidelines are to help the driver choose and maintain an optimal trajectory through lanes narrowed by roadworks or emergencies, or in construction zones, or in other difficult-to-navigate situations. Such systems rely on very precise positioning only permitted by good ADAS sensors and updated and detailed maps. The corresponding technologies are not yet at the right level to allow very reliable guidance lines. DVN is nevertheless convinced that from 2025, the ADAS systems will be at the needed level to provide this function.

For L3-4-5 autonomous driving, this road projection can also be useful for drivers to check the intended trajectory of the car at night and so reassure the passengers—and provide for the human driver to take back control and make a course correction if necessary (assuming, of course, that the driver -passenger is still attentive and that a steering wheel is still present in the car).

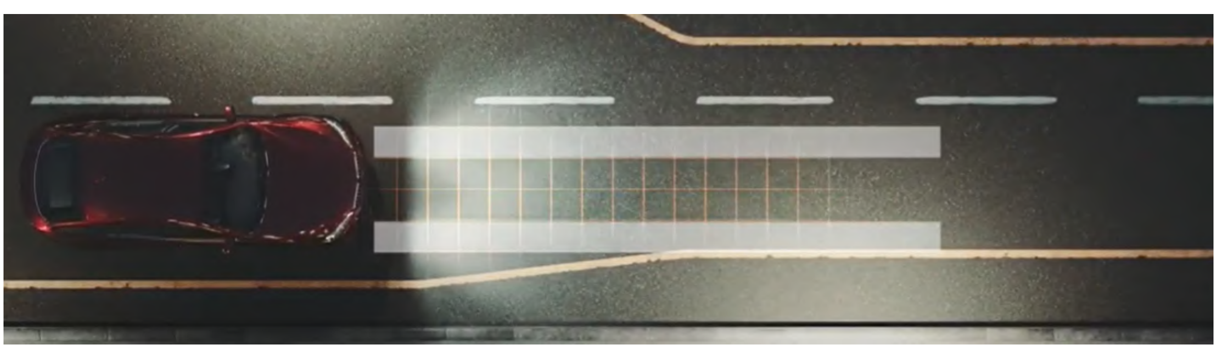


Image Guidance lines (Osram)

HD headlighting systems will surely be able to provide a variety of lane and waypath guidance lines.

6.1.1.2 Signs for the driver

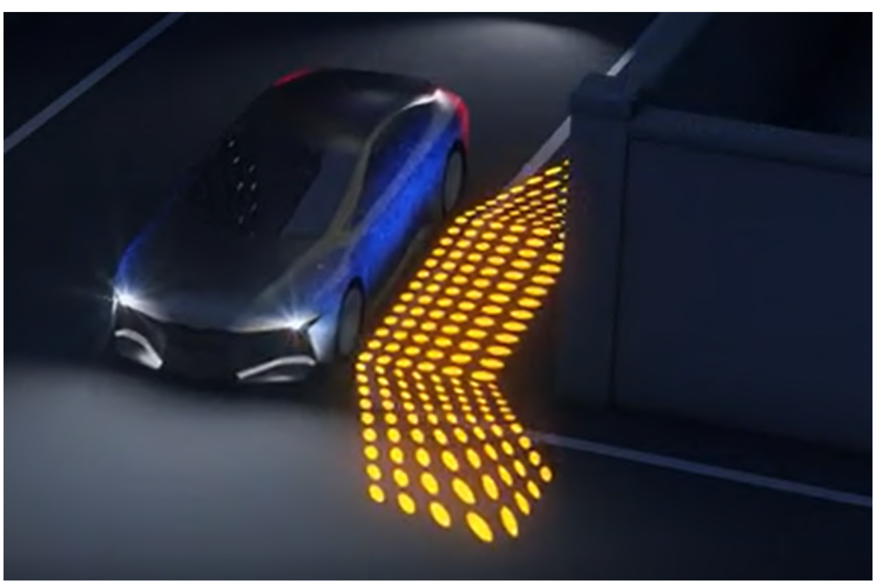
Different information can be shown to the driver to improve safety for instance as seen below when an animal has been detected, or to give the speed limit, or warn of an upcoming curve, etc.
However, this information can also be transmitted to the driver through head-up displays.
It seems currently that most car makers are preferring the head-up display as this system works both day and night, while road projections are mostly for after dark.

Road-projected signs to the driver could be realised by HD headlighting systems or by specific MLA (Micro Lens Array) systems.

6.1.2 Road Projection to other road users

Road projection of turn signals, for instance, will reinforce the traditional turn indicator and in some case be the lone signal seen by others depending on their position. This kind of road projection of a traditional function but with new mode of communication is certainly one of the most interesting new front functions for safety improvement.

However, as with every new means of communication to others in traffic, a standard must be established so that the new kind of turn signal is interpreted quickly and correctly with a minimal learning curve.
Self-driving cars must have provisions to replace longstanding nonverbal communication (eye contact, nods, waves, etc) among drivers and between drivers and pedestrians. So road-projection turn signals and suchlike will also be helpful in contributing to AVs' communication with other road users.



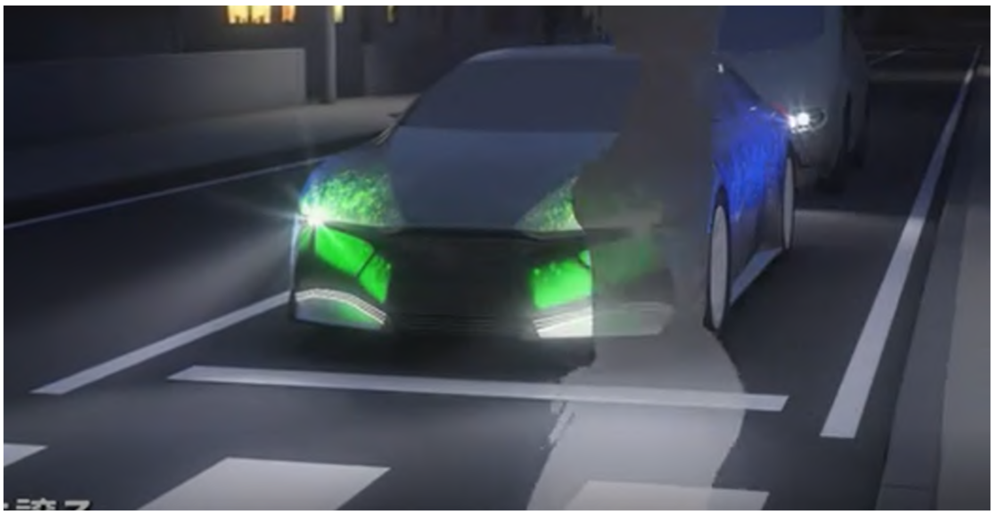
Turn indicator by road projection (Koito)

These different road projection for other users particularly at short range could be mainly realised with MLA systems.

6.2 New front communication functions by signals or displays

New communication functions to other road users and particularly to VRU (vulnerable road users) can also be realised by signals or by displays installed in headlamps, in bumpers, or in the grille. This will be particularly useful to replace the traditional nonverbal communication between drivers and pedestrians at crossings. One important communication to present in autonomous mode will be the intent of the car to stop and to allow the pedestrian to cross the road.

Many proposals have been put forth, most of them with green colour, but no consensus exists yet, and regulations do not yet exist. New studies are necessary as soon as possible to decide the norms as this kind of communication will be absolutely necessary in AVs



Sign to allow pedestrian to cross the road (Koito)

7. Existing Rear Functions

ARS (Adaptive Rear-light System)
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 car's position.

Multi-level tail lamps
The brake lights and indicators are operated at varying intensities depending on the current driving state and ambient brightness levels (day/night). The brightness of the brake lights will be automatically dimmed at night to avoid dazzling anyone behind. The light distribution is broadened to ensure the lights do not become too dim to fulfill all legal requirements. This provides three intensity levels in rear stoplights and rear DI for better conspicuity in bright daylight but without excess glare after dark.

Emergency Braking Display system
The Emergency Braking Display (or "progressive brake light" or "emergency stop signal") systems now being introduced are designed to impart a higher level of urgency and clearer warning of hazard under severe braking. 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.

8. New Rear Functions

"It is sufficient for a driver of a vehicle to lose control for just a fraction of a second for a human tragedy to occur. The road transport system should therefore be able to take account of human failings and absorb errors in such a way as to avoid deaths and serious injuries" is a mission statement of the "Vision Zero" program developed in Sweden in the late 1990s.

According to a NHTSA report, 29% of accidents are rear-end collisions. So it is very important to prevent accidents from the rear even if the fancy lights installed to do so will mainly be seen by the following drivers or other users and not directly by the driver (i.e., vehicle buyer) themself.

8.1 Prevention of rear-end collision by improved signals

We have already seen that ARS with its adaptation of rear lamp intensity can help improve the conspicuity of the car by optimising rear light performance in accord with ambient conditions. But in some cases, the following driver could be inattentive and even with optimal lights would not see the slow-down of the preceding car. Naturally, ADAS systems and particularly AEB in his car could slow down or stop the car in case of danger, but only few cars are currently equipped. In these conditions, the leading car could be equipped with a rear radar or a lidar and thus try to alert the following driver by sending a specific signal of danger. This can be realised practically with the current signal functions, for instance the hazard warning with the maximum intensity or with the emergency braking display system. Or with even a more intense signal of danger flashing for instance. However, for any of these the regulations would have to be amended.

8.2 Prevention of rear-end collision by road projection

We have already seen in a previous chapter that road projection could be helpful at the front of the vehicle. This new kind of function could also be used at the rear to communicate. Precise information can be sent by rear road projection explaining the type of danger. For instance, a SLOW DOWN message with indication of the speed or speed limit, or a warning of a crash or hidden obstacle ahead, etc. The information is naturally coming from the ADAS sensor, for instance with front sensors detecting a danger ahead. But as seen previously, in some case, rear sensors could emphasise this road projection when the following car is detected as a potential danger due to its speed or direction not adapted.

Road projection indication of global danger (Koito)

Road projected Indication of danger and need to slow down (Marelli)

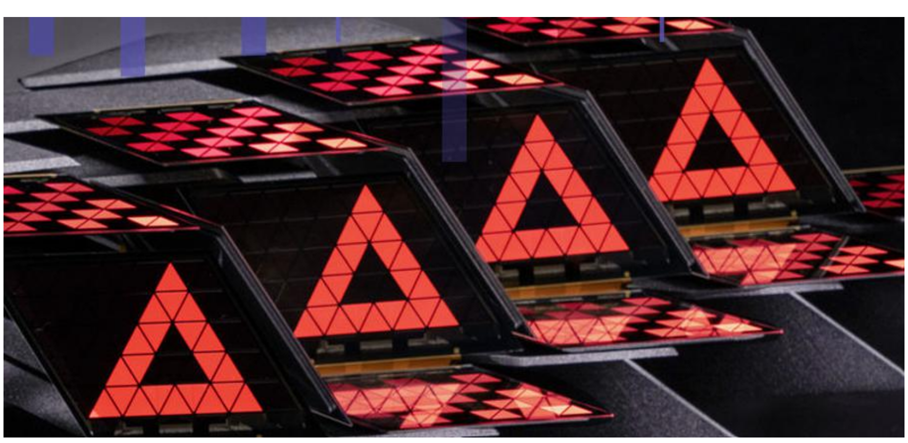
Similarly, when sensors on the side and the rear that can be used also for blind spot detection will detect a cyclist or motorcyclist or even a car door being opened, a signal can be sent to the occupants of the car itself and a road projection perhaps with a strong blinking signal can be projected on the road from the rear or from the door.

Another difficult situation is departing from parking in rearward position. In that case, the driver is often not able to see potential dangers (VRUs, other vehicles). So it is important to send clear information about the vehicle's movement, by means better than the traditional reverse light function that can easily be swamped and rendered invisible by sunlight or even general lighting in a parkade. A road projection system with an appropriate signal for instance a dynamic arrow would reduce the risk of crashes.

For the front, we have seen that many road projections can be realised as a complementary function of the main ADB functions with HD headlamps. For the rear, this is not possible and so a specific device needs to be installed. MLA technology can be used, as these different road projections are generally for short range.

8.3 Rear communication with displays

Information to following road users can also be communicated through displays. For communication needing few digits, a specific arrangement of the elements of the signal function can already send more clear messages than the traditional vehicle lighting functions. This can be realised as shown below by Audi by OLEDs, or by LEDs through surfacic light transmission.



OLEDs rear communication – (Audi)

In a further step ahead, where more detailed information is required, a display with for instance μLEDs can be used.

µLED rear communication – (Marelli)

These different ways for rear communication are not yet catered for by vehicle lighting regulations. Messaging standardisation will be required to ensure against ambiguity within and across cultures. And certainly even then, there will be a learning curve while people learn to look for the messages—and learn to trust them.

To be noted that these different communications could be used by human following drivers, but they would certainly be even more useful with AVs, their sensors being able to have a better vision than human beings, and their artificial intelligence increasingly better able to drive correctly, consistently.

Outlook

Currently our civilisation strives for the maximum level of safety for every circumstance—naturally, motoring is included. New advanced driver assistants and autonomous car capabilities, with increasingly performant sensors are demonstrating strong benefit for safety. Cameras, lidars, radars, and other sensors are rapidly improving by every measure of performance, packaging, and price—and their ever-higher levels of artificial intelligence, In parallel, lighting with AFS, ADB or ARS have also demonstrated a strong added value for safety improvement.

Progressively, we have seen the link between lighting and AD/AV being reinforced, each reciprocally needing more and more from the other. In the future, AD/AV systems will need not only to give information to the driver, but also to other road users—as well as receive information from others or from the environment. And for this communication, lighting will be one of the main levers. The two realms will also be more and more physically associated with with the integration of ADAS sensors in lighting products.

Currently due to the coronavirus crisis, priorities are elsewhere. But we are convinced that the way to improve road safety will is through close coöperation between AD/AV systems and lighting, and that an important part of lighting innovations in the next ten years will be in this domain.

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