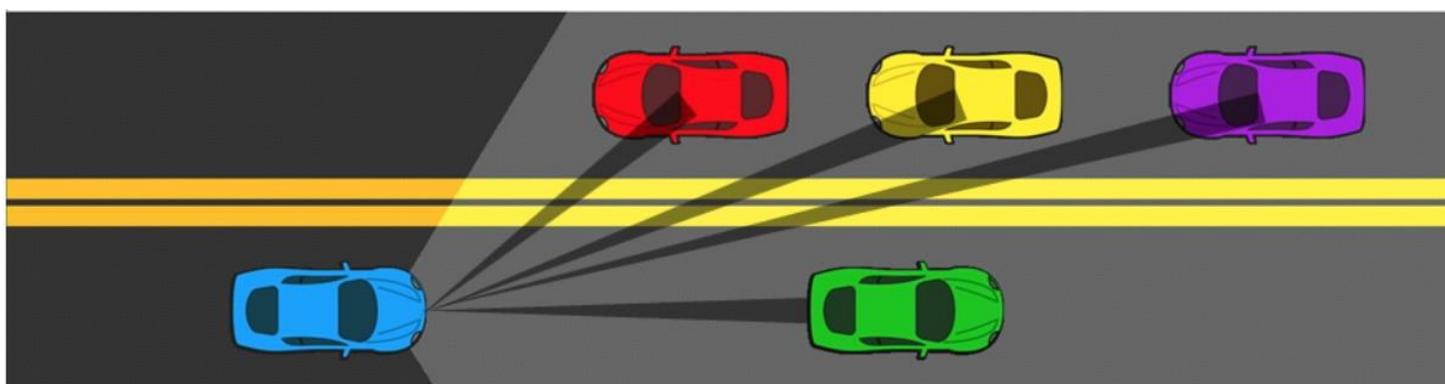


Adaptive Driving Beam

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Adaptive Driving Beam, 2010-2030

History • Status • Future

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Executive Summary

Along with the advent of LEDs as primary light sources in vehicle lamps, ADB (adaptive driving beam, also called glare-free high beam) is the greatest innovation in decades. ADB gives high-beam seeing with low-beam glare, finally resolving the seeing-versus-glare dilemma which for nearly a century vexed industry, regulators, researchers, and drivers alike. This report presents the origins of ADB; describes how we had to wait for electronics and onboard cameras to evolve in the 2000s to a level that would support practical ways to realise this longstanding dream, and the arrival in 2010 of the first mechanical ADB system with an HID light source.

An important chapter is dedicated to the presentation of four beam-shaping concepts: the **mechanical system** came first, in the VW Touareg, and is still used today with different methods. The **matrix beam** launched in the 2014 Audi A8 as a solid-state system (no moving parts!) allowing possibility of lighting between shadow zones. **Pixel lighting** came along first with a complex system in 2016 in the Mercedes E-class with 84 pixels, then with high-resolution using DMD, LCD, and μ LED technologies. And **scanning systems** use MEMS or spinning mirrors.

The next chapter describes the achievements of tier-1 suppliers Marelli Automotive Lighting, Hella, Koito, Stanley, and ZKW with exclusive interviews of their R&D directors; and also of Tier-2 suppliers Lumileds, Nichia, Osram, Texas Instruments, and others arriving in the market. There's a chapter on how to assess the ADB lighting performance—a very tricky thing to do accurately, precisely, and repeatably. There's a detailed description of the method devised by Marelli AL and further developed with Darmstadt University and GTB members until it was precisely reproducible and scientifically accurate, and then discussed in the GTB deliberations. The target is to qualify this ADB rating system as a GTB position paper, though no decision on the matter has yet been taken by GTB. Then a chapter describes the status of ADB regulations worldwide, as well as the increasingly problematic and frustrating USA exception. Then comes a synthesis, the evaluation of lighting performance in relation with the number of pixels or segments, and analyses the market prevalence of ADB in Europe, Asia, and provides forecasts for the USA.

The last chapter is about the future of ADB. After starting as an option in premium brands, we are now in the second step, with ADB becoming standard fitment in premium cars and an option on increasing numbers of increasingly lower-segment vehicles. This involves increasing volumes, further development, and decreasing prices. In the same chapter, a new projects prognosis to 2026 explains weaknesses and strengths of each of the 11 technologies currently used in ADB systems.

To conclude, the report explains how as a very effective safety system which can save lives, ADB has the potential of becoming mandatory in some regions of the world. A lot of research and even more communication is necessary before this could be realised, but in any event it is certain that low/high-beam systems are outdated technology and ADB has a bright future.

About Driving Vision News

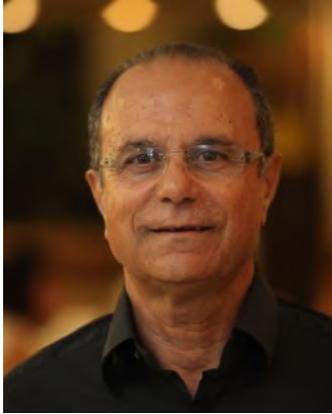
DVN is the vehicle lighting and ADAS industry's journal of record, dedicated to keeping the community informed and communicating about the latest progress and developments.

DVN's three pillars are:

- **Technological watch** with weekly news, analysis, and crucial information on innovation and ongoing developments in lighting, ADAS, and related matters; there are also monthly deep-dive reports and quarterly brief reports with sharp focus on cutting edge technologies, company profiles, regulatory matters, and other relevant content available only from DVN.
- **Networking** of high-level decisionmakers, researchers, innovators, practitioners, academics, and regulators to make new business connections with two workshops per year in rotating locations throughout America, Europe, China, Japan, India, and Korea. DVN Workshops gather over 300 participants.
- **Promotion** of DVN's member companies, numbering at least 150. We facilitate the knowledge, recognition, and application of innovation, which in turn paves the way for commercialisation, enabling to build new relationships through DVN Community to forge new business worldwide. The DVN Gold membership roster includes 30 automakers, 30 lighting & ADAS tier-1 suppliers, 15 light source suppliers, 50 tier-2 & -3 suppliers, and a wide variety of universities, research outfits, and consultants. DVN Gold members receive all publications and attendance privileges at all DVN Workshops. Basic members—2,500 and counting—receive Newsletters and can obtain access to other DVN publications and functions.

About the authors

Hector Fratty



Hector Fratty's entire career has been in vehicle lighting. From 1995 to 2006, he was Valeo Lighting's chief of R&D. His level of expertise in lighting gained him recognition as one of Valeo's five Master Experts.

In 2008, he initiated the launch of his own company, Driving Vision News, which has become the automotive lighting and driver assistance industry's journal of record dedicated to keeping the community informed and communicating about the latest progress and developments.

Wolfgang Huhn



From 1981 to 1986, Wolfgang studied electrical engineering at TU Darmstadt. From 1987 to 2000 he was with BMW. In 1999 he got his PhD at TU Darmstadt, and from 2001 to the end of 2020 he was Audi's Lighting and Vision Systems Development Executive Director. In 2021 he retired from Audi and started at DVN as a senior advisor. He is chairman of the GTB WG strategy. Dr Huhn has greatly influenced the evolution of lighting technologies, and has received the Ferdinand Porsche Award for the introduction of the Audi R8 full LED headlamp, and was awarded DVN's Person of the Decade 2000-2010.

Jean-Paul Ravier



Jean-Paul graduated from the Institute for Space and Aeronautics Engineering and the Institute for Administration of Enterprises. He worked for over 41 years at Valeo, including 29 years at Valeo Lighting where he held a variety of management positions first in IT and finance, and then in R&D, projects, and innovation, including in Japan from 2005 to 2009 at Ichikoh as a board member and managing director. He retired from Valeo in 2013. Shortly thereafter he was appointed chair of the ELS, and held that position through the end of 2017. He is now Development Advisor for DVN.

GTB, Geoff Draper



Geoff retired from Koito in 2008 after a 47-year career in lighting and was elected GTB President, a position he held until December 2020. He is now engaged by DVN as Senior Regulatory Advisor on a part-time basis. Geoff developed an interest in international regulatory harmonisation and, in 1989, was elected chairman of the GTB Harmonisation working group and subsequently he led the GTB Front Lighting group, CIE TC-4-45 and the SAE Pedestrian Visibility Taskforce.

Until his retirement, Geoff was a member of the ISAL Steering Board, Honorary President of the ALE Forum (China), and a regular contributor to Driving Vision News and its workshops. He was voted "DVN Personality of the Year" in 2017

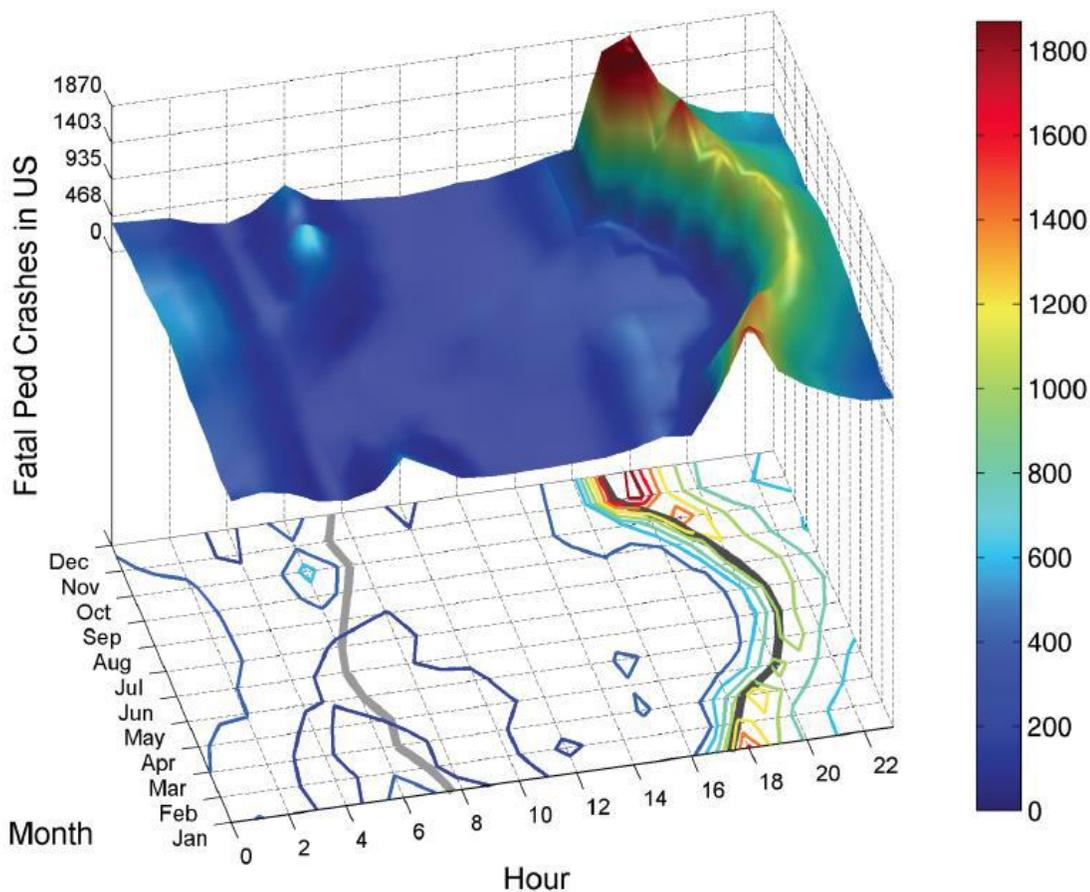
Foreword

The authors thank DVN Chief Editor Daniel Stern for his editing, image selection, and content contributions.

Introduction

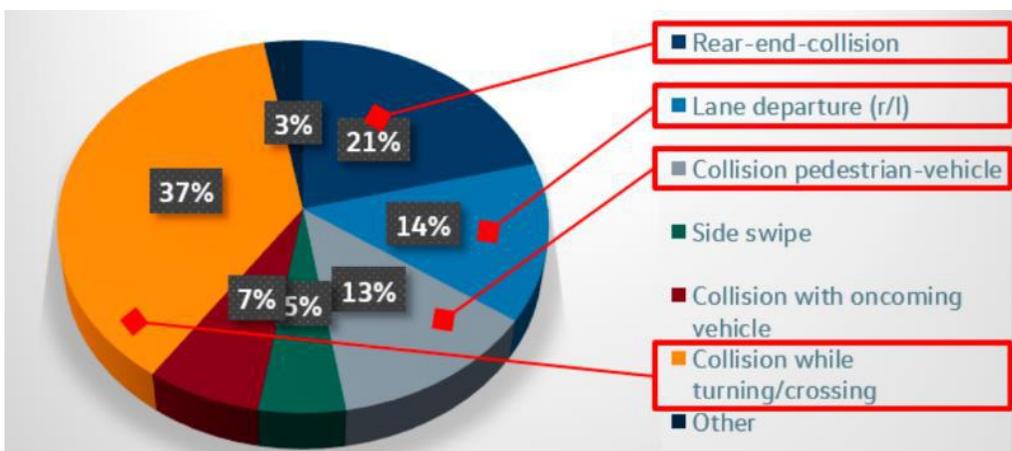
This report focuses on the light production and modulation part of the ADB system. Other system components—cameras, ECUs, Image processors, sensor fusion, and software—will be covered in a future report.

The main motivation for developing new lighting functions is safety during night drives. The relative severity of accidents after dark is almost twice as high as during daytime. This plot of pedestrian deaths per month-hour shows how dangerous the dark is:



U.S. pedestrian deaths per month-hour (image: UMTRI)

This next chart shows the causal distribution of nighttime crashes. Focusing the development of novel light functions on the four accident types indicated in red addresses 85% of all nighttime crashes:



Night crash causes (image: IAV)

Glare-free high beams are already strongly enhancing illumination for safety. And high-resolution ADB is rapidly evolving with dynamic bending light, marking light, and soon novel light-based assistance systems and communications with other road users. All these functions are contributing to improve road safety and comfort

In this report, after a look at the history and current main ADB technologies, we analyse how high-resolution headlamps provide new levels of adaptivity during all night-driving situations. This new versatility of light distribution, fused with modern sensor technologies, shows significant advantages in range and visibility for the driver. Too, high-resolution systems allow assistance projections on the road for driver information and assistance for further gains in safety and comfort.

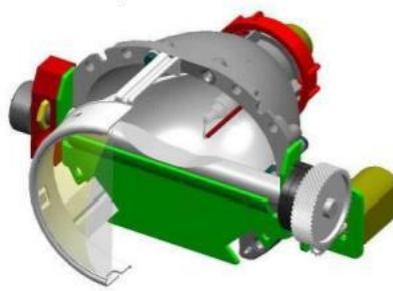
1. ADB's Origins: Cracking the Seeing/Glare Dilemma

Since the early-1920s when multiple-beam headlamps were invented, drivers have been frustrated by the seeing/glare tradeoff: low beams keep glare down to a civilised level, but offer insufficient seeing distance; high beams offer better seeing distance, but produce too much glare to use when other road users are present. Despite numerous advances in the technology and technique of headlamps—halogen light sources, newer kinds of optics, HID light sources, LED light sources—this basic dilemma remained. For that reason, there has long been a dream to provide full-time high beam performance without the glare. But the technology did not exist to do so in an effective, affordable manner; the solutions proposed, such as polarised headlamps and car windows, were impractical and so weren't commercialised.

We had to wait for the arrival of electronic systems and on-board cameras in the 2000s to think about practical ways to realise this longstanding dream. An early effort at modulating the light beam with greater precision than just high or low beam was the adjustable cutoff of the BMW 5 Series in 2007; the light was adapted dynamically so the cutoff would fall just short of the position of other drivers, but with no vertical cutoffs it was not really an ADB system. And camera-driven high beam assistants (automatic, situationally-responsive high/low beam switching) on the 2009 Mercedes S-Class and Audi A8 were a major improvement over previous photocell-based systems, but still confined to the basic high/low beam, so no ADB there, either.



Adjustable cutoff: maximum sight range in traffic



Adjustable-cutoff projector: rotating drum cutoff shield

After several years of technical development and regulatory discussions, the first real ADB system appeared at the end of 2010 on the VW Touareg.

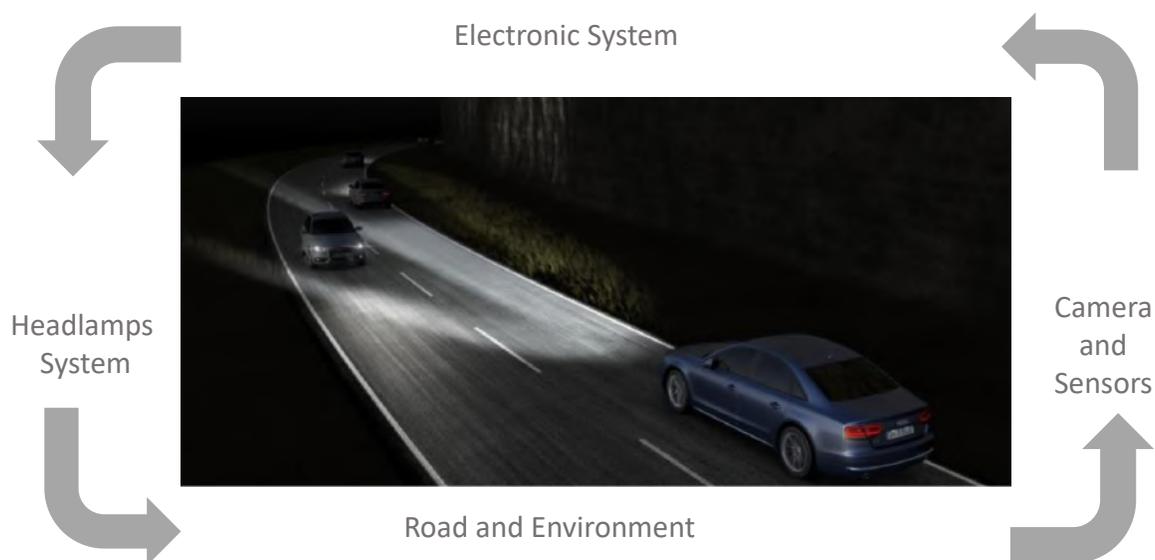


The adaptive driving beam or "glare-free high beam" works to put as much light on the road as possible, except where other road users could be glared by it. The basic idea: high-beam seeing with low-beam glare. A camera is used to detect and keep track of other road users' positions, so one of the first difficulties was to make a good identification of road users and features, and to distinguish among them to allow an appropriate response: leading cars versus oncoming cars versus retroreflective signs, and so on.

A second issue was to define and configure the ability to adjust the light position to de-glare where necessary without making new problems of inadequate light where the driver needs it. For the first

systems with HID light sources, only mechanical systems were possible to modulate the light distribution; a specific L-shaped beam in each headlamp was specified, moving horizontally to create and adjust a de-glared zone. Extensive night test driving was done to optimise system response across numerous situations; the data gathered on these test drives informed the coding of the most complex software ever used in headlighting systems up to that point. And once the hardware and software were designed and built, it was necessary for car makers to put highly accurate, very precise systems on their production lines to perfectly align the headlamps and the camera.

ADB: The First Camera-Driven Lighting System



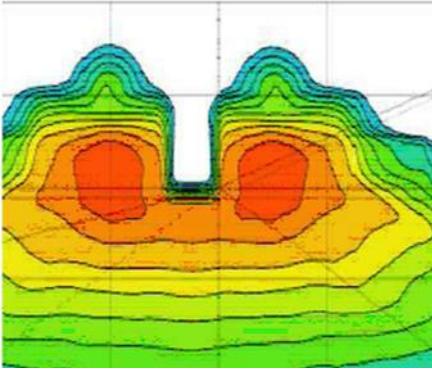
This first mechanical ADB system introduced in 2010 was considered one of the most important breakthroughs in the history of vehicle lighting, so very quickly everyone involved in lighting began striving to improve ADB performance and functionality.

The main directions for improvement were smoothing the light movement to avoid distracting the driver, enlarging the lighted area by shrinking the shadow zones for more precision in the de-glared zones, increasing the number of other road users that could have their own shadow, and naturally the old moving targets of better homogeneity and range remained. An important step was the introduction of the full LED matrix beam, at first with 25 segments in 2014 on the Audi A8. The matrix modulation was in the high beam only, so the low beam stayed smooth and calm—free of the hectic light movement unavoidable in highly dynamic mechanical systems. This was achieved by the control of the luminous flux of the LEDs by pulsewidth modulation (PWM). The Audi strategy was to replace mechanical hardware by electronics and software. The headlamp makers didn't support this approach in the beginning, as they had huge money invested in developing high-end mechanical ADB systems; they wanted to replace the HID light source by LEDs and carry on using the mechanical ADB for more years. The functional improvements for the end customer and the reduction in mechanical complexity brought the matrix technology to dominance, though, along with its high potential for future improvements.

Two years later in 2016, another significant milestone was the presentation of a lighting system with 84 LED pixels: the multibeam system on the Mercedes E-Class. A very special approach by Mercedes was the modularisation of the LED pixel light source. They defined an optical interface and cut the electronics as a separate module out of the headlamp. At first this was a shock for the tier-1 suppliers, as a big part of the value generation went away. In the next generation the headlamp makers improved so fast that they could win back ownership of the module in most cases, Overall this courageous sourcing strategy did not change the market, but the high-end headlamp makers are now much better in electronics and micromechanics.

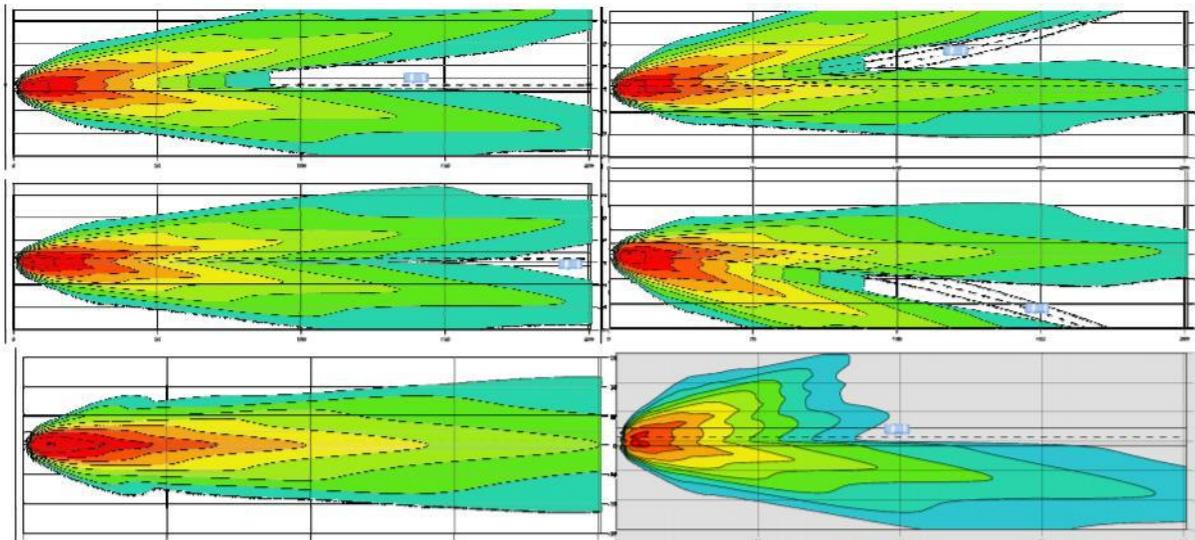
2. Four Beam Shaping Methods

1st Concept: Mechanical



Mechanical ADB isolux

The main principle of the first ADB systems was to create a vertical cutoff in each headlamp, the headlamp on the left producing the left part of the beam and reciprocally, the right headlamp producing the right part of the beam. With information about the position of other road users, the two vertical cutoffs would be horizontally adjusted so as to centre the de-glared zone around the other road users.



Bird eye Isolux of mechanical ADB in different positions

Examples of mechanical ADB systems

HID light source with rotating shield

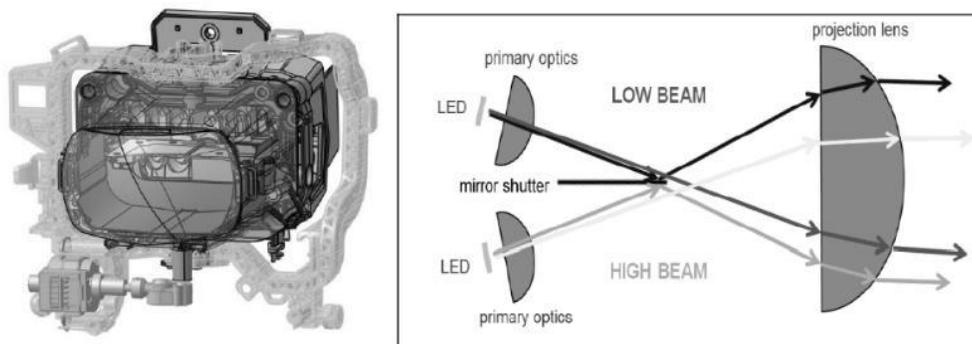
The first systems—by Hella in 2010 on the VW Touareg, and by Valeo (projector shown here) on the VW Phaeton, used a rotating-barrel cutoff shield inside an HID projector module. This rotating shield incorporated several different cutoff profiles; typically one for low beam, one for high beam, one for ADB, and a flat one for the tourist solution (driving in an other-hand-traffic country). The movement of the cutoff below the position of other users was accomplished by vertical aiming by levelling systems known already for years, while the horizontal movement was done by another stepper motor. Three stepper motors are therefore used simultaneously with this system.



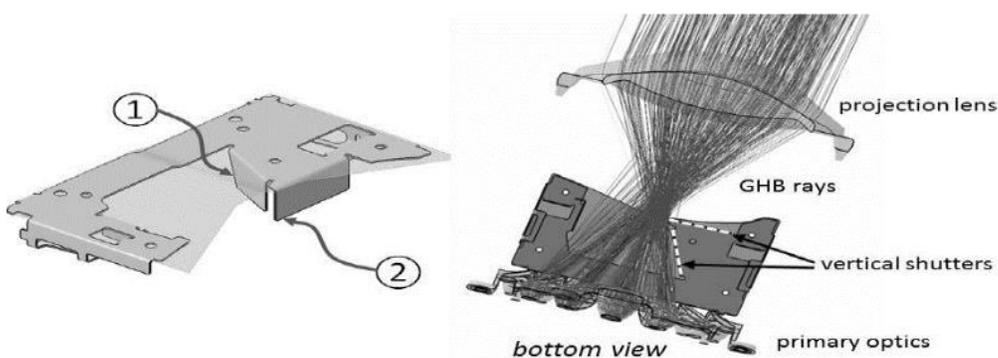
In 2010, LEDs were still expensive and offered limited performance, and so HID was preferred for the first ADB module. One light source on each side of the car meant the entire left and right beam were moved to achieve the ADB function. But soon after, LEDs began their inexorable advance, progressively pushing out the Xenons. Modernised ADB projector modules with LEDs appeared.

A good example of this kind of new concept is the 4th-generation e-Light developed by Automotive Lighting, with full AFS & ADB functionality. A mirrored shutter with high reflectivity boosts overall

efficiency of the low beam above 50% with 7 LEDs and flux in beam of 750 to 800 lm. The high beam is made with 4 LEDs and without mechanical parts. To get the ADB functionality, with the help of the bending light motor, a two-part vertical shutter was added to the bottom of the mirror shutter to create a vertical cutoff line, one part of the vertical cutoff being built by the right headlamp and the other part by the left headlamp.

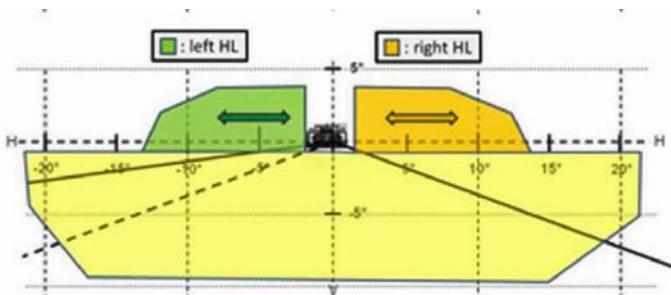


4th Generation e-Light



Sail Beam

The introduction of LEDs, and the fact that several light sources could be used, led to the creation of new systems for mechanical ADB. One such was called "sail beam": instead of moving the entire beam laterally, only the upper part is moved.



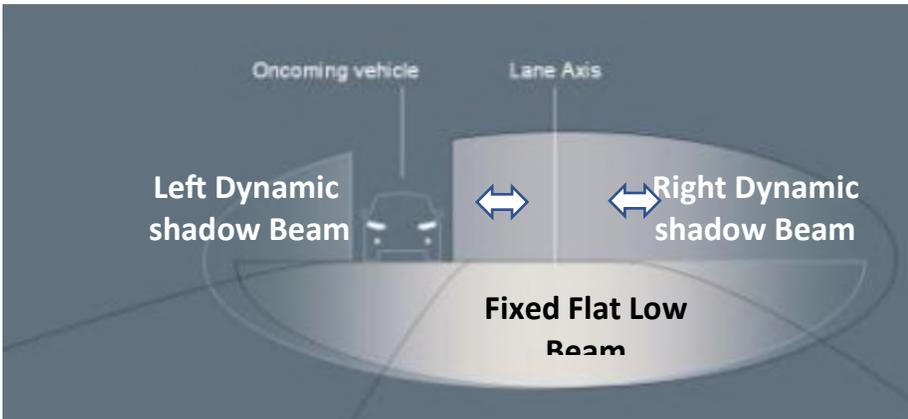
These specific beams for ADB have the shape of sails, with a vertical cutoff adjusted around the other users. The lower part of the beam, with a flat cutoff, remains fixed. This greatly reduced the distraction of "dancing light" on the road surface visible to the driver.

These sail beams could be realised by relatively simple projector or reflector units integrated in a swivelling module. One advantage of these systems is also their efficiency, as no shield is blocking a part of the light for the ADB mode.

Dynamic Shadow



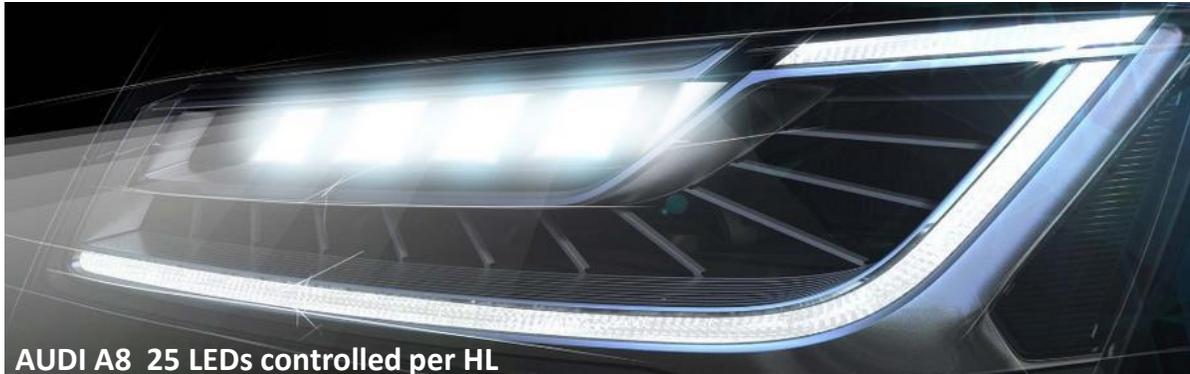
Dynamic shadow systems developed by Valeo (shown here on a Ford Galaxy) sought to improve driving comfort by eliminating the visible movement of the light. Here, only the position of the cutoff is moved in an otherwise-fixed upper part of the beam. This is achieved by an internal shield in a projector unit moved horizontally. This is sort of the opposite of a sail beam.



Principle of Dynamic Shadow system

2nd Concept: Matrix Beam

The mechanical ADB systems did a lot for improved safety. But in the permanent race for progress, the lighting industry was also searching for more style and novelty; for ADB with a more modern touch with a totally solid-state system. Matrix beam systems met these targets when they appeared in 2014 on the Audi A8.

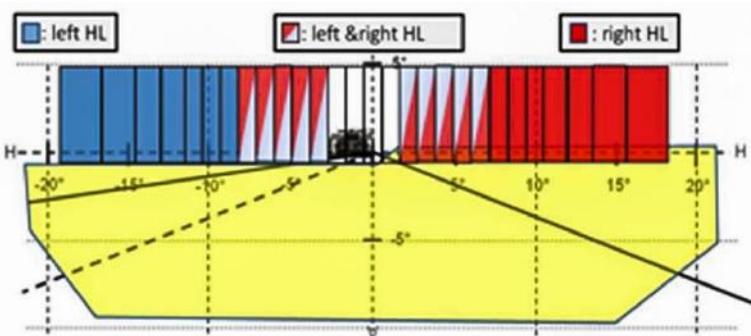


AUDI A8 25 LEDs controlled per HL

First matrix beam: 25 LEDs in Audi A8 headlamp by Hella

The main principle of the matrix beam is to produce the high beam above the low beam by the juxtaposition of several vertical segments of light, each segment lit by an LED.

By switching off individual chips of an LED array, the glare-critical areas of the high beam distribution



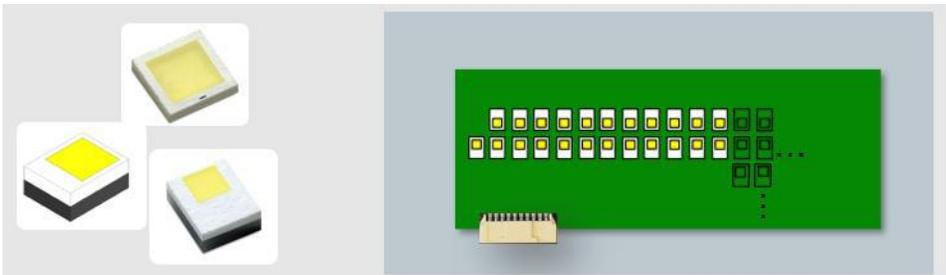
Principle of one-row matrix beam with juxtaposition of light segments

will be darkened without need of mechanical actuation. This is a higher-resolution system that gives additional possibilities such as lighting between shadowed-out vehicles.

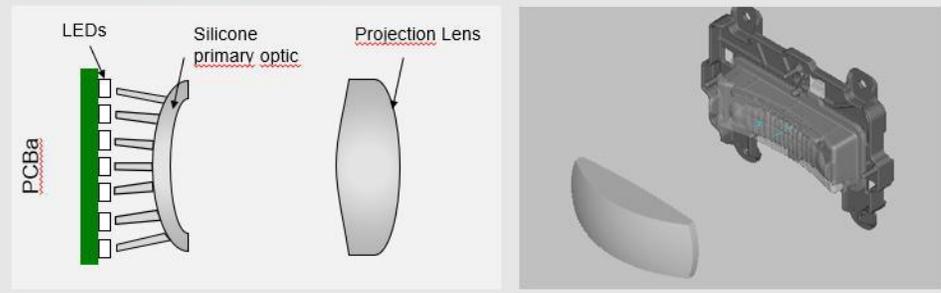
Each segment can be addressed individually and brightened, dimmed, or switched off. Segments can be composed with reflector or projector optics, using one or more LEDs per segment. Multiple vehicles—not just one at a time—can be shadowed out of the high beam, the rest of which remains to light the equipped driver's way.

The main challenges of this technology are the compromises involved: a greater number of LEDs means more smoothness and beam precision, but also greater cost. When all the LEDs are lit, the overall amount of light and beam depth remain close to that of the full high beam, allowing for an inherently stable function despite high beam/ADB transitions. The direction of the hot spot (I_{\max}) can also be controlled independently from the position of the dark tunnel, thus creating a real bending light effect in ADB, as well as in high beam.

A major challenge is to place all the segments exactly right next to each other without gaps (which would create dark lines) or overlap (bright lines). While this can be controlled to some degree with highly precise arrangement of the LEDs on their board, in some projector units the LED-to-LED distance is too critical to achieve consistently; in those cases, to realise a continuous projection of the segments with no dark or bright lines between them a primary optic is used. This was particularly necessary when matrix beam systems first appeared and there was not yet built-up expertise in how to build them.

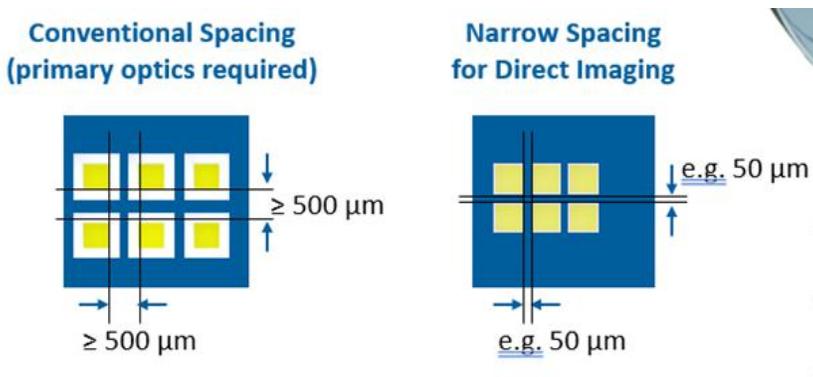


Schematics of optical system



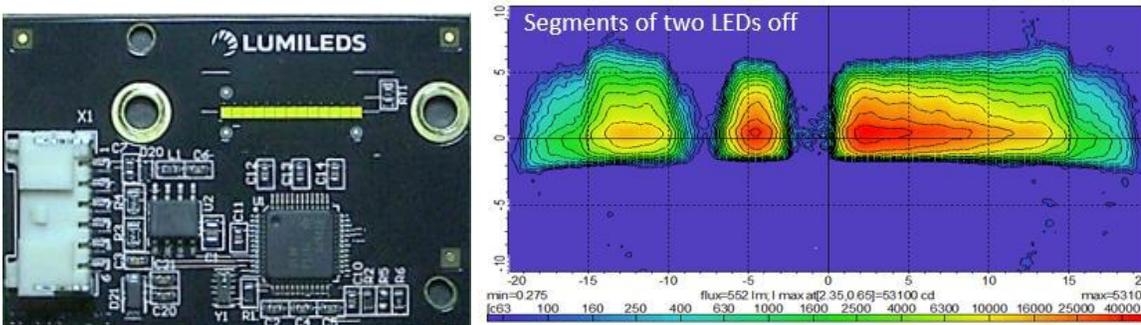
Matrix beam with primary optics (image: Hella)

Since then, major improvements have been made in LED array manufacture; individual LEDs can be as close as 0.5 μm from their adjacent neighbour, eliminating the need for primary optics.



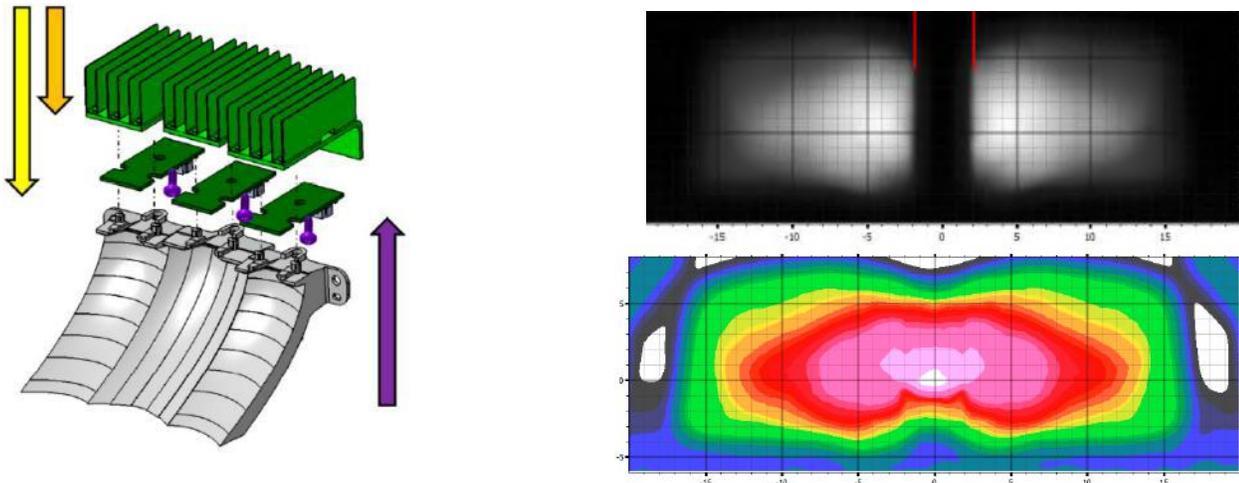
Distance between chips: modern LEDs can have a narrow spacing

Example of modern LED array for direct projection: 13 LEDs, 50 μm spacing (Lumileds)



Number of segments for matrix beam

The number of segments to be used for matrix is an actively ongoing discussion. ADB got started with only three segments, with attendant limits to system performance. Here is a 3-segment Varroc module; each reflector has a bi-chip LED. High-beam flux: 790 lm



Nevertheless, to put enough light close to the other road users without glaring them, to correctly illuminate the road in curves, and to have good smoothness, more segments are necessary. The following study presented in a DVN Workshop by Varroc explains the interest in more segments:

ADB SYSTEM	STRAIGHT ROAD	RIGHT EU CURVE	LEFT EU CURVE	HILLS	SUM
3 segments	++	0	+	0	3+
10 segments	+++	++	++	+	8+
17 segments	+++	++	++	++	9+

Consequently, despite the cost involved with a higher segment count, most matrix systems have more than 10 segments—for instance one of the first presented by Mercedes on the CLS, shown here, with 24 segments.



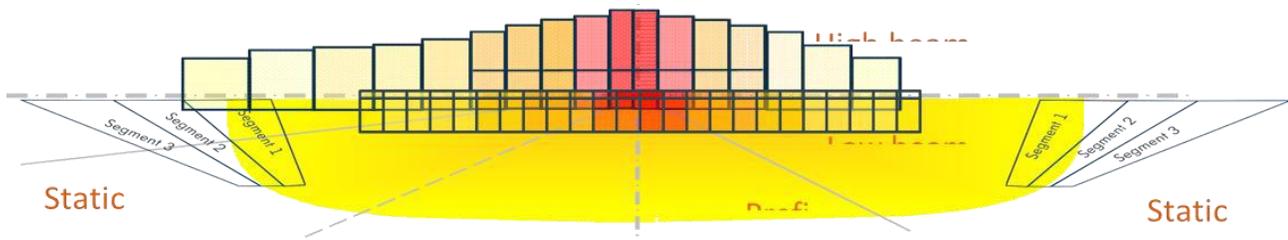
But now matrix beam is no longer reserved to upper class vehicles. The recent Opel Corsa shown here is the first B-segment vehicle with a matrix beam.

One of the best-performing matrix beam systems is the VW IQ Light installed on the 2018 Touareg. The low beam, high beam, and ADB functions are realised by a module with 48 LEDs; a total of 128 LEDs are individually controlled in each headlamp.



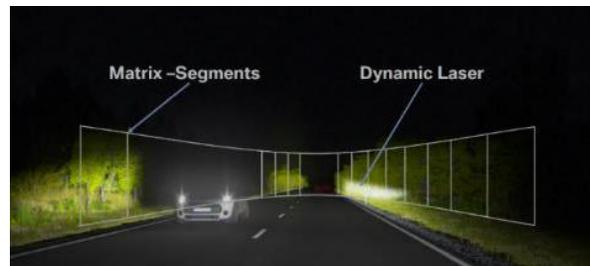
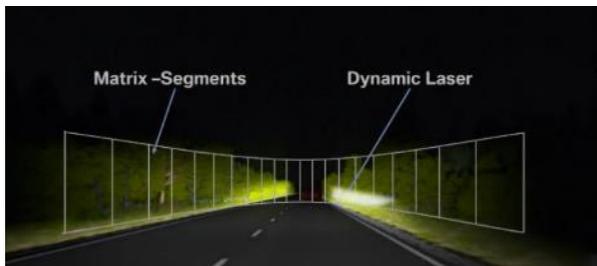
At the bottom of the headlamp, five reflectors are used for the forefield low beam distribution (yellow in diagram below), and at the inboard part, there are three small lenses for the bending light function. Total light flux: 2,600 lm with a width of 60°L to

60°R. The static bending light allows an overall width of 90°L to 90°R.



Combined matrix and mechanics: Dynamic laser ADB from BMW

The principle of this application, presented by BMW in 2015 on the 7 Series, is to combine a relatively traditional matrix beam with an intense kind of sail beam powered by a laser light source (active above 60 km/h) and horizontally swiveling in a relatively limited area in the centre.



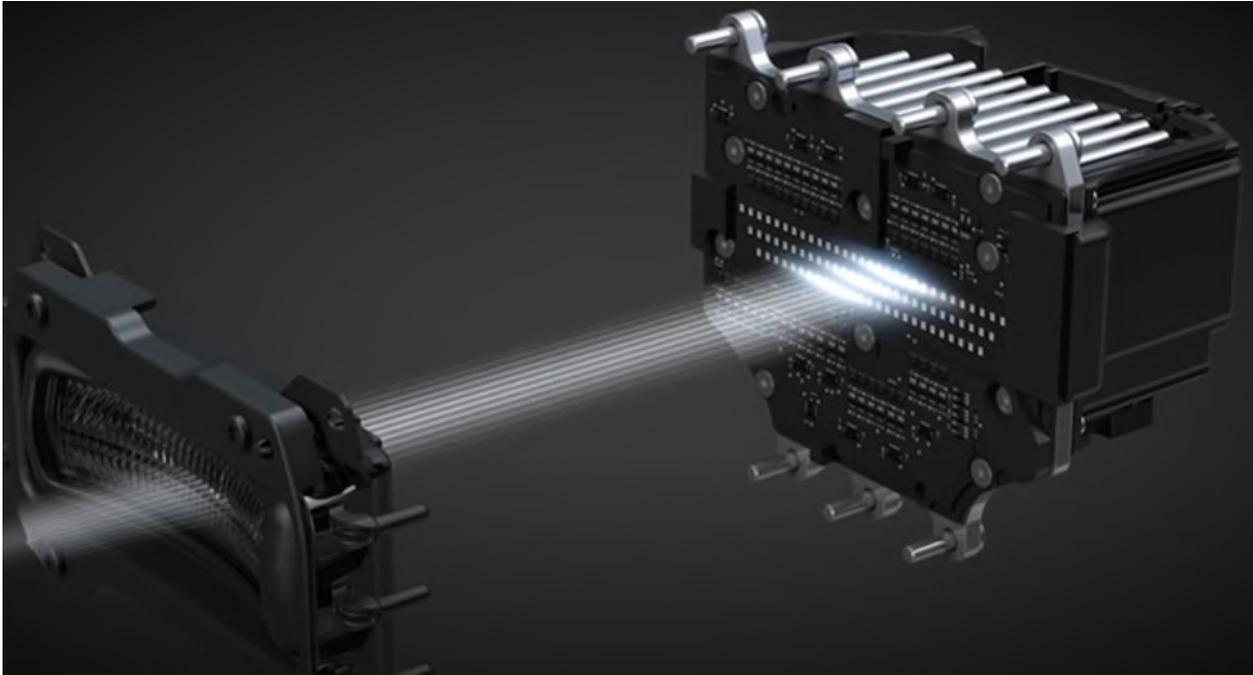
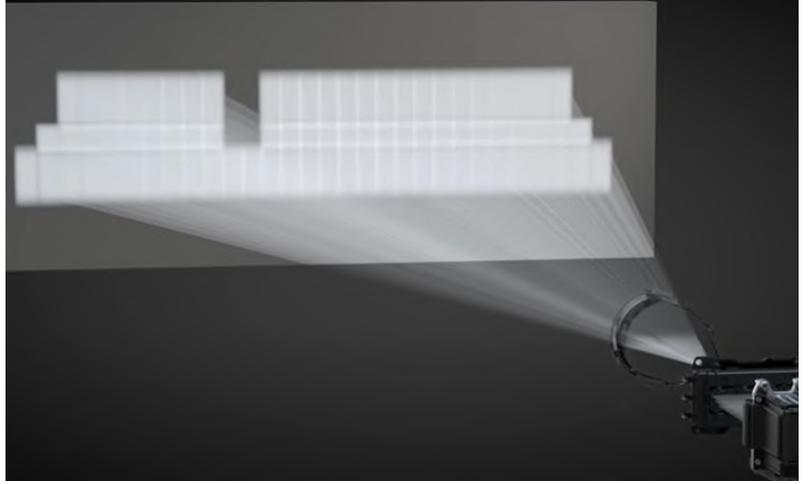
The system is built with a laser module and double-reflector optics integrated in a swivelling module with a resolution of 0.1°. The laser puts 170 lm in a 125-kcd spot.

3rd Concept: Pixel Lighting

When the number of light segments is greater than 50, particularly when several rows are used and there are up to 1,000 segments, it's called a pixel light system.

The principle is like the matrix one, with de-glaring achieved by extinguishing the pixels where other road users are. But thanks to more pixels, more light can be projected surrounding more precisely the other users. Naturally, driver comfort is also improved, and with at least 100 pixels, new functions can be installed—like spot marking light to show the driver pedestrians outside the main headlight beam. And there begins to be the possibility of optimising the amount of light hitting retroreflective road signs so they're visible without being so bright they dazzle the driver.

At first these systems were complex, particularly for the electronic control of each LED. The LED arrays available required primary optics made of injection-moulded of silicone. The first significant application was on the Mercedes E-class in 2016: LED array in three rows, and primary optics for 84 pixels.



High-Resolution ADB

Above 1,000 pixels, we enter another domain of lighting: high-definition systems.

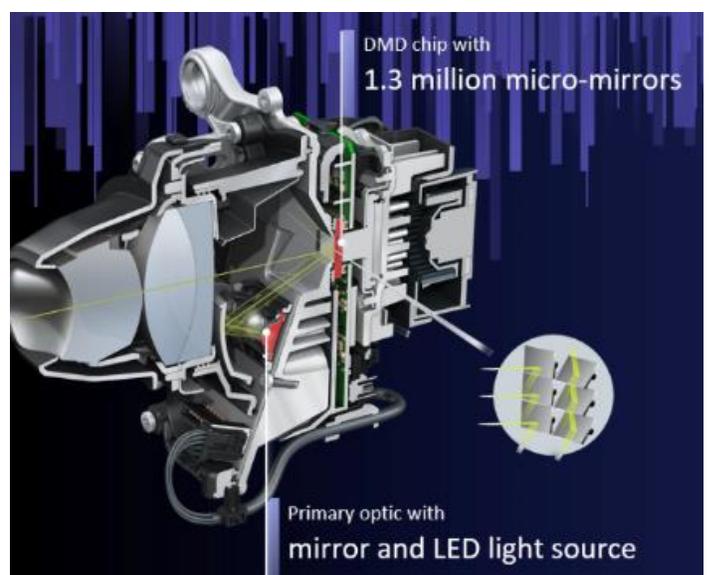
These new systems are targeting not only to be excellent ADB systems, but also to bring new functions for driver assistance and communication. Besides the basic spot marking light function already possible with pixel lighting systems, HD lighting allows for road projections that can be used for guidance lines, navigation, information to the driver or to other drivers, etc.

These systems are clearly the future of headlighting, and several technologies are competing for dominance (or at least wide adoption): DMD, LCD, scanning, and μ LEDs.

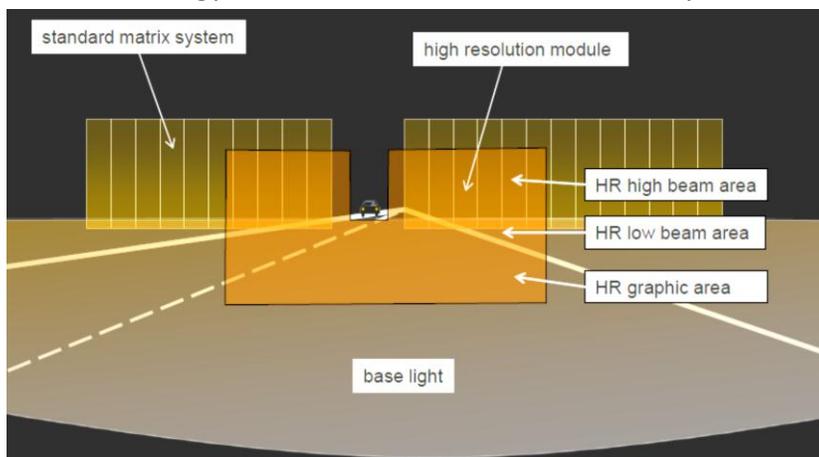


DMD technology

The DMD module, currently produced only by Texas Instruments, uses powerful LEDs whose light is refracted and directed by 1.3 million micro-mirrors. The beam field is limited, requiring the use of other lights to complete the beam—for instance with a matrix module and a base light module for the foreground.

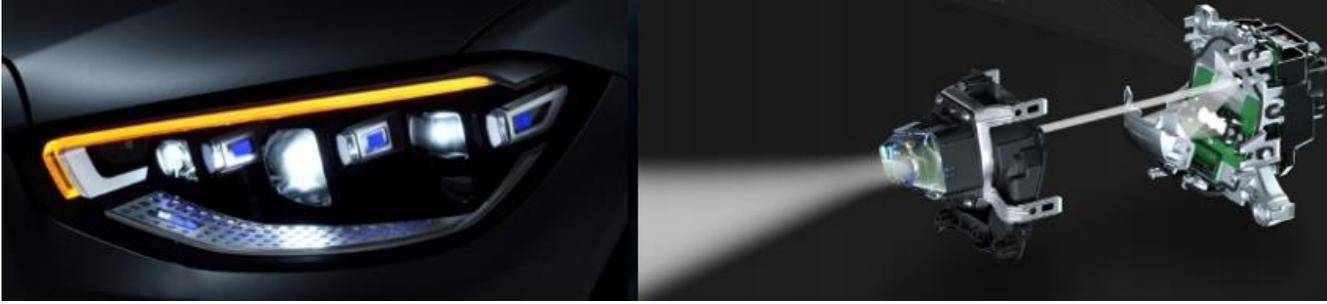


This technology was introduced on the market by Mercedes in 2016 on the S-Class Maybach coupé.



Composite beam of Mercedes S-Class (image: Marelli AL)

In the Mercedes S-Class, a high-resolution DMD module with $7^\circ \times 14^\circ$ optical field is used with a low-resolution 84-pixel multibeam module.



Mercedes S-Class DMD module and headlamp

The DMD module is positioned to drive AFS and ADB and to provide symbol projection for performance, assistance, and communication.

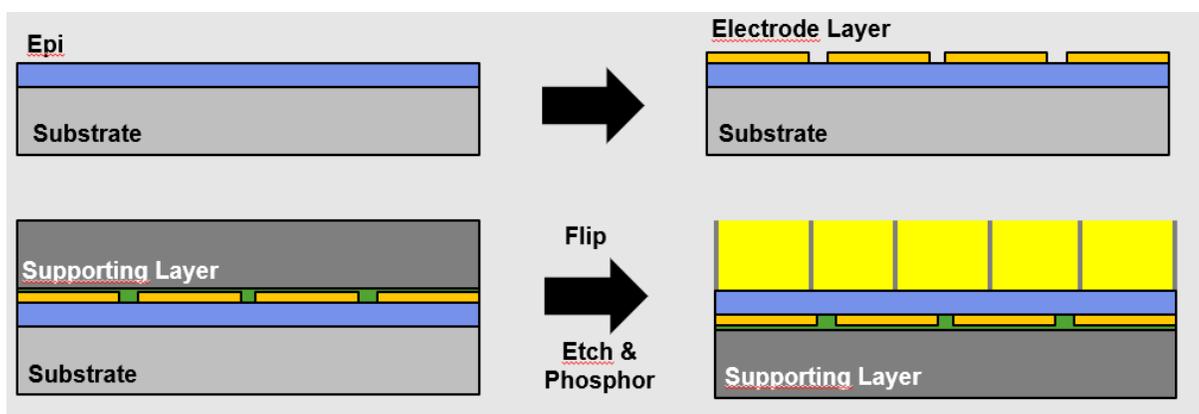
Other high-class vehicles are now using DMD systems to provide excellent headlighting, and this year Texas Instruments introduced a new DMD chip. However, the high price, high power consumption, and single DMD supplier are limiting the applications.

MicroLEDs and Monolithic LEDs

Projection of an LED array has an important advantage compared to DMD or LCD in relation to energy efficiency: as an *additive* technology, only the useful LEDs are switched on (compared to *subtractive* technology in which light from active LEDs is blocked or shunted out of the beam pattern, thus "wasting" it).

But to extend from the LED array with 84 LEDs to the domain of HD systems above 1,000 pixels, the simple traditional juxtaposition of individual LEDs is not possible as their electronic control would be too complex. A new technology called μ LED ("microLED") was therefore invented. The LED layer is differentiating μ LEDs and Monolithic LEDs: μ LEDs when they are individually realised and put at a certain distance, Monolithic LEDs when they are realised in the same epitaxial process as the other layers with the possibility to be closer each other. This new μ LED/monolithic technology uses production processes developed for the manufacture of silicon microprocessor chips.

The electronics for the individual control of each LED are directly on the substrate, followed by the deposition of the LED layers in the epitaxy phase, and finally the deposition of the phosphor layer. Silicon walls allows high contrast (300:1) while distance between LEDs can be reduced to 25 μ m.

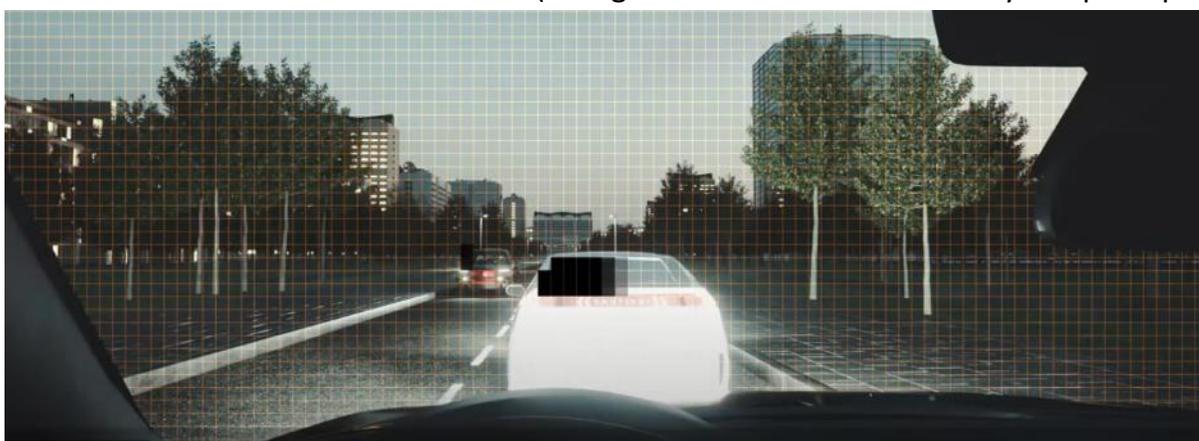


Process for monolithic μ LEDs

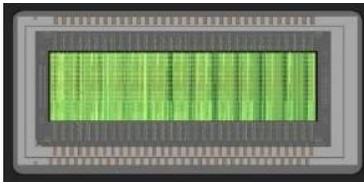
A strength of this technology is that several major LED makers—Osram, Nichia, Cree, Lumileds—are now proposing it for automotive application. Besides HD systems where μ LEDs/monolithic can be used for projecting images, road marks and other information to enhance safety, μ LEDs/monolithic can also be used for the realisation of displays, in automotive or for general applications.

MicroLED industry

Osram were among the first to market with μ LEDs, and they have begun development of the second generation of their hybrid "Eviyos" LED featuring 25,600 pixels on an LED chip with pixel pitch of 40 μ m, which fits the definition of microLEDs (though Osram do not call the Eviyos a μ LED product).



25-kilopixel definition: de-glaring only other eyes, thus enlarging the light field (image: Osram)



Nichia are partnering with Infineon for the development of an HD light engine with more than 16,000 μ LEDs for automotive headlight applications.

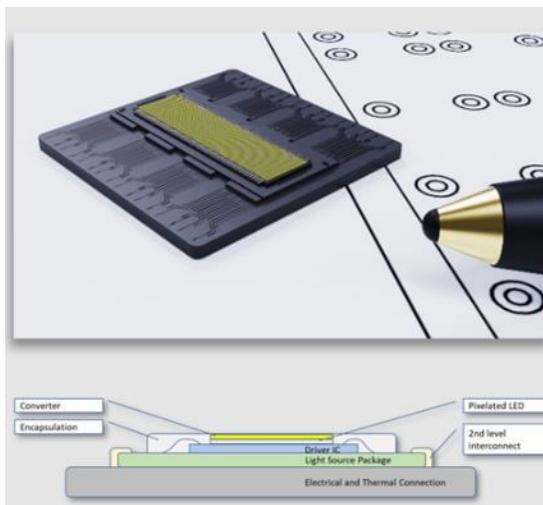
Hella are launching a new high resolution lighting system with more than 30 kilopixels. The new system, comparable to the light output of Nichia and Osram, integrates even more pixels in one light, cementing the involvement of μ LED technology in automotive headlamps.

Valeo, in coöperation with **Cree**, revealed at the beginning of 2019 a 4-kilopixel μ LED high-resolution lighting system called PictureBeam Monolithic. Characteristics presented by Valeo at a DVN Workshop:

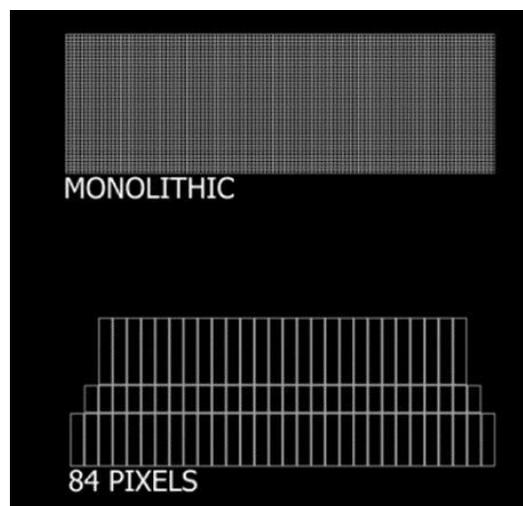


- Flux on the road: 900 lm
- I_{max} : 81,250 cd
- FOV: 35°H × 8°H
- Pixel count: 3,696
- Resolution: 0.28°
- Dimension: 105H × 90D × 125L (mm)
- Power consumption: 55 W

As μ LED/monolithic technology is seen as the best way to achieve HD systems with affordable cost in the coming years, its development has been accelerated by integrations within the industry, bringing the technology closer to widespread commercialisation. μ LED mass production is expected to ramp up within the next three years.



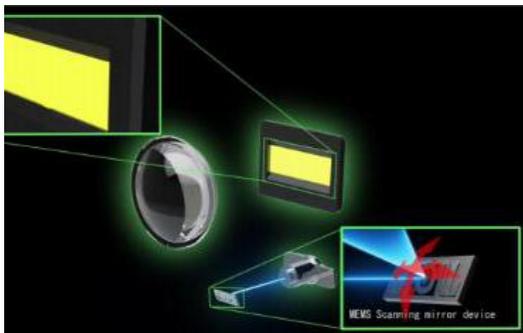
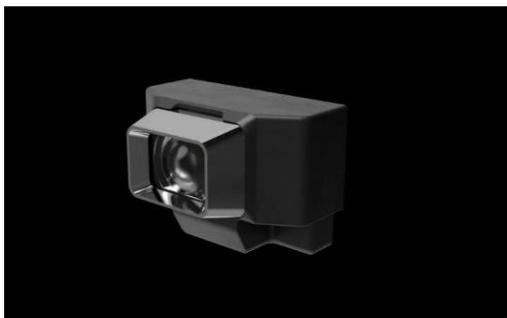
μ LED chip layers and size



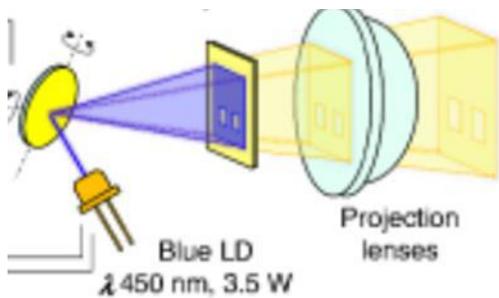
PictureBeam Monolithic vs. 84-LED pixel

4th Concept: Scanning Systems

The scanning concept is based on deviation of a laser beam by MEMS (micro electromechanical system). The high operating speed of the scanning components allow for a high-luminosity, narrow light distribution by narrowing the scanning angle of the mirror. Such a system can illuminate an object with 10 per cent reflectance 185 m away, with sufficient brightness to recognise it. The extreme morphability of the beam distribution mean the high-intensity area can be swiveled without changing the brightness, and it is possible to swivel without mechanically moving the optical unit.



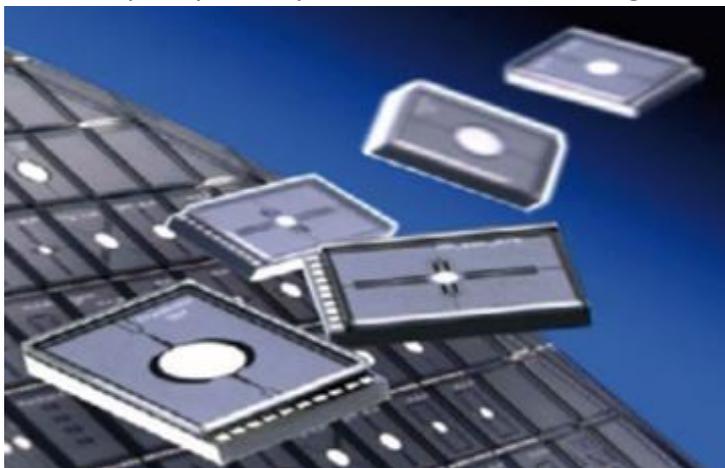
The light distribution is created by a blue laser scanned by the MEMS mirror to draw a two-dimensional image on the phosphor, and the image is projected by the projection lens. The scanning angle of the mirror is controlled in the horizontal and vertical axes, and control of the width and the brightness of the light distribution is done by changing the scanning angle of the mirror. A shadow zone is formed by turning off the laser at an exact position of the mirror.



One axis is in a resonant mode and the other one is electronically controlled, the reflected light then scans along a phosphor layer. The support of this layer, which may be transmissive or reflective, is positioned at the focal plane of a projection system. A white light is therefore projected, being the admixed result of blue light from the laser and the phosphor-converted yellow light; just like

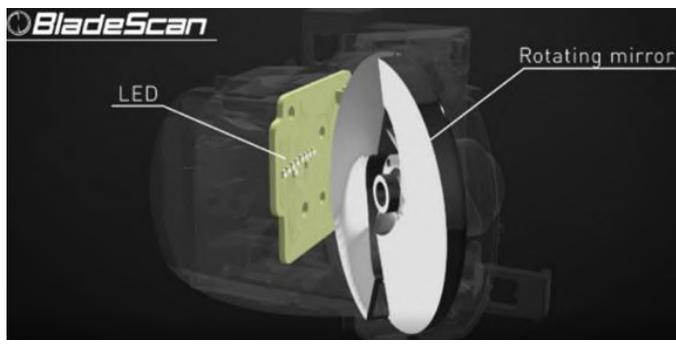
in white LEDs.

Several challenges are still ahead: more powerful lasers and better global efficiency are needed, and the heat resistance of the MEMS must be improved, as must phosphor layer definition to avoid light spread/bloom and to have precise contour of emitted pixels particularly for road projections and other resolution-critical tasks. Currently there are no commercial applications of this principle, but active research is under way by research institutes including Fraunhofer in Germany and Tokyo University in Japan.

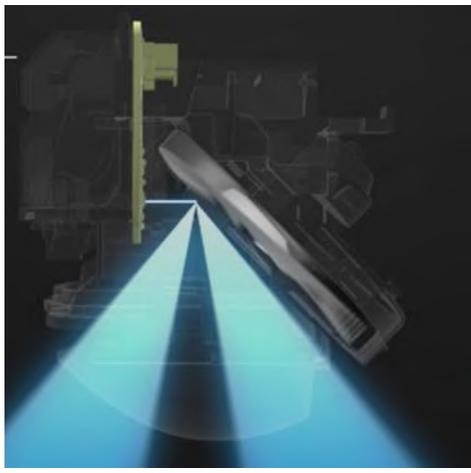


BladeScan

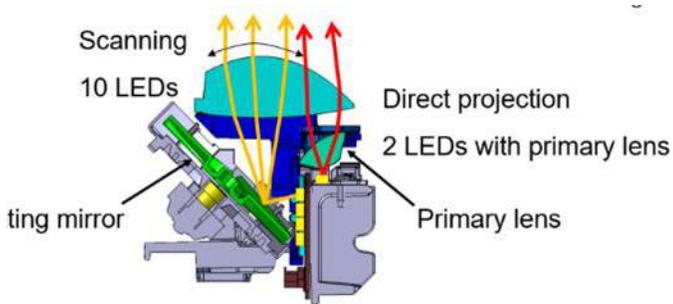
Koito's BladeScan system uses a spinning mirror illuminated by LEDs to realise a high-definition scan-built beam.



LEDs emit light towards a helicoidal rotating mirror. A specific pixel is produced by each LED for each position of the rotating mirror. Its rotation is therefore scanning the entire field. In ADB mode, a black area is obtained by darkening some LEDs at certain specific points in the mirror's rotation, precisely in synchronisation.



This is a relatively affordable system compared to other HD solutions. It delivers good accuracy with high definition. Toyota have equipped their 2019 Lexus LX and several other models with this technology, even now some lower-range models.



Comparison of traditional ADB Systems

Comparison of traditional systems—including mechanics in a single module, sail beam, dynamic shadow, and matrix beams—are not straightforward. Each maker develops ADB modules with different specifications, and these are then built into front lighting systems with other components that influence the overall result. Nevertheless, some main characteristics can be defined between these technologies:

Comparison traditional ADB	Mechanics One module with Xenon	Mechanics One module with LEDs	Sail Beam	Dynamic Shadow	Matrix beam
Performances	++	++ → +++	++ → +++	++ → +++	++ → ++++
	Limited by a unique source	In relation to power of LEDs	In relation to power of LED sources	In relation to power of LED sources	In relation to number of LEDs
Smoothness and comfort	+	+	++	+++	+ → +++
	Good precision, but too much light moves	Good precision but too much light moves	Good precision, Fixed foreground	Good precision, No light moves	In relation to number of segments
Energy effectiveness	+	++	+++	++	++ → +++
	35W+5W (ballast)	Some light lost with the shield	Global efficiency could reach 50%	A part of light is lost with the horizontal shield	Depending on technology used for realization
Cost effectiveness	+	++	+++	+++	+++ → +
	No more used in recent developments	Unique module could be standard	Potential to be cost effective, but standardisation difficult	ADB module can be standard	Depending on number of segments
Compactness	+++	+++	++	++	+++ → +
	Compact thanks to unique module	Compact thanks to unique module	Needs several modules	Needs several modules	In relation to number of segments / modules
Style differentiation	+	+	++	++	++ → +++
		Only by shape of the lens	Several options with modules	Several options with modules	Many options for realization

Comparison of Pixel and Scanning systems for High resolution ADB

These systems are not only targeting ADB functionalities, but also new functions like spot marking light, road projection, and communications, so their comparison needs to take into account their ability to achieve a wide variety of functions.

Comparison HR ADB	LED array (till 1000 pixels)	DMD (Typically 1,3Mp)	LCD (Typically around 1Mp)	μLEDs	BladeScan	Scan with MEMS
Precise ADB	++	++++	++++	From +++ with 4000 px to ++++	+++	++++ (target to be demonstrated)
Marking Light	+++	++++	++++	+++ to ++++	+++	++++ (target to be demonstrated)
Simple road projections	-	++++	++++	+ to +++	++	++++ (target to be demonstrated)
Road writing	---	+++	+++	- to ++	-	++++ (target to be demonstrated)
Energy Efficiency	+	---	---	+	+	-
Cost effectiveness	-	--	---	++ (Potentially)	++	Not yet clear
Style differentiation	=	=	=	=	=	=

Technique	Micro-LED	DLP	LCD
Beam width	± 90°	± 18°	± 5°
Resolution	>10 kilopixel	>1 megapixel	>30 kilopixel
Maximum luminous flux	10,000 lm	4,000 lm	9,000 lm
Propagation loss	0%	47%	60%

Comparative properties of HD headlighting techniques

How much light is available?

With an etendue-matched lambertian light source for DLP illumination, the current maximum seems to be 4,000 lm. The required illumination optics are assumed to have an efficiency of 80 per cent, and the DLP device itself has an efficiency of 66 per cent, which results in an overall loss of 47 per cent—that is, an overall efficiency of 53 per cent, cutting the available light in half before it even reaches the imaging optics.

LCD modules equally require illumination optics, which are similarly assumed to give 80 per cent efficiency. Polarising and processing the light will bring efficiency down to 50 per cent. Lower resolution on the same area will result in higher efficiency and vice versa. Overall for LCD systems, 60 per cent light loss is assumed, i.e., an efficiency of 40 per cent. If a light input of around 9,000 lm is postulated, around 3,600 lm will reach the imaging optics.

MicroLED does not share these prerequisites, so theoretically no loss of the emitted light occurs before the light arrives at the imaging optics.

3. Latest ADB Developments by Tier-1 Suppliers

Marelli Automotive Lighting



Digital light module h-Digi®

Marelli Automotive Lighting offer a wide portfolio of adaptive and intelligent headlamps, from simple ADB solutions realised by standard LED modules to highly sophisticated ones with digital h-Digi® modules offering an outstanding light modulation. From 2023 on, their high-definition lighting systems will be supported by microLED technology.

In 2020, the high-volume production for the Mercedes S-Class' Multibeam LED high resolution ADB started. Previously optional, it is now standard equipment. The optical system includes a low-resolution 84-Pixel multibeam module and a high-resolution 1.3-megapixel DMD h-Digi® module with a 7° × 14° field.



The DMD module is positioned to drive AFS and ADB supplementing the light distribution in an extremely precise way and to provide symbol projection on the road surface including stop warnings—a backwards-pointing arrow with concave sides to warn the driver to stop, in case the driver misses a stop sign, a red light, a wrong-way sign, or suchlike; and roadwork warning and guidance lines with symbols to warn the driver when approaching roadworks, and guide lines to project the vehicle's width forward into the driver's view are indicating the width of the vehicle, supporting the driver's efforts to centre the vehicle in their lane.



DVN: Where are Marelli AL in the development and production of ADB?

Andrea Stella: Marelli Automotive Lighting started the first ADB project on the market based on a mechanical shutter system in the Xenon headlamp in 2010 on a Volkswagen, followed by a mechanical system based on LED projection in the Mercedes S-Class in 2013. Meanwhile, a wide range of segmented high beam systems from Marelli-AL is on the road. They have been adapted to different car segments and cover up many various performance levels.

Starting from the 7 segments of our standard s-Light module up to a 3-row-matrix system for low and high beam with 84 pixels in different car brands.

Also ADB systems supported by laser boosted functions in BMW are available as a high performance option on the market.

In terms of ADB accuracy and cutoff line shaping, the highest performance available on the road today is achieved by the DMD headlamps with 1.3 megapixels on Mercedes S-class, Audi e-tron and on the recently presented new Mercedes C-Class. The next step to spread high resolution headlamps to a wider range of car segments is the development of microLED matrix systems, which will also provide—like DMD—the option for driver assistance road projections for more safety.

DVN: We see very well the short-term success of DMD. How do you see the long term future of this technology?

Andrea Stella: In comparison to other high-resolution technologies, DMD provides the best resolution in the field of view reserved for high-definition illumination. There are several reasons, why this technology was the first high-resolution technology on the market and was the "icebreaker" for driver assistance projections. A pixel amount of more than 1 megapixel leads to an angular resolution close to that of the human eye. So there will be a market for this technology also in the future, mainly in the field of road projections and animations, with visible advantages coming from the highest resolution of DMD.

DVN: The microLEDs are very promising and they are being developed by all lighting suppliers. What is your position about the number of pixels: 15,000, 40,000? Or even more?

Andrea Stella: Yes, I agree, all lighting suppliers are currently working on this new technology with micro-LED light sources from different suppliers. This technology shows significant advantages in terms of lower complexity and less mechanical space compared to DMD technology.

On the other hand the field of illumination can be designed larger; the resolution on the road is a result of the number of pixels and the optical system. More pixels will increase road projection possibilities and the quality of the light distributions, but a smaller number of pixels can represent an advantage in terms of cost. Scalability of light source sizes and number of pixels allows to adapt the systems to different car segments and headlamp budgets.

DVN: Stanley made a lecture at the 21st DVN Workshop showing the benefits of LCD. Are you working on LCD?

Andrea Stella: LCD technology was from the beginning one of our technology candidates for high resolution and we also made investigation in this field. Meanwhile microLED technology fits much better to the styling and mechanical volume needs and efficiency of today's headlamps.

DVN: Koito have strongly communicated on their spinning-mirror BladeScan system. Do you have an opinion on this technology in comparison with μ LED?

Andrea Stella: It goes against the tide of elimination of "macro-mechanics" from headlamp systems.

It shows some interesting aspects, however, in my opinion, DMD and micro-LED technologies are more flexible in creating road projections and animations.

Hella

Hella announced their "Solid State Lighting | High Definition" first time at the end of 2019. The technology allows for new safety and functionality prospects unreachable in the past: new animations, new beam shapes, new road projections. MicroLEDs enable new features on LED displays in front by new technology approaches, which are highly attractive to customers and boost safety and styling significantly.

Hella are further miniaturising of the light source so that more than 15,000 LED pixels can be individually and intelligently controlled. A first series order has been acquired for the integration of the technology into a headlamp which should be on the road next year. By controlling the individual pixels, the light distribution on the road can be generated directly at the light source and projected onto the road via a multi-stage optical system. The great number of pixels and the enlarged light-emitting surface allow new applications with higher light quality and performance.

High definition solid state LED (HDSSL) light sources are being developed for future HD headlamp lighting modules. Based on the μ AFS ("Micro-AFS") research project, this technology is about to take a significant step forward in terms of smaller pixel sizes and larger light-emitting surfaces. Orders of magnitude higher number of pixels and higher brightness, with application-specific aspect ratio and increasingly polyvalent ASIC integration, will unleash new lighting functions. Important evaluation criteria for HDSSL light sources include maximum achievable luminance, contrast between the pixels, homogeneity of the luminance, and the colour as well as the overall electro-optical efficiency.

For the LED pixel layer, there's a variety of feasible designs. The LED layer can be one single monolithic chip with several pixel areas defined by current barriers inside the epitaxial structure, for example, or the light can be generated by separate individual LED pixels with a certain distance, an approach broadly known as μ LED technology. Hybrid solutions mixing these two approaches are conceivable, with pixels separated only to a certain depth or the separated space between the pixels filled with specific material.

The integration of LEDs and ASIC (application-specific integrated circuits) allows significant improvement of functionality. The light flux can be adjusted by PWM or current control of individual pixels or partial areas comprising several pixels. With higher pixel density and one HDSSL light source, the PWM generation can be integrated into the silicon device to reduce the transfer rate bottleneck. Appropriate parallel or serial digital data interfaces of the components for video and control data are useful for a variety of different system architectures. In such a setup, the HDSSL light source can be seen as an advanced monochrome display. For current control and communication interfaces, analog and digital circuits are combined in what is called mixed-signal ASIC. Additional features such as pixel error detection, thermal sensor integration, supply voltage control, adjustable PWM frequency, and others can be integrated into the ASIC.

HDSSL and LED displays offer new means for digital front lighting, which can bring benefits in safety, styling, entertainment (animation) and communication for the vehicle owner and other road users. These technologies provides the basis for freely programmable lighting functions. New safety functions such as optical lane markers or further individualisation possibilities such as coming and leaving-home animations and communication functionalities can be implemented by high-precision digital pixel switching. In addition, Hella's SSL|HD technology enables automakers to develop new business models on a pay-per-use basis. In this context, the hardware and capability for a variety of lighting functionalities is built into the vehicle, but they're only activated once paid for on request, in line with individual user requirements and desires.

Interview: Michael Kleinkes, Hella's Executive VP of Technology & Innovation



DVN: How's it going with development and production of ADB?

Michael Kleinkes: Since the introduction of camera-controlled headlamp functions in 2009, we have used the opportunities of visual sensing by cameras, software algorithms, and optical technologies to provide the best possible illumination for drivers. This approach we have strongly further developed. Next to the offer of basic headlamp versions for entry-level vehicles, all our advanced headlamp technologies offer the opportunity for ADB functionalities. Therefore we offer a set of modules with different level of ADB functionality depending on customer requirement—for example: simple, cost-efficient ADB solutions for entry-level vehicles as well as state-of-the-art high end ADB solutions with over 100 individual controllable pixels. We can produce ADB headlamps in all major markets.

DVN: We see very well the short term success of DMD. How do you see the long term future of this technology?

Michael Kleinkes: We are evaluating all possible technology-steps in Lighting; our conclusion is to focus on a more end-customer-value-centric solution, SSL|HD (Solid State Lighting|High Definition), also called μ LED. Our approach is to find the right balance between improving nighttime visibility and related new features supporting this and clear focus on user experience.

Our main focus is on high-tech lighting, concentrating on safety and comfort functions during night driving. Symbol projections like a snowflake to indicate weather conditions, should be visible 24h and therefore it is our practice to place it in the HUD (head-up display). And of course, cost and affordability are very important. Other functions besides headlamp applications are for sure interesting in and around the car to be realised with DMD.

DVN: μ LEDs are very promising, and are being developed by everyone in the lighting industry. What is your position about the right number of kilopixels—15? 40? more?

Michael Kleinkes: As a major player in LED matrix systems for headlamps we have consequently developed this technology further. From just 25 LEDs in 2013 to over 84 in 2016 and now 102, we are using the trend of miniaturisation of light sources offering higher pixellation for higher precision of the beam pattern and related ADB features. The trend of miniaturisation is ongoing and finally the question will be, how many pixels are enough? We should avoid the more-means-better pixel count war. To find the right balance between pixel count and the sweet spot of function and costs, we take also the architecture of the headlamp (package space/ weight) and the reduction of complexity (e.g. variant reduction to cover ECE and USA) into account for our customers. So for example in which area of the FoV a pixellated beam pattern should be active or is a digital headlamp leveling possible and requested. Considering this we actually believe based on technologies we oversee, that the right number might be in the area of 16 to 25 kilopixels.

DVN: Hella worked on LCD. A night drive test of it two years ago was very impressive on homogeneity and resolution. Now Stanley have made a lecture at the 21st DVN Workshop showing the benefits of LCD. What is your opinion?

Michael Kleinkes: As you note, a couple of years ago we have already worked on LCD technology; first within a public funded project and later with the intention for series introduction.

LCD was an interesting technology with regards to our optical concept and the opportunities of LCD

shutter for generating the pixels. Nevertheless we have experienced back then some commercial and technical challenges for realising LCD within a series project. That was primarily the reason for stopping our development activities there. At the moment we are observing the technology further as part of our technology screening.

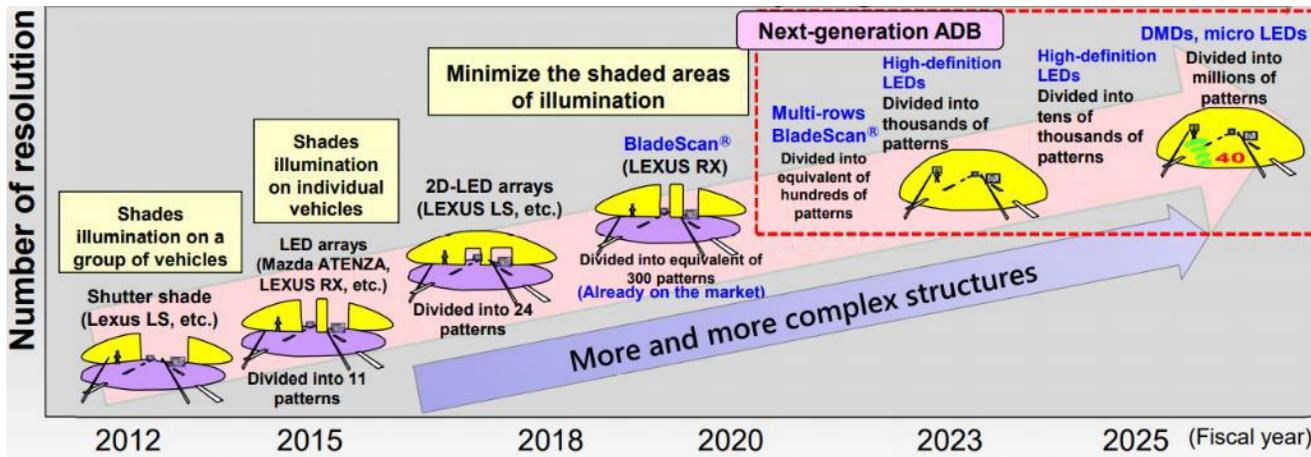
DVN: Koito have strongly communicated on their spinning-mirror BladeScan system. Do you have an opinion on this technology?

Michael Kleinkes: BladeScan is an interesting technology with a good opportunity for generating a precise ADB tunnel and related features in one horizontal level. The interaction of the mechanical rotating mirror and the LED light source control are for sure well done. Our approach focussed on full digitalisation and the consequent further development and usage of the opportunities LED light sources offer. Advantages like miniaturisation, activation of pixels only when needed and arrangement of LED arrays in lines and rows offer great benefits we intend to further utilise on our path of digitalisation of light.

Koito

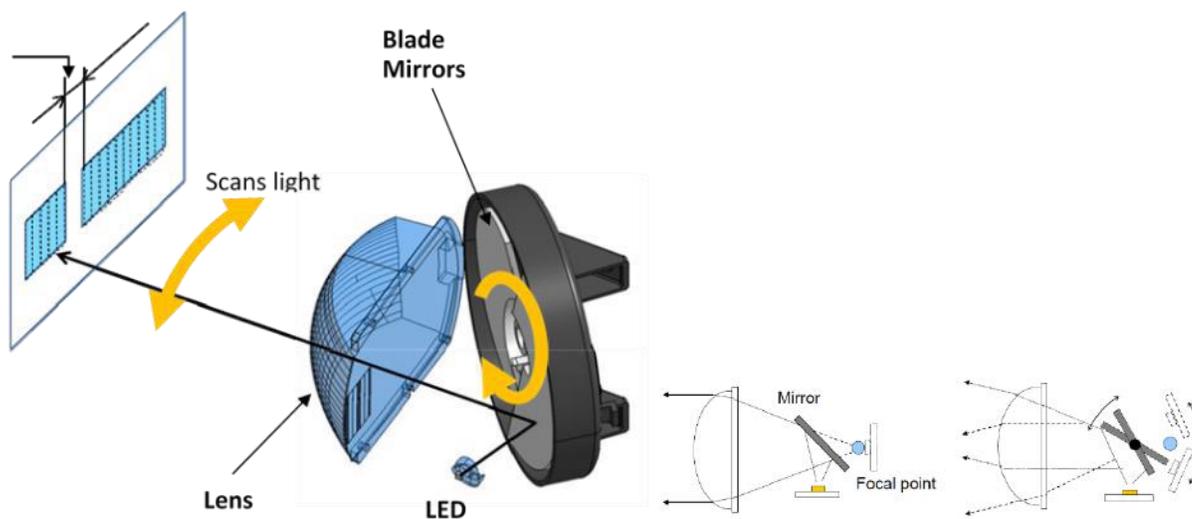
Kenji Arima, Koito's R&D director, presented at the 21st DVN Workshop a roadmap, a timeline over which Koito think the vehicle lighting industry has to offer certain improvements in ADB and its extension to high resolution with microLED, DMD, and of course Koito's own BladeScan.

Koito ADB Roadmap

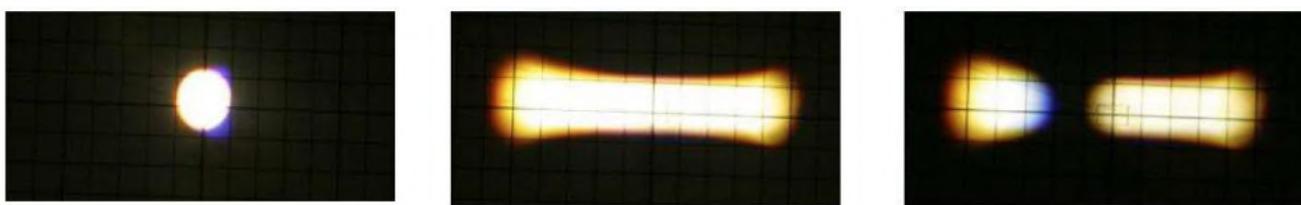


Koito have entered mass production of their BladeScan ADB. They are promoting the wide use of ADB by commercialising this technology, in which LED light is beamed onto two fast-revolving blade reflectors, which build a beam pattern by using the residual image effect (persistence of vision).

Principle of BladeScan

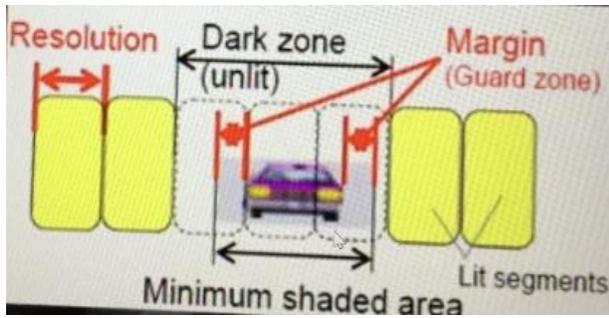


By turning on and off 12 LEDs in line with the rotation of blade reflectors, BladeScan ensures high-resolution light distribution equivalent to the use of 300 LEDs and minimises the shadow areas.

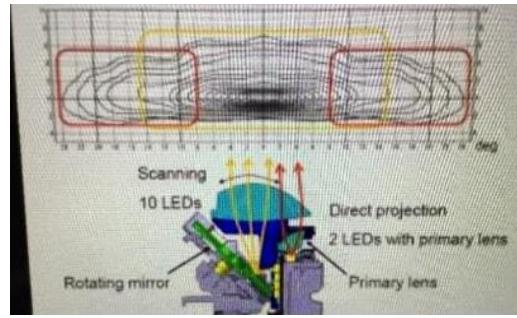


BladeScan static spot (left), scanned spot (centre), scanned spot with de-glared zone (right)

The system enables to light the vicinity of oncoming and leading vehicles and the area between them, and helps drivers to detect pedestrians early, thus contributing to reduced traffic accidents.



BladeScan minimising the dark zone



BladeScan module and Isolux curves



BladeScan lets the driver see pedestrians at a greater distance compared to conventional ADB

BladeScan: a different approach

μLED technology uses thousand of pixels to provide the resolution needed to minimise the de-glared zone. BladeScan allows a vast reduction of the number of light sources to just 10 LEDs pointing at a double mirror spinning at 6,000 RPM, plus two

additional LEDs for the field of view, combining switching LEDs with rotating mirror technology. The result is very competitive functionality with higher resolution at lower cost. A solution such as this recommends itself as an upgrade to low-level technology, and as a standard technology on upper-middle segment vehicles. As always, to optimise the available safety benefit, function and cost must be appropriately balanced.

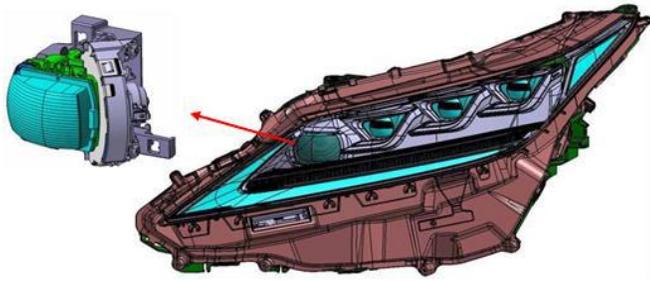
BladeScan durability

Vehicle life assumption of 15 years means about 10,000 hours of headlamp use if they're used for 1.8 hours per day. Testing, done with continuous operation of the mirror and motor under high temperature, started in 2017 with 20,000 h at 80°C and 400 h with vibration akin to that induced by a stone-paved road.

Technology comparison

	ADB 12 segments	BladeScan 12 LEDs	Pixel-based 4K
Mass	200 g	290 g	600 g
Output	750 Lm	700 Lm	900 Lm
Power	25 W	30 W	55 W
Resolution	1.5°	0.1°	0.3°
Availability	Now	Now	2022
Module cost	1	1.14	tbd

BladeScan applications



Toyota equipped their 2019 Lexus RX (innermost projector) and 2021 Lexus LS (underslung projector) with Koito BladeScan ADB technology and will continue with two other applications in the coming years.



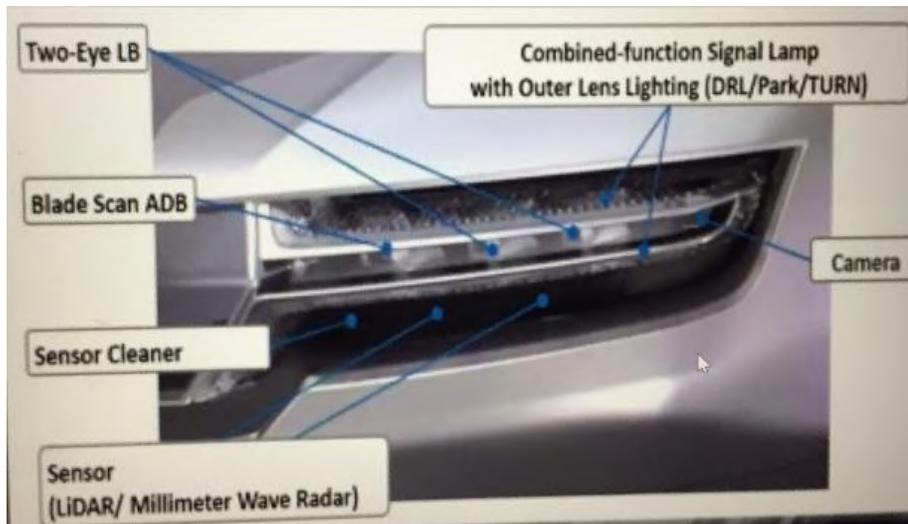
Lexus RX



Lexus LS

Outlook for new approach

BladeScan cannot currently provide road projections, but a new generation is in development and could be adapted to create horizontal segmentations.



Koito's new approach: BladeScan for use with low profile designs

Interview: Koito's Kenji Arima, Executive Vice President of Technology



DVN: Will you tell us about Koito's development and production of ADB?

Kenji Arima: We believe that ADB will greatly contribute to reducing traffic accidents at night and that it is a technology that needs to be installed in all vehicles. In order to expand the use of ADB, we have a development policy for different grades of vehicles. We are developing higher-resolution ADB for high-end vehicles and standard ADB for low-end vehicles at lower prices, and we will continue to develop ADB to meet the various demands of our customers.

DVN: We see very well the short term success of DMD. How do you see the long term future of this technology?

Kenji Arima: DMD has realised the ultimate high-resolution ADB and has shown the potential of ADB and the direction of its evolution. On the other hand, it is still difficult to expand its use to mass-market cars due to cost issues. The future of DMD will depend on whether the cost can be reduced so that it can be installed onto mass-market cars. We also believe that the ultra high-definition light distribution control technology of DMD will bring users a different kind of joy than ADB. We will continue to actively consider new product directions.

DVN: The Koito BladeScan ADB is very promising. Do you think this technology could compete the μ LED technology with 15 kilopixels or more?

Kenji Arima: We see BladeScan and μ LED as options for our customers, not as competitors, and we are ready to provide both. BladeScan is an ADB that maximises the number of horizontal divisions while reducing the cost increase compared to conventional ADBs. The main difference in performance between BladeScan and μ LED is whether or not there is vertical division. Our challenge is whether we can propose new value using the vertical partitioning function, whether that value matches the needs of the customer, and whether the customer will accept the cost. Depending on these results, the ADB products we can offer will vary further from vehicle to vehicle.

DVN: BladeScan is on the Lexus RX and LS models; what's been the feedback about performance and reliability so far?

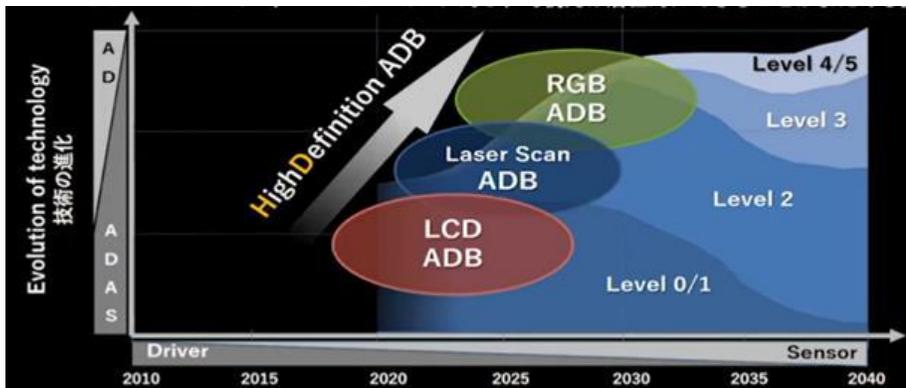
Kenji Arima: BladeScan was put to the market in 2019 and to date we have not experienced any problems. It has been very well received in terms of performance and we continue to receive orders from customers. We believe that BladeScan is one of the best solutions currently available, as it achieves high safety performance in an affordable manner.

DVN: Hella communicated two years ago on LCD and at a recent DVN Workshop, Stanley made a lecture showing the benefits of LCD. What is your opinion on LCD technology?

Kenji Arima: LCD is a mature technology with low cost, and its application to ADB is a natural progression. However, we believe that there are still some issues to be overcome before we can bring it to market. We are developing multiple types of high-resolution ADB, and LCD is no exception. Our policy remains unchanged so that we will bring to market the technology that satisfies the performance, cost, and reliability requirements.

Stanley

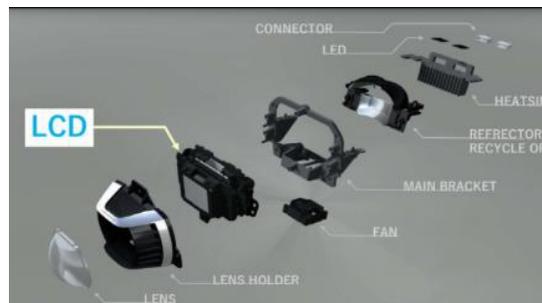
Stanley are developing two different ADB technologies: LCD, which was their first entry, and laser-scan/MEMS.



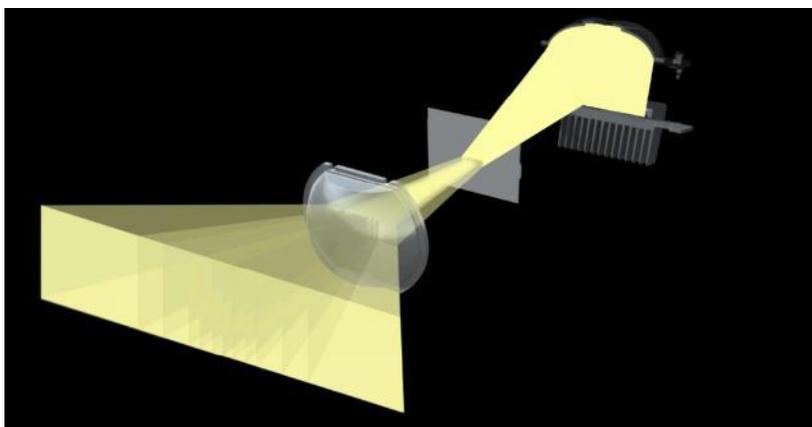
Stanley ADB roadmap



LCD ADB module



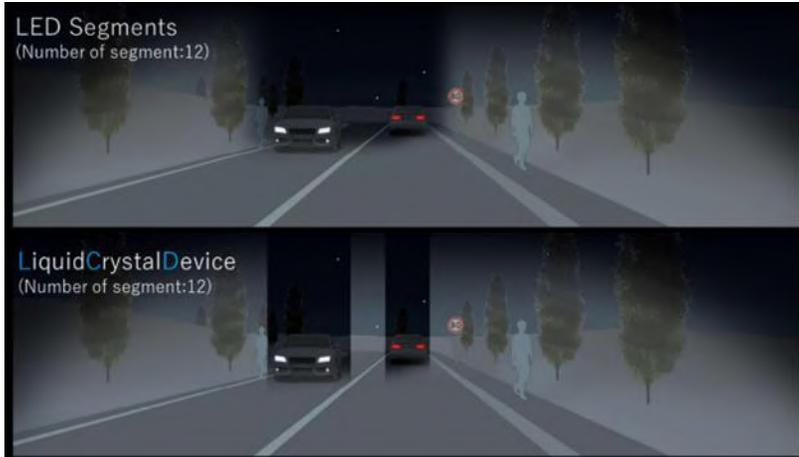
LCD ADB module structure



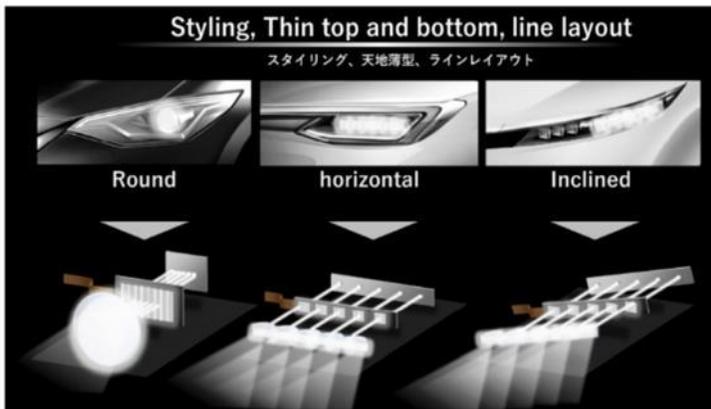
LCD ADB module ray trace. Light utilisation efficiency is 30%.

The five benefits of LCD

- Independence of segments (no superposition)



- Segments can be thinner with high contrast and possibility to control brightness
- Shape of segments is flexible, allowing for curved segments (motorcycle).
- Road projection (for instance, width guidelines) can be provided
- Style freedom allows a range of headlamp shapes.



Laser and MEMS Scanner

Advanced LED technology enables innovative automotive lighting including ADB by which each single LED pixel can be controlled independently for a wider range of applications. Based on similar concepts, Stanley propose an innovative way to combine laser and MEMS mirror, which allows high precision light and sensing functions.

Stanley use blue laser light which can be reflected with a MEMS mirror and converted into white light with phosphor to build a headlight system. Via reflection with controlled angle of the mirror, light distribution can be formed in different shapes. The segments of brightness control reached 64,000 segments in a 400 × 160 grid. In addition, laser beam scans in high speed creates "planes" of light for the driver to ensure visibility at both short and long distances. To provide appropriate light distribution to match driving speed with a combination of lasers and the MEMS scanning mirror device—to realise light distribution of high precision—it is critical to integrate laser beams with advanced optical technologies including lenses and reflectors, supported by mechanical technology.

Valeo

Valeo, in cooperation with Cree, revealed at the beginning of 2019 a 4-kilopixel μ LED high-resolution lighting system called PictureBeam Monolithic.



Valeo PictureBeam Monolithic presented at CES 2019

The makers hail it as the first complete high definition lighting system that provides both glare free high beam and road marking functions together with high performance low beam and high beam in a single compact module.

This solution incorporates a scalable LED array in which the pixels of the light beam are formed directly at the light source. The module is therefore smaller and weighs less than other HD lighting systems on the market, making it easier to integrate into all vehicle classes. This new LED array innovation enables the ability to scale up to thousands of pixels. Under the control of Valeo's electronic system, each pixel can be individually switched on, off or adjusted at will based on driver needs and road conditions.

With around four kilopixels, the PictureBeam system provides a high-resolution ADB with light all around the detected vehicles. It brings the function one step closer to being a real glare-free high beam, with a high accuracy in the cutoff position.

The technology is based on a monolithic LED, developed and produced by Cree, with 3,696 pixels to produce a high definition beam on the whole field. This module also makes it possible to do road marking for ADAS. Resolution is 0.28° in both directions in the complete angular range of the high beam (20° outboard to 16° inboard), so the complete field of view where light needs to be finely adjusted is covered, to keep a high-intensity light level everywhere except where it could dazzle other road users. This resolves the previous problem, even with high resolution, that a dark shadow only consisting of 0% (deactivated) or 100% (activated) pixels is perceived as a distracting inhomogeneity in the beam (the "dancing light" effect).

The module comprises four major components corresponding to the main functions to be addressed:

- Monolithic light source to emit light
- Projection optics to project the light emitted by the source
- Cooling system to evacuate the energy emitted by the source
- Electronic board to drive and power the LED allowing driving each pixel individually



PictureBeam Monolithic ADB, 4-kilopixel (above); conventional ADB (below)



Compared to other HD systems like DMD or LCD, for which the light source is separated from the spatial modulator, PictureBeam is a compact and simple solution. The low beam delivers a flux of 1,250 lm (with the flat module), and an I_{max} of 25 kcd. The high beam delivers a flux of 2,100 lm with a hot spot of 75 kcd.

PictureBeam Monolithic Road Projection

Road marking consists of projecting patterns on the road, with positive or negative contrast. These are to help the driver, as well as other road users, with mostly safety related features. They could be lane marking, highlighting certain hazards, road sign projections, informational displays, and other suchlike.

Until now, most of these functions have been demonstrated with projection units using hundreds of kilopixels, like DMD or LCD technologies, and not with discrete pixelised light sources.

PictureBeam Monolithic Road Projection is based on a monolithic LED with 1,232 pixels to project elements on the road. The solid angle covered by this module roughly corresponds to the solid angle covered by a DMD module. This module also participates in the ADB. Valeo won a CLEPA Innovation Award—first prize in the Safety category—for the system.

Interview: Benoit Reiss, Valeo Lighting Innovation Director



DVN: The Valeo PictureBeam Monolithic is very promising, confirmed by the CLEPA award and impressive night drives. Where are you in this development and when will the first product be in production?

Benoit Reiss: The PictureBeam Monolithic system is a unique solution offering in one module the most efficient lighting solution and road marking functionalities, improving in several aspects the safety of all road users. And you are perfectly right, this technology has been recognised in 2020 by the CLEPA awards. Tests made on the road were conclusive and confirm that the system can reduce substantially the driver's stress when driving at night. SOP is expected in 2023.

DVN: Will you stay with your present pixel count, or are you working toward higher counts?

Benoit Reiss: We are working on these two solutions, as both solutions provide different benefits and differentiation and both are excellent to their task. The 2.5 kilopixel allows a full high beam pattern from one single compact module with a resolution at 0.3°. Thanks to this product and the system driving law that we have developed we offer a very smooth ADB function with a minimised black window around the detected vehicles. Our PictureBeam Monolithic provides a 30° field of view that can cover the entire road width, instead of the 20° offered by other HD systems. This means optimal vision for the driver with increased comfort and safety. This module, fully standalone since it also integrates its own HD ECU, is also able to do road marking functions, such as lines marking and other simple symbols.

The second solution we are developing—from 15 to 25 kilopixels—will be dedicated to high precision road marking with an effective resolution comparable to DMD solutions. It will be on the road by 2024.

The next step will be the combination of complete HD high beam and HD roadmarking; meaning we are exploring the possibility of a 40-kilopixel module. There are two ways to make this work: the integration of two 20-kilopixel modules, or a source with a higher number of pixels; that is a technical challenge. This second solution is leading to a much bigger source (unless we drastically reduce the luminance of a single pixel), which is generating industrial constraints, as well as technical challenges regarding electronics, optics and thermal designs which are under study. From an electronic system point of view, both solutions also require a specific graphic interface that we have already developed with our Picture Control Module.

DVN: We see very well the short term success of DMD. How do you see the long term future of this technology?

Benoit Reiss: DMD technology provides a very good resolution and matches with automotive constraints. However, there are several drawbacks due to the complexity of the system, limited field of view and also overall power consumption. At Valeo, the reduction of CO₂ emission is central in our strategy, and our ambition is to expand our portfolio of technologies that contribute to low-

carbon mobility. This is the reason why we decide to invest in solid state type systems with optimised power consumption.

DVN: Stanley presented their LCD technology at the 21st DVN Workshop. Do you think there is a future of this technology and are you working on it?

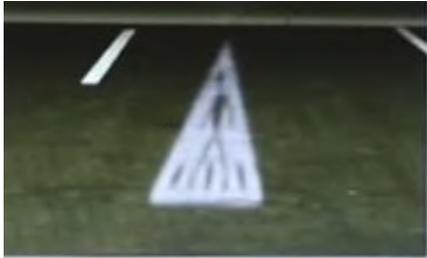
Benoit Reiss: LCD characteristics are similar to the DMD, as its principle consists in blocking or redirecting the light which is not used. Our PictureBeam Monolithic switches off completely the corresponding pixels and uses only the required energy, which is why, for this reason and all the other ones explained above, it corresponds to our vision of the future.

DVN: Koito BladeScan is on an increasing number of models. Do you think there is a broader future for scanning, and are you working on it?

Benoit Reiss: Scanning systems presented some interest from the beginning, and this is the reason why Valeo has investigated the technology with our first PictureBeam solution. As with Monolithic, this kind of solution is using only the required energy without light shade. However, it requires mechanical mirror movements that we prefer to avoid. On the contrary of Monolithic systems, the BladeScan solution has limitations in "2D" ADB, meaning that we cannot bring the light as close as possible to the detected vehicle. Upon driving conditions, Monolithic brings more comfort and safety to the driver when compared with BladeScan.

ZKW

In a recent DVN workshop, ZKW analysed the requirements for a good road projection system. First systems under development with μ LEDs could have 15 kilopixels, compared to 1.3 megapixels in a DLP system. 15-kpx resolution is enough for a good ADB, but not sufficient for good road projections. To be specific, a 15-kilopixel system can have a 20° horizontal FOV and 6° vertical. That means 60 lines, including 20 above the horizon, and so 40 lines on the road, not enough for detailed projections.



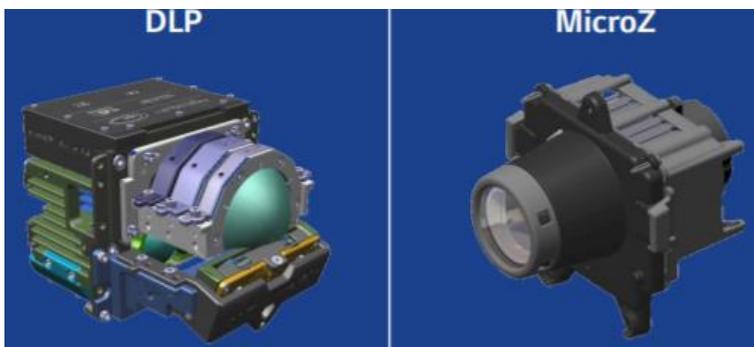
15-kilopixel System
 24° H FOV – $0.1^\circ = 240$ pixels
 6° V FOV – $0.1^\circ = 60$ lines



130-kilopixel System
 24° H FOV – $0.03^\circ = 720$ pixels
 6° V FOV – $0.03^\circ = 180$ lines

An improvement could be to have 130 kilopixels with the same FOV. In that case, the foreground projection with 120 lines is enough for good precision in projected symbols. But for a good projection, it is not enough to have a μ LED source with 130 kilopixels, the optical system must also be improved. A multi-lens system is so necessary giving precise imaging and good contrast, but at the price of complexity, cost and lower efficiency and intensity.

ZKW developed their MicroZ module to address the issues of precision of the lens shape, the lens temperature by a combination of plastic and glass lens, the lens surface tolerances, and the assembly.



	DLP	MicroZ
Resolution	High	Low
E_{max}	High	Higher
Complexity	High	Low
Chip availability	No, one supplier	Yes

Interview: Jürgen Antonitsch, ZKW's Outgoing CTO



DVN: What is the state of ZKW's developments in ADB?

Jürgen Antonitsch: ZKW develop systems from low to HD resolution. We are in volume production with our system and the next generation of the modules starZ (next generation ADB segment light module) and MicroZ (first generation μ AFS module) and ECUs are on the way. ADB has arrived globally as a high-quality lighting function. Only the US is still lagging behind.

DVN: We see very well the short term success of DMD, including interesting night drives with ZKW two years ago. How do you see the long term future of this technology?

Jürgen Antonitsch: Yes, ZKW can supply systems with DMD technology. The great advantage of DLP is the very high resolution. The disadvantages are the costs, the efficiency and the more complex system with an additional high luminance light source. If the customers require a very precise complex imaging, then the DLP is the best choice. But due to the single source, I think that the future is limited. We are discussing the 500-kilopixel chip, which is from our point of view enough for the applications we see at the automakers, on the other hand we observe the fast evolving μ LED technology, where we will have a serious alternative soon in place.

DVN: MicroLEDs are very promised and developed by all lighting suppliers. Gerald Boehm made a lecture at the 21st DVN Workshop showing the benefits of μ LEDs, using 15 and 130 kilopixels. What is your recommendation about the number of pixels?

Jürgen Antonitsch: I think we have to separate between realistic and highly optimistic case. As a first approach we see approximately 25 kilopixels and we expect around over 100 kilopixels as a next step. Just this is an alternative to the high resolution of DLP.

DVN: What is your opinion about the two other technologies which compete with μ LED, scanning and LCD?

Jürgen Antonitsch: As I understand, LCD comes with a big disadvantage: it is many times bigger than DLP. DLP has the best image quality but is expensive and inefficient. μ AFS is more efficient, but has a lower resolution than DLP and therefore a poorer image quality. It depends on the requirements of customers which technology is the right one. At the premium level, DLP will still be the best solution. μ AFS will prevail in the middle range and lower segment. When μ AFS gets over 100 kilopixels, it can replace the DLP. Laser scanning is the most flexible, efficient and high-performance technology in terms of light intensity and field of view, but the costs to enter the market are currently too high.

4. Latest ADB Developments by Tier-2 Suppliers

Lumileds

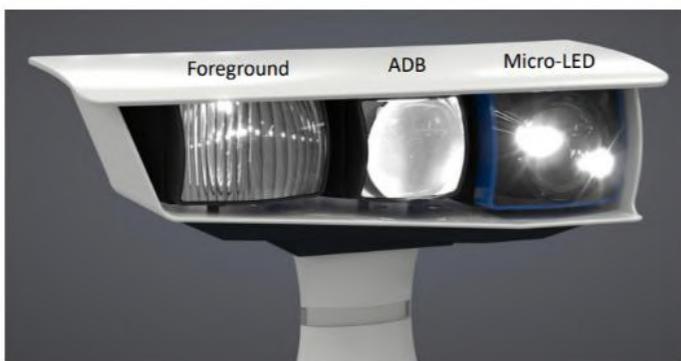
Lumileds' market view on the global adoption for ADB suggests in the next 5 years it is expected that the adoption of ADB will increase up to 16% to 25% per region. Notably, the USA is not shown in this chart since ADB is still not yet allowed there.



Lumileds' enabling light source technologies are: discrete, smallest footprint LEDs which allow very close spacing and which have very narrow tolerances for basic ADB functionality with single and multi row LED spacing. Typically, these applications will use about 12 (single row) to 100 (multiple row) LEDs per headlamp and can be applied with direct imaging optics.

For advanced high-resolution headlight applications, Lumileds announced their development of a high-resolution 20-kilopixel microLED light source device.

Lumileds made a mockup to show the possibilities of their Luxeon NeoExact and their microLED, and demonstrated Beam pattern examples for dynamic road marking and ADB with de-glaring regions as small as necessary.



full-field demonstrator with one microLED per headlamp

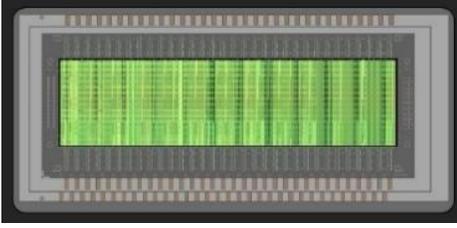


Foreground Module	ADB Module	Micro-LED Module
Horizontal range: $\pm 40^\circ$	Field-of-View: $6^\circ \times 40^\circ$	Field-of-View: $7^\circ \times 21^\circ$
LED: LUXEON NeoExact	LED: LUXEON NeoExact	LED product: Micro-LED
Light-emitting area: 4 mm^2	Light-emitting area: 18 mm^2	Light-emitting area: 32 mm^2
Optical concept: Direct image	Optical concept: Direct image	Optical concept: Direct image
Optic size: $60 \text{ mm} \times 40 \text{ mm}$	Optic size: $43 \text{ mm} \times 40 \text{ mm}$	Lens diameter: 40 mm

The results were presented at the VISION congress in March 2021:

	Foreground module	ADB module	Micro-LED module
Horizontal range	$\pm 40^\circ$	40°	21°
Vertical range	15°	6°	7°
I_{max}	20,000 cd	76,000 cd	60,000 cd
Flux in Beam	800 Lm	2,150 Lm	800 Lm

Nichia



Nichia have been working on enabling light source technologies to support future applications. These applications are primarily in the interior, but for exterior lighting, Nichia are developing their white laser technology: light-on-light projection with ultra-high luminance laser light. And Nichia are also developing their own active pixel LED device with 16,384 pixels, shown here. It's being designed in partnership with Infineon. Full automotive qualification is currently in process, and market introduction is expected in 2023-24.

Technology Portfolio

**Dynamic control
Additional function device**

ASIC Integration, Micro LED,
Safety function



Micro LED
Pixelated
Light Source
With ASIC

White Laser
GigaWhite
With Safety
Function



Semi-System Integration

Integration of further
functionalities

P&P Lighting Module



Projector LD Array imp.



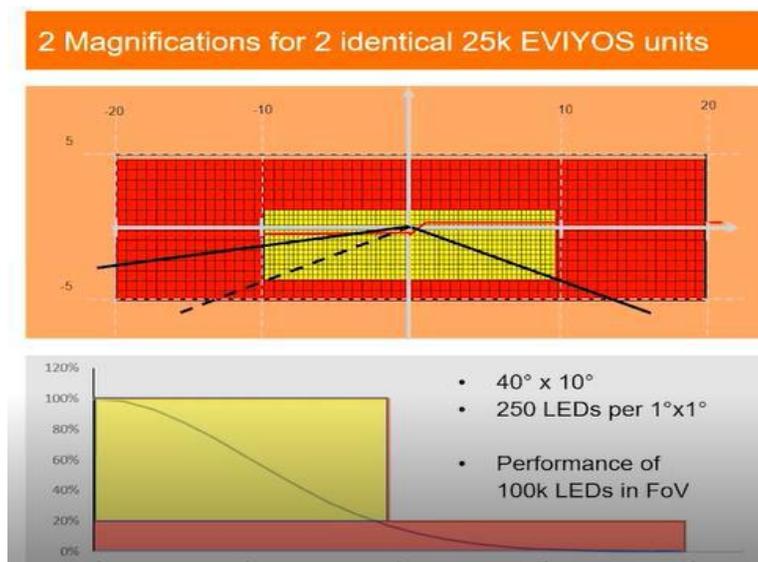
AR-LD Concept



Osram

Osram were part of coöperative research supported by the German Federal Ministry of Research and Education to propose a new active matrix LED light source. A multi pixel flip chip LED array is directly mounted to an active driver IC. A total of 1,024 pixels can be individually addressed through a serial data bus. Several of these units are integrated in a prototype headlamp to enable advanced light distribution patterns in an evaluation vehicle

Osram have begun development of the second generation of their hybrid LED, Eviyos 2.0, featuring 25,600 individually-addressable pixels on an LED chip with pixel pitch of 40µm. This is Osram's technology response to support future high-resolution headlighting applications. A demonstrator device has been constructed with two Eviyos devices per headlamp.



Spanning the large field of view

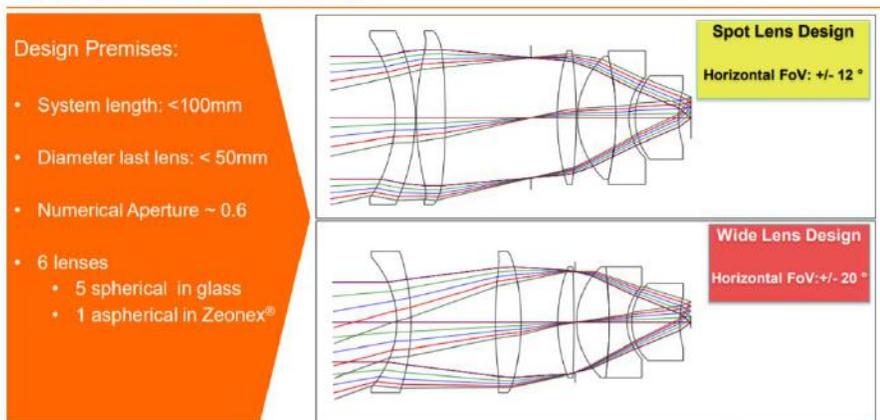
Their target is to find the best compromise between a high-resolution centre zone and a large, lower-resolution zone outside the centre. This enabling technology will enhance safety and comfort for future headlights with swivelling high beam, bending light, ADB, lane marking, and symbol projection.

Osram made a mockup of their Eviyos 2.0 device to show the possibilities of their µLED developments, and presented it at the VISION congress in March 2021 with specifications:

- 40 µm Pixel Pitch
- 25,600 Pixels
- High Contrast >> 250:1
- Low $R_{th} \ll 1.0$ K/W

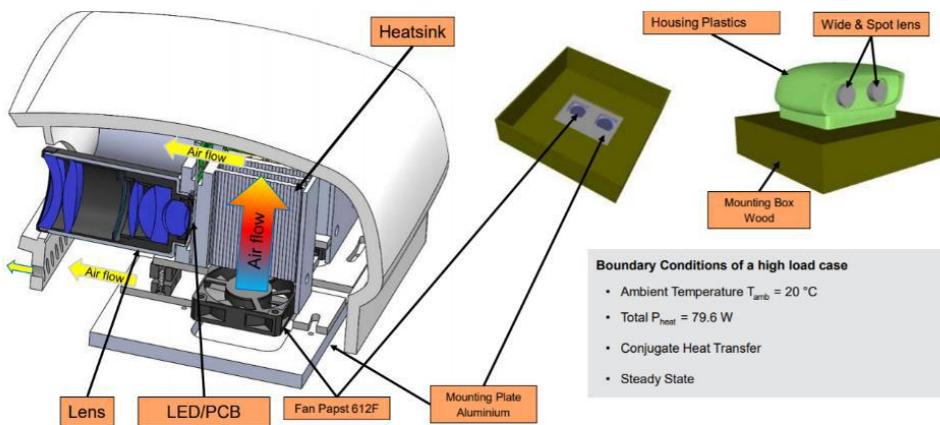
Optical Reference Lens Design

Opto Semiconduc



Two modules are used, one for spotlight and one for width light.

<p>Spot lens simulation</p> <ul style="list-style-type: none"> • System length: 100 mm • Mechanical diameter last lens: ~54 mm • Effective diameter last lens: ~50 mm • Simulated at 0.3 lm/px • Luminous intensity: 58.5-64.5 kcd • Scattered light: 100 cd • Efficiency: ~35% <p>Spot lens measurement</p> <ul style="list-style-type: none"> • Efficiency ~32% 	<p>Wide lens simulation</p> <ul style="list-style-type: none"> • System length: 100 mm • Mechanical diameter last lens: ~44 mm • Effective diameter last lens: ~41 mm • Simulated at 0.3 lm/px • Luminous intensity: 17.9-27.5 kcd • Scattered light 50 cd • Efficiency ~35% <p>Wide lens measurement</p> <ul style="list-style-type: none"> • Efficiency ~34%
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The mock-up shows that using 2 Eviyos devices could achieve a high-resolution LED headlamp, with the thermal and optical concept having been confirmed.

Texas Instruments

DLP Auto

The Texas Instruments 1.3-megapixel automotive DLP system is confirmed equipment for 43 car models across 12 brands by 2023 for headlight, HUD, ground projection, window display, and holographic cluster applications.

The system provides resolution only where it is needed; its modular design offers scalability across trim levels; it is cost-competitive with microLED solutions, and TI say it is futureproof by dint of its provisions for camera support, object detection, automated calibration & alignment, etc.

Static projectors are becoming common in vehicles for customisation, but offer limited uses. DLP technology enables dynamic projection around the car for communication such as vehicle warning messages and customizable welcome sequences or messaging.

DLP Products are automotive qualified, and support RGB images and video.



Vehicle to Pedestrian Communication



Orchestration and Personalisation

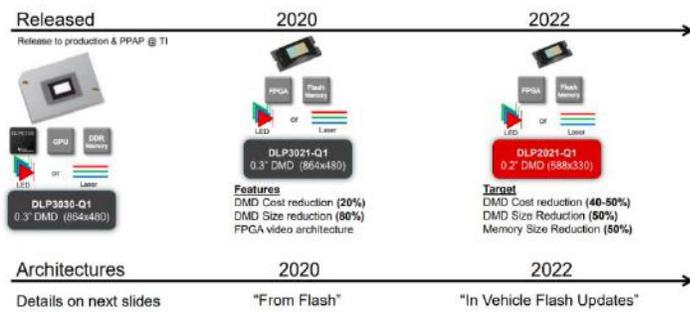
TI say innovations in silicon and packaging technologies will enable high performance automotive qualified chipsets.



High resolution headlight roadmap

 <p>DLP5531-Q1 0.55" DMD (1152x1152)</p> <p>Released</p> <p>Features</p> <ul style="list-style-type: none"> • First DLP chipset for HL • Uses DLPC230-Q1 Controller • Module BOM ~\$250 (est.) 	 <p>DLP5533A-Q1 0.55" DMD (1152x1152)</p> <p>2020</p> <p>Features</p> <ul style="list-style-type: none"> • Cost optimized • Drop in replacement to DLP5531-Q1 • Module BOM ~\$160 (est.) 	 <p>DLP462x-Q1 optimized solution (0.46" 960x960)</p> <p>2023 Target</p> <ul style="list-style-type: none"> • Smaller package to reduce cost • Optimised resolution • Module BOM ~\$95 (est.)
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Dynamic Ground projection roadmap



Other suppliers (currently mainly of LED displays)

PlayNitride

MicroLED technology supplier PlayNitride say they aim to dramatically slash the cost of μ LED chips within five years to meet the requirement of mass production; for now the company are raising funding.



CEO Charles Li says the two major keys of Micro LEDs are to make them small and cheap, which is the current challenge for commercialisation. To achieve the goal, it is critical to connect the supply chain from wafer manufacture, chip process, transfer technology, display module, backplane driver and system tuning. Most of the processes already exist, but need more integration in resource and technology.

Reducing production cost of μ LED is essential for mass production, and PlayNitride have set a five year target to cut by 95 per cent the cost of making μ LEDs. Li says equipment supply is crucial to achieve the goal. His company continue to raise funds to push their technology advancement and approach mass production. Apart from the USD \$86m raised last year for production expansion, PlayNitride plan to raise another \$50m to keep accelerating production and technology progress.

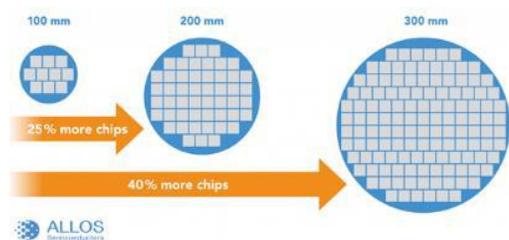
In April 2020, PlayNitride and AUO jointly developed a flexible μ LED display which targets automotive display applications.

Allos

To address wafer size mismatch and to tackle the yield challenge in μ LED production, Allos have applied their unique strain-engineering to show outstanding uniformity and reproductibility for 200 mm GaN-on-Si epiwafers. The company say they are successfully proceeding along the roadmap to 300mm production.

Yield plays a crucial role to make μ LED displays successful; it has a direct impact on manufacturing complexity and cost. To enable the needed cost reductions, large wafer diameters are essential. This is particularly true for μ LED applications in which wafers from CMOS-lines are integrated with LED epiwafers, for example by bonding. Here the matching wafer diameter has an enabling role comparing to the smaller diameters available from GaN-on-sapphire.

Allos say their technologies scale successfully to 300 mm on a new reactor. Scaling up from 100mm diameter—the typical wafer dimension for GaN-on-sapphire—has an even bigger business impact for μ LEDs than in other parts of the LED industry. Beside the well-known effects of lower cost per



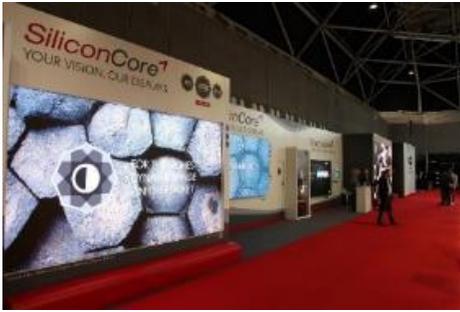
area when using larger diameters, the jump to 200 mm and 300 mm GaN-on-Si for microLED production enables the usage of CMOS facilities that have a much lower cost and additionally higher production accuracy than conventional LED lines. A further effect arises because most μ LED manufacturing concepts either include mass transfer

technologies that are using large area transfer-stamps or monolithically integrated displays.

SiliconCore

SiliconCore showcased their Lotus 0.83mm technology with a μ LED display at ISE 2020. The μ LED display, according to SiliconCore, is three times as bright and 50% more power efficient.

The Lotus 0.83mm LED display, with a brightness of 2000 nits, features SiliconCore's



latest innovation, LISA—a proprietary encapsulation process that guards the high-density LEDs and ensures colour uniformity and a long lifetime. Its cool surface is dust- and water-resistant, which makes it durable and suitable for touch and custom install applications. The specialised optical coating does not obscure the visual properties of the LEDs, and improves the contrast ratio providing a more realistic image and no glare.

Samsung adopts μ LED chips from PlayNitride and reportedly plans to increase investment in the coming 2020 for μ LED volume production.

Rohinni, a US-based μ LED technology company, partnered with K&S for microLED placement solutions and are reporting orders for their co-development. In addition, Rohinni launched two JV in 2019 with Luumii and BOE.

Epistar, a Taiwan-based LED expert, will partner with the Leyard Group to build a micro/miniLED production centre in Jiangsu province, China. Epistar also will increase their capital expenditure for MiniLED to meet increasing demand.

Glō, a Swedish-American company, have partnered with Japan's Kyocera and JDI to develop μ LED displays for automotive applications.

5. Assessing ADB

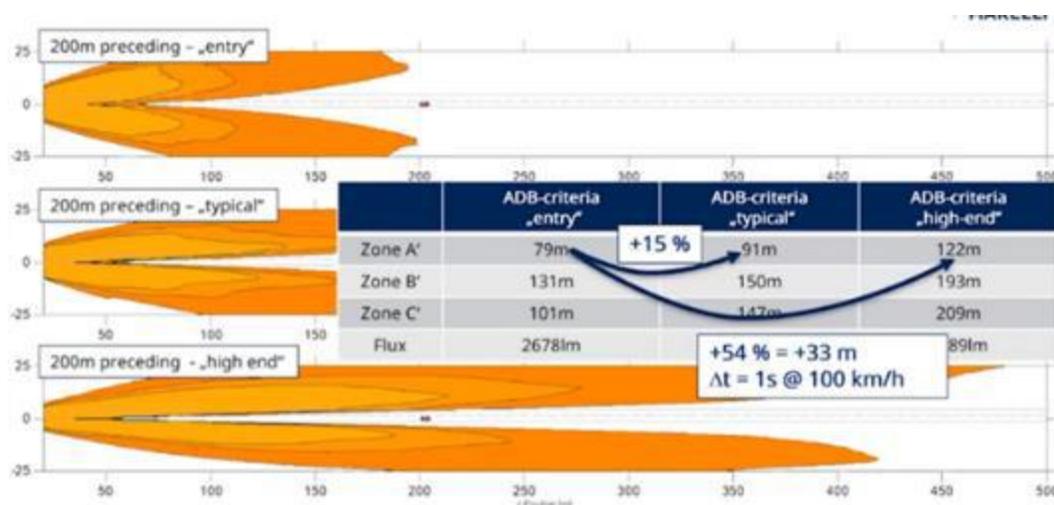
Marelli AL have devised a practical ADB rating method that provides a representative and easily-understood result. The rating covers the performance of the light distribution but not the system performance, including camera and software. It needs to be extended to a full ADB system rating in a second step.

The original Marelli rating method was further developed with Darmstadt University until it was precisely reproducible and scientifically accurate. The target is to qualify this ADB rating system, as developed by Marelli AL and Darmstadt University so that it can be published by an internationally accredited organisation making it freely available to assess the light quality from any kind of ADB system.

GTB, as an international group accredited with special consultative status by the UN ECOSOC, have been invited to study the proposed rating method. The GTB Committee of Experts are awaiting the outcome of a formal vote by 18 national member delegations. If the vote reaches a positive consensus, the rating method can be published on the public pages of the GTB website. There will be the usual complaints that GTB is taking too much time to reach a conclusion, but this is a fact of life when an international consensus is required in order to comply with the legal requirements associated with the ECOSOC accreditation.

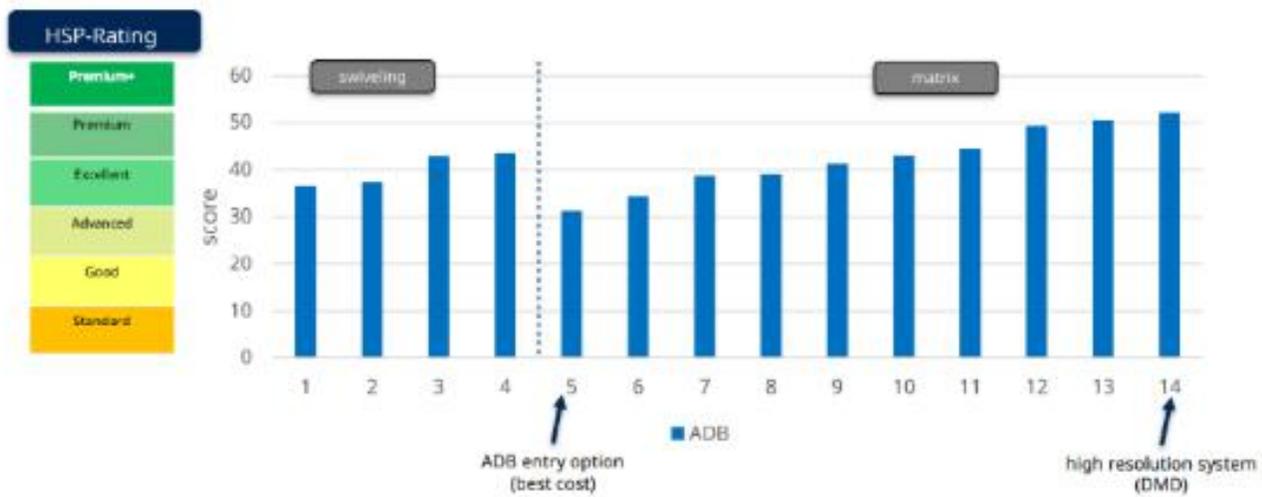
The evaluation method for the performance of traditional headlamps was developed jointly by GTB and the CIE Technical Committee (CIE-TC 4-45) and published as CIE Standard, CIE 188:2010. This standard was developed to evaluate the static performance of traditional headlamps, particularly by the measurement of the range in three zones with the 1-, 3-, and 5-lux isolines.

ADB systems have complex, moving beam patterns and no internationally-agreed rating system presently exists. The rating system proposed by Marelli's Dr. E.O. Rosenhahn is inspired by the procedure defined in CIE 188:2010, but adapted to ADB. Some could consider the maximum intensity, or the resolution, or the gradient of the vertical cutoff as important for the evaluation of performance but the most important factor for safety is the seeing range down the road.



One of the main features of ADB is the good perception of pedestrians. The average height being 1.77 m for males and 1.64 m for females, the height of 1.5 m is chosen for measurements of the beam. The different situations considered by ECE Regulation 149 are used, for instance 200 m leading car or an oncoming car at 50, 100, and 200 metres, and the points with 1, 3, and 5 lux from

the left side and the right side of the road are measured. The average of these distances is the base of the rating.



ADB headlamp system safety performance ratings (image: Marelli AL)

A headlamp rating is determined with low beam, high beam, and ADB, weighted respectively 30 per cent, 30 per cent, and 40 per cent; the rankings are presented as grades: Standard, Good, Advanced, Premium, and Premium+.

Literature surveys reveal that other scientifically accurate and fully reproducible ADB rating methods are not available. All other methods used today are based on subjective impressions (including the "expert will give a yes-or-no opinion" test in UN Regulation 149 which, at least nominally, is what stops US regulators accepting it. The results of these other methods have a certain value, but they are problematic. They can't be compared across observers, or across test days and times, because of environmental influences (like weather or road conditions), car influences (like headlamp adjustment or suspension parameters) and many others.

In parallel to these ADB assessments based on photometric values, the behaviour of the ADB systems in different road conditions should also be evaluated. The huge data currently collected for autonomous driving could perhaps be used in the future with AI for such a validation. But huge software developments are needed first, and standardisation would be, in these conditions, a much further step not currently predictable.

6. Regulations

UN Regulations: Valid Worldwide...Except in the USA

Approval of ADB is based on the technical requirements of UN Regulation 149 as an extension of the AFS requirements. Besides the goniometer light distribution measurements and functional checks, it includes a night drive in normal traffic and on the test track. Here some situations are tested, like the avoidance of glare to bicycle riders, system behavior under different situations and speeds. The test takes several hours of night driving, and has a central subjective element, wherein an expert gives a pass/fail opinion. Most administrations except the USA are content to apply the UN technical requirements, irrespective of whether they apply type-approval or self-certifications systems, and so industry goes along with it.

ADB in Asia

Japan is a signatory to the UN 1958 agreement; they apply the UN Regulations on lighting, and participate in the mutual recognition of type approvals. Whatever is allowed in Europe is therefore allowed in Japan.

Korea does not apply the type approval system but follows the evolution of the UN technical requirements and incorporates them in its national self-certification system.

China and India operate their own national standards systems but they also follow the evolution of the UN technical requirements.

ADB in USA – Not Yet, If Ever

A final rule defining and specifying ADB for use in the USA was scheduled for publication by the end of October 2020, but that date—like all other ADB dates promised by NHTSA over the past ten years, came and went without action, and there is now further indefinite delay. The agency commissioned, and then rejected, a thoughtful and appropriate SAE translation of the UN R123 (now R149) requirements into terms compatible with American law, and NHTSA's proposed rule drew nearly unanimous horrified condemnation from the auto, lighting, and testing industries and safety advocates. The proposal effectively kicked both legs out from under ADB: peak intensity to remain capped at a small fraction of the international maximum, thus hobbling the system's ability to provide a seeing range improvement, and de-glared zones must not be darker than an old-fashioned fixed low beam, thus destroying the ability of an ADB system to provide glare relief. Moreover, an ill-considered old NHTSA rule stands to make major problems for ADB. It prohibits horizontal aim-adjustability of the headlamp unless a costly and problematic onboard aim indicator called a VHAD is installed. Such devices were happily abandoned over 20 years ago after a brief, unsuccessful period of their use, and IIHS headlamp performance tests have proven the ban on horizontal aimability was unwise. ADB systems which *must* be horizontally aimable to calibrate the locations of the shadow zones correctly. Furthermore, the test protocol proposed by NHTSA is onerous, burdensome, and a successful result could be overturned by NHTSA at whim. Industry finds itself bracing for impact once NHTSA's final rule is eventually published; at that time the SAE Lighting Systems Group will hold a meeting to review the regulatory text as a group. The NHTSA proposal is widely felt to have been so faulty that even if NHTSA adjusts it, it will be an inferior regulation driving increased costs and providing lower safety performance.

How Can the U.S. Impasse be Overcome?

The challenge has been discussed many times in the DVN Workshop Regulatory Sessions. The overall conclusion is that the US government's almost gleeful automatic rejection of international technical consensus, and a deep-seated reluctance to introduce changes to Federal Motor Vehicle Safety Standard 108 because of perceived potential legal consequences, is a serious roadblock to safety improvement made possible by new technologies.

It is to be hoped the new Biden administration will open the door for new initiatives to un-stall lighting progress in the States. The real technical issue concerns the need to remove the subjective testing of the ADB, currently defined in the UN Regulations, and replace it with a performance-based objective test method. Exactly this was done with the SAE J3069 translation of the rest-of-world ADB requirements into objective terms compatible with U.S. law, but NHTSA—who commissioned J3069 in the first place—summarily rejected it. The terms of reference of the GRE Informal Group on Simplification include the requirement that test requirements shall be suitable for use in both type-approval and self-certification systems, and the phase 2 simplification agenda makes specific reference to this objective.

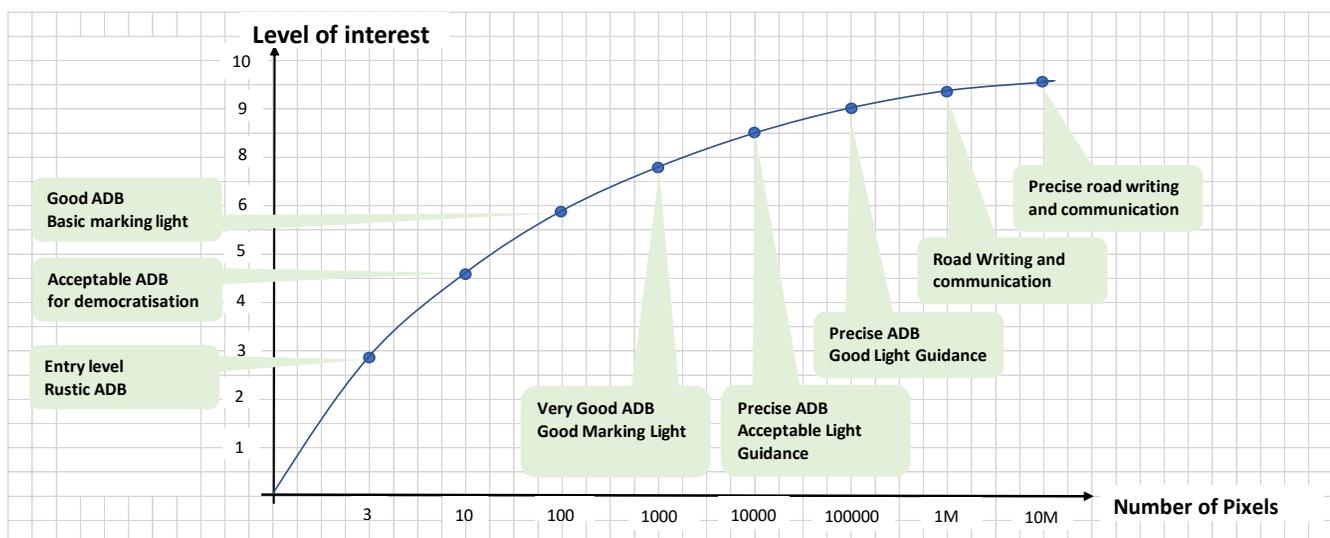
The long awaited NHTSA NPRM on ADB is, in theory, an attempt to define objective test requirements but, as explained above, this may satisfy the US politics but it will not result in the US having access to the ADB technology that is shown to save lives! Anticipating this situation, GTB decided to start work on the development of a laboratory-based test method to assess the performance of ADB. The GTB-VLLTP task force was established in 2019 with Geoff Draper taking the chair and Dr Thomas Reiners acting as secretary. The task force was starting to make progress on this very complicated technical subject but the pandemic delayed further development. After the retirement of Geoff Draper, Thomas Reiners remained as secretary of TF-VLLTP and is acting as the TF caretaker while working on a draft process description. Thomas expects to have a first draft available in Summer 2021. Meanwhile, GTB is looking for a new chairman of TF-VLLTP with a strong vehicle manufacturer background; this position is expected to be filled once things come back to normal after the pandemic.

There is a high level of agreement that the way forward is to test ADB in a laboratory under controlled conditions, but meaningful progress to develop an internationally accepted test protocol will only be made if the US Regulators show interest to reach a compromise. As the world starts to emerge from the pandemic and the political situation in the US will perhaps be more supportive of true harmonisation, it is to be hoped that a new initiative will be taken by GRE and the US will go back to the table to develop the UN technical requirements for lighting at the World Forum (WP29) in Geneva.

7 Synthesis

The interest in safety of ADB is now universally recognised even if the world's second-largest auto market, the USA, still considers it illegal. The development of ADB is going towards two important directions: One for democratisation, with relatively simple ADB with a reduced number of segments taking advantage of the now systematically installed cameras and of recent progress of LEDs makers toward affordability; and another direction with more and more pixels to offer both more precise ADB and new functions from marking light and guidance light to more complex and more demanding functions with road writing.

So how many pixels are necessary? There is no right answer. More pixels mean more cost. On the other hand, even if the interest is always increasing with the number of pixels, the real interest is following a kind of logarithmic curve of diminished returns, meaning that each step with increased resolution is bringing progressively less benefit. There will be room for each category as the range of car models is large and so the offer with ADB is adapted to the purse of everybody.



Naturally as for every technology—look at what occurs for smartphones or TV sets—today's premium high-end resolution will certainly be tomorrow's standard mainstream resolution. There are so many developments ongoing around μ LEDs/monolithic LEDs, not only for automotive lighting, but for numerous applications, that costs will significantly decrease in the next decade. This will pave the way for the democratisation of high definition ADB integrating many new functions for better and better safety benefits.

One of the huge challenges of ADB in the future will be its adoption in cities, as most people are using their cars in these conditions. Most present ADB systems are inactive at city driving speeds. The integration of new functions allowed by high-definition systems and by new embedded intelligence will certainly push for a larger adoption of these systems in these conditions. Despite all the advantages of ADB and HD lighting for safety, the adoption rate is slowed down by the extra cost, particularly in current conditions with so much effort being put toward electrification and the development of autonomous and connected cars, not to mention the economic consequences of the coronavirus pandemic.

The following figures and chart trying to anticipate the future adoption of these ADB systems by taking into account these factors are so a bit less optimistic than some years ago, but nevertheless

showing that ADB systems will progressively take a very important share in the market. For that, we assume also that U.S. regulators will eventually allow at least some kind of ADB-adjacent system in the next 2-3 years.

% ADB adoption	2020	2025	2030
Europe	12%	35%	60%
China/Korea/Japan	8%	25%	50%
Others including USA	0	4% †	20%
World adoption	5% *	18% *	35%

DVN forecast except () IHS data*
 † if NHTSA will act to allow ADB in USA

8 ADB's Future

Will ADB become mandatory? Should it?

Many automotive safety systems were premium-segment extra equipment with a high price in the beginning. In cases where the safety aspect was significant and visible, these safety systems did spread out fast into the premium market.

The next step was usually standard equipment in premium cars and an optional offer in lower segments. The prices decrease fast with increasing volume, further development, and competition in the market. Scientific studies prove the road safety benefit and show the influence on crash statistics, eventually to the degree that it is statistically evident how many fatalities could be avoided if the system in question were mandatory. Then whatever system or function is at hand becomes mandatory in several regions of the world. Consider the CHMSL (central 3rd brake light), or the daytime running light as examples of this progression.

Each case is different; this series of steps has taken anything from years to decades—think of safety belts, air bags, ABS, and ESP. In some cases the process isn't yet complete as there's still debate (or quarrel) over things like headlamp levelling systems, amber rear turn signals and side turn signal repeaters (in the USA), and side marker lights and retro-reflectors (outside the USA). In the ADB Systems lifespan we are in the phase of increasing volumes, further development, and decreasing prices. ADB systems are at the brink of becoming standard equipment in premium cars. In a wide spread of cars over nearly all segments, ADB is on sale as an option with good take rates.

Now the path splits: Will ADB in future be a nice comfort feature for lighting-oriented drivers in central Europe and some Asian countries? Or will it become a nearly worldwide mandatory safety system which is scientifically proven to reduce crashes and save lives in night traffic?

The interest in these two possibilities for stakeholders could not be more different. The only and mayor point everyone agrees on is the traffic safety improvement. Look at the following scenario: The night driving safety advantage is very visible during each night drive outside city limits, press articles appear, first statistical data appear. International research institutes and governments will become aware of this and look deeper into the real-world effects. Longer-term statistics by independent organisations will follow in several countries. Sturdier evidence will be published of what we as lighting community already know and experience every night.

Will the lighting suppliers initiate such a scenario? Will research institutes start this process? When it will start? GTB surely has a role, as the international automotive lighting and light signaling expert group. The possibility of supporting mandatory ADB should be discussed in the GTB Committee of experts and decided carefully. Some creative combinations are thinkable, like no levelling required for ADB headlamps, ADB for LED headlamps only, and other ideas to make the system cheaper for the consumer. Then it could be supported as a scenario in a GTB position paper (after introduction) as a worldwide safety option. The GTB has developed the regulations to make ADB a legal system. This was a big achievement because it saves lives. Now the final step could be started on the long run.

Which technologies will become the ADB spearhead? Which ones will disappear?

We can consider that the competition of the technology is heavy and very interesting because of the relatively high number of different solutions at this point in the game. Let us compare some characteristics and performance of the different technologies and guess what progress and success they could have achieved in five years. Therefore we need to know what the important parameters in five years are.

- Vehicle electrification will go fast. The result is that we will have a high market share of electric vehicles in the annual sales worldwide. For ADB this means the power consumption and the weight of the ADB system will be more relevant than today.
- Styling departments ask for extremely narrow lamps and wide shapes with light bands over the full car width. This means that the package space will shrink dramatically, especially the system height for the whole headlamps including ADB systems. Small package sizes of the ADB system will be a big advantage in the competition, a precondition, more than power consumption. If you find no space for your product you do not need to reduce its power because it will not exist.
- ADB system cost must be reduced. EVs create a much lower profit for the car makers, mainly because of the high battery cost. Governmental support for EV sales will end, and the market will define the prices of EVs. Battery cost is usually measured in \$/KWh. Today in 2021 the price is above \$100/KWh, coming from over \$130 about three years ago, with a tendency to rise a bit because the high demand overcompensates the technology progress. Let us guess the \$100/KWh barrier will fall and the progress in energy consumption per EV will decrease, it is still a ways to go until the profit of a combustion-engine car will be met.

Considering the above main trends of the Automotive market, the ADB system with the best compactness, slim appearance, cost, energy efficiency will certainly be used for mainstream application. The matrix beams from 5 to 20 pixels are potentially gathering these advantages with the evolution of small and cost-effective LED arrays, and we think that this technology will spread largely to medium and low range cars in the next five years.

But for more premium applications, the differentiation in lighting systems will be realized through high-definition systems. The technology will still be pulled by higher resolution.

It appears now clearly that a unique module will not be able to realize all the beam with high definition, at least in the next five years. We shall have combinations of high-definition module particularly for the central field, and another module for the width.

During the next five years, the competition for high-definition modules will be mainly between micro-LEDs and DLP, each have now clear cost reductions perspectives. Thanks to their better energy efficiency and better cost and packaging, micro-LEDs will take a major part of the market despite their still handicap for definition.

LCD and MEMS will have their way more and more difficult as huge efforts will be concentrated on micro-LEDs technology, helping to decrease its cost much more quickly than LCD and MEMS that would be at the best emerging. We do not think so that these technologies could have the chance to survive in this fierce competition.

ADB New Projects Prognosis to 2026

Under the above circumstances, the following table was developed. Please notice that all values are under high tolerances, partly estimated as a result of a discussion of experts.

Technology	Estimated Cost [%]	Est. Road Flux (Lm)	Pixel #	Quality High Beam	Quality Road Proj.	Power/W	Weight/kg Volume/ l
1. Mechanical	20	700	1	Low	No	25	0.5/0.7
2. Matrix low	20	700	4 to 10	Low	No	20	0.2/0.1
3. Matrix high	25	1000	11 to 84	Medium	No	35	0.3/0.2
4. μ LED 5	30	800	5	High	Poor	0 - 55	0.5/0.3
5. μ LED 25	40	700	25	Excellent	Med	0 - 60	0.5/0.3
6. μ LED 100	50	1000	100	Excellent	Excellent	0 - 100	0.5/0.4
7. DMD 1M	100	300	1.3 M	Excellent	Excellent	40 - 60	1 / 1
8. DMD 200k	40	300	200	Excellent	High	30 - 50	0.5/0.5
9. BladeScan	30	700	dynamic	Medium	Med	30	0.6/0.5
10. LCD	40	700	30.000	High	High	50	0.7/0.7
11. MEMS	100	1000	dynamic	Excellent	Excellent	30	n/c

1• Mechanical, 1-segment with dynamic size, swivelling (partial high beam)

No new projects in 2026

2• Matrix (up to 10 Segments)

On the way to democratize Matrix ADB on small and medium cars

3• Matrix (11 to 84 segments)

Mainstream Matrix ADB in 2026 alone. Associated with MicroLeds or DMP on high range cars.

4• MicroLED 5,000 pixels

First applications in 2022-2023. Established high range cars and premium segment option in 2026

5• MicroLED 25,000 pixels

Sufficient quality for basic road projections. First applications 2022. Still a high range premium option in 2026.

6• MicroLED 100,000 pixels

Enhanced field of view. Still not available. First applications in 2026 on high range cars as option

7• DMD 1 million pixels

Super Luxury segment option, only small volume. 500k pixel version with reduced cost, size and power estimated 2024

8• DMD 200,000 pixels

Premium segment option with additional functions

Reduced Chip size, reduced electronics, CAN FD interface, scalable.

9• Blade Scan

Nice but likely an intermediate application with low volume. Attractive cost, but no full market accessibility

10• LCD

Did not make it to mass production

11• MEMS

Not yet available. High Tech. Promising Technology.

Still few chance to be in production in 2026

Matrix and microLED will be the basis for development of numerous diverse solutions, especially in matrix LED reflection versions. Small and affordable compact cars will show up with 4-segment matrix LED headlamps; today this seems to be the lowest number of segments which makes sense. In case of projection solutions several standard modules will be available with different number of pixels, up to 84. The standards will be driven by the headlamp makers (not by the component makers and not by the car makers) still in 2026 projects. Cross-supplier solutions, standardised by the car makers, will show up for a while and disappear soon, like the 84-Pixel Mercedes solution in 2016 and the standard rear lamp LED module of VW around 2005. Most approaches did not even make it to serial production because the set makers prevented this in advance by lower cost offers. The reasons for the high assertiveness of the set makers, is their integral technological expertise in lighting, electronics, and micromechanics, as well as the final responsibility for the homologation of the headlamp as a component. Their market power over the component- or subsystem makers like Osram, Osram-Continental, Lumileds, Nichia, or Lear is very strong.

Outlook: Future of ADB

ADB is a very effective safety system. ADB can save lives, there is nothing more to expect from an automotive safety system. ADB has the potential of becoming mandatory in some regions of the world. A lot of research and even more communication is necessary before this could be realised.

On the other hand, ADB depends to a certain degree on styling. This is totally different to all other mandatory safety systems like ABS and ESP. This prevents a consequent standardisation and speaks against a mandatory requirement. At least one reproducible and scientifically correct performance rating system is necessary to categorise the ADB performance and to prevent underperforming systems on the market. Fortunately, such a performance rating system is under development by GTB members with the scientific support of the Darmstadt Technical University.

The next but one step in ADB development could be laser scanning systems with a totally flexible resolution. They have the potential to act as "augmented" systems like we see in first augmented Head Up Displays (HUD) which helps the driver with additional information, projected directly into their field of view.

A future MEMS laser scanning system could have the advantage to show the driver a critical issue in a night drive like a nearly-hidden pedestrian, seen by sensors but hardly visible by humans, directly on the road with a high-resolution high-brightness signal as part as of the light distribution. A MEMS laser scanning system can be predominant in several use cases.

All possibilities have one thing in common: ADB has a bright future.

List of DVN Gold Members

Car Makers

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Aston Martin, UK
Audi, Germany
Bentley, UK
BMW, Germany
Daimler, Germany
FCA, USA
Ferrari, Italy
Ford, Germany
Geely, Germany
GM, USA
Honda, Japan, USA
Hyundai Motor, Korea, Eur.
Jaguar-Land Rover, UK
Mitsubishi Motors, JP
Nio, China
Nissan, Japan, Europe, USA
Opel, Germany
Porsche, Germany
PSA, France
Renault, France
Shanghai-VW, China
Seat, Spain
Skoda, Czech Republic
Toyota, Japan, Europe, USA
Volkswagen, Germany
Volvo Cars, Sweden

DVN-Interior

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Faurecia, France
Coindu, Portugal
Everlight, Taiwan
Ford, USA
Grupo Antolin, Spain, Ger.
Inova, Germany
Honda, Japan,
Marelli, Japan
Melexis, Germany
Mitsubishi Motors, Japan
NBHX Trim, Germany
NIO, China
Novem, Germany
Osram, Germany
Preh, Germany
Recticel, Germany
Renault, France
SMR Automotive, Australia
Sensata, UK, France
Texas Instruments, USA
Valeo, France, Spain, China
Weidplass, Germany
ZKW, Austria

Set Makers-Tier 1s

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DH Lighting, Korea
Elba, Romania
Farba, Turkey
Feka, Turkey,
FlexNgate, USA
Grakon, USA,
Grote, USA
Hascovision, China
Hella, Germany
Ichikoh, Japan
J.W. Speaker, USA
Koito, Japan, Europe, USA
Lightworks, Germany
Lumax, India
Magna, USA, Austria, Italy
Marelli,AL Germany, USA
Mind Opto, China
Myotek Industries, USA
Mobis, Korea
NAL, USA
Neolite ZKW, India
Nordic Lights, Finland
Odelo, Germany
Phoenix lamps, India
Plastic Omnium, France
SL Corporation, Korea
Stanley, Japan
Valeo, France, Spain,China
Varroc, Germany, Czech R.
Xingyu, China
ZKW, Austria
Zodiac, France

Light Source Suppliers

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Anrui Opto, China
Brightek, Taiwan
Cree, USA
Diodes Dynamics, USA
Dominant Opto Tech., Malaysia
Everlight Electr., Taiwan, Germ.
Excellence Opto., USA, Taiwan
LG Innotek, South Korea
Lumileds, Netherlands
Nichia, Japan
Osram, Germany
Samsung LED, Korea
Seoul Semiconductor, Korea
Soraa Laser Diode, USA
Tungsrang, Hungary

Univ., labs, Consultants

20

Andaltec, Spain
CEA Leti, France
Darmstadt university, Germany
DEKRA laboratory, Nederland
FEP, Franhauser, Germany
Fudan university, China
Hannover Leibniz .(HOT), Ge.
Institut d'Optique, Fr.
Karlsruhe Lighting Institute, Ge
LAB, France
Light Sight Safety, Belgium
Nuremberg university, Ge
Pacific Insight, USA
Parma university, Italy
Pforzheim, Germany
Rensselaer university, USA
SLD Laser, US
UMTRI, USA
University of California, US
YoungNam University, Korea

Lighting Suppliers Tier 2s

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3M, USA
Altran, Spain
AML Systems, France
Ansys, France
Aspöck Systems, Germany
ASYST Technologies, USA
Auer-Lighting, Germany
Bicomoptics, China
Bühler Alzenau, Germany
Covestro, US, China, Europe
Dajac, USA
DBM Reflex, Canada
DesignLED, UK
Docter Optics, Germany
EcoGlass, Czech Republic
Elmos, Germany
GXC Coatings, Germany
Holophane, France
IMS, Netherland
Infineon, Germany
Inova Semiconductors, Germany
Instrument Systems, Germany
Jenoptik, Germany
Keboda, China
Less, Switzerland
Liteon Technology, Taiwan
LMT, Germany, China
Luminus, USA
Lumitex, USA
Mektec, Germany
Maxell Frontier, Japan
MD Molding, Portugal
Mentor Graphics, Europe, USA
Mitsubishi Electric, Germany, Jap.
Nalux, Japan
NXP, UK
ON Semiconductor, Europe, Asia, US
Optoflux, Germany
Panasonic, Japan
Proper Group, USA
Red Spot, USA
Sabic, USA
Sapphire, USA
Sea Link International, USA
SMR Automotive, Australia
SUSS Micro Optics, Switzerland
Synopsis, USA, Germany
TechnoTeam, Germany
Texas Instruments, USA
TQ Technology, Taiwan
Weidplas CH, Switzerland
WL Gore, USA
Yeji, China
Zollner, Germany