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Tran Quoc Khanh

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11th International Symposium on Automotive Lighting

Steering Board

Foreword

It is a pleasure to present you the proceedings of the 11th International Symposium on Automotive Lighting, which takes place in Darmstadt on September 28-30, 2015. This conference is the document of a series of successful conferences since the first PAL-conference in 1995 and shows the latest innovative potentials of the automotive industry in the application of lighting technologies.

These proceedings result from the work of a lot of experts in the automotive and optical industry, administrative bodies, research institutes and universities. It summarizes the findings of more than 200 authors and co-authors and gives a scope of their expectations for the future. In 2015, the ISAL Steering Board could identify the following focus topics:

- The blue laser technology with stable phosphor systems giving the highest luminance for the development of the new high beam booster systems with very small size and apertures
- Pixel-light headlamps with two dimensional LED-arrays or glare-free high beam with vertical segments and driver assistance with the interaction between light sources, cameras, digital image processing and headlamp systems
- LED technology generally and the new high-current and high luminance white LEDs are promising solutions for innovative headlamp developments
- Energy efficiency, CO_2 reduction and methods for their realization
- Traffic accident analysis, traffic and automobile regulations
- Optical measurement, human eye physiology and mesopic research.

Besides the modern LED-headlamp developments for higher class vehicles with a luminous flux of about 1100 lm, some headlamps with LED low beam have been demonstrated performing a luminous flux of 600-650 lm on the road using about 11-13 W electrical power. Parallel to the development of LED-array for pixel light headlamps, other technologies like LCD and DMD-systems are subjects of intensive research in order to reach a traffic space resolution of more than 10,000 pixels. This development must be hand in hand with the improvement of the image processing like camera and sensor technology as well as efficient embedded algorithms. Quality of sensors, image processing and sensor fusion will determine the future of driver assistance.

During ISAL 2015, we will have a podium discussion on the test strategy and the acceptance tests for the ADB-headlamps with some contributions of GTB, universities and other institutions. The aim of this podium discussion is to analyze the advantages and some deficits of the current ADB-systems in order to have an acceptance on the American market.

We wish you a very informative and successful ISAL 2015 in Darmstadt. We hope that this year's event and these proceedings will give you inspiration and motivation for your work during the next 24 months.

Yours sincerely,

Prof. Dr.-Ing. habil. Tran Quoc Khanh

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I. General Topics

RENAULT Full LED Headlamp Strategy

BEDU François, RENAULT S.A.S., France

Keywords: Full LED Headlamp, Light signature

1 Abstract

The 1st intention of Lighting LED functions has begun in 2009 in RENAULT. After 5 years of intensive work, the 1st application of Pure LED Vision module has been launched on the market with New Espace. At the same time, this vehicle is emphasizing the brand signature, with the introduction, on the front face, of a lit "C" shape.

RENAULT is the 1st one to propose on the market a full LED headlamp as standard equipment on a D-segment vehicle.

The strategy of development of the full LED headlamp will be more and more visible during 2015 – 2016 with the launch of new vehicles. The Pure LED Vision modules have been developed to replace Xenon headlamps and a high level of standardization has been achieved on the headlamps.

2 Introduction

After the development of rear signaling functions with LEDs at the beginning of last decade, the introduction of LED front signaling functions was the logical 2nd step for CO_2 reduction reason. In this trend of fuel consumption optimization, bulb low beam was the lighting function with the highest remaining consumption [1].

In 2009, for the new generation of C-D segments vehicles, the choice of technology used in the headlamp was a crucial topic. Due to the interdiction of Mercury and lead in the parts, the application of Xenon D1S system was forgotten. An investment in a new ballast with D3S bulb was required. Thus, internal thoughts have begun about LED LowBeam function. Rapidly, the idea has been to replace Dynamic bending light biXenon module by two modules: one for LED lowbeam and another for highbeam.

3 Genesis of full LED Headlamp

The lighting team which has begun to experiment LED lighting development with daytime running lights on different vehicles from B to D segments (Zoe, ClioIV, Espace IV, Megane

III, Scenic III) has decided with styling department to launch an expertise study. Two suppliers were selected with different objectives:

- Define the technical feasibility of what will be called later Pure LED vision modules and optimize the cost [2],[3].
- Improve LED knowledge and update technical requirements to prepare the launch of the multiple RFQ for the new C-D segment line-up.
- Validate the styling intention with the presentation of physical mockups
- Validate the photometric performance of the modules.

Figure 1: First styling intention of full LED modules

4 Lighting Signature origin

In parallel to the LED modules pre-development, the 1st intention of light signature was also evaluated during the expertise phase. Due to a problem of physical packaging, this intention was canceled. The definition of Espace V headlamps has begun with an economical DRL solution.

In 2012, with new Megane's research of concept, Product planning proposes to focus on lighting with an emphasized light signature. Very quickly a theme emerged of the discussions between styling and Lighting teams. A new expertise study is launched with the objective to define optical concept to fulfill the request: An "out of the box" signature at the front end and a 3D signature at the rear end inspired from lightbrush images are decided.

After discussions with Project management, these signatures are carried back completely or partially on the different preceding vehicles like Espace, Kadjar and Laguna.

Figure 2: ***RENAULT ESPACE 5*** *full LED headlamp with light signature*

Figure 3: RENAULT KADJAR full LED headlamp with light signature

5 Strategy of development and standardization

In order to minimize the R&D cost and the price of the parts, a complete strategy of development has been defined.

First of all, the low beam and high beam modules are unique for the 2 suppliers nominated on C-D segments line-up in order to avoid multiple developments for the different projects.

Secondly, an outsourcing of a complete line-up of LED driver is decided due to a lack of efficiency from Tier one supplier. Renault defines the specification and interface of the driers and give the development and production to an electronician company. This LED driver line-up is able to manage from 1 to 3 functions. One of this driver is used for the full LED headlamp and all of them are shared in the Alliance with Nissan.

Finally, a new automatic levelling system is integrated in the platform CMF-CD. Instead of a dedicated ECU with two height sensors, RENAULT has developed a software and integrated it in a standard ECU of the vehicle. A unique rear height sensor is used. This system is also shared with Nissan for their models using the same platform [4],[5].

6 Lighting Performance

For the photometric performance, the target is linked to the 1st goal: replace all the Xenon headlamps. Due to the difference of color, the flux target was 20% lower than Xenon but significantly higher than Halogen.

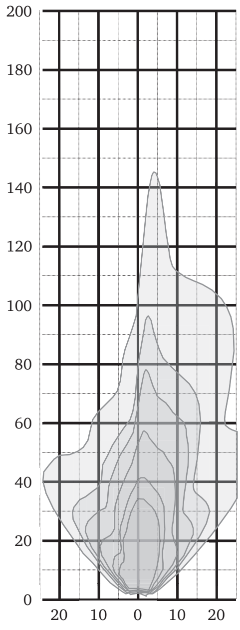
During the development, the light distribution has been focused on homogeneity and width of the beam. This can be seen in the table below based on TC4-45 criteria

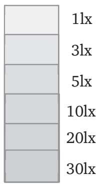
	Zone A	Zone B	Zone C	Zone D	Zone E	Light Flux	Opp. glare
HAL	81m	86m	54m	13m	13m	753lm	0,35lm
XEN	**95m**	103m	**64m**	16m	**18m**	**1295lm**	0,51lm
LED	86m	**110m**	59m	**18m**	15m	974lm	0,62lm

Figure 6: Low beam performance comparison between Halogen headlamp, Xenon headlamp and Espace V full LED headlamp

	Zone A	Zone B	Zone C	Zone D	Zone E	Ped. Width	Light Flux
HAL	191m	57m	32m	79m	125m	15m	1459lm
XEN	**205m**	**61m**	32m	55m	**166m**	17m	**2220lm**
LED	188m	51m	**63m**	**84m**	162m	**18m**	2150lm

Figure 7: High beam performance comparison between Halogen headlamp, Xenon headlamp and Espace V full LED headlamp





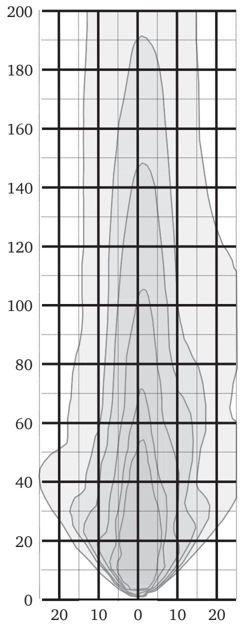


Figure 4: Espace V Lowbeam isolux

Figure 5: Espace V Highbeam isolux

7 Summary and Outlook

The 1st generation of Pure LED Vision Module are now developed and under deployment on numerous vehicles. This wide application has become feasible for due to a limited cost increase and a clear adhesion to this strategy of the styling department. The strategy of standardization exposed and shared with Tier1 suppliers on the modules, the separated sourcing of the LED driver and its communization with Nissan to increase volume effect and finally the optimization of the automatic levelling system are the three main factors from technical point of view.

The 2nd generation of Full LED headlamp is now under development and will arrive soon on the market with the difficult objective of decreasing cost for lower range models.

The strategy of the 3rd generation is ongoing and will be more challenging with several objectives:

- Which concept of full LED headlamps can replace halogen headlamps in terms of cost
- which new features with high customer value must be integrated in the headlamps
- which improvement in the standardization must be done to create new opportunity of cost saving.

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Future of lighting: Aesthetic, Dynamic and Interaction

Stephan Berlitz, Vesna Krstajic, AUDI AG, Germany

Keywords: Aesthetic, Dynamic and Interaction

1 Abstract

Aesthetics, dynamics and interaction – these terms characterize future lighting technologies. How to put vehicle lighting into motion to create new, dynamic forms of expression. The light interacts intensely with the driver and the surroundings.
Aesthetics: design is more than just styling, it is the aesthetic expression of the brand values.
Dynamics: The light comes alive; it moves and takes on new forms of expression and differentiation. A chip with hundreds of thousands of micro mirrors that can be individually controlled extremely quick divides the light into tiny pixels. This will enable the ideal light pattern for virtually every situation, such as special lighting for construction zones and similar bottlenecks. Organic light-emitting diodes (OLED) at the rear or on the flanks will also enable novel functions in the future that clearly indicate to other road users the intentions of the driver in front of them. When braking, for example, their light flows quickly forward, augmenting the brake light at the back of the car.
Interaction: The lighting of the future will interact with other road users and with the driver. It will increasingly become an information medium. In the future, a novel laser tail light that assumes the shape of a warning triangle in the fog or rain could effectively keep trailing vehicles at a safe distance.

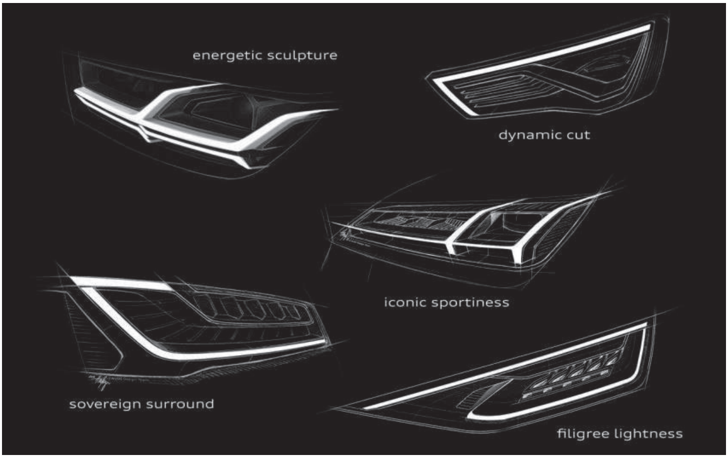
2 Introduction

Lighting technology is a field in which there is a big competition. Audi already offers LED headlights in many model series. They define the appearance of the cars, and because they illuminate the road so well, they also make a major contribution to active safety.
The automotive industry is already developing the lighting technologies of tomorrow. Three central themes are emerging. The lighting of the future will react even more intensively to environmental conditions, it will communicate in various ways with its surroundings and thereby help to further increase active safety.
With the Matrix LED headlights, Audi has already indicated that the lighting of the future will feature full-electronic control, making new dynamic features even more versatile.
The next steps will be laser headlights for the high beam and innovative interior lighting.

3 Aesthetics

Design means more than just styling – it is the sensuously tangible expression of the characteristic values. Audi lighting gives Vorsprung durch Technik an aesthetic form and underscores the progressiveness, sportiness and sophistication of the brand.

Exterior lighting as a signature
In each model, the headlights and rear lights comprise an integral, characteristic element of the sculpture. The make the Vorsprung durch Technik particularly apparent – by day and by night. The daytime running lights are a powerful signature, complemented by the rear lights and – in the most recent models – the dynamic turn signals. Even at a great distance an Audi is recognizable as an Audi. As the car gets closer it quickly becomes apparent which model it is. No other brand works with such a large number of signatures. The concept of lighting signatures began with the introduction of LED daytime running



lights in 2004, one of the brand's first lighting innovations. In what at the time was the top model, the A8 W12, five LEDs inside the headlight formed a graphic resembling the five on a die. Two years later the new A6 Avant was given an eye-catching signature for the rear lights: 27 separate light-emitting diodes formed a flat trapezoid. They changed the streetscape permanently – as did the A4/A5 family, which followed somewhat later with distinctive LED signatures at the front and rear.
The next step in this development were the homogenous daytime running lights introduced in the new Audi A6 in 2011. LEDs behind thick-wall optics formed an elegant

wave in the headlights oriented on the outer contour. The tail lights in the form of a flat U-bend were also continuous.
Audi is making another statement with the new third-generation TT: The tail lights, which are continuously active once the ignition is switched on, follow the design of the daytime running lights for the first time. Both are grille-shaped structures with emphasized verticals, a motif derived from the R18 e-tron quattro Le Mans race car. In the new Q7, Audi has further refined this look to a double arrow.
Besides the design aspect, the daytime running lights and the tail lights are also very important for safety, and the same is true for the turn signals. The dynamic turn signals, which send unequivocal signals to the surroundings, quickly moved into additional models following their 2012 debut in the Audi R8. As an animated element, it represents a new highlight. Furthermore, other road users recognize the situation as much as one second sooner.
The lighting signature strengthens the presence of Audi models in the streetscape. It gives the cars a self-confident and focused look – with different nuances. Compact models such as the A1 have a more youthful signature, whereas that of the flagship A8 emphasizes the car's supreme control.

Matrix LED technology

The Matrix LED headlights available for several model series underscore the groundbreaking expertise in automotive lighting technology. They illuminate the street extremely well in any situation without blinding other road users. The high beam comprises small light-emitting diodes – twelve per headlight in the Audi TT and 25 in the Audi A8 – with groups of five LEDs shining through a common reflector.
When the light switch is set to Automatic and the high beams are on, navigation data are used to switch the system on outside of urban areas at speeds of just 30 km/h (18.6 mph) and above. As soon as the camera with which it works detects other vehicles, the controller immediately switches off individual LEDs or dims them in 64 stages, creating several million possible light patterns. Oncoming and preceding vehicles are excluded from the light pattern, while all other areas between and adjacent to them continue to be fully illuminated. As soon as the oncoming traffic has passed, the high beam once again shines homogenously and at full power.
The LEDs in the Matrix LED headlights also assume the function of cornering lights, selectively brightening or dimming to shift the focal point of the light along the curve. They do this shortly before the wheel is turned based on predictive route data provided by the MMI navigation plus. Audi is the first manufacturer to completely replace the otherwise mechanical elements with software. This will be the major trend in front lighting for the future.

4 Dynamic

Audi brings vehicle lighting to life. New luminous surfaces and flowing movements transform light from static to dynamic. This creates entirely new forms of expression, perception and differentiation. They enhance safety while also honing the brand's appearance.

Dynamic turn signals
The dynamic turn signals send clear, unequivocal signals to the surroundings regarding the intended turning direction. Other road users can quickly detect this even if visibility is poor or with their peripheral vision – an important contribution to safety.
Depending on the model, the turn signals are either individual LEDs or LED blocks. When the driver activates the turn signal, these light up sequentially from the inside out. After 150 milliseconds, all segments are bright; for another 250 milliseconds they illuminate with full intensity. The LEDs then go dark before repeating the lighting sequence.

Laser spot
In summer 2014, the laser spot for the high beam made its production debut in the Audi R8 LMX high-performance sports car, the exclusive special-edition model in the R8 series. It was used shortly before that in the Audi R18 e-tron quattro race car at the 24 Hours of Le Mans.
With the new laser high beam spot, which will be available in additional models in the future, one laser module per high beam generates a cone of light extending several hundred meters. There are four powerful laser diodes in each module, each only three-tenths of a millimeter (0.01 in) in diameter. They generate a monochromatic and coherent blue laser beam with a wavelength of 450 nanometers. A phosphor converter converts it into white light suitable for roadway use with a color temperature of 5,500 Kelvin.

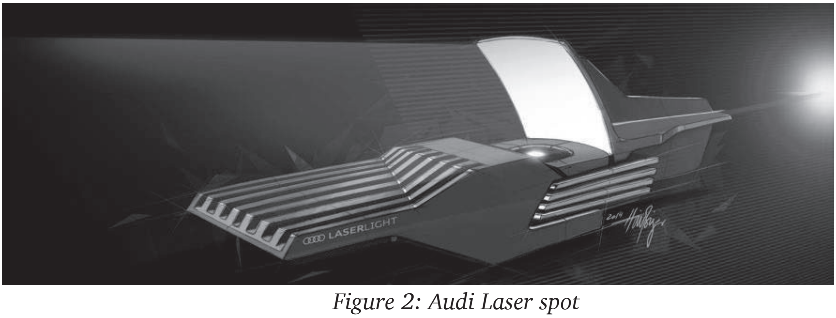


Figure 2: Audi Laser spot

The laser spot, which is active at speeds of 60 km/h (37.3 mph) and above, offers the driver major advantages with respect to visibility and safety. An intelligent camera sensor system detects oncoming road users and dips the lights automatically.

Adaptive brake lights

Audi introduced the adaptive brake lights to its model range back in 2008, and it is now standard in all models. If the driver brakes strongly enough at speeds above 50 km/h (31.1 mph) that deceleration exceeds 0.7 g, the brake lights send a clear alarm signal to the trailing traffic by pulsing three times per second. Shortly before the car comes to a stop, the emergency flashers activate with normal frequency.

Matrix laser technology

Audi is taking the next step in the development of automotive lighting technology with the Matrix laser headlights. Broken down into tiny pixels, the beam of light and illuminate the road in high resolution and with precise control. The brand's developers and designers have thus opened up entirely new possibilities.

The technology that Audi uses in the Matrix laser headlights is abbreviated DMD (digital micro mirror device) and is also used in many video projectors. At its core is a matrix of hundreds of thousands of micro mirrors, whose edges measure just a few hundredths of a millimeter in length. With the help of electrostatic fields, each individual micro mirror can be tilted up to 5,000 times per second. The light is projected onto the road as a function of the position of the individual mirrors, optimally adapting the illumination of the road to the ambient conditions for the driver.

DMD technologies makes it possible to create a nearly infinite number of light patterns. The car can thus generate the ideal light for any driving situation. The technical possibilities are virtually unlimited. Targeted light helps the driver to stay in the lane through construction zones, for example. When turning or moving through intersections, it can show the driver the way, even projecting arrows or similar graphics onto the road, if desired. The high-resolution light can highlight important traffic signs or very precisely prevent the blinding of other road users with glare.

The Matrix laser headlights mean a huge degree of added safety for the driver and others nearby, as well as for the piloted driving of the future. In urban traffic, for instance, they can lay down a pattern of light and dark zones directly in front of the car. This acts as a sort of crosswalk and indicates to pedestrians that they can cross the street safely.

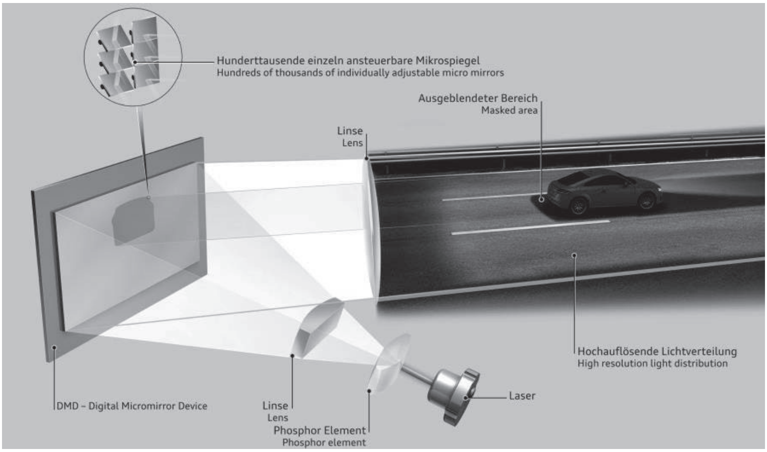


Figure 3: DMD (Digital Micro mirror Device) Technology

Construction zone lighting

Construction zone lighting is a new, future function of the Matrix LED or Matrix laser technology. It projects two strips of light about 15 m (49 ft) long onto the road to indicate the vehicle's width. The new light pattern is a great help when driving through construction zones or similar bottlenecks. The driver can follow the light as if it were rails.

The exterior lighting of the future

External lighting design using OLED technology will be as intelligent as it is attractive. One plausible scenario is that the light reacts to the driver as they approach the car. It moves with them and indicates important vehicle contours or the door handle. When the driver gets in, the light follows as subtle OLED lighting is activated.

Unlike classic LEDs, which consist of semiconductor crystals, OLEDs are made from an organic material. In its initial condition the material is a thin film layer – the coating is only a few thousandths of a millimeter thick – on an absolutely flat surface such as highly polished display glass.

When an electrical voltage is applied, the molecules in the paste emit photons and the surface lights up. Depending on the distribution of the electrical input, the illumination can be either uniform, include specific light-dark effects or – typically Audi – generate dynamic movement.

5 Interaction

The designers and developers are increasingly turning vehicle lighting into an information medium by replacing one-way signals with interactive lighting technologies. The lighting adapts to the prevailing conditions and communicates with both the driver of the car and its surroundings.

OLED lighting
Audi is working on the use of organic light-emitting diodes (OLED) in the rear lights. One of the models for this is a light unit in which several OLED surfaces are positioned upright and one behind the other. It creates fascinating three-dimensional effects. Since the material can only withstand temperatures up to 80 Celsius, OLED lighting requires extensive thermal management.

Laser rear fog light
The laser rear fog light – another predevelopment project – fulfills an important safety function. Generated by a laser diode at the rear of the car, it presents the trailing driver a bright, clear signal, thus keeping them at a safe distance. If visibility is good, the beam from the laser rear fog light, which is fan-shaped and inclined slightly downwards, is seen as a red line on the road. The width of this line depends on the distance to the trailing vehicle: At a distance of 30 meters (100 ft), the line is about as wide as the car. This clear signal is an unmistakable warning to the driver behind to maintain a safe following distance.
In fog or spray, the laser beam strikes the water droplets in the air and makes them visible; the line is then seen as a triangle. The laser rear fog light looks like a large warning triangle.

Car-to-X communication
Car-to-X communication – the networking of cars among themselves and with the traffic infrastructure – also offers considerable potential in the lighting area. If cars share data among themselves, they can fine-tune the brightness of their headlights to one another. Consequently, together they can brightly illuminate the road, yet prevent glare at intersections or when facing oncoming traffic. When stopped at a red light or in a traffic jam, the headlights can be dimmed. Oncoming cars or cars in a crossing can even be detected without being visible for the front camera.

Interior lighting

Besides road lighting, the second major field of work for the Audi lighting developers and designers is interior lighting. The interior light directly affects the driver and the passengers. It influences their mood and sends them important signals to further enhance safety.

Figure 4: Interior Lighting styling study

Another topic are the moods and emotions evoked by colors of light – the color white alone has a wide range. Audi generally uses cool, "technical-looking" light corresponding to the progressive character of the brand.

In the new Audi Q7, the owner can adjust the color of the light virtually at will if the vehicle is equipped with the top version of the ambient lighting. A choice of 32 colors is available both here and for the marker lights, which are extremely narrow light guides that trace the contours of the instrument panel, in the doors and on the center tunnel console.

In a predevelopment interior styling study even further future ideas have been realized. The marker lights work intelligently together with the Exit Warning assistance system. If either the driver or a passenger want to open the door even though a bicycle or a vehicle is approaching from the rear, the light guide lights up in signal red and pulses at short intervals.

The interior study shows just how far the new information and safety functions could go in the future. The layered oak used as a decorative inlay on the center tunnel console, in the doors and on the instrument panel is backlit by LEDs. The light serves as a warning when exiting the car or parking. If the driver activates piloted driving in a traffic jam – a future assistance system – portions of the steering wheel rim light up in green. As soon as the driver has to take over the wheel again, the lighting changes color to red.

6 Lighting innovations in Audi race cars

From the racetrack to the street and vice-versa: At Audi, the developers of race cars and production cars collaborate extremely closely. The topic of lighting has proved to be particularly fruitful.

In the early days of the collaboration, most of the ideas originated from the production developers. In 2003, the reflector for the LED daytime running lights migrated from the top model A8 W12 to the racing version of the A4, which competed in the German Touring Car Masters (DTM). Three years later, the very successful R 10 TDI Le Mans sports car prototype adopted the daytime running lights and tail light signature of the R 8. In 2010, the R 15 TDI used the high beam reflectors from the LED headlights of the street sports car.

The situation changed in the new decade. Now racing – the world's toughest test bed – is providing inspiration for production. This was then the case for the LED headlights of the R 18 TDI from the 2011 season, for example. They delivered roughly 100 watts of power, around three times as much as in a street car, and thus light up the road over one kilometer ahead. The racing headlights required no electric cooling – the slipstream flowing through a special cooling duct was sufficient. It absorbed the heat of the LEDs, which was dissipated via tiny cooling elements made of graphite foam. The substructure of the reflectors and large portions of the housing were made of carbon fiber-reinforced polymer (CFRP). Each headlight weighed only around two kilograms (4.4 lb), a model for the production developers, who also wanted to reduce weight significantly.

In 2013, the R 18 e-tron quattro Le Mans sports car prototype presented the evolutionary step: the Matrix LED technology. A few months later, it made its street debut in the updated Audi A8 flagship. In June 2014, the racing and production developers documented their close collaboration with a double premiere: The new R 18 e-tron quattro and the special edition R8 LMX simultaneously presented the laser spot for the high beam at Le Mans. The grille-like appearance of the racing headlights served as the inspiration for the daytime running lights of the new Audi TT and Q7 production models.

7 Summary and Outlook

Aesthetics, dynamics and interaction - these terms characterize all lighting technologies developed by Audi. Their design brings Vorsprung durch Technik to life and underscores the brand values of progressiveness, sophistication and sportiness. Audi puts vehicle lighting into motion to create new, dynamic forms of expression. The light interacts intensely with the driver and the surroundings.

The next step: Matrix laser technology
One of the next steps will be the Matrix laser technologies. A chip fitted with hundreds of thousands of individually controlled micro mirrors divides the light of a laser into tiny pixels. This technology makes it possible to create the ideal light pattern for virtually any driving situation or even to project graphical information onto the road.

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Lighting innovations of future BMW vehicles

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Keywords: Laser, OLED, Customizing, Micro-lens-array, Adaptive Light Functions

1 Abstract

This paper describes future automotive lighting functions in a comprehensive and detailed.

2 Introduction

New vehicles are equipped with an increasing number of innovative lighting systems and functions. These lighting systems have to deal with the conflict between security, functionality, design and efficiency.

Light functions can generally be categorized into illuminating lighting functions and signaling functions. BMW's primary task of the new innovative illuminating functions is to increase road safety. However, innovations in signal functions emphasize the emotionality of the brand character and appearance of a BMW (see figure 1).

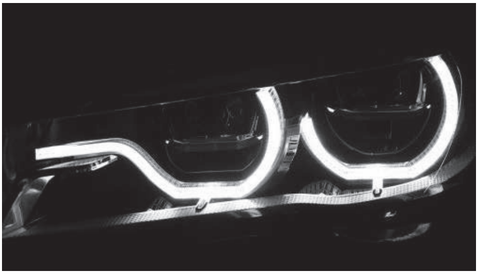

Figure 1: BMW Laser Iconic Lights

3 Innovations in signal functions

The brand-shaping character of a vehicle is increasingly realized by the use of new lighting technologies, such as OLED, LED, laser, 3D light guide and mirco-optics. These technologies can improve the design of a vehicle significantly by creating brand signatures, so-called light icons, with a high value of brand recognition. These light icons have to be always perceived in the same way even with different ambient brightness, be it day or night.

Brand-shaping headlamp appearance

With the introduction of the BMW 7er Series LED headlamp in 2012 the idea of a double round-light icon also in the low beam was implemented for the first time in a BMW [1]. With the new generation of laser headlights this idea is continued by a new approach. The new approach is to reconstitute the divisions of the high beam. In conventional LED headlamps with projection modules or reflectors the full low beam is generated by the module in accordance with the ECE and FMVSS regulations [2]. This new approach realizes a part of the low beam (Sign-Light) from the three-dimensional daytime running or position light guides in order to meet the scattered light values according to ECE R123 (S50, S50LL, S50RR, S100, S100LL, S100RR)(see Figure 6). To implement the position / daytime running light according to the legal requirements the sign light is realized by another separately controllable LED Channel.

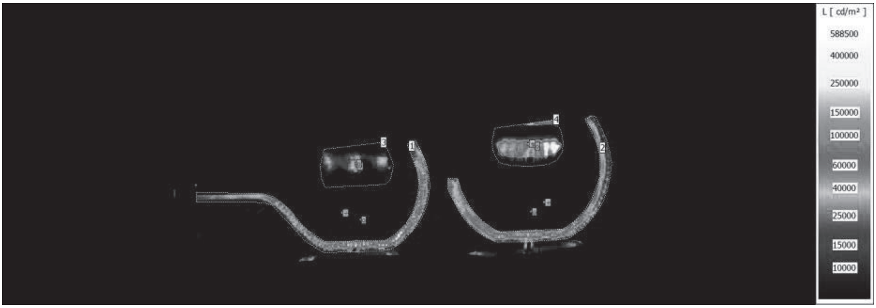

Figure 2: Luminance picture of future Laser-headlamp

	Position lamp	Low beam	DRL
Region 1	10340 cd/m²	43450 cd/m²	96110 cd/m²
Region 2	10640 cd/m²	44770 cd/m²	99950 cd/m²

Table 1: Overview of the luminance levels of BMW Icons in different function modes

The division of the low beam light distributions can create an appearance that is characterized by a large Michelson contrast of 0.23 between the low beam projections modules and the three-dimensional light guides (see Figure 2). For comparison, a BMW 4-LED headlamp has a Michelson contrast of 0.04 in the low beam. The typical BMW icons of the IconLight headlamp has for the first time three different luminance levels in accordance with table 1, which create a recognizable appearance under any situations. In accordance with the homogeneity criterion for [3] the light icons have a value of 0.11 for each of the two light guides. Additionally, future laser headlamps have a white staging light on the sides of the central bar of the two low beam modules.

Welcome- and goodbye-light orchestrations

The development of the BMW light icons does not only take place in the front with the signal functions of the headlamp, but also in the entire vehicle. At the CES 2015 BMW has already shown potential dynamic staging using an OLED tail light. In the future different staging sequences can be created by individually controllable OLED segments (see Figure 3). The technology will evolve in such a way that in the future the customer might be able to choose between different welcome light animations in the front and the rear. With this possibility a vehicle owner would be able to individualize his/her light and thus his/her vehicle.

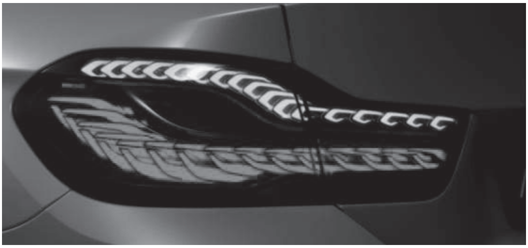

Figure 3: OLED Staging [4]

Welcome-light carpet

Another upcoming highlight that will significantly enhance the premium feel of a BMW at night is the BMW Welcome Light Carpet. This novel light function is activated by unlocking or opening the car and welcomes the customer by projecting a full-size brilliant light graphic onto the entrance areas on both sides of the car. The light module is integrated inside the front sill cover and projects light beneath both doors to the street avoiding any blocking or disturbing swiveling effects alternative module positions (e.g. door, mirror) would cause (see Figure 4). This super low module position along with the demand for impurification tolerance and full image quality can only be fullfilled by the world's first application of a novel projection technology called Array Projection Technology [5],[6].

Figure 4: Exterior design of the BMW Welcome Light Carpet.

The working principle of an array projector is inspired by nature's insect eyes: A so-called micro-lens-array (MLA) is illuminated by a high-power LED and projects hundreds of single images that superimpose with each other to create an integral image even under very small incidence angles. A MLA inside the Light Carpet module consists of a multitude of 150 projectorlets, each containing a condenser microlens, a chromium slide and a projection lens within a package size of only $11x11x3mm^3$ (see Figure 5). The unique layout of a MLA leads to significant technical benefits compared to standard LED projectors regarding compactness, image quality, illuminance homogeneity and impurification tolerance [7], [8].

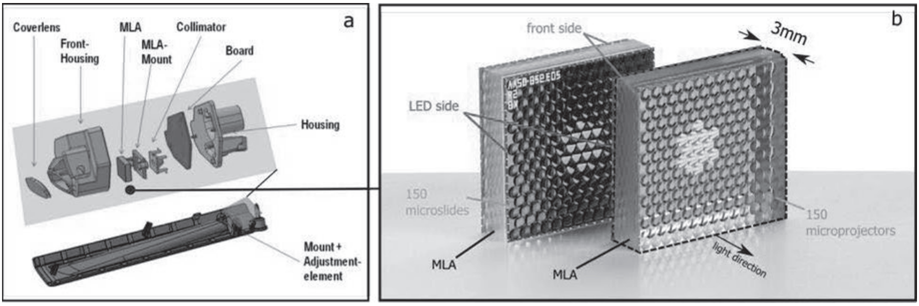

Figure 5: a) Explosive drawing of the BMW Welcome Light Carpet module. b) Detail view of the frontside and backside of two micro-lens-arrays (MLA), the core optical element of the Welcome Light Carpet module. It's optical layout is based on array-projection technology

So the Welcome Light Carpet provides premium light quality and creates the most exclusive welcome scenario within the market. It will substainable change the night perception and recognition value of upcoming BMWs.

4 Innovations in illuminating light functions

The introduction of laser light sources in BMW headlamps glare-free high beam is realized, which cannot be achieved by other technologies considering performance, package and efficiency. Vehicular lighting systems and lighting systems in general are developing rapidly at the moment. In addition to the creation of new adaptive lighting functions, the development of light sources is also speeding up [9].

Whereas the function based developments, like marking light [10], are enabled by new camera and sensor systems, the progress of light sources enable both: increased safety levels and new styling possibilities. With the development of a new, laser based light source, with significantly enhanced luminance it is possible to set up efficient and high performing lighting systems within an extremely small package.

One example is the high beam system of the BMW i8. It comes close to the allowed maximum high beam intensity, using a reflector of just about 30mm x 30mm.

Laserbased glare-free high beam

Ideally, the luminous intensity of the resulting hotspot is proportional to the luminance of the high-power white pc-LED, the efficiency ratio of the luminous flux on the road to the luminous flux produced by the light source, the aperture of the lighting module and the number of the LED chips as highlighted by the following equation [2]:

$$I_{hotspot} \sim A \cdot N \cdot \eta \cdot L_S$$

This equation shows that by the use of a high luminance light source the size of the complete system can be reduced. The correlation is indirect proportionally. Ideally, the use of a light source with a ten times higher luminance can reduce the area of the optical element by this factor.

The reduction of the light emitting area of a light source has a huge impact on the size and the efficiency of an optical system. Considering the Ètendue – term, the surface of a reflector can be decreased, if the light source itself decreases in its size. This potential can be used to design a much smaller package for a glare-free high beam by using the new developed laser light source.

In addition, because of the optimal point source like optical behavior of the new light source, the optimal concept can be simplified. So for example a glare-free high beam system with a sharp vertical cutoff line can be realized with a reflector-only-system. The projected area of this reflector is possible with less than 30 x 30 mm and without shutter but distributes the light in such a efficient way that the optical performance of the current systems are improved.

Beside the efficiency, the adavantages created by the implementation in glare-free high beam systems are the main reason for the use of a laserbased light source.

Modern, swivelling led low and high beam systems are partitioned in several functional areas, as there are: forefield, cut-off line and kink for the low beam and symetrical as well as glare-free high beam (see Figure 6). A part of these elements is swivelled with a accuracy of up to 0,1°. By the split of the available optical area in many elements, each element has just a limited space available. For not swivelled, fixed, array based high beam systems, where even the high beam is divided in up to 12 elements the light efficiency and maximum light intensity is limitied.

To provide the driver with the best possible safety and perception of a glare-free high beam system a certain light intensity of the ADB part of the high beam is compulsory. At this point standard light sources tend to struggle in the area of conflict between function, efficiency and design, whereas laserbased systems can provide sharp edged light distrubitions with a high maximum intensity by using the high luminance.

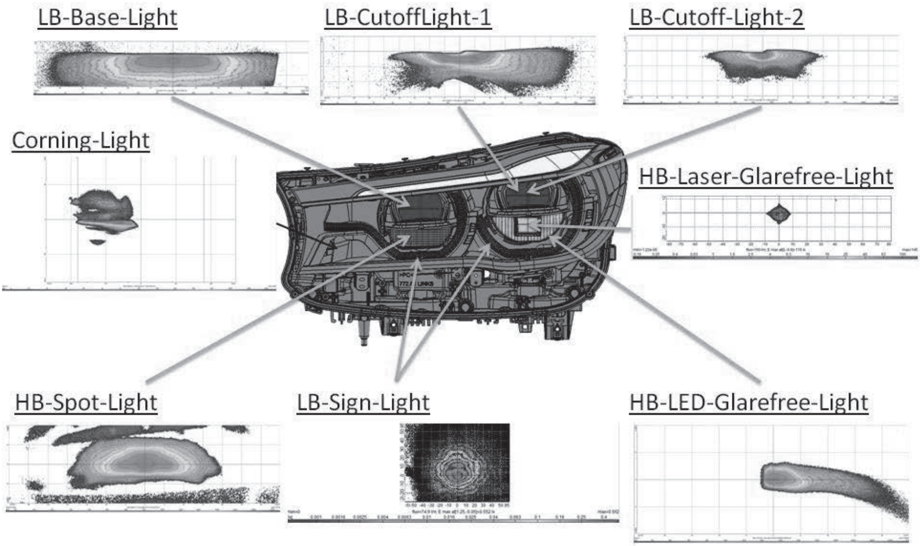

Figure 6: Division of the low beam light distributions of the BMW Laser Iconlight headlamp

Summed up, in the application glare-free high beam, the laser based light source can use and show all of its advantages:

- Small package
- High system efficiency
- Optimal light distribution
- High luminous intensity

Photometric performance

The performance of the laser headlamp in full high beam below and above 60 km h and the performance in the glare-free high beam operation mode according to the BMW high-beam evaluation method is shown in Table 2. In this evaluation method, the 1, 3 and 5 lx isolux lines are used to determine the visibility range [11]. The laser light source is completely turned off for safety reasons below 60 km/h. Above 60 km/h, the laser light source is activated. With the additional laser light source the range of zone A and zone B is almost doubled.

	Laser headlamp full high beam <60 km/h	**Laser headlamp full high beam > 60 km/h**	**Laser headlamps ADB - proceeding car in 120m**
High beam Range Zone A [m]	174	349	144
High beam Range Zone C [m]	154	283	216
High beam Range Zone D left 2m Height [m]	6,5	7,0	7,0
High beam Range Zone D rights 2m Height [m]	6,1	6,9	6,9
High beam Range Zone D left [m]	11,6	11,7	10,9
High beam Range Zone D right [m]	11,5	12,1	11,8
Max. Illuminance left headlamp [lx]	79	279	265
Max. Illuminance right headlamp [lx]	99	276	244
Flux left headlamp [lm]	1348	1798	1401
Flux right headlamp [lm]	1328	1763	1350

Table 2: Overview of laser headlamp full high beam and glare-free high beam performance

Anti traffic sign glare

To ensure the best possible illumination for the driver, the lighting system adapts intelligently over the network with the vehicle sensors to traffic situations, environmental factors and the surrounding.

Many drivers complain about feeling glared by traffic signs while driving with high beam [12]. This effect is intensified by the use of extremely performing headlamp systems with significantly higher illuminance levels. The conflict of aims between the highest possible high beam range and low traffic sign glaring is solved by an adaptive image-based real-time control of the headlight brightness.

During the activation of glare-free and full high beam the system is able to respond to high light intensities on traffic signs with three different dimming steps to ensure the optimal illumination of the road. Figure 7 illustrates the control loop of the system consisting of the camera system, the controller, the mobile lights and the control system.

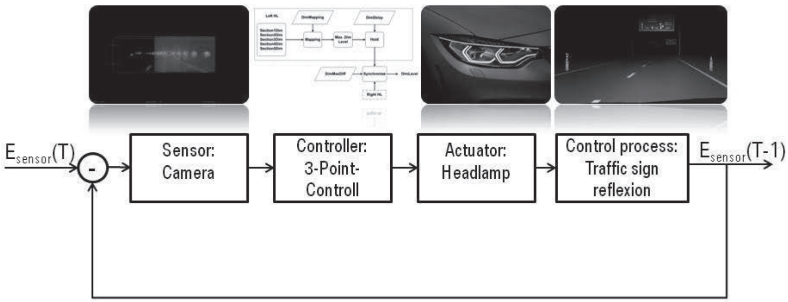

Figure 7: control loop anti traffic sign glare.

In a variety of night time driving with experts the following knowledge was gained: The subjective glare is highly dependent on the age of the particular driver. This information must be taken into consideration when designing the control strategy for anti traffic sign glare. For future generations of vehicles, the function of anti traffic sign glare will therefore be individually configure able for the driver.

In addition to the camera-based control system, the light functions are controlled by an acting background navigation system. This does not only allow the improvement of the change between the light distributions (town light to highway light, two-sided activation of the glare-free high beam at country roads), but also enables the implementation of new features with which the road safety can be improved while driving at country roads or highways. Examples of these are, among others, the predictive curve light, S-curve light, narrow passage guidance light and intersection light.

Dynamic eco-light function

The requirements for the illumination of an urban, lit environment differ completely from the ones for driving on country roads or highways. In urban areas there are lots of traffic jam situations when the low beam of a vehicle lights only the rear of the preceding vehicle. This part of illumination does not contribute to an increase in road safety but is a possible irritation for the preceding vehicle driver and in addition an unnecessary energy consumption.

Therefore, a function for saving energy and CO2 was implemented that detects a preceding or stationary vehicle using a stereo camera and that dims the low beam on an energetic optimum. Depending on the different headlights between 25% to 33% energy can be saved by the help of this eco function. The dimming of the low beam is performed depending on the distance including a hysteresis (<10 m) and the speed (<20 km/h) of a detected preceding vehicle. The approval of Eco-dynamic lighting function is another variant of the city light distribution. Due to the increased use of LED light sources, a further amount of the energy savings will be achieved. The change of the low and high beam, the position light and the license plate light according to EU Decision more than 1 g CO2/km is saved compared to conventional technologies [13]. Because of this future BMW vehicles are considered as a European eco innovation.

A social trend the entire automotive industry has to face in the future is the growing urbanization and, consequently, the increased use of car sharing portals as mobility services. Many of these customers do not need all the available light functions all the time because they drive the vehicle only in urbanized areas. Nevertheless, there will be the wish of customers to improve the light performance and functionality at unscheduled overland trips. For this request light functions such as a cornering light, glare-free high beam or a high beam boost that could be activated temporarily can increase traffic safety especially at cross-country trip.

5 Summary and Outlook

The content of this paper reflects the increasing customer requirements regarding the design and function. The BMW Group responds to these demands by creating innovative, new lighting functions. These light innovations do not only increase the safety on the road, but fascinate the customers with the high quality design. This fascination is created by new lighting functions while driving and also when the vehicle is accessed by all lighting components around the vehicle. Another focus for future developments is the individualization of the functions to the demographic change and the different preferences of customers.

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An auto-leveling system using an acceleration sensor

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Keywords: Automatic leveling, Acceleration sensor

1 Abstract

Under UN regulations, auto-leveling is mandatory for LED headlamps. Current systems calculate the vehicle pitch angle from the vehicle heights measured by a sensor mounted either on both or one of the axles and control the optical axis of the headlamps. Being heavy, however, these vehicle height sensors account for a large part of the system's cost and so there is a great demand to reduce their weight and cost.

To meet the demand, we have developed a smaller, lighter, and lower-cost auto-leveling system by replacing conventional vehicle height sensors with an acceleration sensor. This involved solving two critical issues:

- While a vehicle stands still, a detected pitch angle directly from acceleration sensor is a sum of the pitch angle of the vehicle against the road surface and the slope angle of the road. A method to extract the vehicle pitch angle is achieved.
- While a vehicle is running, an acceleration sensor is heavily affected by movement of the vehicle and a signal of vehicle pitch angle is submerged in the movement. A method to detect pitch angle under dynamic acceleration is achieved.

This paper shows details of these methods and accuracy of the system which is comparable to a system that uses two vehicle height sensors.

2 Introduction

Too much glare might not only annoy preceding and oncoming drivers but also hinder their field of vision and safe driving. Under UN regulations, auto-leveling is mandatory for HID and LED headlamps, but it has been confirmed by GTB's experiment that excessive glare is caused when the optical axis of the headlamps turns upward as the vehicle pitch angle moves, regardless of the type of headlamp light source [1].

Current auto-leveling systems calculate the vehicle pitch angle from the vehicle heights measured by a sensor fitted on both or one of the axles and control the optical axis of the headlamps. Being big and heavy, however, these vehicle height sensors account for a large part of the system's cost. Further, it is time-consuming to design how to fit the vehicle height sensors on the vehicle body and route the wiring harness.

If the auto-leveling system could be made smaller, lighter, and lower-cost, it would be affordable for a wider variety of vehicles and offer safer headlamps for drivers. We have therefore developed a static auto-leveling system that eliminates vehicle height sensors and instead calculates the vehicle attitude angle with an acceleration sensor built into the ECU. This paper discusses the principle of how to calculate the vehicle pitch angle from acceleration data, which is the key to developing an auto-leveling system using an acceleration sensor.

3 System Configurations

3.1 Conventional vehicle height sensor types

(a) Two-sensor types

As shown in Fig. 3-1, the system measures the front and rear vehicle heights with vehicle height sensors fitted on the front and rear axles and calculates the vehicle pitch angle by equation (i). While this system can accurately calculate the vehicle pitch angle, two-sensor types are heavy and expensive.

(b) One-sensor types

The system predicts the vehicle pitch angle with a vehicle height sensor fitted on the rear axle only. One-sensor types are lighter and lower-cost than two-sensor types, but while meeting the regulations, they tend to shorten the visible distance and prevent the headlamps from delivering their full performance (see Fig. 5-1).

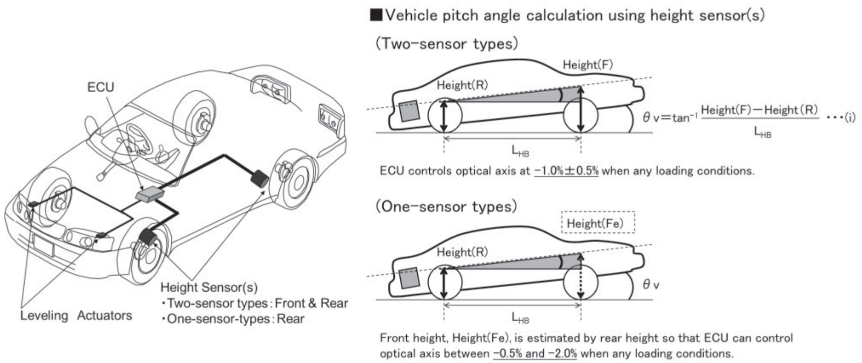

Fig. 3-1 System configurations of vehicle height sensor types

3.2 Acceleration sensor types

To solve the above problems of the vehicle height sensor types, we have developed a static auto-leveling system that eliminates vehicle height sensors, and instead calculates the vehicle pitch angle with an acceleration sensor built into the ECU, and controls the optical axis of the headlamps (Fig. 3-2). This makes the system much smaller, lighter, and lower-cost than the vehicle height sensor types, while eliminating the time required for designing how to cleverly fit the vehicle height sensors on the body.

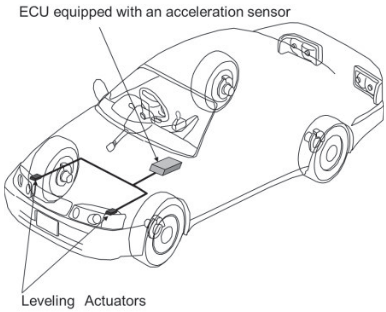

Fig. 3-2 System configuration of the acceleration sensor type

Small sensors capable of detecting angles include gyro sensors and geomagnetic sensors, but we chose acceleration sensors to replace the vehicle height sensors considering their angle detecting accuracy and other issues discussed below.

The optical axis is controlled relative to the direction in which the vehicle pitches. Hence we defined the vehicle pitching direction in a vehicle coordinate system made of a vector in the vertical direction and a vector in the longitudinal direction of the vehicle with the sensor fitted in an attitude as shown in Fig. 3-3. Once the vertical direction and the longitudinal direction are determined, the horizontal direction is uniquely determined. Although the figures are shown in two dimensions for simplification, we calculate the vehicle pitch angle without limiting the fitting attitude of the sensor by defining the vehicle coordinate system using a triaxial acceleration sensor. Angle is calculated using an acceleration sensor as shown in Fig. 3-4. From the gradient of the gravity acceleration vector relative to the reference axis measured while the vehicle is parked, we can calculate angles using the longitudinal component (x) and the vertical component (z) of the gravity acceleration vector in the vehicle coordinate system defined in Fig. 3-3. In principle, we can calculate the vehicle pitch angle and control the optical axis based on the above concept. In practice, however, we have to solve two questions before making the system really work. The next section describes how we addressed these issues.

Question 1: How to extract the vehicle pitch angle while parked?

The angle to be obtained in the calculation in Fig. 3-4 involves the vehicle pitch angle and the slope angle of the road. We have to extract the vehicle pitch angle from the result of this angle calculation.

Question 2: How to correct errors?

In Question 1, we calculate the vehicle pitch angle by calculating relative values. Since this causes accumulated errors, we must provide the system with a means of correction.

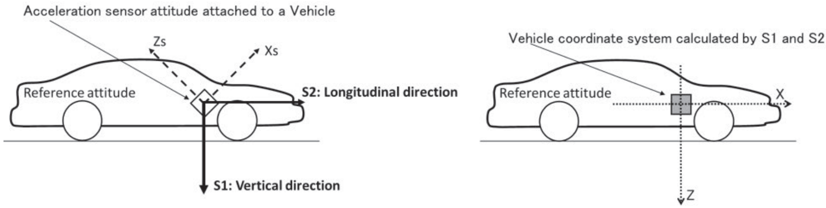

Fig. 3-3 Definition of the vehicle coordinate system

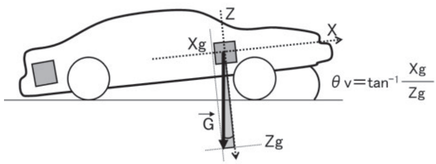

Fig. 3-4 Gradient calculation using gravity acceleration

4 Methods

4.1 Q1: Extracting the vehicle pitch angle

With a vehicle height sensor type, we can calculate the vehicle pitch angle directly from vehicle height values as shown in Fig. 4-1. On the other hand, with an acceleration sensor, the angle is calculated from the gravity acceleration while the vehicle is parked, so the angle involves both the vehicle pitch angle and the slope angle of the road. By definition, this calculation cannot give the vehicle pitch angle itself. Therefore, we have to extract the vehicle pitch angle from the gradient angle (“sensor angle”) calculated using gravity acceleration.

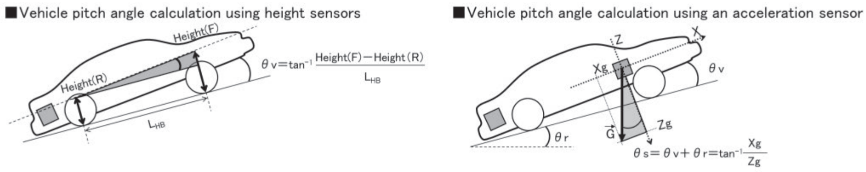

Fig. 4-1 Calculating the sensor angle

The vehicle pitch angle can be relatively calculated as shown in Fig. 3-2. First, the vehicle pitch angle and the slope angle of the road in the initial state (Point A) are both assumed to be 0%. Then, the vehicle moves from Point A to Point B without stopping along the way. Here, the load basically does not change while running (the vehicle pitch angle is kept at 0%), so, when the vehicle stops at Point B, the sensor angle represents the slope angle of the road at Point B. In other words, the difference between the sensor angles before and after the running represents the change in the slope angle of the road. The slope angle of the road can be calculated by subtracting the vehicle pitch angle from the sensor when the vehicle stops.

If the vehicle is loaded with baggage in the trunk while the vehicle is parked at Point B, the change in the sensor angle sensed when the trunk is loaded represents the vehicle pitch angle, since the slope angle of the road does not change while the vehicle is parked. Then we can get the vehicle pitch angle by subtracting the slope angle of the road from the sensor angle.

Thus, by repeating the cycle of calculating the slope angle of the road sensed the moment the vehicle stops and calculating the vehicle pitch angle while it is parked from the initial state, we can relatively extract the vehicle pitch angle from the sensor angle calculated using the gravity acceleration vector.

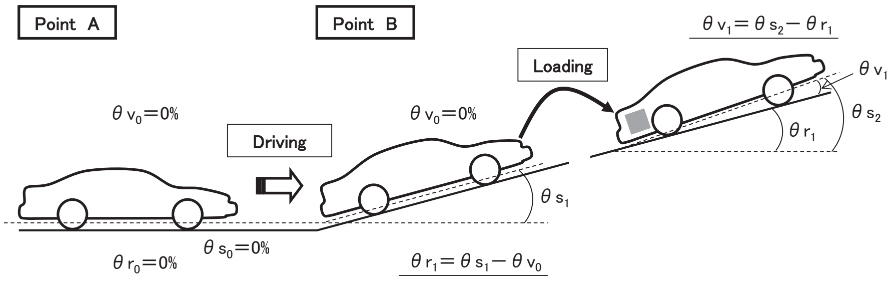

Fig. 4-2 Extracting the vehicle pitch angle

4.2 Q2: Correcting errors

As shown in section 4.1, the vehicle pitch angle while parked is calculated by integrating the relative change of the sensor angle. Generally, errors accumulate in the process of such integral calculation, so we have to correct these accumulated errors. There are several ways to correct the errors, but the most practical one for an auto-leveling system is to calculate a reference for correction by another method and then to correct errors by comparing the vehicle pitch angle calculated while parked and the reference. By getting precise and frequent correction timings, we can quickly correct errors and keep the optical axis accurate.

While the vehicle is parked, only the gravity acceleration works and so it is difficult to acquire information enabling the above correction. Instead, we considered calculating the vehicle pitch angle while running. With vehicle height sensors, the same equation holds whether the vehicle is running or parked as shown in Fig. 4-1. With an acceleration sensor, however, the dynamic acceleration of the running vehicle is added, and the angle calculating equation for the parked vehicle no longer works. Since the output of an acceleration sensor is the composite of the gravity acceleration and the dynamic acceleration, it can be expressed as shown by the equation in Fig.4-3. The equation shows that the sensor value involves the vehicle pitch angle and the slope angle of the road even while running. In other words, when calculating the vehicle pitch angle while running, too, we have to find a way to extract the vehicle pitch angle from the sensor value.

Accordingly, we developed a method for calculating the vehicle attitude angle while running using the following movement acceleration vector. The movement acceleration of the vehicle during acceleration or deceleration parallels to the road surface. Since the acceleration sensor outputs a composite value of the gravity acceleration and the movement acceleration, the output of the acceleration sensor while running draws a trajectory parallel to the road surface, as shown in Fig. 4-4. When the load condition changes, the trajectory itself remains unchanged, but the vehicle's coordinate system inclines as the vehicle pitch angles changes, so the trajectory's gradient viewed from the vehicle's coordinate system looks changed. This rule does not change even when the road surface inclines. Thus, we can calculate the vehicle pitch angle while running by calculating the gradient of the trajectory viewed from the vehicle coordinate system. This principle also eliminates the slope angle of the road contained in the output value of the acceleration sensor and extracts the vehicle pitch angle.

The above model allows us to calculate the vehicle pitch angle while running, but, in actual running, the output of the acceleration sensor significantly varies due to the effects of vibrations, etc. acting on the vehicle, lowering the accuracy of calculation. Hence, in calculating the vehicle pitch angle in actual running, we collect and process data that are not greatly affected by vibration and other effects as shown in Fig. 4-5.

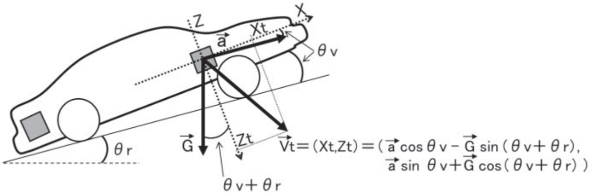

Fig. 4-3 Dynamic acceleration and gravity acceleration

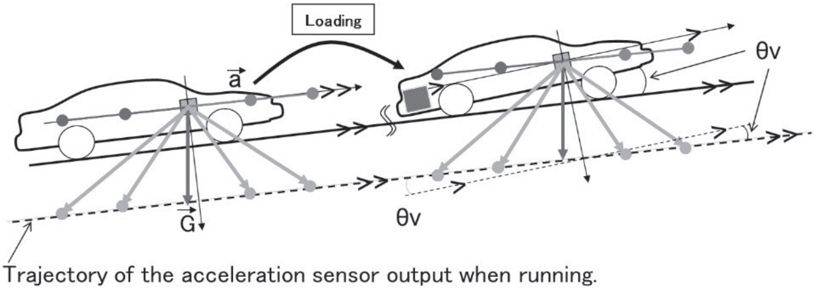

Fig. 4-4 Calculating the trajectory

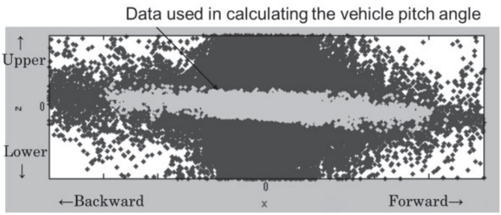

Fig. 4-5 Distribution of acceleration while running

5 Evaluation

5.1 The optical axis precision while parked

We evaluated the precision of the optical axis while the vehicle is parked. The result showed that the developed product achieved an optical axis precision equivalent to two-sensor types under each load condition as shown in Fig. 5-1. This is because it can detect the vehicle gradient itself with the acceleration sensor just like two-sensor types.

One-sensor types estimate the vehicle pitch angle from the rear vehicle height and the precision of the optical axis reduces under certain load conditions. The developed product provides greater optical axis precision than one-sensor types.

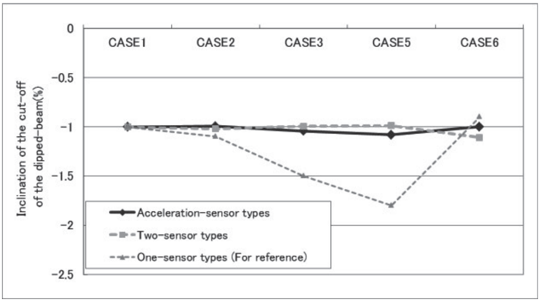

Fig. 5-1 Optical axis precision while parked

5.2 The optical axis precision while running

To check the precision of the optical axis while the vehicle is running, we calculated the average values of the vehicle pitch angle to be calculated when the vehicle ran 200 km in the load conditions of Case 1 and Case 6. The result showed that the developed product achieved an optical axis precision equivalent to that of two-sensor types (Fig.5-2). The result also confirmed that the principle of calculation of the vehicle pitch angle while running explained in section 4.2 is correct and detects the difference of loads.

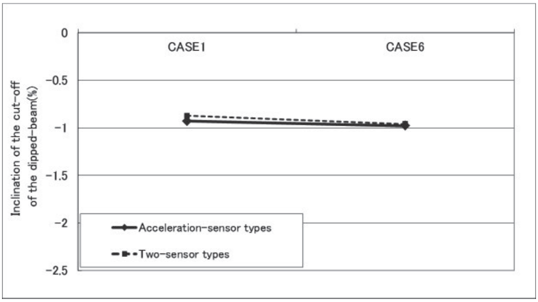

Fig. 5-2 Optical axis precision while running

6 Summary and Outlook

We have developed an auto-leveling system using an acceleration sensor integrated into the ECU instead of vehicle height sensors fitted on the axles. This paper described the principle of calculation of the vehicle pitch angle necessary to make the system work. The developed product achieved an optical axis precision equivalent to vehicle height sensor types by calculating the vehicle pitch angle by adding changes in the gravity acceleration while the vehicle is parked and correcting accumulated errors generated in the above calculation with the vehicle pitch angle calculated from the trajectory of the movement acceleration of the vehicle while running.

In the future, we will integrate the product with AFS and ADB functions and thereby offer drivers headlamp systems which make driving safer.

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Possibilities to introduce a High End Lighting System in the Non- Premium Market

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Keywords: LED, Glare-free high beam, ADB, Opel, Matrix

1 Abstract

In recent years the complexity of lighting functions has increased intensivly. Dynamic bending, full AFS or glare-free high beam systems are executed with different light sources. Today, high end premium lighting systems are designated for the premium market.

This paper describes and characterices the technical key aspects of a high-end premium lighting system. It clearly states how brightness, homogenity, segment resolution, need to be developed to ensure a lighting system with sophisticated design at an affordable price.

It also deals with additional software-controlled lighting features which need to be established, evaluated and validated to minimize the system costs while offering premium lighting performance.

2 Introduction

Short Introduction and motivation of the paper. (style: standard)

In the past, the OPEL exterior lighting strategy has been to offer high-end lighting features at an affordabl costs to the mass market. So far, OPEL has offered its Adaptive Forward Lighting (AFL) system in HID technology in most of its car lines. These systems provide different Low Beam patterns such as town, country, motorway, adverse weather light combined with a static cornering light (Figure 1). To improve drivers visibility in curves, the OPEL AFL systems are equipped with a mechanically swiveling module. Up to now, simple sensor inputs (steering angle, vehicle speed tec.) have been used to control headlamp lighting functions while AFL headlamps have been usually connected to a camera system to provide a high-beam auxiliary function.

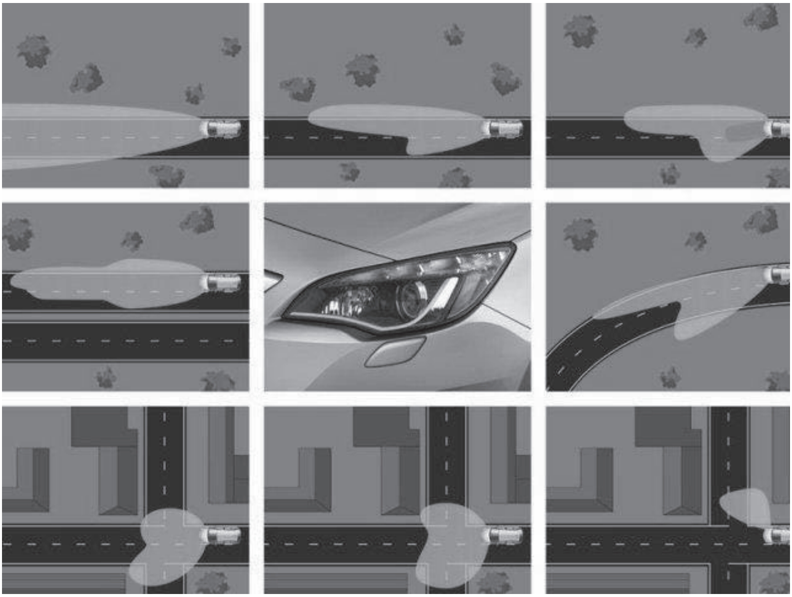

Figure 1: Todays OPEL AFL HID Light Distributions

Based on its current lighting strategy, OPEL is proud to introduce the LED Intellilux Matrix system in the compact segment. It's the first time that a high-end premium lighting system has been offered on the mass market. In order to provide the necessary technology for the OPEL Astra Segment, five-years of development were required to define and locate the technologically-relevant system requirements.

3 Challenges during the production development

During the development phase of the first serial-productoin LED Matrix headlamp, new technical solutions had to be established. LEDs as multiple light sources offer new potential compared to single light sources like the conventional HID technology. Conventional headlamp development is no longer applicable for LED Matrix headlamps. The complexity of the system has increased dramatacilly. To enable the start of the production development different prototypes with different light and Matrix technologies had to be prepared and evaluated in different clinics (Figure 2).

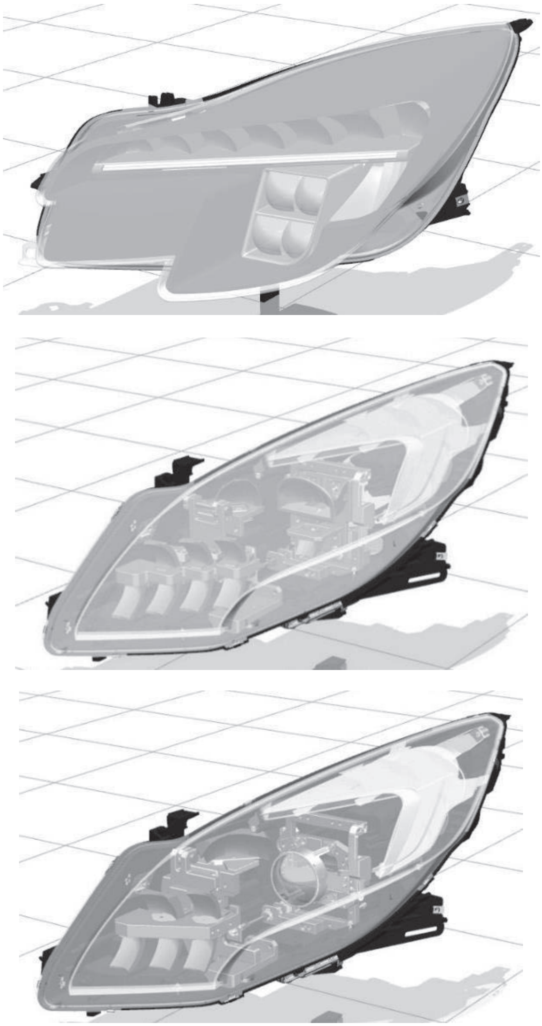

Figure 2: Different headlamp prototypes

The interaction between the headlamp and the vehicle increases the complexity and limits the requirements for the lighting system. Facts like object detection timing, camera opening angle (Figure 3) or object clustering are now part of the headlamp development.

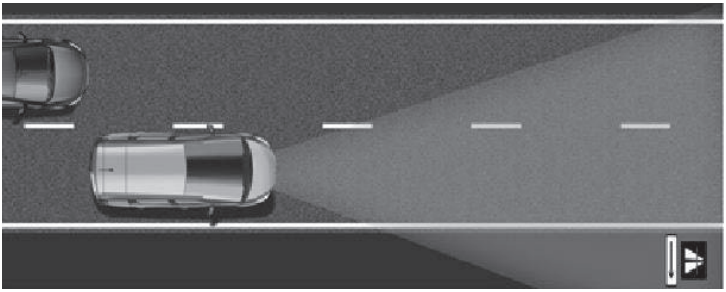

Figure 3: Camera viewing angle

4 LED Low Beam Patterns

The LED Matrix technologies make it possible to drive with high beam or partial high beam at all times. As a result, the focus of different, required low beam patterns is determined by low speed and town conditions. The new Intellilux headlamps offer six different low beam patterns.

Country Light:

The Country Light distribution (Figure 4) offers the basic beam pattern with deactivated cornering lights. The activation profile is connected to the LED Matrix High Beam.

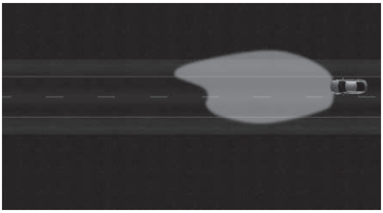

Figure 4: Country Light

Town Light:

The Town Light distribution (Figure 5) is comparable to the Country Light with cornering lights dimmed down to 20% intensity (increased beam spread at low speeds).

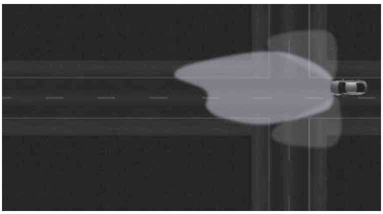

Figure 5: Town Light

Stop Mode Light

The Stop Mode Light (Figure 6) distribution is the Town Light without cornering lights (reduced electrical power with engine off).

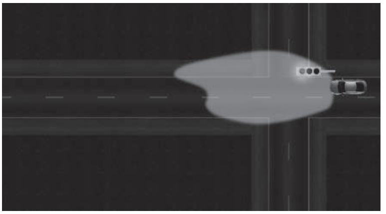

Figure 6: Stop Mode Light

Cornering / Curve Light

Full intensity of the Cornering Light (Figure 7) with turn on or steering wheel turned. Also used as static bending light with curve radii up to 500 meters.

Figure 7: Cornering / Curve Light

Tourist Mode

The Tourist Mode (Figure 8) provides a slightly reduced intensity while leveling is moved slightly downward.

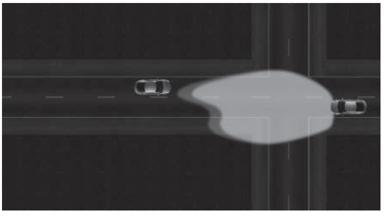

Figure 8: Tourist Mode

Backing-up Light / Maneuvering Light

By activating the reverse gear, the Country Light is activated with both cornering lights and both back-up lights on (Figure 9).

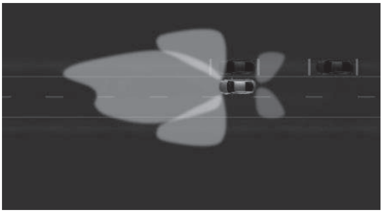

Figure 9: Backing-up Light / Maneuvering Light

Under low speed conditions, the non-swiveling modules of the LED Matrix headlamp have to be designed similar to former HID swiveling systems. The same effects is achieved by adapting the low beam and cornering patterns and adding an intelligent LED control system.

5 LED Matrix High Beam Patterns

On the basis of a static LED Matrix High Beam light distribution the complete high beam concept had to be redeveloped. The advantage of a LED Matrix system is that objects can be illuminated glare-free, which increases driver visibility compared to conventional systems. The weak point of the system is the dynamic behavior in curve conditions. A wider high beam spread is necessary to illuminate smaller curve radii as well. The design of the outside segments is smoother compared to the typical single Matrix segment. Vehicle system factors that are limiting such as detection angle of the front camera or data speed on the BUS system have also been considered in designing such new beam patterns. The final high beam spread is increased from +/-13° to +/-21° (Figure 10).

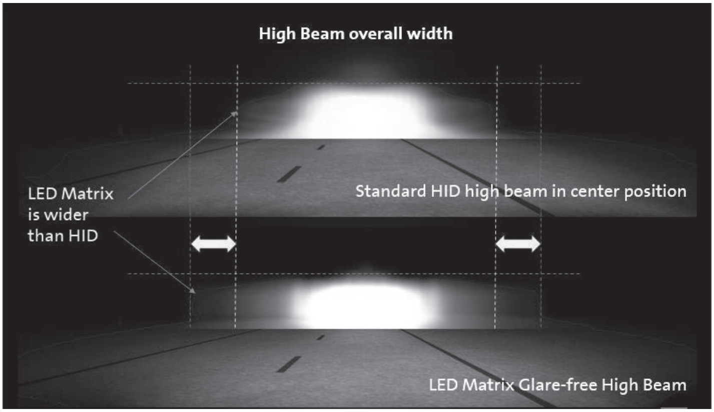

Figure 10: Width of high beam pattern of swiveling versus static Matrix systems

6 Motorway Mode

Driving on motorways under high speed conditions and with high traffic densities require software-relevant adaptions of the Matrix system. The wider high beam distribution leads to a performance decrease on motorways, so the Intellilux system has implemented a specific motorway mode. This system automatically calculates when a vehicle is driving under specific critical conditions. In such cases, the high beam spread is optimized towards the upcoming traffic (Figure 11).

This feature guarantees a smoother performance adjustment by ensuring the glare-free high beam functionality under high speed conditions with higher traffic densities.

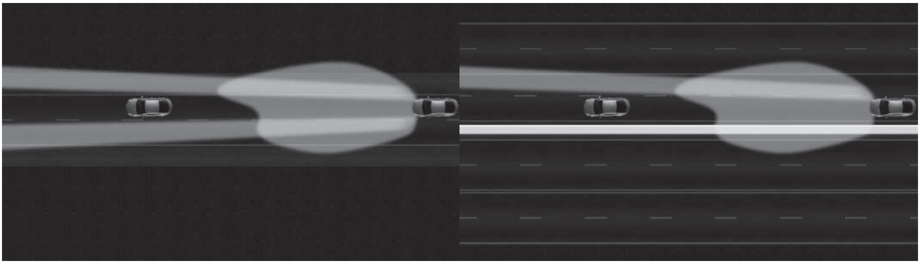

Figure 11: Glare free high beam under conventional conditions versus motorway conditions

7 LED Matrix High Beam Resolution

To enable a premium lighting system in the compact segment, a specific high beam resolution is required. The new Astras IntelliLux system offers 16 single elements which can function individually according to traffic emergence probability . Their width, height and intensity have been designed on the basis of curve radii and other relevant driving conditions to enable a perfect high beam resolution (Figure 12).

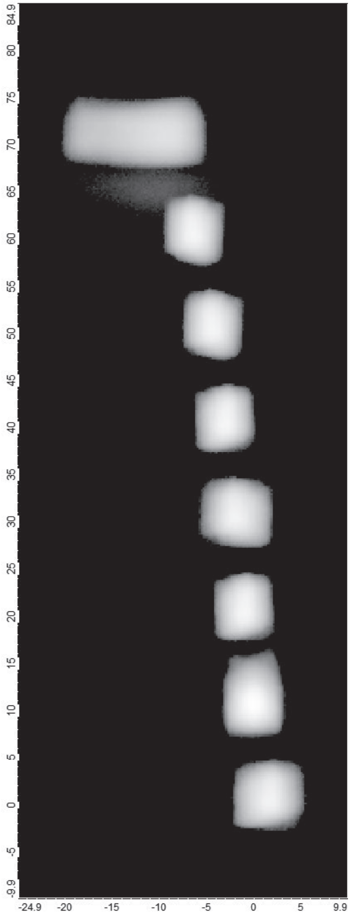

Figure 12 – LED Matrix High Beam Resolution

8 Welcome Light

The new Astra offers a specific Welcome Light sequence. When the vehicle is opened, the lighting system welcomes the driver by flashing the High Beam Units and pulsing its dipped beam. The pulsing dipped beam signals that the lighting system is ready to be started.

9 Summary

With the LED IntelliLux Matrix Headlamp, OPEL is entering a new chapter for exterior lighting systems. It's the first step in developing and offering high-end premium lighting technologies on the mass market. OPEL points out that recently introduced premium driver assistance systems are not designated for the upper segments. The challenge of developing such a high-end system has been achieved by using the latest LED technology and implementing complex solutions and software adaptions.

The Mercedes-Benz Headlamp of the Future: Higher Resolution with Greater Intelligence for Enhanced Safety

Björn Böke, Dr. Markus Maier, Dr. Jörg Moisel, Florian Herold; Daimler AG, Germany

Keywords: adaptive driving beam, LED, MULTIBEAM, High Range, Laser

1 Introduction

Maximum illumination for the driver with minimal dazzling of oncoming traffic are important criteria in automotive lighting systems. And it was an important issue even back in the 1950s when traffic volumes started to increase inexorably. Computer pioneer Konrad Zuse then had the idea [1] of using multiple headlamps, each of which illuminated one area of the road and switched off via photocells as soon as other vehicles were detected. This function is known as partial high beam.

Due to the size of the bulbs used at the time, this technology was not able to be realised as the headlamp would have been extremely large. When the blue LED was developed, however, it suddenly became possible to miniaturise the light sources to the extent that a large number of white light LEDs with luminous surfaces in the millimeter range could be mounted behind a lens. This technology is used in the Mercedes-Benz MULTIBEAM LED headlamps, is systematically being further developed and supplemented with new, groundbreaking functions.

FIGURE 1: MULTIBEAM LED headlamps in the Mercedes- Benz CLS-Class

2 The MULTIBEAM LED Headlamp

The new, unique MULTIBEAM LED headlamps combine the best light technologies. They are exceptionally bright and automatically illuminate the road surface with a precision-controlled distribution of light, without dazzling other road users. The MULTIBEAM LED headlamps extend the existing functions of the Intelligent Light System (Adaptive High-beam Assist, country mode, motorway mode, fog lamp, active light function, LED daytime running lamps) with a series of other outstanding light innovations:

- Anti-dazzle, high-resolution high beam which responds faster and more precisely
- Anticipatory, camera-based curve illumination function
- Navigation-assisted functionality for roundabouts

The MULTIBEAM LED headlamps implement all illumination functions using LEDs, thus combining the strengths of state-of-the-art light technologies. As such, they are able to tailor the illumination to virtually any traffic situation by distributing the light more precisely and faster than ever. They ensure far, bright illumination of the road surface and the edge of the road at all times, without dazzling other road users in the process. All of which enhances safety, for the other road users too.

The key element is the new, anti-dazzle high beam. The adaptive Highbeam Assist Plus, which is integrated in the MULTIBEAM LED headlamps, enables the vehicle to be driven with the high beam on continuously. For this purpose, the camera positioned behind the front windshield forwards the angular positions of other road users to the headlamp, which then sections out the light in this area. The light distribution of the MULTIBEAM LED grid module, which can be changed instantaneously, enables the headlamp to respond in just 10ms. The turn indicators, the position and daytime running lights are realised using a multifunction optical fibre that characterises the typical Mercedes-Benz night design. The MULTIBEAM LED headlamps also include the "welcome home" function. When the vehicle is unlocked the vehicle welcomes the driver with the familiar blue fibre-optic ambience.

3 The technology of the MULTIBEAM LED grid module

The precision LED grid module was premiered in the new-generation Mercedes-Benz CLS-Class. The module comprises a printed circuit board with LEDs, a primary optics and a secondary lens, which controls the distribution of the light cast on the road. In these MULTIBEAM LED headlamps, the 24 LEDs in the grid module generate the highly dynamic high beam and ensure that the high beam adapts perfectly to every traffic situation thanks to the fast response and actuation speeds in the millisecond range. Every one of these LED chips can be driven electronically, independently of the others. Mercedes-Benz is fine-tuning this precision LED grid module for the current and future generation of MULTIBEAM LED headlamps together with a development partner.

Future generations of the MULTIBEAM LED headlamps will have a much higher number of pixels and take the next step toward perfect adaptation of the entire headlamp [FIGURE 2]. The precision grid module in the sedan of the future will be enhanced to include 84 high-power LEDs, whereby light distribution will be segmented vertically as well as horizontally. Instead of the 30° inclination observed in conventional low-beam modules, a right-angled inclination is produced that results from the grid distribution pattern. Together with the basic light, the bottommost row of the grid forms the foundation of the low beam, whereby the range sector is actively controlled by the second row.

The familiar technology structure of the precision LED grid module will also be used in the future generation. It is still based on a primary optics and a secondary lens. The gaps in the LED package are closed via the primary optics to project a homogeneous light distribution onto the road. This optics comprises a highly transparent, silicone-based material and works on the principle of total internal reflection similarly to an optical fibre. In addition to meeting the optical requirements for minimal absorption, the material is also compatible with intricate geometries that are essential to realise this complex optical configuration. Every LED is overlapped by an optical fibre that is positioned in front of the LED luminous field in a strictly maintained clearance gap. The total light flux emitted by the LED is aligned and directed toward the secondary lens via the external geometry of the optical fibre.

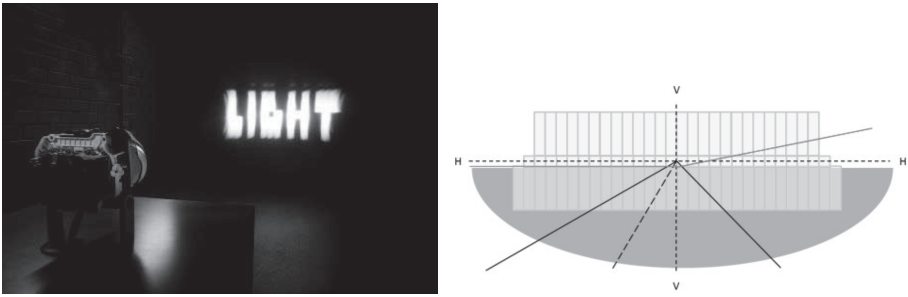

FIGURE 2: The new MULTIBEAM LED grid module (l) and schematic light distribution of a right-aligned module (r)

This convergence enables a high level of overall lighting system efficiency that produces an illumination output of 150lx in 25m at a pixel width of 1.2°. Unlike matrix high-beam systems that use overlapping segments from individual reflectors, the concept of directly integrating the primary lens as described in this article facilitates a distinct separation of channels with a high level of contrast and illumination output at the edge of a segment. The brightness gradient between a fully powered and a dimmed segment is optimised by the targeted microstructure of the secondary lens surface so that the transition period leverages the ideal alignment of perimeter definition and harmonious lighting for the driver.

Increasing the LED count allows ever finer and brighter segments to be actuated such that the resolution of the grid can also be increased in the perimeter area, and illumination output is elevated. Segmentation of the low beam makes it possible to implement the active curve light using electronics only. With no mechanically movable components integrated in the assembly, the driver is also provided with optimal cornering illumination when only the low beam is used; all the functions of the Intelligent Light System are supported as normal.

Segmentation of the wide low beam places additional requirements on the optical system. Projecting the outermost pixels necessitates opening angles of over 40°, which must be illuminated in a color-neutral fashion. To compensate for chromatic aberration, a two-component lens system with microstructuring of the lens surface is used [FIGURE 3 (b) and FIGURE 3 (c)]. The material mix of PMMA and PC meets all optical requirements while allowing headlamp designers sufficient freedom to customise the lens design.

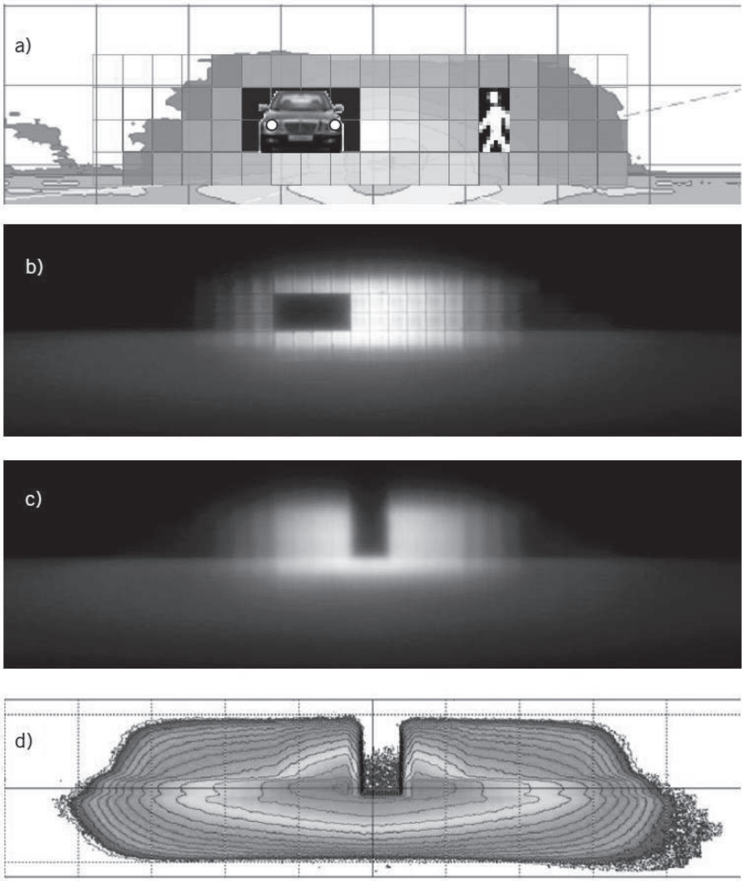

FIGURE 3: MULTIBEAM LED module with increased resolution:
a) Schematic diagram with the partial high-beam function,
b) Initial prototype, pixel limits still visible (experimental safety vehicle 2009 [2]),
c) Prototype with optimised lens system,
d) Isolux measurement of a module in development

4 Component requirements

As is the case with other optical systems that utilise small focal lengths, component tolerances are crucial. FIGURE 4 shows the principle dependencies at the optical interface. If the distance of the light-emitting surface to the primary lens deviates from the target defined by 100μm, the efficiency of the optical system is reduced by 10%. Due to the geometry of the luminous LED surface and the associated input coupling surface of the optical fibre, a minimal loss of just 2% is observed for a lateral displacement of the same amount. What is easy to achieve with a single LED optical fibre pair represents a considerable challenge when arranging 84 pairs in a series-production process. To ensure high system efficiency while at the same time protecting componentry, a process for aligning the LED grid to the primary optics is employed. Camera-guided precision robots position the two components at the ideal distance calculated and maintain this position throughout the integrated bonding process. The differences in brightness that result from the individual tolerance clearances of the 84 pairs are measured in a subsequent step and counter-calibrated electronically to produce homogeneous light distribution.

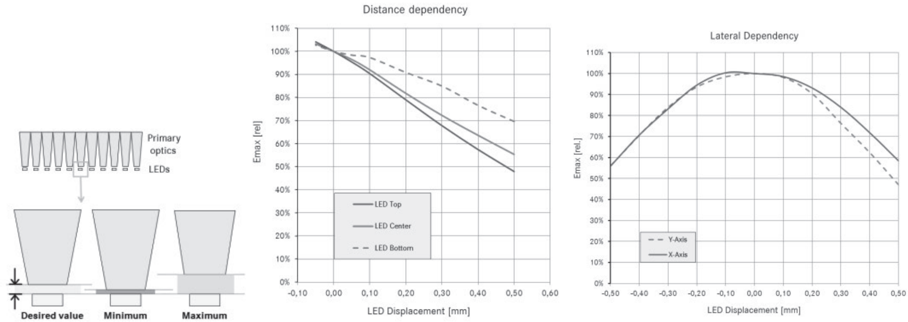

FIGURE 4: Efficiency of an LED optical fibre pairing with respect to clearance and offset tolerance limits

5 Better safety with improved functions

Increasing the LED count to 84 individually addressable pixels facilitates new functions and innovations, which also enhance safety. In partial high beam mode it is now possible to generate multiple dark areas in the light distribution and thus specifically mask up to four oncoming road users or road users ahead. Thus the high beam activation percentage is increased further during the journey. Its range and illumination can be used without annoying other road users or even putting them at risk.

Promoting social acceptance of state-of-the-art, high-output headlamps requires due attention to be paid to avoid dazzling other road users. Hazard lighting, for example, assists the driver by illuminating endangered pedestrians or animals close to the road. One of the problems with this technology is that the person or animal illuminated is also dazzled by the headlamp, which can lead to a loss of orientation or undermine the instinct to flee. By illuminating only the body of the object with the lower light arrays while omitting the head, MULTIBEAM LED headlamps can draw the driver's attention to the danger without dazzling the person or animal ahead. However, this level of sophistication can only be realised if the camera used to distinguish the head from the body does identify these areas reliably.

The high illumination outputs of current headlamps can even dazzle the driver through backglare from retro-reflective objects such as traffic signs. With the MULTIBEAM LED technology, the camera senses this danger and selectively darkens the areas in question with a high level of accuracy.

In built-up areas the Citylight function is automatically activated, which also contributes further to reducing the dazzle experienced by other road users. Citylight adjusts the light distribution and optimises the width so that the driver is able to identify earlier hazards in the nearby vicinity such as pedestrians crossing the road.

In driving situations that involve heavy rain, the benefit of the headlamps is greatly reduced, while the potential for the driver to be dazzled by the scattered light emitted by oncoming traffic is greatly increased. Headlamps with MULTIBEAM LED technology open up new, innovative possibilities for avoiding dazzling oncoming traffic, thereby making a considerable contribution toward improving road safety.

6 LED Headlamp with additional high beam spot: HIGH RANGE LED HIGH BEAM

Mercedes-Benz intends to enhance its next-generation LED headlamps by including a HIGH RANGE LED high beam. Thanks to state-of-the-art high-power LEDs in driving situations with no oncoming road users or road users ahead, the additional high beam provides high beam ranges of over 600m. Long ranges are possible in principle with any light source (H7, Xenon, LED, Laser). Much more important is the available installation space and the implemented bundling and convergence. The more pronounced the bundling, the greater the reduction in side illumination [FIGURE 5]. In order to fully utilise the legally permitted illumination output of 344lx at a distance of 25m, Mercedes-Benz resorts to the usage of sophisticated, reliable LED technology. In addition to the much more cost-effective, efficient overall system compared with a Laser light source, the LED also provides wider light distribution at a range of 600m. All of which translates into enhanced safety for the driver.

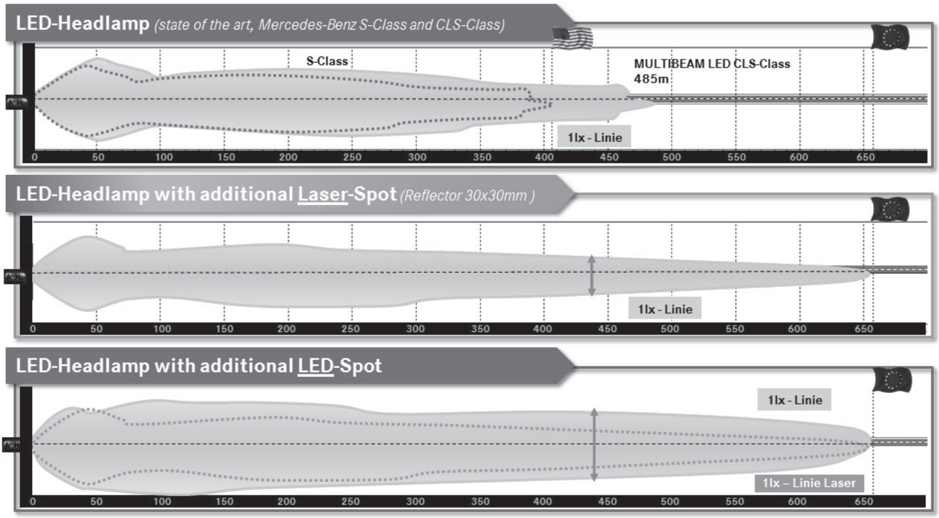

FIGURE 5: Comparison illustrating range of additional high beam (Isolux lines bird's-eye view - headlamps r/l superimposed at a distance of 1.2 m)

7 Outlook and further Increase in Resolution

In 2014, Mercedes-Benz launched the innovative MULTIBEAM LED headlamps with 24 LEDs in the CLS-Class. The headlamp control technology combines the grid light source with the tried-and-trusted mechanical technology of the LED Intelligent Light System. The high-power LEDs provide a range of 485m. Mercedes-Benz is set to unveil MULTIBEAM LED headlamps with a grid light source made up of 84 LEDs in the near future, paving the way for even higher resolution of the light output. Thanks to the freely configurable light distribution, all functions of the Intelligent Light System in low-beam and high-beam mode can be generated for the first time purely electronically, with no mechanical actuators. This facilitates a host of new, adaptive light functions, which make driving at night even safer, not only for the driver, but also for other road users.

This technology will continue to be optimised. Over the medium term, 1024 individually addressable pixels per LED chip will further increase visibility at night, thus enhancing safety even further. In the "μAFS" research project, the partners Infineon, Osram, Fraunhofer Gesellschaft IZM, Hella and Daimler have just achieved a breakthrough: an innovative LED chip with ultra-fine structuring. Monolithically structured pixel LED semiconductor layers were built up on a silicon substrate which, via the integration of circuit parts, allows the selective control of more than 1024 individually addressable pixels per LED chip. This LED technology developed in the project sponsored by the Federal Ministry for Education and Research (BMBF) is to be installed and tested in a Mercedes-Benz experimental vehicle in 2015. The resolution, which has once again been improved significantly, will, in turn, also substantially increase the precision and brilliance. All of which brings Mercedes-Benz ever closer to its objective of a constantly activated high beam outside built-up areas.

8 Summary

MULTIBEAM LED headlamps offer the driver superior illumination and maximum functionality. The technology incorporated in the grid module is based on the positionally accurate projection of an LED grid by a primary optics and a projection lens that can be designed as required. The contrast achievable in partial high-beam situations by adopting this approach can be adapted by adding a microstructure to the projection lens and is only defined by the individual's perceived comfort levels. Boasting innovative, adaptive light functions, the MULTIBEAM LED technology sets new standards and taps the full potential afforded by integrating 84 pixels per headlamp. Mercedes-Benz also intends to enhance its next-generation LED headlamps by including a HIGH RANGE LED high beam. Unlike today's Laser headlamps, this can be done with LED technology at a much lower cost and with a justifiable effort. At the same time, Mercedes-Benz will be able to exploit almost fully the legally permitted illumination output in Europe. The next development step will entail increasing the pixel count further substantially to over 1000 pixels, paving the way for new light functions, increasing the precision of the light distribution and hence enhancing road safety.

9 References

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Styling Oriented: Graphic Light Technology

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Keywords: styling, signaling, led

1 Abstract

The Automotive Market is permanently expecting more flexibility in its Styling expression. Light is one of the sectors seekers.

The Graphic Light Technology (GLT) offers the possibility to create almost any light signature at a minimum thickness. The benefits for customer are to optimize trunk volume, to simplify body of the car and to allow a maximum of flexibility for signaling functions.

This paper describes the optical solutions throughout the lit aspect improvement methods, and the impacts on the manufacturing process.

2 Introduction

GLT is dedicated to the stylists of Automobile Manufacturers.

It is based on 2D light guide combined with optical sub millimetres' patterns ensuring the light distribution. Thanks to the arrangement of this elementary optics, whatever the desire of the artist, almost any light signature can potentially become a high quality signalling function at a minimum thickness, size and tilt around.

On one hand, linear light guides have proved for years their efficiency to achieve demanding functionality like a Daytime Running lamp.

On the other hand, surface shape light guides are already on the market, but mainly for cosmetic purpose, because not powerful enough to perform a function by itself.

GLT is combining both to obtain the best of each.

3 Definition of the optical solution: the optimal pattern shape

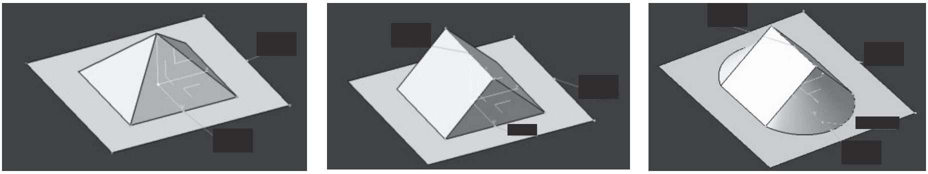
The basic requirement of the optical solution was to find the best decoupling face of the sub millimetre patterns, working by total internal reflexion. Several shapes have been tested:

1_ Pyramid shape: already used on some products. But the decoupling face area is limited.

2_ Tent: Inspired from current light guides prisms. It maximizes the efficiency for a given width, but homogeneity was not at the level required.

Hence the following solution:

3_ Tent with conic sides to spread light, favourable for homogeneity at big angles.



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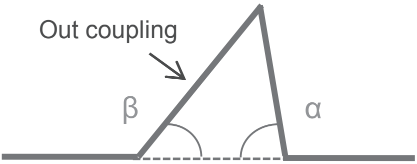
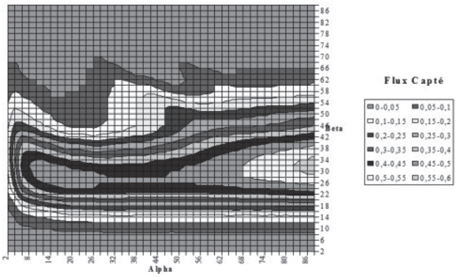
Next step was to define the best angles of the two facets, compromise between performance and process. With the help of an abacus giving the flux exiting the light guide relatively to Beta and Alpha (fig. 4), the best compromise led to an angle of Alpha > 50°.





Then the study focused on a specific but trendy challenge: a perfect homogeneity of a rectangular surface illuminated from one single edge of the light guide.

A convexity in the directions transverse to the light path has improved homogeneity between LEDs,