14th International Symposium on Automotive Lighting

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April 4–6, 2022

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14th International Symposium on Automotive Lighting

Steering Board

Foreword

It is a pleasure to present you the proceedings of the 14th International Symposium on Automotive Lighting, which takes place in Darmstadt on April, 4-6, 2022. Caused by the global Covid19-pandemic, this conference had to be shifted to 2022. 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 lighting technologies, together with the sensor technology and AI (Artificial Intelligence).

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 2021, the ISAL Steering Board could identify the following focus topics:

- Headlamp Rating Systems and their practical relevance for a global use
- High Resolution Headlamps and Digital Light, not only for high beam but also for low-beam range in the cities in the context of an international urbanization
- Road Projections (Front field and near-field)
- Communication between automated vehicles and other road users
- Light source technology generally with the innovations in Laser and LED-OLED
- Simulations as promising test environments

While in the last couple of years, focus was placed on high-resolution headlamps and this topic still remains relevant today, the most pressing topic for this year's ISAL is the evaluation of headlamp light distributions on the road. The main influencing parameters are the visibility (object detection probability), the homogeneous illumination and the effective lateral width of the light distribution. A key factor for an optimal illumination on the road is the correct adjustment of the headlamps in the system of the vehicle. Another strong topic for this year's symposium is the ongoing investigation on road projection and its benefit for the driver. What kind of symbols should be projected onto the road in front of the driver and what benefit do they lead to?

Similar to ISAL 2019, ISAL 2021 will host a podium discussion on the latest research and international opinions regarding the evaluation methods for headlamp lighting distributions and on how these methods can find the way into international regulations.

We wish you a very informative and successful ISAL 2021 in Darmstadt. We hope that this year's event and these proceedings will give you inspiration and motivation for your work during the next months and years.

Yours sincerely,

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

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I. Light Sources

Amazing Backup Lamp – how to get white light out of a rear lamp with a red covered lens/glass

H.P. Schiffert, Mercedes-Benz AG, Germany

Keywords: Light Source, LED Rear Lamp, Backup Lamp, Light Color Conversion, Design Freedom, Improve Appearance Of Rear Lamps

1 Abstract

In this abstract, we would like to show the development, the principle and implementation of a backup lamp through a red outer lens, without additional color filter elements and optics, realized with a specifically developed light source. The innovation aims to provide more creative freedom in the design for the appearance of rear lamps and to simplify the production process of the lamps.

The elaboration shows a solution that can emit white light color from a rear lamp with a red cover, taking into account legal color requirements and light values for a backup lamp. It describes the examination and selection of suitable materials and plastics, the properties and definition of a specific LED light source, as well as test results according to the legal requirements of the first prototypes. A comparison with conventional backup lamps as well as the advantages and disadvantages of the application are developed. In the last step, we would like to go into the necessary steps for solution approaches from the first simulations, the achievement of a high degree of maturity and to get ready for a successful implementation in series production.

2 Introduction and Motivation

One of the most crucial and challenging necessities for the development of rear lamps in modern luxury cars for the premium segment is firstly to find the optimum for the safety-relevant functions, secondly a technology that is high innovative as possible and thirdly has the maximum design freedom in the division of the lighting function areas. Under these three conditions, we get the option for rear lights, which are best integrated into the appearance of the entire vehicle.

One part of a seamless design is a clear, uniform and clean appearance of the rear lamps. Provided that the rear lamps should be implemented uniformly with a red appearance, we were unable to implement a purely red outer lens due to the legal color requirements for lighting functions. Two light functions, the direction indicator and the reversing light, have limited these requirements of our design wish. Figure 1 shows the two clear backup function areas left/right, which do not allow us a uniform red appearance for the rear lamps. The turn indicator areas left and right already implemented in red.

Figure 1: Appearance of the rear lamps with clear functional fields for the reversing light on the vehicle [4]

Thus, the question for the solution of the task is clear. How can we transform the clear transparent functional field in an equally red appearance with innovative LED-Systems?

For the turn indicator, a solution for yellow emitting light through a bright red outer lens was found. We know bulb lamp systems from the past, which have also enabled a red appearance of the light function through an additional filter lens between the light source and the bright red outer lens. Nevertheless, the current challenges for very small optical systems in LED technology and its spectral power distribution characteristics, provide more difficult conditions for systems that can be implemented in series.

In Figure 2, the clear transparent functional field for the reversing light can be seen based on a current series car lamp. However, as can be seen in Figure 3, the desired appearance is a completely red-looking rear light without visible separated functional areas. Figure 3 shows the goal of the content of this article.

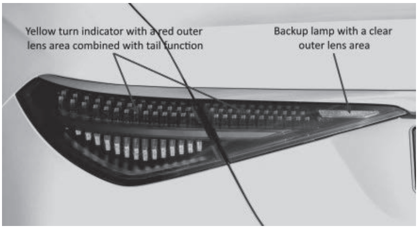

Figure 2: Rear lamp with clear backup function area in a red covered outer lens [4]

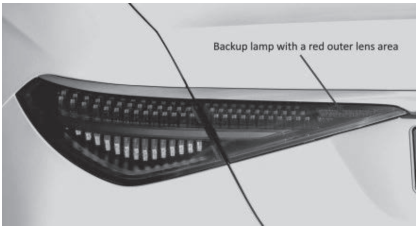

Figure 3: Rear lamp with a seamless red covered outer lens without clear function area

3 State of the art and basic parameters

In the first steps, we have to evaluate the existing parameters and requirements in order to achieve the necessary characteristics for a suitable definition of an optical unit.

Light color:

The light color and thus the target range of the color mixture after transmission through the outer lens must be within the valid legal regulations e.g. UNECE [5]. A specific color range within the legal regulations with corresponding tolerances is therefore required to ensure all operating states and environmental influences such as temperature, geometric tolerances, manufacturing tolerances, degradation of luminous flux, color shift over temperature, color binning's, etc.. In the CIE 1931 Chromaticity Diagram (Figure 4), taking into account previous reversing lights according to the manufacturer's specifications or according to the state of the art of reversing lights, a specific area is defined as a possible target window.

Filter properties:

As an outer lens/glass of the lamp, we used the existing material with the known specific spectral transmission properties of the material. In this example, we use the polymer from Röhm 8N red [3]. The specific color of the materials used for the outer lens is shown in Figure 4 in the CIE 1931-Diagram with the corresponding (x,y) coordinates from the manufacturer datasheet and corresponding material thickness of the lens.

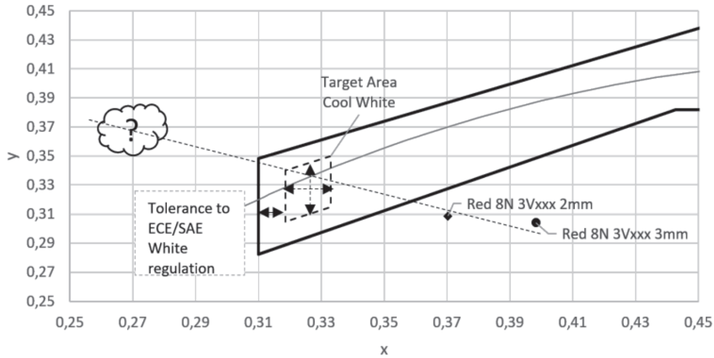

Figure 4: Chromaticity coordinates (x,y) CIE 1931 Color ECE White with an example of a target area for backup lamp and outer lens material color coordinates

In Figure 4 and 5 we can see the dependence of the thickness of the lens material with the corresponding color code 8N 3Vxxx. Because the outer lens also acts as a color-mixing filter, the definition and tolerance of the thickness of the lens is crucial for defining the spectral color distribution of the light source. Compared to transparent clear lenses, the efficiency of the optical unit should not be ignored, as transmission and color mixing through the lens result in significant losses.

Figure 5: Dependences thickness (left) and color grade (right) of the outer lens

In the summary of the existing parameters of the optical unit of the lamp, we were able to determine the material specifications and to meet the legally required light color. Since no further filter level is provided, the light color must be generated for transmission through the red outer lens by the light source itself. The light color mixed with the transmission properties of the red outer lens should give mathematically a white spectral power distribution, which is suitable for the backup function.

4 LED – Simulation and Characterization of the light source

After initial investigations of the idea with filter plates made of different materials and colors, already existing light sources and optical prototypes, the analysis for finding a solution was carried out with parallel using lighting simulation tools.

As a next step, after ensuring that technical feasibility is very likely to be possible, we were able to include further support for technical elaboration with the idea. Together with Lumileds Germany GmbH, we were able to find an experienced light source manufacturer to achieve products suitable for series production. Thus, we had a partner with all the necessary knowledge and influencing variables for the characterization of a suitable light source to “integrate” the color filter into the light source in order to avoid additional filter plates or complex optical units. Together we analyzed all technical conditions such as optical requirements, materials and the basic idea in order to find an efficient and as fast as possible a solution suitable for series production.

The basis of the filter material was given, it is the same material which is already used for the turn-indicator function in the cover lens of the rear lamp. This gives us the opportunity not to have a separate production cycle for the creation of the cover lens and thus to have a flexible and cost point taken into account. The second question was, does the transmission curve in Figure 6 allow a corresponding transmission without high losses in the necessary wavelength ranges of spectral absorptivity?

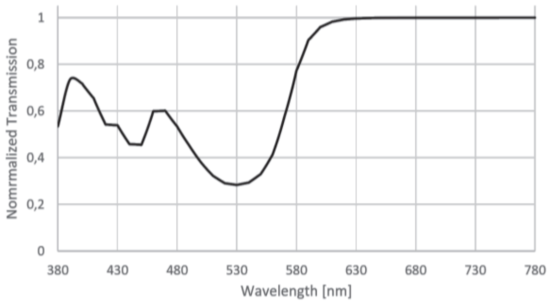

Figure 6: Spectral Absorptivity data from Roehm for Plexiglas 8N red [3]

In the third step, it was important to validate the requirements for a high quality reversing light. This results in the properties of the optical system and the necessary performance parameters. The power parameters are decisive for the choice of the package of the LED, the operating range for all electrical, optical and thermal characteristics such as minimum/maximum forward current, forward voltage, luminous flux, viewing angle, thermal resistance, degradation, etc.. As a suitable starting point for all the mentioned and required parameters, the selection fell on the existing LUXEON Versat 3030 350 package. It is a packaged LED with a blue die and phosphor converted, has a flexible operating range and a suitable package size.

In several simulation steps, the task was to determine the appropriate color characteristic, more precisely the corresponding phosphor conversion adjusted to the cover glass. As a result, the spectral characteristic can be seen in the Figure 7, which acts on a green appearance in the light color.

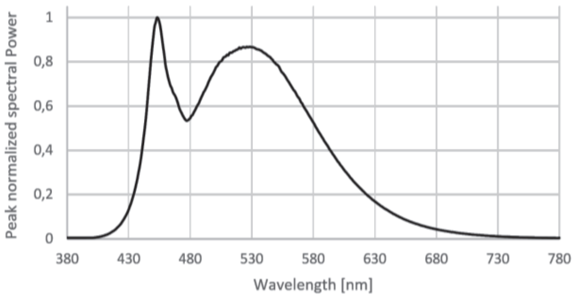

Figure 7: LUXEON Versat 3030 350 green spectral power distribution [2]

As the result of the simulation, assuming all defined input parameters, Figure 8 shows the spectral intensity curve after transmission through the red Plexiglas 8N outer lens.

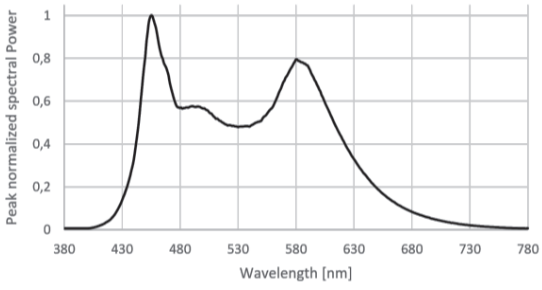

Figure 8: Spectral density after transmission through red outer lens [2]

On this basis, prototypes of the LED can be used for intensive further investigations and for the validation of the simulation results.

5 Experimental Setup

The dimension of the LED package (Figure 9) and the performance class is decisive for later use in the widest possible variety and variants of separate or combined optical (Figure 10) units of the reversing light.

Figure 9: LED package – First samples and package dimensions [1]

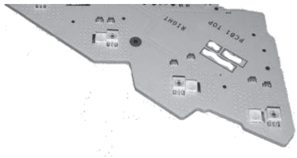

Figure 10: First Prototype – PCB with green LED for backup lamp

For more detailed investigations and assessments of the light distribution and flux performance on the road, for measurement purposes, evaluation with the reversing camera and demonstration purposes, a car set of rear lights with modified backup lamps was set up and installed in a vehicle (Figure 11, 12).

Figure 11: Lamp Car Set with red covered outer lens

Figure 12: Lamp Car Set with a backup lamp through a red lens

The result of the light distribution on the vehicle and on the road is impressively good. No conspicuous color shifts and a clear homogeneous color gradient in the near or far field or in larger angular ranges.

Further photometric and colorimetric measurements were realized on the Goniophotometer. The comparison with the existing series lamp with conventional clear cover lens and white LEDs could be carried out directly to find out the conclusions about the overall efficiency of the optical unit.

Above all, the factors for more precise results for light transmission compared to conventional backup lamps were exciting. The efficiency of the light source itself, its thermal behavior, and the efficiency of the optics with red material, the material thickness and the color or wavelength were precisely determined and evaluated. The advantages and disadvantages of the optical unit under real driving conditions and safety aspects for the customer have been revealed.

6 Color analysis

For detailed color analysis, spectral measurements of a batch of the LEDs under different driving conditions were very important for further detailing and specification of the light source to be developed. Among other things, the following operating conditions have to be investigated for more precise color examinations:

- Case temperature: 25°C, 55°C, 85°C
- Current levels: 150 mA, 250 mA, 350 mA, 500 mA
- Thickness of the lens: 2,5 mm, 2,7mm

In order to get an impression, excerpts of the investigations are presented in the following diagrams [2]. The first two diagrams show the color shift under the influence of the thickness of the lens at a temperature of 25°C from a series of measurements.

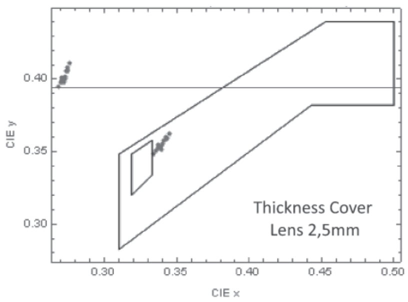

Figure 13: Individual LEDs before and after transition at T=25°C; t=2,5mm

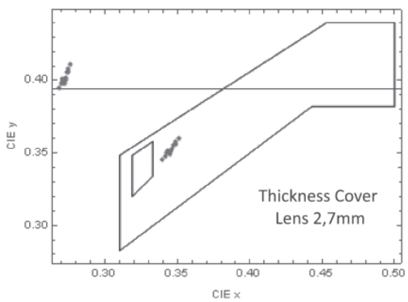

Figure 14: Individual LEDs before and after transition at T=25°C; t=2,7mm

The next two diagrams [2] show the color shift under the influence of the thickness of the lens at a temperature of 120°. What we can see is that both parameters (temperature and thickness lens) causes different vector directions of color shifts.

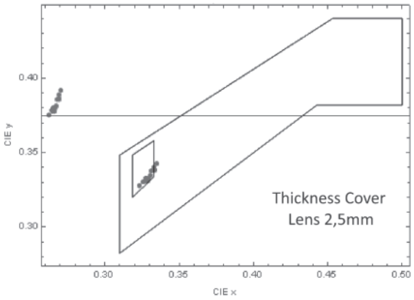

Figure 15: Individual LEDs before and after transition at T=120°C; t=2,5mm

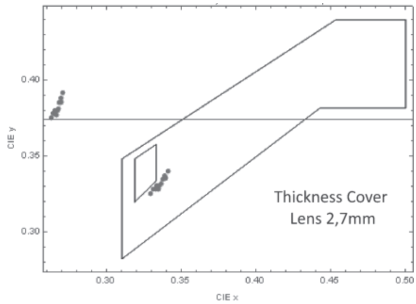

Figure 16: Individual LEDs before and after transition at T=120°C; t=2,7mm

Therefore, all parameters are essential for the development and thermal design of PCBs of series products. The decisive factor in the next chapters is to describe further sizes/limitations (batch size, color binning, etc.) in order to achieve the fully developed light source in maximum quality.

7 Optimization of the LED and definition of the color binnings

The LED-Prototypes, created under non-standardized automated series production processes, show significant deviations from the optimum in the CoA (color over angle) x-/y-direction measurement (Figure 17). Through further optimizations and adjustments of the process steps in the production of the phosphor, the accurate CoA could be successfully achieved (Figure 18).

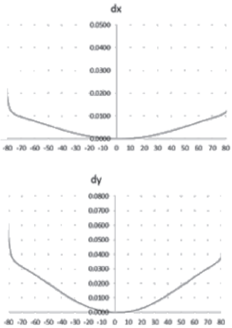

Figure 17: State of the first LED-samples color over angle (CoA) emission characteristics [2]

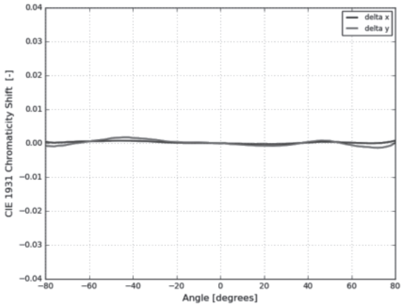

Figure 18: Improved LED with series production process color over angle (CoA) emission characteristics [1]

Another challenge was to define the appropriate batch size (Figure 20) for a stable optical system, taking into account all tolerances and operating conditions for a legally compliant fulfillment of all requirements. Here, restrictions in the shape and size of the color binning had to be implemented and secured for a stable series production process of the entire rear lamp.

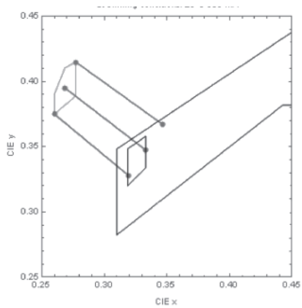

Figure 19: Color points of LED at binning conditions and color shift by cover glass [2]

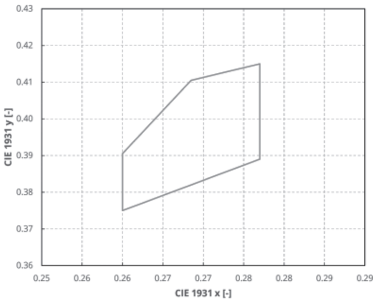

Figure 20: Final color bin structure for LUXEON Versat 3030 350 ST PC Green [1]

Regarding to our operating conditions with the given variation of temperature and current, according to our component requirements defined test conditions, we have to evaluate the position and dimension of the bin window in the CIE 1931 Color Diagram. Out of the batch, we have to ensure that LEDs from the upper Edge, Center and lower Edge of the bin structure fulfill after transmission within the legal requirement but mostly in our color target window.

8 Summary and Outlook

In 2020, Mercedes-Benz introduced the new S-Class. It is the first vehicle in our portfolio that has a red colored area for LED turn indicator and offers the possibility to combine the new technology for backup lamps behind a red colored lens separate or together with other light functions. This gives us full flexibility and design possibilities for new and forward-looking designs for the future series. With this new innovative light source, there is finally a solution to get a low cost, high efficient, small sized and easy to handle feasibility for color mixing optical unit. These are the beneficial effect of the technology compared to units with separate filter elements. The necessary LED qualification and internal test requirements were successfully completed and ready for mass production.

9 Acknowledgment

The author thankfully acknowledge Lumileds Germany GmbH, especially Mr. Dr. Harald Willwohl and Mr. Andreas Timinger, for their support and commitment from the idea to series development.

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Automatic controlled Lighting Systems
- Safety for all road users

Dr. Rainer Neumann, Varroc Lighting Systems, Germany

Keywords: Safety, ADB, Regulation

1 Abstract

Headlamps are getting more and more complex in providing several functions aside low beam and high beam. The complexity cannot be handled by the driver without being less concentrated on the driving task in the different traffic conditions. Therefore, these new devices will have an automatic mode, thus providing the best light distribution for the corresponding situation automatically.

Adaptive Driving Beam (ADB) is the most popular example for such automatic systems with increasing attraction in all segments of vehicles, providing safety benefit for all road users, approved in ECE since nearly a decade [1], unfortunately not yet released in US market.

Additionally, styling does require e.g. super small headlamps in the front, aside to the specific vehicle brand identification by means of an appropriate designed Day Time Running Light (DRL). This is another challenge for lighting engineers which can be solved with a special concept with excellent light performance results.

Based on such kind of innovations the paper describes the safety relevant features of new functionalities, which will be introduced in the market. Projection of Light Pattern and symbols to create awareness to the driver and other road users should be integrated into the total lighting concept of the future. Information and Communication is a key element in improving safety on the road. The corresponding regulation approval process has already started.

2 Introduction

The innovation process in Automotive Lighting was always accompanied with the modern, updated styling requirements. What is cool, and what should be realized is a balance between the technical opportunities and the requirements and ideas of stylists trying to realize an identity of the corresponding brand with the proper technical features. On the other hand, technical specialists are concentrating on the original function of automotive lighting equipment : seen and to be seen. Safety should have the first priority and features, which can be realized with new technologies need to have a safety aspect and/or a comfort factor for the driver to be able to drive safe at night. With the increased traffic density, the more complex traffic scenarios and the increased average age of the drivers the required, optimized light distribution should not be a question of the dynamic and fast reacting driver, it should be and will be generated automatically by means of the installed system. The automotive lighting system is therefore an intelligent combination of detecting and identifying of the actual traffic situation and the optimized means to realize the best light pattern and visibility at night. Starting with automatic systems like the switch on of the lights when it is getting dark in the early 80's to meet with the reduced visibility at the dawn period, there have been introduced several automatic systems, offering a switch between low beam and high beam, depending of the existence of preceding vehicles and/or oncoming vehicles, detected by a camera system.

A field test study, executed over 3 years, including 3.7 million vehicles recorded in various traffic situations found out, that the installation of an automatic switch between low beam and high beam (called Intellibeam) compared to standard lighting systems leads to a reduction in night time driving of 35% (see Fig. 1). These tremendous accident reductions were mainly detected on rural roads and with involvement of vulnerable road users (bicyclists, pedestrians) and animals. This demonstrates clearly, that the need of automatic operating lighting systems under the boundary conditions of an increased amount of tasks for the driver in recognizing the traffic should lead to a consideration to require such automatic systems as a mandatory option in the future. That would fit with the requirement of a mandatory DRL (daytime running light) in the ECE regulation (ECE R87), where the reason for introduction was also the safety aspect.

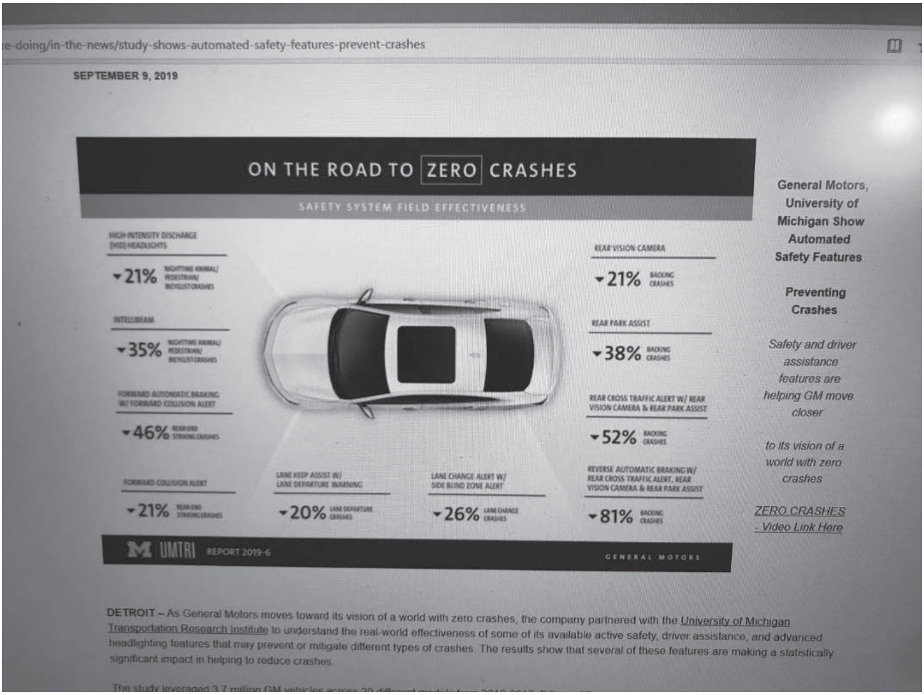

Fig. 1 : Field Test Results of UMTRI Study 2019 [2]

3 ADB is the basis for future automatic Lighting Systems

In ECE regulation 123 (which will be ECE regulation 149) the requirements for an ADB system have been defined. Headlamps with ADB functionality have been introduced since a decade ago with a lot of success. Especially the experience in the field with encounter situations (detection of an oncoming or proceeding vehicle) to make sure no other road users will be glared was extremely positive. Practically no complaints have been reported.

Additionally, to the ADB function one can further increase safety at night-time driving by means of projection symbols and/or pattern on the road to create awareness, support and instructions for the driver and other road users. After a long discussion with the regulation authorities in GRE, we finally could convince the members in the autumn meeting of GRE 85 in 2021 to approve 2 symbols and one pattern in the future regulation ECE R149:

- A snowflake projected on the road to create awareness of an icy and slippery road
- A vehicle accident symbol projected on the road generating attention to a potential accident ahead
- A pattern being projected in front of the vehicle to support a driver in a construction zone area where the driving lanes are typically narrow to guide the driver safely through this specific area (see in Fig.2).

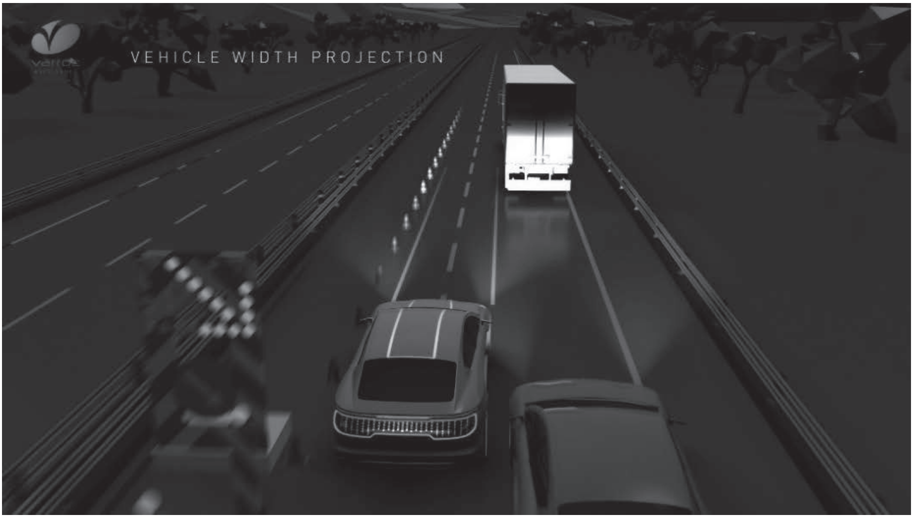

Fig. 2 : Guiding lines in construction zone areas

All features will appear as it is appropriate automatically.

Such scenarios have been tested and evaluated by several institutes and universities, under different conditions. The encouraging results could be used to convince the authorities to approve such projections on the road.

Of course, a potential distraction of other road users as well as the glaring aspect had been included in these research studies [3, 4].

There are other road projection symbols and pattern, which have to be considered as a safety feature in the future. In Fig. 3 one can see the recommended safety distance a vehicle driver has to respect when overtaking a bicycle or motor bike to allow a safe overtaking process. In Germany there has been recently introduced a mandatory distance of 1.5 meter and 2 meter respectively. This is hopefully reducing the accident rate and severe crashes in the future. With a pattern as shown in Fig. 3 the vehicle driver can easily respect this hint during the overtaking process.

Fig. 3 : Safety distance recommendation when overtaking

The complete system (ADB and road projections) has to be integrated into the future vehicle concepts, i.e. we should discuss about the stepwise introduction of a mandatory automatic lighting system to make sure that the safety improvement when driving at night will be available for all road users. To reach such a target one could consider to start with the automatic high beam / low beam (in US : Intellibeam) as most of the new vehicles on the road are equipped with a camera to detect preceding and oncoming vehicles, which makes it feasible to switch automatically between the two modes low beam and high beam.

We are currently engaged in adding to the ADB feature and the projection of front lighting symbols and pattern the opportunity to introduce projections and symbols for signal lighting functions. As an example we have already in plan to ask for approval for the parking and deparking situations. As an example, in Fig. 4 one can see an example by using "Chevron" pattern for communicate the intention to depark for other road users.

Fig. 4 : Awareness signal in deparking situations

That can be applied in backward deparking in a garage, in parking along the street or in parking areas like in a mall. Together with other situations with slow speed and high speed application it will be studied in detail by various universities and institutes to verify the advantage and safety aspect correspondingly. Based on the experience we have made with approving front lighting projections of signs and pattern the potential distraction aspect will be considered as well.

4 Summary and Outlook

Automotive lighting systems will be developed in the future comprising new features for safety improvement and most important will have an automatic operation mode. ADB is the most prominent system , approved in ECE and already a decade in operation. The driver will get the optimized light distribution including projection symbols and pattern in every driving situation in the future. He will be able to concentrate exclusively on the specific traffic situation. As several studies have investigated, that the automatic mode is leading to a significantly reduced accident rate the demand for introducing a mandatory equipment on all new vehicles with such systems needs to be discussed now. Here we should also include the findings from UMTRI study with a so called Intellibeam (automatic switch between low beam and high beam as a result of detection of oncoming or preceding vehicles [2]). The newly developed headlamp rating system: Headlight Safety Performance Rating (HSPR) [5], includes for the first time headlamps with ADB and verifies these systems as the best direction for an improved safe driving at night. From a regulatory point of view we should introduce new features and functions only once it is proven with some research studies, that there is a safety aspect and/or an awareness factor for road users accompanied. That will lead to a better acceptance of the responsible regulation authorities and will differentiate to some proposals generating only some entertainment effects [6].

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Design and experimental investigation of a technology demonstrator for hologram-based vehicle headlights

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Keywords: holography, computer generated hologram, headlight

1 Abstract

Unique design elements play an important role in the signature of car brands and models. Holograms as optical elements can provide nearly arbitrary design signatures for exterior and interior vehicle lighting. However, common holographic systems are based on collimated illumination, while divergent light sources like light emitting diodes (LEDs) are used for vehicle lighting.

Previous work has demonstrated the manufacturing of volume holographic cell arrays (VCAs) for divergent illumination. This paper now presents an illumination concept of such VCAs, as well as a design concept of a reflection type hologram-based headlight that does not require the use of projection lenses or reflectors for beam shaping.

Raytracing simulations were performed to evaluate different illumination concepts. As a result, total internal reflection- (TIR) optical elements were used for narrowing the radiation characteristics of the LED light sources to provide high luminous flux at the VCAs. Three white light LEDs and TIR optical elements were used to illuminate three VCAs, respectively. At this point a monochromatic green low beam light distribution is generated by the VCAs. A working and fully functional technology and design demonstrator was built to validate the results. In future works, the VCAs are to be optimized regarding beam shaping quality and generating a white light distribution suitable for ECE regulations.

The here shown results were investigated during the unpublished master thesis of Lukas Hiller. The work was supervised by Markus Giehl and Jörg Wallaschek.

2 Introduction

Since the introduction of hologram technology by Gabor in [1], holograms became well established for a wide range of technical applications. Since 2014, the Research Institute for Lighting Technology and Mechatronics (L-LAB) has been investigating the use of holograms for lighting purposes in automotive applications as part of dissertations and student projects [2–8]. In this context, holograms replace conventional optical elements in headlights and taillights. The functions of lenses, reflectors and optical apertures are performed by special holographic photopolymer films [9–12]. In this work, the holograms are volume holograms exposed into the photopolymer films by laser interference. The central research tasks have been the design and exposure of the holograms into the photopolymer films. Furthermore, the use of holograms in headlights and taillights shows potential in saving cost, package space, and weight [6]. If the illumination does not satisfy the Bragg condition [13], the photopolymer film is transparent. This allows for novel designs and the possibility of creating multiple lighting functions from a common functional area.

The reconstruction of conventional holograms requires a collimated illumination or point light source. This requires the use of a cost-intensive laser beam source or a complex optical system for collimating an LED. For the use of holograms with divergent light sources a holographic exposer is developed at L-LAB and computational methods are evaluated [2, 3]. This paper investigates the development of a demonstrator for hologram-based automotive headlights. A concept for hologram-based headlights is shown.

3 Working principle of the VCA

Volume holograms are selective regarding wavelength and illumination direction [14, 15]. This is caused by the recording process of the hologram, where two wavefields, the reference and the object wavefield, are superimposed and the corresponding characteristic interference pattern is stored in a recording medium. For good contrast of the interference pattern coherent monochromatic exposure light sources with high beam quality are needed. Today, single frequency continuous wave (cw) lasers offer a good approach for hologram exposure. After developing a hologram, it can be illuminated with one of the recording wavefields and the other wavefield will reconstruct. Usually, the reference wavefield is used to illuminate the hologram such that the object wavefield reconstructs in the designed image. The illumination direction and the wavelength of the reference wavefield must be the same as in the recording process, otherwise the efficiency of the reconstructed wavefield will drop drastically. Deviations from the intended illumination direction, wavelength and the drop in efficiency were investigated by Kogelnik [16]. In automotive lighting applications LEDs are state of the art, but they cannot be used for hologram exposure directly due to the lack of coherence. Following, laser sources are used when manufacturing holograms and the radiation characteristics of the LED must be compensated during the recording process. A detailed description of the recoding and calculation process for these holograms is given by Giehl et al. in [2, 3]. In this paper, only a short recapitulation on the working principle of the VCAs is given.

Figure 1 shows the principle sketch of the reflective VCA illumination. The VCA is divided into an array of $m \times m$ subholograms. Each subhologram is recorded with a reference wavefield that has the same direction as the corresponding light ray emitted by the LED ϱ. The angle between the optical axis of the LED and the optical axis of the VCA is called central reference beam θ_0. Per subhologram the reference angle differs slightly because the LED is divergent and has a Lambertian radiation characteristic. At the VCA the object wavefield σ reconstructs and the image is formed in the target plane.

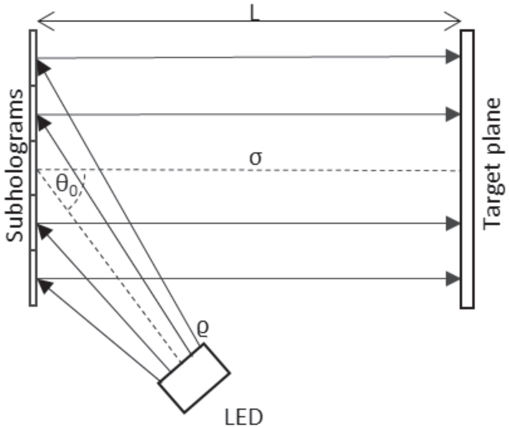

Figure 1: Principle sketch of the reflective VCA illumination. A VCA consist of multiple subholograms. The LED rays ϱ illuminate the respective subholograms and the object rays σ are reconstructed. Each subhologram varies by the reference angle to match the radiation characteristics of the LED. The central reference angle is θ_0.

In the here shown application the hologram image is an automotive light distribution, e.g. a low beam or a high beam. The VCA image is formed by the superposition of multiple rectangles, where each rectangle is formed by one subhologram. Following the calculation of a VCA is relatively fast, because each subhologram only has the function of a slanted hologram grating for beam steering and a holographic lens for magnification. The principle of this calculation is described in detail in [2]. Every subhologram image can be understood as a light package that has a direction and a magnification. To generate gradients in the VCA image and light distribution, multiple light packages are overlapped. The spatial resolution is of the image is restricted by the count of $m \times m$ subholograms and the gradient resolution is restricted by the maximum count of overlapping light packages.

The displayed principle provides a good approach for headlamp light distributions, where a low resolution might be sufficient. However, some limitations are given by the exposure device for the VCAs, that need to be considered when developing the illumination concept.

4 Illumination concept

The previous mentioned limitations and properties of the exposure device are displayed in Table 1.

Table 1: Limitations and properties of the exposure device for the key parameters. θ is the altitude measured from the normal of the hologram surface, ϕ is the azimuth, where 90° is the center, α_H is the horizontal and α_V is the vertical maximum aperture angle of the hologram image.

Parameter	Limitations and Properties
Wavelength	532 nm
Reference beam angles	$\theta \approx [5°, 70°]$, $\phi \approx [5°, 175°]$
Object beam angles	$\alpha_\mathrm{H} \approx \pm 7.5°$, $\alpha_\mathrm{V} \approx \pm 3.75°$
Subhologram size	$0.655\mathrm{mm} \times 0.655\mathrm{mm}$

To compensate the LEDs Lambertian radiation characteristics the reference beam angle of the exposure device needs to cover a wide range in the altitude θ and the azimuth ϕ direction. A light distribution is formed by the superposition of object beams.

Typically, a low beam has a width of $\pm 20°$ and a height of $\pm 10°$. As displayed in Table 1, the object beam of the exposure device cannot cover the needed aperture. However, the demonstration device will use an multi VCA approach to overcome these limitations to generate the low beam light distribution of Figure 2.

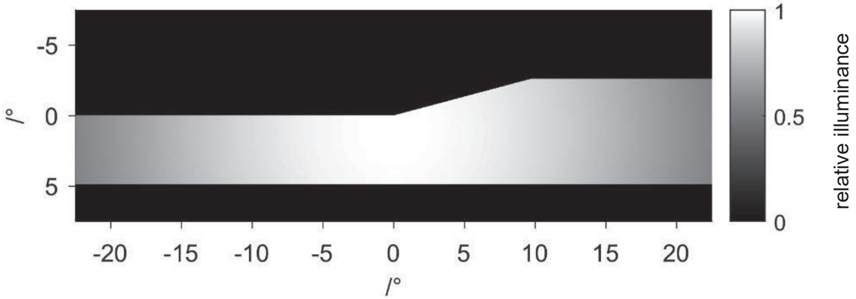

Figure 2: Design low beam distribution for the hologram-based headlight demonstrator. The vertical aperture is limited by the object beam angle range of the exposure device. To cover the horizontal aperture multiple VCAs are used.

The light distribution in Figure 2 has a width of $\pm 22.5°$ and a height of $\pm 3.75°$. Three VCAs are used, where each VCA has an aperture of $\pm 7.5°$ in width and $\pm 3.75°$ in height. The respective VCAs are arranged with an offset angle of $15°$ to cover the complete width. The height is smaller compared to real low beam distributions.

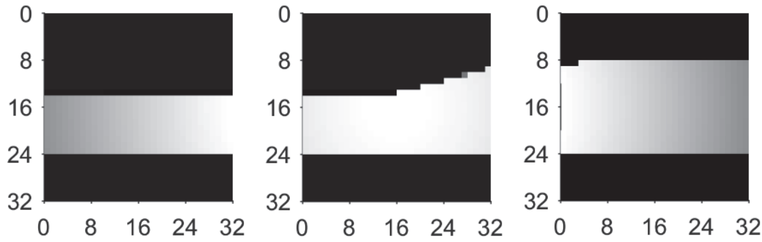

Figure 3: VCA image concept. Three VCAs cover the displayed low beam distribution the resolution per VCA is determined by 32×32 *subholograms*

Figure 3 shows the VCA image concept, where three VCAs with 1024 subholograms each are used to generate the low beam distribution of Figure 2. In this approach the resolution is limited to $32 \times 3 = 96$ light packages in the width and 32 in the height.

5 Raytracing simulations

As the next step the VCAs must be illuminated by a LED respectively. The VCAs are reflection type holograms, therefore the LEDs must be located at a position, where they do not interfere with the reconstructed light distribution. A good LED position was found with the central reference angle $\theta_0 = 50°$ and a distance of 55 mm to the VCA center.

Phosphor converted automotive LEDs with a Lambertian radiation characteristic are used. To compare the luminous flux at the VCA by using a TIR optical elements or direct illumination, raytracing simulations are performed. The VCA illumination setup is modelled in a computer aided design (CAD) software, as mentioned above, and transferred to a raytracing software. Here, the VCA surface is defined as an illuminance sensor array with the same resolution as the VCA. The subhologram count and size defines the VCA to $20{,}96 \text{ mm} \times 20{,}96 \text{ mm}$.

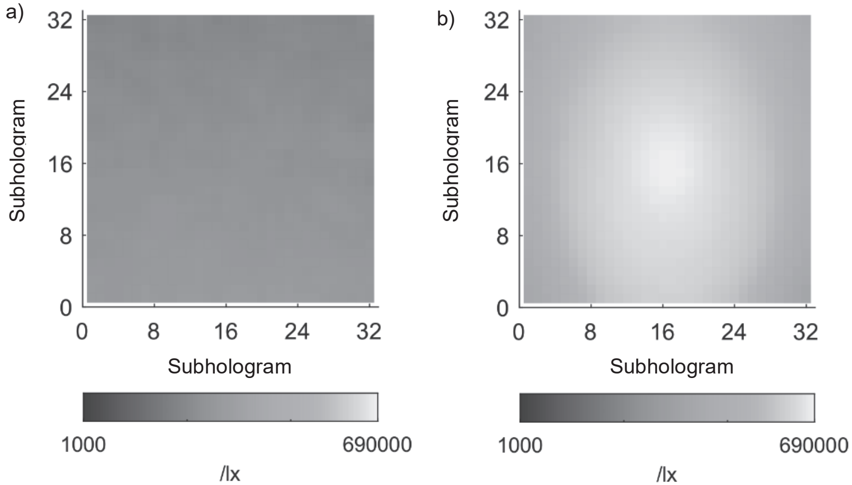

Figure 4: Raytracing simulation results of the luminance at the VCA. Two approaches are investigated: a) direct illumination and b) narrowing of the radiation characteristic with an TIR optical element.

Simulation results are shown in Figure 4. With the given distance and angle, only 3.1% of the LEDs luminous flux are used by the VCA when illuminated directly. By mounting the TIR optical element in front if the LED the effective luminous flux is increased to 61.5%. For the direct illumination the illuminance is more homogeneous at the VCA, where the illuminance is much higher for illumination with the TIR optical element. Due to efficiency reasons the TIR approach is chosen for the demonstration device.

6 Design and Results

Starting from the simulated illumination setup with three VCAs and an offset angle of 15°, the hologram-based headlight demonstration device is constructed. Figure 5 a) shows the demonstration device. It consists of a hologram screen, a housing, three LEDs and heat sinks and the TIR optical elements.

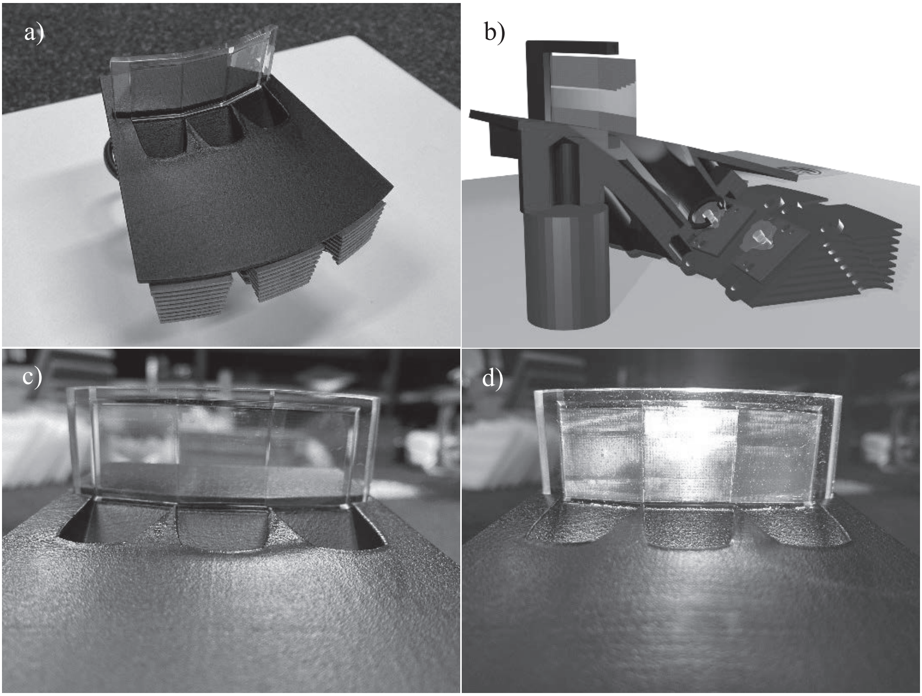

Figure 5: a) demonstration device for hologram-based headlights; b) sectional view of the demonstration device; c) VCA screen in the non-illuminated state; d) VCA screen in the illuminated state

The hologram screen is made from transparent PMMA material and the respective VCAs are laminated on the front surface of the screen. For the housing and heat sinks additive techniques are used to manufacture the complex shape.

Three light tunnels, the TIR optical elements and heat sink mounting points are integrated into the housing as shown in Figure 5 b). By integrating the TIR optical elements in the housing and mounting the LEDs to the heat sinks a relative adjustment possibility of the LED to the TIR optics is provided. The heat sink is mounted by three screws and spring washers to the housing to adjust the offset and angle of the LED. This adjustment is necessary due to the soldering tolerances of the LED to the printed circuit board (PCB).

Hiding the LEDs in the light tunnel and laminating the VCA to the transparent screen are key design elements of the demonstration device. As shown in Figure 5 c) and d), the screen is transparent in the non-illuminated state and reflects green, when illuminated. The green color is caused using a monochromatic VCA designed for 532 nm. In future front light systems, additional light functions such as a turning signal could be placed behind this transparent hologram screen.

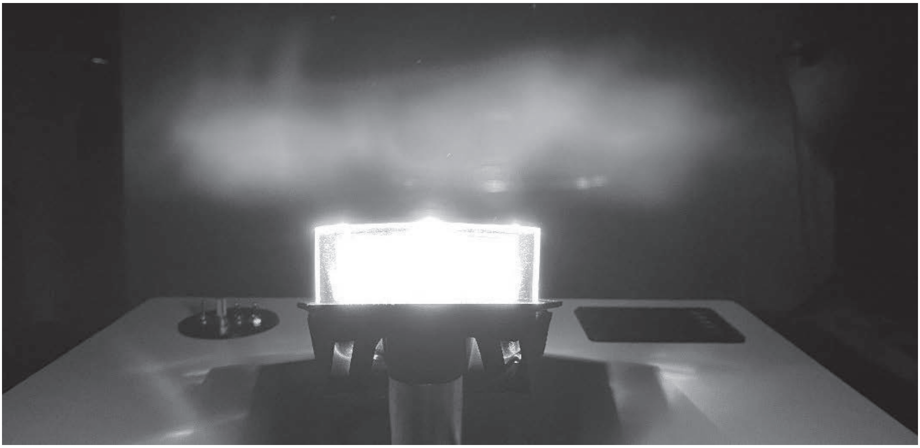

Figure 6: Light distribution of the demonstration device. Although illuminated with white LEDs the VCA image is green, caused by the wavelength selectivity of the hologram.

Another design feature is the size of the headlight demonstration device. With 114.84 mm width, 72.19 mm height and a depth of 100.19 mm it is smaller compared to other headlight systems. The light emitting surface, in this case the hologram screen, is also smaller compared to state-of-the-art systems. It measures 20.96 mm in height and 62.88 mm in width.

The proof of principle of generating the light distribution with the demonstration device is shown in Figure 6. At this point the light distribution is green and the image quality must be improved. However, the cutoff line is similar to the design of Figure 2.

7 Summary and Outlook

In this paper the illumination concept, the design and the construction of a hologram-based headlight demonstration device was presented. The target to show a proof of principle of the hologram technology and the affiliated design aspects were fulfilled. The reduction of installation space and the reduction of components were realized, as well as a transparent light emitting surface in the non-illuminated state.

However, future work must improve the image quality of the light distribution and the color of the image must be white to fulfill the ECE regulations for headlights. First, simulations for white light VCAs must be performed and experimental investigation will follow to update the here presented demonstration device.

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Development of surface emitting T-Stop optical system HLED

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Keywords: Automotive Lamp, homogeneous lamp, Slim module, Phosphor Rear lamp for automobile, Luminous flux Droop

1 Abstract

The existing OELD technology is not only a very expensive technology but also only low-performance functions such as Tail or Position can be carried out. Therefore, only a flat structure can be applied to the existing OELD so that there are many design restrictions from the perspective of lamps requiring various designs.

In this regard, HLED technology can function a stop. A surface light source in the thickness of slim type and that does not require the inner lens was implemented through a simple structure by applying LED Chip, phosphor and optic resin (Silicone), away from the lighting image realization method using the reflective surface and inner lens constituting the existing rear lamp optical system. As a result, it is expected to increase the brand identity of the vehicle innovatively.

Based on the optimization of structure through the application of flip Chip LED and the combination of Red Phosphor and Optic Resin, a surface light source of 5.5mm slim level without inner lens has been implemented and various pattern images could be realized using pattern technology and silicon molding manufacturing technology. Therefore, the design freedom has been increased.

The reliability test for vehicles requiring high reliability such as the high thermal resistance and vibration were passed in the self-test and proved that it can be applied to vehicles.

2 Introduction

In the automobile market, research on new lamp design is actively progressing due to the development of display technology in recent years. Vehicle lamp optics technology focuses on high luminance, low power consumption and high light source efficiency. In addition, a reduction of weight and volume, conformity to standard lighting regulations and integration design of vehicle body should be taken into account.

In order to meet all of these strict conditions, the advantages of HLED systems are currently in the spotlight in the automotive lamp industry. HLED technology is realizing design trends and new functions in the automotive lighting. In addition, the technology has already being reviewed to apply to some of the new mass-production models, which is scheduled to be gradually expanded in the future. The advantages of HLED include the high brightness, reliability, low power consumption and long lifespan.

This technology was named as HLED, which has the meaning of High Performance, High Definition and Homogeneity.

Vehicle tail lights are generally considered one of the most important safety devices of automobiles, and a tail lamp attached to the rear of the vehicle can protect the vehicle safely, especially at night or in low-light situations. The color of the light shining from the rear light is defined as a Red Color. Regulations for red lamps applied to vehicles are specified in the CIE color coordinates of ECE Reg.48 (International Commission on Illumination). [1][2]

In general, an optical system using a red LED is based on a semiconductor material such as AlGaInP, AlGaAs or GaAsP. LEDs are semiconductor p-n junction devices, and the electrical and optical properties of all semiconductors vary with temperature. LEDs use about 20% of the power to emit light and the rest is converted to heat.

When the temperature is above 70°C, energy efficiency, luminosity and service life are reduced. [3]

The dependence of temperature versus output intensity is different among Blue LED (InGaN/GaN), Green LED (InGaN/GaN) and Red LED (AlInGaP/GaAs). [4]

Red LEDs are most affected by temperature, while the Blue and Green are the most insensitive to temperature. Prolonged use of the LED in a high temperature environment can cause the LED package to overheat and cause the device to fail. As a result, as the temperature increases, the luminous flux decreases, and accordingly, the lighting efficiency decreases. Also, bright colors change due to wavelength shifting phenomena. Therefore, designing vehicle ECE regulations for Red lights becomes very complicated.

However, only the characteristics of the LED itself cannot fundamentally solve the heating generation problem. The recently developed white LED to improve LED light source characteristics, uses phosphor conversion LED technology based on Blue Chip.

Therefore, the developed white light source is very bright and also has good energy efficiency.

Thus, the purpose of this study is to develop a high-efficiency Red LED optical system for vehicle tail lights using phosphor-converted LED technology using the characteristics of Blue LED.

The final goal of this study is to solve the problems and improve weaknesses of the existing vehicle's Red LED lamp optical system and apply the improvements in practice.

3 Further structuring

The characteristics of LEDs each have their own properties of bright colors or wavelengths, etc. In particular, the luminous flux of LEDs is greatly affected by temperature changes. Figure 1 shows the typical output intensity of InGaN/GaN Blue, InGaN/GaN Green and AlInGaP/GaAs Red LEDs versus ambient temperature. [3]

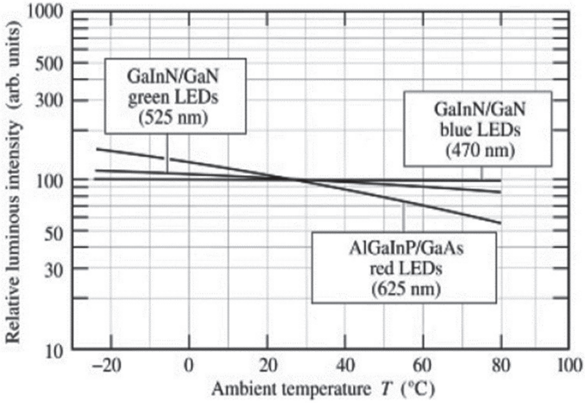

Figure 1: Typical output intensity of InGaN/GaN blue, InGaN/GaN green, and AlInGaP/GaAs red LEDs versus ambient temperature (after Toyoda Gosei Corp.,2000).

The relative luminosity of LEDs according to temperature changes is all different. It seems that the light output change of Blue LED (GalN/GaN 470nm) is significantly lower than that of Red LED (AlGalnP/GaAs 625nm). This means that the heat drop of Red LED is much larger than that of Blue LED.

This is because of the characteristics of the material inside the semiconductor system as a semiconductor p-n junction device. In theory, the current passing through the p-n junction depends on the voltage drop and junction temperature. [5]

A Red fluorescent material was applied to this study, using the advantage of Blue Light (Phosphor conversion Red LED) and a test was conducted based on the light conversion principle to output the Red light. As mentioned earlier, the blue light shows its characteristics that increases the temperature and decreases the speed of the luminous flux.

Figure 2 shows the LED conversion system of Phosphor conversion Red. The first Blue light is first absorbed by the Red Phosphor through the excitation process. Afterwards, only the radiant light (excluding non-radiant light) was converted into the Red light and emitted during the relaxation process. [5]

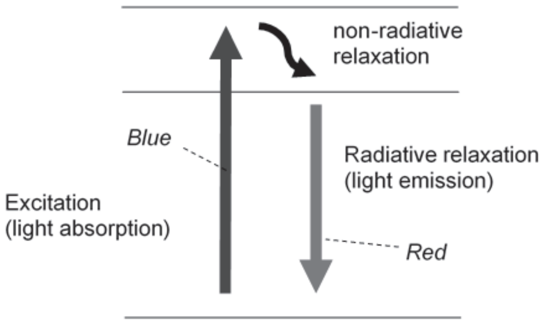

Figure 2: Phosphor conversion system

The electron energy level of the activated ions in the phosphor is consistent with the number of Red photons emitted and expressed as follows.

$$\text{Photons (red emission)} = \text{Abs} \times \text{iQE} \times \text{Photons (blue incident)} \quad (1)$$

Here, the photon (Red emission) is the photon quantity emitted from the Red Phosphor, Abs is the absorption quantum efficiency meaning absorption power, the photon (Blue incident) is the absorbed Blue photon quantity, and iQE is the internal quantum efficiency, which means, that is, the conversion capability, a very important parameter for the photon conversion. The absorbed blue light wavelength shifts to the Red light wavelength and is emitted. (Figure 3) [6]

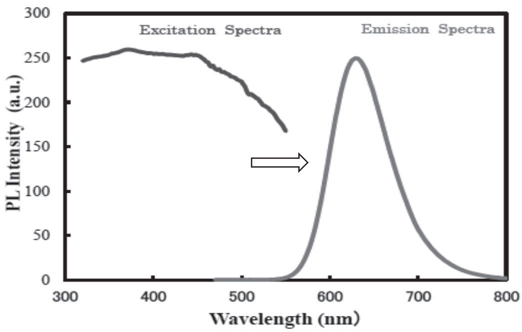

Figure 3: Wavelength shift phenomenon

4 Summary and Outlook

In this test, the optical characteristics of HLED (Blue LED Chip + RED Phosphor) based on the phosphor conversion and the Red LED chip already applied to vehicle lamps were compared and analyzed to develop the Red LED optical system for vehicles. In the case of the new Blue LED chip + Red Phosphor, a fluorescent material was applied based on InGaN (455nm) blue LED, and AllGaP (614nm) LED was applied to the previously applied Red LED chip for comparison.

The flux drop ratio affected by temperature change, the most important variable in the vehicle ramp performance, was measured.

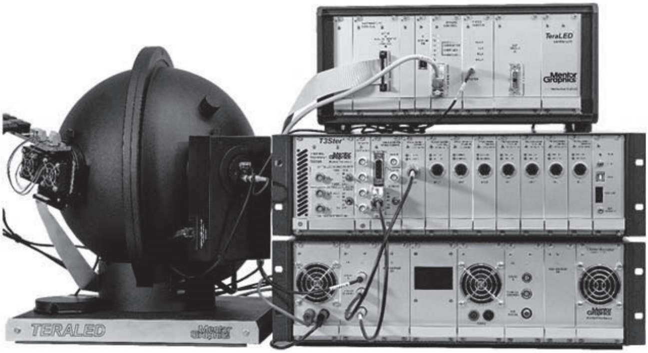

Figure 4: Measuring equipment (T3Ster TeraLED system) (automation.siemens.com)

The T3Ster Terra LED system was used to measure the optical properties (Figure 4). In addition, the characteristics of LED temperature, heat radiation and luminous flux were measured during the conversion of electrical energy from LED to light energy.

The graph in Figure 5 shows the test results for the change in LED luminous flux according to the temperature rise. In case the room temperature increases, the amount of reduction in luminous flux of HLED is much better than that of a general optical system applying a Red LED chip. In general, reliability tests for vehicle lamp temperatures are conducted at a maximum of 85°C.

The rate of decrease in luminous flux at 85℃ is -48% (614nm) in the case of Red LED, and is in the range of about -12% in the case of HLED. As a result, it is shown that HLED has three times better luminous flux characteristics than the Red LED CHIP optical system. Moreover, when the temperature changes, the CIE coordinate value of the LED also moves. In Figure 6, the amount of shift in the CIE coordinate value according to the temperature increase is shown below.

$$\Delta\{CIE\text{-}x,y\}= \{CIE\text{-}x: CIE\text{-}y\}25℃ - \{CIE\text{-}x;CIE\text{-}y\} \quad (2)$$

The light performance of the lamp decreases depending on the temperature inside the vehicle. However, HLED proves that it has excellent heat resistance unlike existing optical systems.

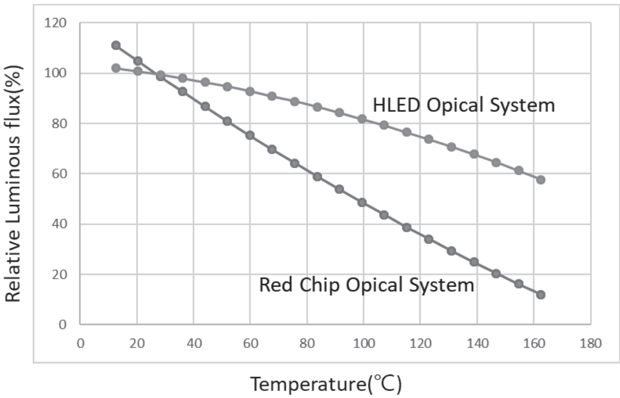

Figure 5: Luminous flux drop of HLED

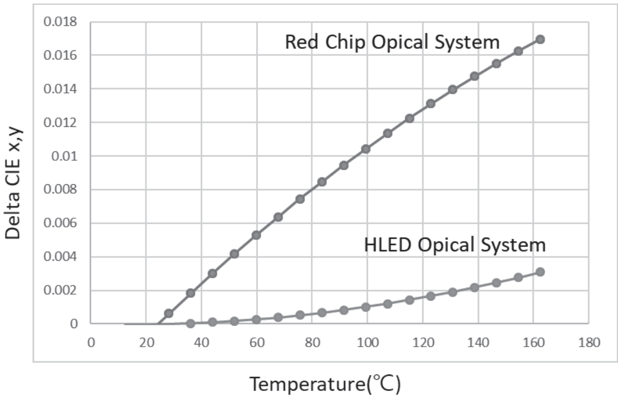

Figure 6: Shift of the CIE coordinate values

(Solid curve: CIE-Δx, dotted curve: CIE-Δy)

5 Conclusion

In this study, it is intended to develop HLED technology using the characteristics of blue LED Chip suitable for vehicle lamps. The final goal was to improve the decrease phenomenon of luminous flux due to the increase in temperature of the existing Red LED for vehicle lamps. The newly developed HLED and the existing Red LED optical system were tested in the temperature range of 25℃~85℃. In this case, HLED showed 3 times better luminous flux characteristics than Red LED at 85℃ based on the internal temperature of the lamp. It means that HLED (Phosphor + Blue Chip) has a very low luminous flux reduction rate compared to the existing Red LED optical system. In conclusion, since the developed HLED is less sensitive to a temperature increase, the luminous flux is lowered and the color change (or wavelength shift) is also smaller than that of the existing Red LED. This makes it easy for vehicle lamp designs to comply with vehicle ECE regulations. Therefore, this can have a critical impact on improving the performance of the existing Red LED in vehicle lamps.

The following advantages can be obtained through this HLED development. (Figure 7)

- Simultaneous realization of Tail and Stop in one HLED area
- Secure the bright and uniform light intensity even when bending or warping
- Light weight, small size and good energy efficiency compared to existing LED lamps
- Lead the global lamp market with innovative products that satisfy functionality and sensitivity

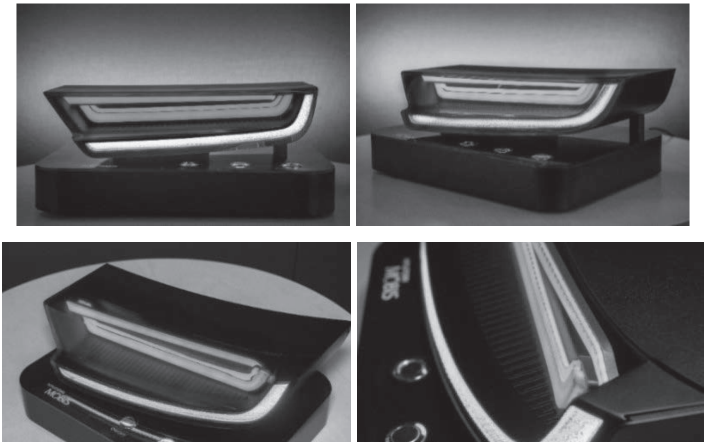

Figure 7: Image of HLED (CISION PR Newswire)

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ECU-Free Exterior Lighting: Disruptive trend for vehicle E/E architecture with focus on exterior lighting

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Keywords: E/E architecture, CAN-FD, LED drivers, actuator drivers, standardization

1 Abstract

Disruptive trends require system-level solutions. Safety, comfort and aesthetics require lighting functions to evolve and become increasingly smarter. Electronic control units (ECUs) are expected to get cheaper to allow wide penetration in the market. The resulting cost squeeze will soon hit a roadblock. Additionally, there is a big trend in vehicle E/E architectures to stop the proliferation of more and more local control units.

Therefore, we propose a paradigm shift in E/E concept for exterior lighting and embrace the trend towards centralization.

Each light module and LED-PCB will have a dedicated highly integrated CAN-FD-LED driver which communicates directly with the Body Control Module (BCM) or a Light-Domain-Controller (LDC), thus negating the need for ECUs.

This change in E/E architecture allows and requires the OEM to integrate the lighting control algorithms inside the BCM/LDC, with no software remaining in the headlamps.

Such CAN-FD-LED drivers are not available, yet, and need to be developed by semi-conductor suppliers.

2 Introduction / Motivation

Exterior lighting is a field of constant progress and evolution. The last decade has seen unprecedented growth in complexity, capability and sheer number of light functions.

Particularly, we see three aspects, where a rise in complexity needs to be met with simplification by standardization and centralization. The light functions themselves are increasingly sophisticated (i.e. adaptive driving beam (ADB), animated signal functions, ground projection, etc.) and demand more computation power and smarter algorithms. Thus, it is more efficient to separate electronic drivers from centralized control units for which software can be sourced independently. Secondly, exterior light has evolved beyond traditional front and rear lamps. Grill illumination, state-of charge displays for BEVs, logo illumination, ground projection etc. are distributed all around the car body. Instead of supplying each location with its own control unit, these functions are better handled by distributed drivers and centralized domain controllers. Software is consolidated, resulting in a cost-efficient system. Lastly, we see the demand from customers for a wide array of options regardless of vehicle size. Urban, climate conscious consumers might choose small cars but expect premium configurations. Technical solutions must be modular with close to zero overhead. All these challenges can me met with centralized control algorithms, either in a LDC or as part of the BCM and standardized, distributed electronic drivers directly on the PCBs.

Changing the E/E architecture for exterior lighting requires a system focused approach. One component of this concept will be replacing the electronic components of ECUs with drivers located on PCB. However, the key element will be the establishment of an open, shared set of specifications. The drivers must be suitable and available to all OEMs interested in changing their E/E architecture towards domain controllers. At the same time, OEMs must be able to use drivers from multiple sources. Semiconductor suppliers will be able to distinguish themselves by offering devices of varying size, cost or efficiency but the interfaces and fundamental capabilities must be standardized.

This paper will address the following topics. System View will address the distribution of involved components and their responsibilities within the domain-oriented E/E architecture. It will also highlight the potential of standardized and simplified wiring. In the chapter Devices, we will present condensed technical specifications for the different driver devices, required for today's lighting applications. Communication will introduce and explain our control scheme and the protocol specification based on CAN-FD frames. Safety and Security will address the increasingly important and intertwined topics of functional safety and data security before the paper closes with a summary and outlook. Some of these aspects will also be published in [1].

3 System View

Traditional E/E architectures employ dedicated ECUs located inside each lamp. High level commands from the body control module (BCM), i.e. activate TI, switch to Class E LB, etc., are received by each ECU and subsequently LED and motor drivers inside the ECU control the currents supplied to the respective channels. This approach is basically an evolution from HID xenon control units. It is our intent to share the responsibilities and capabilities of a traditional ECU between distributed drivers located on function PCBs inside the headlamp and a central controller, either the BCM itself or a light domain controller. All “smart” functions, i.e. the control algorithms will be located in the central control unit, while the drivers will be placed on the PCBs. There is no software remaining inside the headlamps, only configuration data. Figure 1 shows how the responsibilities of an ECU will be shared.

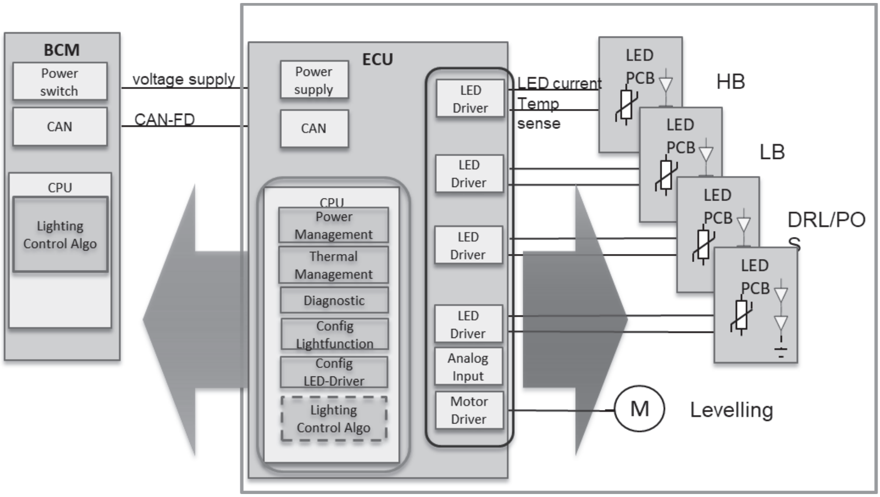

Figure 1: Traditional approach. Both algorithms (software) and electronic drivers are combined in a lamp ECU. We propose to separate these functions, with centralized algorithms outside the lamps and drivers situated on PCB.

Figure 2 shows a simplified view (only left mount) of a proposed ECU-free system. All components will be supplied by the vehicle voltage supply and the command signals will be exchanged via CAN FD. Consequently, all wiring can be simplified and easily standardized with a 4-wire bus architecture connecting all components. This is a stark contrast to highly individual and wide-sprawling wire-harnesses of current lamps.

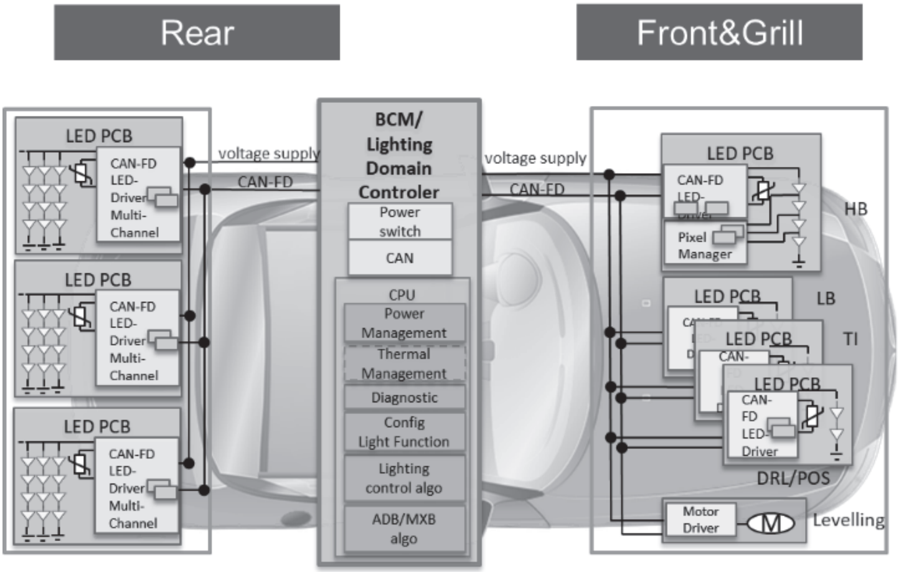

Figure 2: ECU-free system view. High level functions are centralized. Components are supplied by vehicle voltage supply. Control signals are exchanged via CAN FD.

Figure 3 shows a flow diagram, how and where the system acts for an ADB driving situation. The core concept lies within the separation of algorithms and electronic drivers which were previously combined inside an ECU. Figure 4 shows a block diagram, how necessary diagnosis functions are shared between BCM and CAN FD drivers. In the same way as function control, low level responsibilities are handled on driver level, while high level decisions are handled on BCM level.

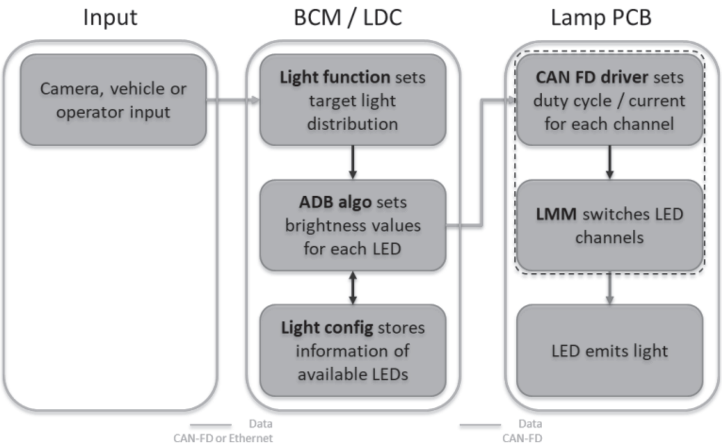

Figure 3: Block diagram of function control. All low-level functions are handled on PCB level. High-level functions are handled centrally, and the commands are sent via CAN FD.

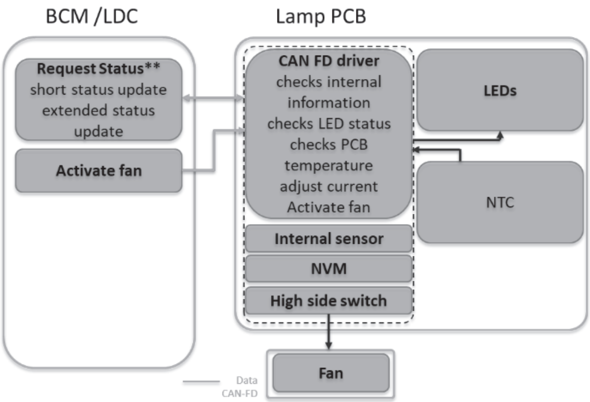

Figure 4: Block diagram of diagnostic functions. The CAN FD drivers are diagnosing themselves and connected components. They can be configured to perform local thermal management. The function leader recurrently requests status updates

4 Communication

With a clear hierarchy present in the system architecture, the communication scheme will be a leader-follower concept without arbitration. The CAN FD drivers inside the headlamp will only send messages upon direct request. Broadcast messages from the BCM/LDC can be sent without worrying about collisions etc. This allows a very efficient use of bandwidth and reduces the requirements on the CAN FD drivers. It is our goal to have this protocol be compatible with CAN FD light, as defined by CiA-604-1

Figure 5 shows the different OSI layers that will be used in the communication scheme. For a successful coverage of the market and the acceptance as an open standard, all lower levels will follow existing and widely accepted standards.

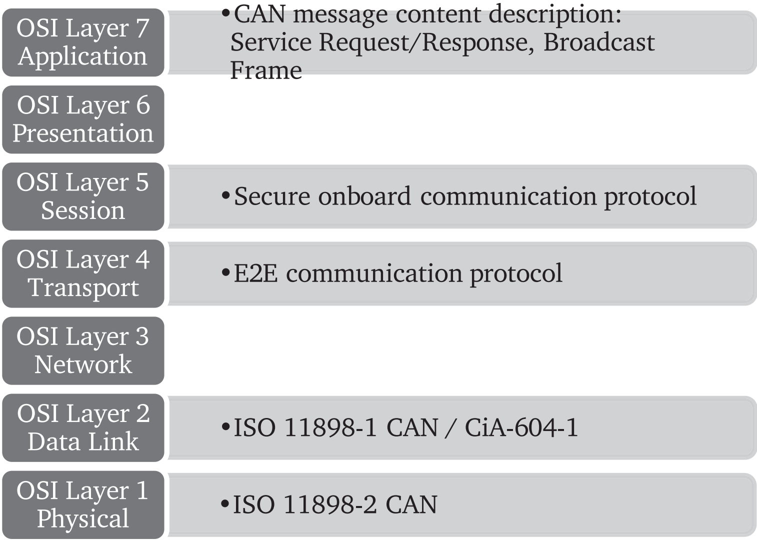

Figure 5: OSI model for communication between BCM and CAN FD drivers. Lower levels are following automotive standards.

All communication will be E2E protected and can be authenticated if necessary, see chapter 6 Safety and Security.

In the leader-follower scheme, there will be three general types of messages. Broadcast messages from the leader to all followers with a certain CAN ID. Request messages from the leader to an individual follower with a certain CAN ID. Respond messages from an individual follower with a certain CAN ID which can only be transmitted after receiving a request.

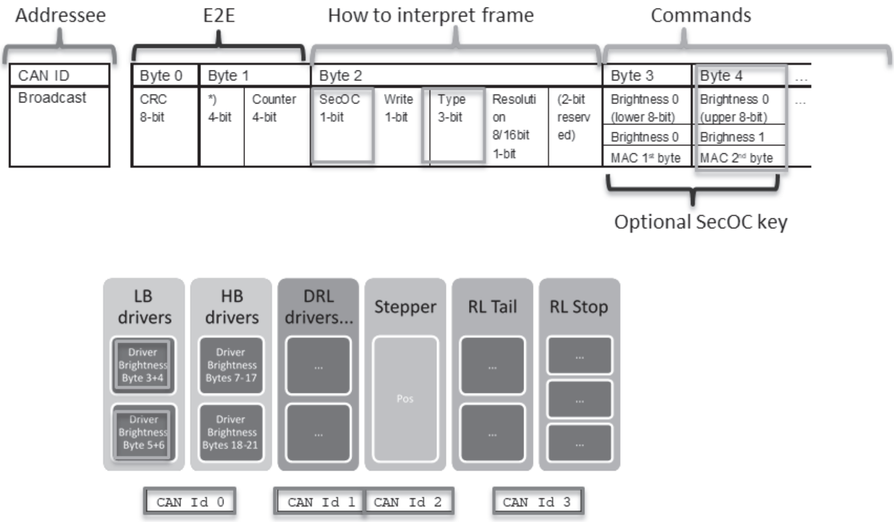

Figure 6: Proposed CAN FD frame for broadcast commands. Drivers are sorted by function into corresponding CAN ids. Individual channels correspond to distinct positions within the broadcast frame (i.e. byte number XY).

The typical function of a broadcast message will be the communication of brightness information for individual LED channels, e.g. the dimming profile of an animated turn indicator. The payload of the broadcast frame will then contain the brightness information for all LED drivers and their subsequent LED chains which listen to the same CAN ID, see Figure 6. The typical function of a request and the following response message are updates about the driver status, i.e. if any error has been detected. In order to safe bandwidth both a short status (no error / error) and an extended status (thermal information, voltage information …) will implemented, with the latter only requested after an error is indicated by the former. Since a follower cannot initiate communication, its means of checking for connection errors depends solely on a watchdog function. The leader will therefore send messages regularly.

Other messages include wake-up / sleep, activate / deactivate session, read memory / write memory and synchronize clock. For detailed information on protocol specification, please contact the authors directly.

Usage of well-established communication standards is paramount for an open and future-oriented architecture. We therefore propose to build upon the following standards as basis for communication, see Table 1.

Table 1: Underlying standards of communication protocol.

<table>
<tr><td>E2E Protocol Specification
AUTOSAR FO Release 1.5.0</td><td rowspan="2">Specification of AUTOSAR End-to-end communication protocol.</td></tr>
<tr><td>Specification of SW-C End-to-End Communication Protection Library
AUTOSAR CP Release 4.4.0</td></tr>
<tr><td>Specification of Secure Onboard Communication Protocol
AUTOSAR FO R20-11</td><td>Specification of AUTOSAR Secure Onboard Communication Protocol</td></tr>
<tr><td>ISO 11898-1:2015</td><td rowspan="2">Provide the physical and data link layer of the OSI model for CAN.</td></tr>
<tr><td>ISO 11898-2:2016</td></tr>
<tr><td>CiA Specification CiA-604-1</td><td>Data link layer of CANFD light</td></tr>
<tr><td>ISO 14229-1</td><td>UDS specification and requirements.</td></tr>
</table>

5 Safety and Security

In this chapter, we introduce two distinct but connected topics. Many of the light functions in front and rear lamps have severe vehicle safety implications. Therefore, functional safety standards, i.e. ISO 26262, will apply to CAN FD based drivers as well. Furthermore, the same standards must be applied to the communication.

To ensure a correct transmission, all communication will be E2E protected, with the drivers only acting on correct messages. If a time-out occurs with no correct messages received, the drivers will automatically refer to a fail-safe state defined in its non-volatile memory (NVM). Depending on the light function, this might result in a certain brightness value, motor position or deactivation of the function.

In Figure 7, we have collected the ASIL requirements for LED drivers in front and rear lamps as well as the requirements on communication.

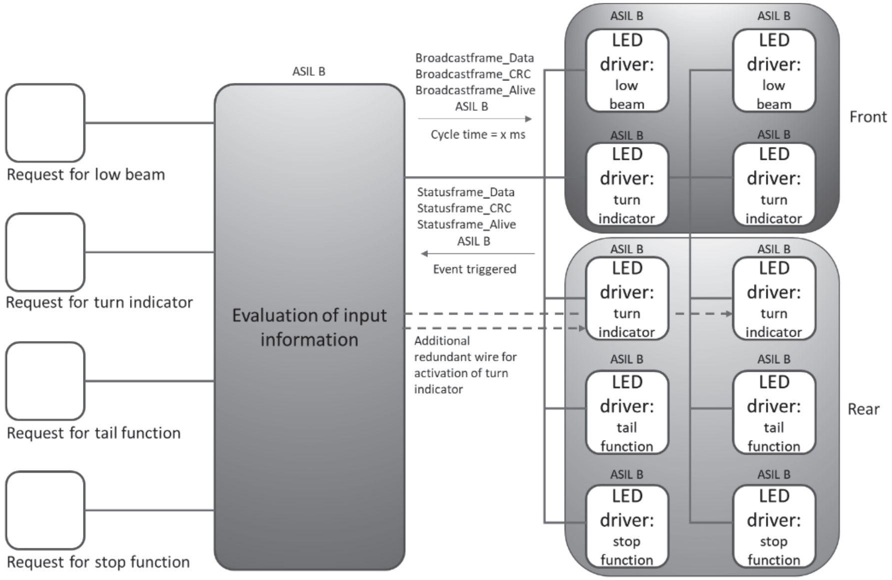

Figure 7: Functional safety requirements affect both the devices and their communication.

Even with the message structure being correct, we foresee the need to also ensure that the origin of the message is valid, i.e. no manipulation by third parties has occurred. We expect the framework to be set in upcoming regulation UNECE R155 and SAE/ISO 21434.

Therefore, the protocol includes the option of authenticating functional safety relevant messages based on AutoSAR SecOC profile 3. This authentication process can also be used to implement theft protection.

It remains an open point, for which messages such an authentication is required and how it will be implemented on driver level. Especially if every driver needs the capabilities for authentication or whether one secure element per lamp can suffice.

6 Summary and Outlook

We see E/E lighting architectures on the threshold of a major change. The traditional approach of ECUs inside each lamp is ill-suited for the fluidity of customer expectation and the required flexibility. Separating software and hardware, i.e. control algorithms and drivers allows for modular solutions. The number of drivers will seamlessly follow the application needs. An easy distribution frees up designers to imagine light functions anywhere on the car without the shackles of a bulky ECU. For the electronics, there will be no difference whether all components are within the same housing or located at different positions. Especially, OEMs will be more flexible to diversify their offering of headlamp options without the limitation or overhead of ECU capabilities. All connections can be standardized and simplified, especially lamp-wire-harnesses will be cheaper, smaller and lighter. Centralizing the control software in a central controller allows for software as a product and easier on-air updates, creating opportunities for both suppliers and OEMs.

Clear tendencies toward ECU-free solutions are already present in rear lamp applications. New functions like grill illumination will only further that trend and we foresee real advantages for all exterior lighting.

7 Acknowledgment

The authors acknowledge discussions and technical input from both inside and outside their respective companies. The input has been very helpful; however, this article only represents the statements of its authors.

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From MLA to CLA – keeping benefits while reducing complexity

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Keywords: Slim Line, CLA = Cylindrical Lens Array, MLA = Micro Lens Array, Wafer Level, Styling, Individualization, Free Contour, Sub Module.

1 Abstract

Headlamp design often calls for slim light apertures and, as a result, focuses on the design of signal functions. Elements for implementing the main light functions often stand in the way of an attractive overall appearance as large, bulky blocks. Various technical approaches for slim main light functions are therefore pushing their way into the market. Compact MLA (Micro Lens Array) and CLA (Cylindrical Lens Array) modules are already on the road in this context and have formed a benchmark, implemented and integrated by *HELLA*.

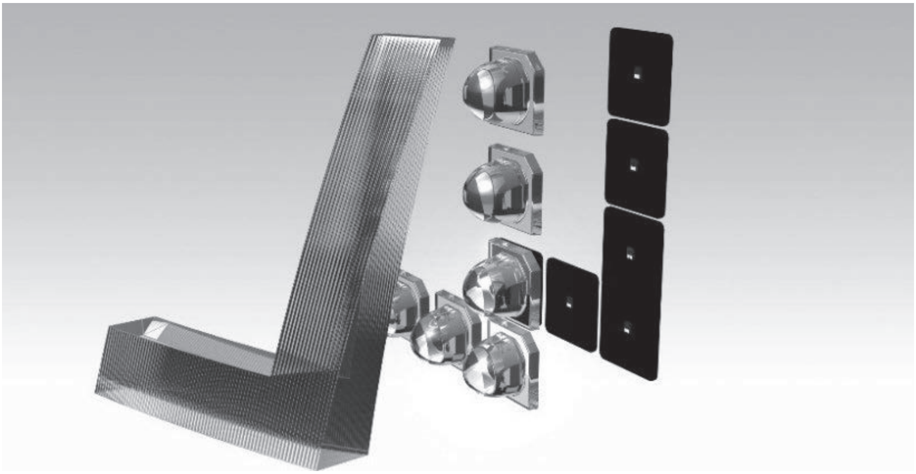

Figure 1: CLA - Individual styling, free contour, and cost-efficient module approach with minimized height & depth. (source: HELLA)

This paper discusses possible solutions like MLA and CLA for implementation of main light functions and slim headlamp styling. Day & night design will be reunited. Furthermore, it presents cutting-edge approach CLA as a solution providing the optimal characteristics for an overall headlamp portfolio.

And that is just the beginning. In particular, the CLA technology offers various interesting advantages over other technologies for the implementation of main lighting functions. First of all, the narrow light emission down to 10mm is visible - and not only for horizontal light emission, but also for vertical, diagonal and completely customized signatures. In addition, the concept is characterized by an unbeatable construction depth and a tolerance-insensitive photometric design. For this reason, among others, all main lighting functions are currently under development on the basis of *HELLA's* compact and robust CLA technology.

2 Introduction

Whenever OEMs sum up their automotive headlamp requirements, they usually demand individual and slim design approaches, high efficiency, minimum costs, and minimum installation space while having a performant light. The term slim in this context describes a light output that has the shape of a free contour, comparable to signal light functions. The wish is to hide all main light functions within the headlamp design representing the eyes of the vehicle. The trend towards slim headlamps consequently allows an even more distinct friendly, aggressive, or athletic impression of design. Furthermore, slim usually means a light output height of less than 20 mm. However, not all requirements can be met 100%. At the same time, it is possible to optimize the light concept to reach these goals as close as possible. Relations between the goals and the characteristics of a headlamp and its contribution must be discussed to find this solution. The table below shows the major OEM requirements with its contributors from a light technical point of view. This point of view was chosen because light and optics effect a slim design mostly.

Table 1: Slim headlamp requirements and its contributors.

efficiency	**individualization & slim design**	**cost reduction**	**volume**	**light**
distance LED to optics	light output	identical in construction (carry over parts)	optics size	homogenous
optics aperture (étendue)	optics independent arrangement	easy setup	cut width	bright
refractive index	unlimited shape and styling	simple optical parts	no. of single optics	legal

Therefore, comparing these characteristics and deriving optical systems just lead to a few answers when maximizing limits of styling and fulfilling required properties. According to Willeke [1, 2] reflectors, projectors with a separate shutter and projection lenses without a shutter fail without a sophisticated tolerance chain from light source over cut-off forming absorber to projection lens. With a height of less than 20 mm reflectors must be actively aligned to the light source and are quite inefficient because of a small étendue. To realize efficient slim output complex TIR optics with a good insensitiveness to tolerances between light source and in-coupling and an integrated shutter are possible but bulky.

A very good example for fulfilling most of the criteria (slim, homogeneous, compact) and entering the market this year is the MLA technology (MLA – micro lens array or multi lens array). An MLA consists of thousands of paired lenses with a shutter in between made of an absorbing metal plane manufactured by a waver-level process. There are more cost-effective injection molding solutions under development.

A second approach, developed and IP protected by *HELLA*, is the CLA concept (CLA – cylindrical lens array). Main criteria here was keeping MLA benefits while reducing complexity. A CLA consists of a few cylinder lenses made by injection molding. A combination of a projection lens with an integrated shutter and the CLA allows a cost optimized slim optical design.

3 MLA Technology

The **M**icro **L**ens **A**rray (MLA) Technology is based on the concept of Köhler illumination also known as fly’s eye homogenizer [3]. This approach is commonly used for beam shaping of lasers or homogenizing illumination in home and cinema projectors. In principle an MLA consist of a lot of small projection systems all projecting in the same angular space resulting in a homogeneous angular distribution independent of the entering distribution homogeneity.

In Detail, a couple of identical lenses are placed on a plane surface very close to each other (array arrangement) and paired lenses are arranged in a distance. Here, the focal points of each first lens array correspond with a focal point of each second lens array. When illuminating the “doubled” micro lens array with spatial inhomogeneous and mostly parallel light each subchannel (lens pair of first and second lens array) sees a different part of the inhomogeneity. As every lens pair also called sub-channel of the MLA nearly illuminates the same angular space (can be transferred to same field plane with an additional condenser lens) the superposed distribution becomes homogeneous. Thus, each inhomogeneity will be spread to the overall distribution. Dividing the inhomogeneous spatial light into thousands of small sub-channels leads to a very homogeneous distribution.

As mentioned, the first lens of a sub-channel collects the spatial light entering the lens aperture and focusses on to its focal point. If placing a very small and precise shutter in between the two lenses it is possible to define a cut-off and the gradient in each direction by absorbing/reflecting of light. Having thousands of channels allows to modify a light distribution very precisely by subtracting light with the shutter.

An MLA can be compared with thousands of small projection modules, consisting of an illumination lens, a shutter, and a projection lens. To illuminate the first lens with “parallel” light requires primary optics in front of the light source. Lenses with a small cut width and TIR collimators both are feasible here.

The complexity of the MLA technology is based on its setup. Two lens arrays with an absorbing/reflecting shutter in between. Several solutions were investigated in the past. Basically, an idea by Fraunhofer IOF [7, 8] in Jena/Germany led to the first product ever using MLAs in a car. The light carpet projects a symbol or a shape on the floor next to the car [5]. The MLA consists of an illumination side and a projection side. The illumination side is an array of hexagonally placed lenses, so that the fill factor is 100%, made