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Review Article

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Signal lights – designed light for rear lamps and new upcoming technologies: innovations in automotive lighting

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Abstract: Signal functions have to fulfill statutory regulations such as ECE or FMVSS108 to provide a clear signal to other road users and satisfy the same standard definitions of lighting parameters. However, as rear combination lamps are very different from one another, and these days are an increasingly powerful design element of cars, automotive manufacturers want an innovative, superior, and contrasting design. Daytime appearances with a new and unusual look and nighttime appearances with unexpected illumination are strong drivers for developing amazing innovative signal functions. The combination of LED technology and different forms of light-guiding optics, new interpretations of common optical systems to develop various styling options, the use of new materials and components for lighting effects, the introduction of OLED technology on the automotive market, and amazing new optical systems, using diffractive or holographic optics in future rear lamps, are paving the way for further, exciting design possibilities. The challenge of new signal functions is to take these possibilities and to develop the appearance and illumination effects the designer wants to reinforce the image of the car manufacturer and to fit harmoniously into the vehicle design. Lighting systems with a three-dimensional design and appearance when unlit and lit, amazing 3D effects, and surprising lighting scenarios will gain in importance. But the signal lights on cars will, in the future, be not only lighting functions in rear lamps; new functions and stylistic illuminations for coming/leaving-home scenarios will support and complete the car's overall lighting appearance. This paper describes current lighting systems realizing the styling requirements and future lighting systems offering new design possibilities and developing further stylistic, visual effects and improved technologies.

Keywords: designed light; holography; light guides; new functions; OLED.

1 Motivation

The signal functions of a motor vehicle represent an important contribution to road safety as they show other road users the current driving condition of the vehicle.

Any vehicles ahead, vehicle braking, or reversing is made visible to other road users by means of the respective signal function, and particularly dangerous situations, such as driving in fog or emergency braking, are highlighted by special signal functions. General legal regulations, such as the ECE regulations or the FMVSS108, describe the signal functions and supply the basis for the universal recognition and understanding of the signal functions for all road users worldwide.

The fast technological advances made since the beginning of the 1990s, essentially characterized by the development of the optic-free cover lens, entailing the shift of the light-distributing optical elements from the cover lens to the lamp interior, and the introduction of the LED light source (light-emitting diode) will be continued with OLED technology, laser-light source, and totally new optical systems using diffractive or holographic optics or other new parts. These provide a vast range of design options but, at the same time, lead to a more differentiated view on the development of signal functions. It is the 'duty' of development engineers to fulfill legal requirements and the creative interpretation of light for an innovative appearance, preferably with a 'wow effect', is another essential aspect of their work.

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The vehicle designers' stylistic demands on today's vehicle lighting are focused on the novelty of a technology and its appearance. HELLA's lighting experts face the challenge of setting their design apart from the competition while defining a brand-typical lighting strategy including the consistent development of the lighting functions from one vehicle generation to the next. Working in close cooperation, the stylists and the lighting experts of the pre-development department produce ideas, concepts, and pre-series quality styling samples, which not only live up to the challenges of the vehicle designers but also present a multitude of new design variants with new optics, new light sources, new surfaces, and materials.

Figure 1: BMW 5series rear lamp, MY 2014.

Figure 2: Porsche Macan rear lamp, MY 2015.

2 Design of current production lamps

Today's rear combination lamps already have a complex design, which often involves a large number of components, optical components and covers, and/or decorative elements. It is becoming clear that vehicle designers are very committed to designing lights to produce a design typical of the brand with great perfection. This work is based primarily on three technological design features: light guide technologies, homogeneously illuminated light areas, and three-dimensional effects [1, 2].

The light guide is a dominating design element in lighting technology. These days, light guides can be found in a large number of lights – in any shape, with a rod-like or sheet-like design. They are easy to manufacture as injection molded parts and, in combination with LED light sources, can be used in many different ways to design signal functions. The rear combination lamp of the BMW 5 Series features flat light guides, known as Edge-Lights, for the tail light. Their front light-emitting edge is used to generate the signal function by also producing a linear-shaped signature and generating the light distribution and intensity for the tail light. The cover of the light guide has a striped illumination pattern to emphasize the depth and design of the function. Here, the light from LED sources is only incorporated in the lateral narrow sides of the light guide (Figure 1).

The rear combination lamp of the Porsche Macan is a rear lamp with a topographic lens, which already has three dimensions, also known as a sculptural design, whose signal functions are all performed using light guide technology (Figure 2). A narrow signal function, positioned centrally, combines the functions of the tail light and direction indicator, while a revolving stop light, which follows the lamp contour, produces a large braking signal, providing a strong warning effect for any vehicles behind. The centrally positioned dual function makes clear that one light guide can be used to produce several functions of different colors with the same light exit. This gives vehicle designers more potential for future vehicles, whose lamps are to become smaller and smaller.

Homogeneously illuminated function surfaces are a challenge; especially with curved and facetted design surfaces, it is a hard job to develop a lighting technology to achieve the customer requirements for homogeneity in all viewing directions. While work initially only focused on tail light functions, vehicle manufacturers are now demanding homogeneity in all other signal functions with flat light exits, too. Additional lenses made from a diffuse, light-scattering material are used in many rear combination lamps. Depending on the signal function and desired intensity, these are backlit by different numbers of LEDs and optic systems (Figure 3). In the simplest scenario, they simply use a number of LEDs, which light up the additional lens directly. Alternatively, a transparent additional lens can also be used, which is then given an erode surface texture or etch pattern on one or both sides to produce diffuse scattering.

Figure 3: Audi A4 rear lamp, MY 2016.

Three-dimensional illumination effects in signal functions have long been important in the design of rear combination lamps. However, particular attention is paid to the installed depth of optical systems. Despite producing a 3D illumination as spectacular as possible, the entire system may only be installed at a small depth so it can be integrated in the limited space available in a rear combination lamp.

The principle of a mirror tunnel [1–3] achieves an impressive tunnel-shaped depth effect in a flat installation pocket (Figure 4).

Here, light is radiated by an optical system located between a semi-transparent mirror in the front section and a mirror in the rear section with the desired contour. This light signature is reflected several times between the two mirror surfaces. With each reflection, part of the light passes through the semi-transparent mirror in the front and can, therefore, be seen as a light image, and with each reflection, the luminance decreases. The appearance of the reflection can be controlled by the shape of the two mirrors. The result is an impressive tunnel-shaped effect whose virtual appearance is much deeper than the actual installation depth of the system.

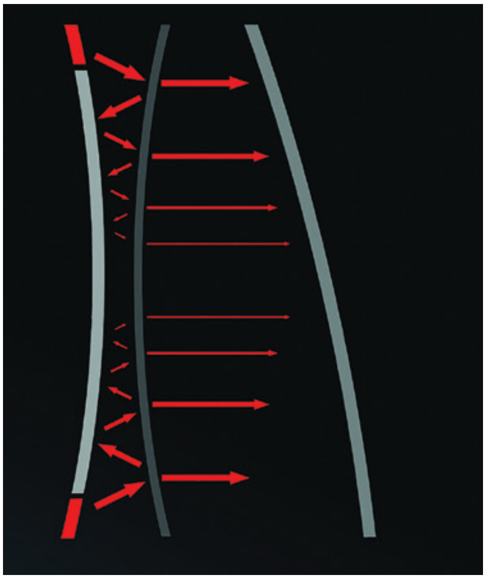

Figure 4: Principle of the mirror tunnel system.

Figure 5: PSA C4 Picasso rear lamp with mirror tunnel system for tail-stop, MY 2014.

The advantage of this optical system is that it is designed to let only part of the light be reflected between the mirror surfaces, while another other part of the light is led past the side of the mirror structure and used directly to generate the light distribution of a signal function (Figure 5).

By applying this principle, any optical system, such as reflectors, Fresnel lenses, or light guides, could be used, and the required luminous intensity would be available for any desired signal function.

3 Light guide systems

Light guides support the styling of a lamp like no other optical system before. The freedom of design for creating new signatures and appearances and the execution of a light guide as a rod-shaped or flat expanded element offer the designer maximum potential for individual styling as well as for the development of brand-typical stylistics [1, 2].

Starting with a specified design signature of a narrow light function, usually pretended by the stylists of an OEM, which extends through a rear combination lamp, a light guide with an adjusted geometry will be designed with a view to the optimal number and distribution of LED light sources to achieve a homogeneous illumination of the function signature in all viewing directions (Figure 6).

The quality and performance of the light guide illumination and homogeneity is controlled by its geometry and the number and distribution of the LEDs, the calculated

Figure 6: Hella styling sample EdgeLight, based on BMW 5series rear lamp.

optical elements to collect and spread the light of the LED inside the light guide, and whether the output surface of the light guide is designed with dispersion optics or a light-scattering structure. Figure 7 shows the light guide geometries used in the styling sample shown in Figure 6.

Rather than a structured output surface, it is possible to further optimize the appearance and homogeneity of the illumination by producing the light guide from two materials. The main part of the light guide is made from a clear, transparent material as usual to guide the light through the light guide to the output edge. The output zone is made by a second, diffuse plastic material, several millimeters thick, producing a bar-shaped, voluminous illuminated signature. In terms of style, the solid, illuminating output zone is a major design benefit because the entire wall thickness of the diffuse output area lights up, and the observer does not just see an illuminating light exit area as in the past. If designed accordingly, i.e. if the clear light guide area can also be seen, the observer gets the impression of a diffuse bar of light floating freely in space. This principle gives vehicle designers new design opportunities for three-dimensional signatures designed as a massive lighting bar.

The approach of a light guide design designed with a diffuse second plastic component provides yet more design benefits. If the diffuse geometry is intended not only for the light guide's output zone, but is partially continued on a light guide surface as a graphic structure, for example, as a striped pattern, this produces further new design opportunities for light guides. Another benefit is that the diffuse structures on the light guide surface can be clearly seen both when illuminated and when not.

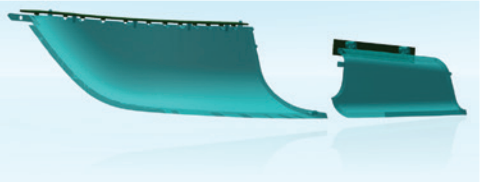

Figure 7: Light guide geometries of the EdgeLight-system used in the styling sample of Figure 6.

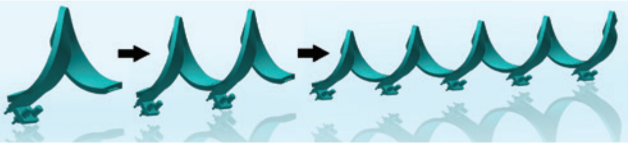

Figure 8: Principle of the light guide helix.

The design freedom of light guide geometries culminates in the development of complex, three-dimensional light guides [3]. An illuminated light guide helix expressively displays the styling potential of a three-dimensionally shaped light guide (Figure 8).

The design concept of a spiral-shaped light guide with homogeneous illumination shows that the photometric layout and the technical design together form the basis for the manufacturability of complex three-dimensional light guide geometries. The light guide helix cannot be produced in one piece in an injection molding process, as undercuts occur in the geometrical shape, which do not allow the part to be ejected.

The solution is a modular system (Figure 8) in which each loop of the helix is planned as an individual module with a light coupling in the lower part, which can be manufactured without problems. By continuously adding one module to the other, each being connected and fastened to a carrier frame in the manufacturing process, the light helix appears in the desired length (Figure 9). This principle can also be applied to other light guide shapes to create innovative and individual three-dimensional illuminants.

When viewed from different perspectives, 3D light guides continually offer the observer a changing, surprising appearance, thanks to their spatial and sculptural

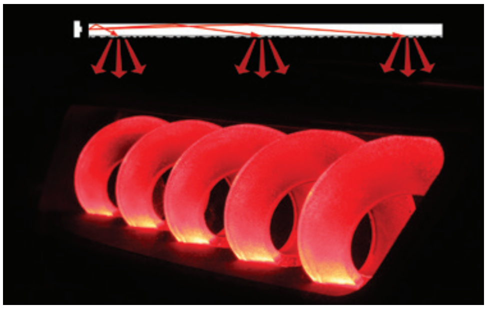

Figure 9: Light guide helix.

design. The fact that the three-dimensional effect can be seen during both the day and night is beneficial.

4 Glowing bodies and three-dimensional illuminants

For various car manufacturers, diffuse, homogeneously luminous surfaces, also called glowing bodies, are a popular design element for the tail light function as described in chapter two. Here, the homogeneity of the luminance is a quality characteristic for the lighting technology used and also for the entire styling of the tail lamp and the vehicle as a whole.

Today's tail light functions of this kind display flat elements featuring only a minor visible depth; nevertheless, these rear lamps display an amazing homogeneous illumination.

The Hella lighting experts have designed glowing body systems in two different directions [1–3]: on the one hand, to allow the use of light functions with higher demands on the luminous intensity, such as stop light, direction indicator, and daytime running light and, on the other hand, to allow diffusely illuminated three-dimensional elements with a depth effect (Figure 10).

The three-dimensional glowing body [1, 2] is not a solid element. It consists of a lens, which is shaped accordingly from translucent material or a transparent plastic material with a surface structure and an optic system arranged behind it. What is special here, however, is that the optic system is designed so that the contour and size of the cover lens is covered completely and that, therefore, part of the light is coupled into the wall of the lens. The light does, therefore, shine through the lens, and at the same time, the lens is used as a light guide. For this reason, round surfaces without sharp edges should preferably be used. The direct light shining through the lens allows high luminous intensities, enabling the system to be used as a stop light, direction indicator, or daytime running light.

5 OLED

The appearance of cars is affected by function and styling, whereby the styling itself is highlighted by illumination and lighting. OLEDs and their completely new styling possibilities will generate unique selling appearances. OLEDs are about 1-mm thin, and thus, they have a very fragile appearance. In order to maintain this appearance, their back is glued on a carrier, which is almost invisible from most viewing angles. By segmenting the OLED active area into several independent light-emitting parts, the OLED signature can be customized, e.g. depending on the traffic situation or the styling requirements, to create a special OLED signature.

Over the last few years, system integration technologies have been developed, e.g. ACF bonding was adapted from display technology for a robust electric connection for OLEDs in automotive applications. This allows OLEDs to be used in the first automotive projects in the very near future. These first cars equipped with OLEDs will drive forward the further integration of new OLED concepts with increased styling possibilities in automotive applications. This next technology step will be transparent OLEDs, multicolor emission of OLEDs, and the use of flexible OLEDs [4].

By using a transparent cathode (e.g. very thin metal layers) in addition to the transparent ITO anode, transparent OLEDs with increased functionality can be manufactured. The new features are transparency of up to 50%. This feature can be used to place a second light function behind the OLEDs, e.g. a LED stop light behind an OLED tail light. A second feature is light emission in all directions. A possible use of this feature is to combine transparent OLEDs with other optical systems, e.g. a reflector with integrated transparent OLED (Figure 11).

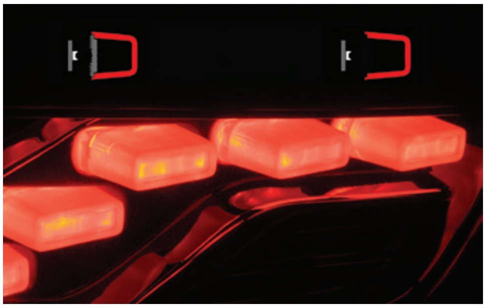

Figure 10: Three-dimensional glowing bodies and principles of the system.

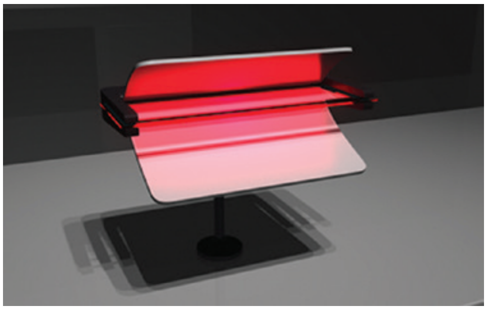

Figure 11: OLED system using a transparent OLED integrated in a reflector.

With regard to the integration of transparent OLEDs, a change to opaque OLEDs will be needed. Owing to the fact that the back is an active area, it can no longer be used as the adhesive area. An alternative assembly method will be a frame holder.

Today, OLEDs are mainly based on flat glass substrate. This material offers the best protection against environmental influence (e.g. moisture), but glass limits the OLED design of two-dimensional shapes. Although we are already able to create three-dimensional designs by a smart arrangement of 2D OLEDs, it will only be through the use of OLEDs on flexible substrates (metal foil, plastic foil, thin glass) that the whole styling potential of this technology can be used. Therefore, the integration of flexible OLEDs into automotive applications is highly attractive. HELLA develops technologies to produce rigid 2½-dimensional OLED modules by attaching flexible OLEDs on a bent rigid carrier. This is a main requirement for the successful use of flexible OLEDs in automotive applications. Initial results of this work were presented in 2014 in a rear-lamp prototype, designed by BMW and equipped with 28 bent OLEDs from LG Chem (Figure 12). The substrate material for these OLEDs was a thin plastic foil offering a minimum bending radius of 10 mm.

The R2D2 (Roll to Device 2) project was started in October 2013. It is supported by the German Ministry of Education and Research (BMBF) over a 2-year period. The project partners Fraunhofer FEP, Novaled, Von Ardenne, Diehl, OSRAM, AUDI and HELLA cooperate in a variety of OLED technology areas. R2D2 addressed the complete value chain, from primary OLED materials through to OLED lighting applications. Novaled develops new charge transport materials. Fraunhofer and Von Ardenne refine the roll-to-roll process for mass production of flexible OLEDs. Diehl integrates OLEDs from Fraunhofer into non-automotive applications (kitchenware, airplane cabin). OSRAM develops deep-red emitters for flexible OLEDs which are integrated into an automotive rear lamp application by AUDI and HELLA. The main challenges for the integration of flexible OLEDs into an automobile are robust fixation and electrical connection. Just as for 2D OLEDs, the fixation must be almost invisible in order to maintain the lightweight and sheet-like appearance of the OLED. By attaching the flexible OLED on a bent carrier, a 2½-dimensional OLED module is produced. The contact pads of OLEDs consist of very thin ITO or metallization layers. OLEDs do not withstand high temperatures. Thus, classic bonding technologies like soldering are not feasible for OLEDs. The applicability of ACF bonding, the preferred bonding technology for 2D OLEDs, depends greatly on the substrate material. Thermal conductive materials require alternative bonding technologies, e.g. elastomer connectors. The results of this technology development in the R2D2 project are demonstrated in a rear lamp prototype equipped with OSRAMs flexible OLEDs, designed by AUDI and built by HELLA.

Figure 12: OLED styling sample of LG, BMW and Hella with bended OLEDs.

The third OLED innovation will be the multicolor OLED. Two or more monochrome OLED units can be stacked in one device and controlled individually. The possibility of changing the OLED color enormously increases its range of applications and styling possibilities. HELLA developed an OLED rear lamp prototype in 2012 with a turbine-like arrangement of 16 red, segmented OLEDs. Today, this luminaire is equipped with new two-color OLEDs (Figure 13). Every OLED consists of two red OLED segments, which can be switched separately. Both segments together can change their emission color from red to yellow. In this way, two lighting functions can be supplied by one OLED light source.

Owing to the enormous opportunities provided by this innovative light source, OLED technology will find its way into automotive lighting in the near future. But the simple opaque 2D OLED is not able to keep all its promises. With an increasing number of automotive OLED products, it will lose its unique selling features unless further developments bring new styling possibilities and increased functionality. The next innovative technology steps will be transparent, flexible, and color-changeable OLEDs to support all future styling requirements.

Figure 13: Hella styling sample with two-colored OLED.

6 New optics: textile fabrics, DOEs and HOEs

New materials also contribute to the new interpretation of innovative lighting effects with a three-dimensional character. A special textile light structure fabric, woven from transparent and black plastic threads, is a flexible and new element for optical devices [3, 5]. Lighting functions designed with this textile fabric element and back-lit by a LED arrangement shows striped representations of each individual LED-light source. The number and arrangement of the LEDs and the installation and alignment of the textile fabric presents the desired pattern of illuminated lines (Figure 14).

Various versions of the textile fabric with regard to visible and invisible LED light spots, color design of the textile fabrics, single or double application, and the selection of width and length of the created light lines hold enormous creative potential for a whole range of signal lamp and interior lighting applications.

Owing to the flexible property of the textile fabric and its thermal behavior compared with other plastic materials, Hella is carrying out investigations into the optimized integration and fixation of the textile fabrics in automotive applications.

The principle of the textile fabric and the styling effect of illuminated lines for each LED can also be achieved using a special optic. Diffractive optical elements (DOE), as a very fine optical structure calculated to the wave front behavior of a light source, are a new way of influencing and defining the light distribution in a much more precise way as with conventional refractive optics. The appearance of DOEs is similar to a very fine eroding structure or a diffusing structure.

DOEs provide a linear diffusor optic with a very large deflection angle in one direction and a very small deflection angle in crosswise direction, displaying exactly the same lighting appearance as the textile fabric.

Figure 14: Hella styling sample of a rear lamp with special textile effect fabric.

Greater potential is achieved as the diffractive optic can be integrated in an injection mold and applied directly to an injection part. Unlike a textile fabric, no further stages of processing are needed. Another benefit is that a lens surface can be formed in a free, three-dimensional way, while the textile fabric element can only be used in a two-dimensional shape or curved only in one direction as cylindrical surface. Further styling possibilities of DOEs can be achieved having different areas of diffractive optics to provide different light distributions or through the arrangement of light effects, e.g. line effects, can produce a three-dimensional light sculpture while showing different orientated lighting lines.

DOEs can also be used for holograms. When we talk about holography, everyone immediately thinks of three-dimensional images of objects. Holography goes back to Dennis Gabor who founded this field of work in 1948. But it was only with the development of the laser in the 1960s that holography became important, and in 1971, Gabor received the Nobel Prize for Physics for his discovery. The holographic principle is based on the fact that with the assistance of interference, the shape of the phase front of a light wave can be made visible as an intensity pattern. To do this, the ‘signal light wave’ has a coherent ‘reference light wave’ superimposed on it. The resulting interference pattern is recorded, and you get a hologram, which, after being illuminated with the reference light wave, is reconstructed by bending the signal light wave.

Photos did not have any depth information. This is quite a different matter with holographic reconstruction: If the observer moves, then the image changes, as it should do for three-dimensional light waves. The observer can – within certain limits – also look behind reconstructed objects. Apart from this graphic application of holography, there is also the option of using holograms in light systems, with new properties, functions, and appearances [6].

Holograms can be generated as a surface hologram. Well-known applications are security-related holograms on ID cards, bank cards, banknotes, etc., or as product logos. The technology used is foil impregnated with the structure of the generated master hologram. These security holograms are often designed as reflection holograms. Implementation as a transmission hologram is also possible, which offers the opportunity of incorporating a holographic or diffractive surface structure into an injection molding tool and depicting the hologram on the surface of a lens in an injection molding process. For this purpose, a tooling insert of a lens tool can be given a holographic surface structure; the challenge here is calculating and applying the holographic optics on curved surfaces and the injection molding process, itself, as well as ensuring a high quality impression of the hologram. Hella is running advance development projects of surface hologram technology to secure volume production.

A second method used to generate holograms is volume hologram technology. Volume holograms are realized through photopolymers extended over a surface in the shape of a foil. In comparison with conventional optical elements, considerably smaller structures are used in holograms, which bend the light in a restricted spectral range. For an observer, the light-bending structures are virtually invisible, and the foil looks transparent. Volume holograms can be made both as transmission holograms as well as reflection holograms. Volume holograms can be replicated very quickly and in large numbers by a laser scanning process. Further processing of the volume holograms and their integration in rear combination lamps is currently being investigated in an advance development project.

The mirror tunnel effect, described in chapter two, can be achieved with a hologram with significantly less effort. All you need are the hologram as a lens and a light source for reconstructing the hologram and generating the depth signature of the lighting function. This means that the new technology can make the required, three-dimensional, shining signatures available in any shape, which is then extremely easy to integrate in a rear combination lamp. In its simplest form, it is as a planar hologram with a light source, but also with the option of using a curved hologram surface and several light sources around the hologram in a larger angular field to meet the visibility requirements of legal light distribution.

Light distribution information for a defined illumination area or a required signature is inscribed in a hologram, which is illuminated by a light source – LED or laser diode – then, the irradiated light is bent according to the information in the hologram so that a light field is generated with the new spectral and geometric intensity distribution, with the result that a lens in front of it, e.g. the cover lens of a lamp, is lit up in a defined signature area. Using this beam-shaping hologram with light output provided by one or more light sources and the scattering effect of the illuminated surface, generated, for example, with an eroded, etched, or laser pattern, the light intensity values are generated for the required signal function, for example, a tail light or a stop light. Because the signature-forming or beam-shaping hologram is positioned deeper in the housing of the rear lamp at some distance from the lens, the observer only sees the illuminated area of the lens while perceiving a conventional optic system behind it.

The light source illuminates the transparent hologram directly. Alternatively, it is possible to design a primary optic between the light source and the hologram to shape the light distribution of the light source. Another alternative to a visible eroded, etched or laser pattern, is to generate the signature area on the lens using another volume hologram with the optical information of a diffuse lambertian scatterer. The advantage of this kind of diffuser hologram is its invisible light-bending structure, i.e. the signature area appears transparent and clear when not illuminated, whereas the signature area lights up homogeneously and diffusely when the light source is switched on.

Holograms can be use as holographic lens if the holographic optic is applied to an additional lens. It generates a light distribution in accordance with the integrated holographic scatter function. It is possible to specify the hologram as a homogeneous surface-emitting panel with a defined light distribution in horizontal and vertical directions to be used for a tail light or stop light.

Surface light guides, also known as so-called light curtains, were used in the past to illuminate a large surface as homogeneously as possible for a tail light. This approach is used in the rear combination lamp of the Peugeot 308cc with full-surface illumination of the lamp in 2009.

The light is fed into the light guide along one edge by a series of LEDs. The light is then carried by the light guide to be outcoupled and emitted by scattering shapes, such as a spread arrangement of scattering elements, a pattern created by an eroded, etched, or laser structure, or a printed grid. The distribution of the dispersion elements is visible in both when illuminated and non-illuminated. The lighting effect as a surface function is very impressive, even though the efficiency is quite low, as a significant proportion of the light is also radiated backward from the light curtain.

Optimizing this system with holographic optic applied to the light guide shows the decisive advantage of transparency here as well [7]. The holographic optic is virtually invisible when not illuminated. Another advantage is a significantly improved degree of lighting efficiency. The light guide is illuminated by one LED at one edge. The holographic optic is applied to the light guide at the back of the required outcoupling area. The light falling on it is scattered according to the inscribed holographic information and radiated out of the light guide, for example, in a diffuse light distribution, a directed light distribution, or a focused light distribution or to present a three-dimensional picture.

Whereas with conventional dispersion elements on the light guide, approximately equal proportions of light are scattered in a forward and backward direction, the holographic optics have the decisive advantage of greater forward scatter; the efficiency is clearly better because more than 90% of the light is scattered in a forward direction and, therefore, available for the signal function!

Other than the transmission hologram, the transparent reflection hologram variant is also possible. A reflection hologram can be used to arrange reflectors in optical systems.

The reflection behavior of the hologram can be specified and realized as required for an application. The most simple implementation is a mirror hologram; more complex ones are reflection holograms with their own specified reflection behavior, for example, with a light distribution function of a conventional reflector with an optical pattern, a directed reflection, e.g. to generate a parallel light bundle – even without using a parabolic reflective surface – or to form a focused light distribution. The shape of the reflector, designed with a reflection hologram, can be defined for the respective application depending on the required reflection behavior and the position of the light source.

As the light reflection takes place in the volume hologram, this provides the advantage of being able to use black or non-reflective surfaces, in particular, for creating new stylish designs and surprising visual effects. The reflector is, for example, designed to be a matt black component with an extremely low and simultaneously diffuse reflection ability and can normally not be used as a reflector for signal functions. If a transparent reflection hologram is applied onto the matt black reflector, the light, which falls on it is reflected in accordance with the function inscribed in the hologram, while the component remains visible to the observer as a matt black component when it is not illuminated. This opens up completely new creative possibilities for designers. The dark rear combination lamps often desired for sporty cars can be made completely black using a holographic reflector. Colorful designs of reflector elements, the use of alternative, non-reflective materials, or designs including interrupted reflector elements, for example, designed as a grid structure, open up completely new design options.

One outstanding advantage of holograms is the possibility of multiplexing two or more holographic functions in one hologram. In contrast to conventional optics, which are each designed for a particular lighting function, a hologram can incorporate several lighting functions with different lighting effects.

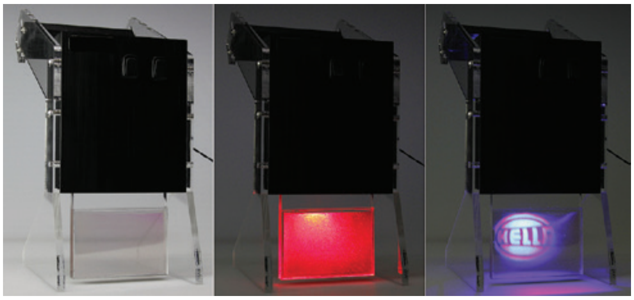

Figure 15: Holography sample with multiplexed function.

Several light sources need to be used for this, each light source fulfills a specified and required lighting function by illuminating the hologram from different reference or reconstruction directions. Here, the light sources can also include various colors so that a hologram can also reconstruct lighting functions in different colors.

A sample shows a lens with a hologram with two different pieces of light information for two light sources which are independent of each other (Figure 15). First, the lens is used as a light guide by a red LED positioned at the top edge and when illuminated displays an even illumination and emitted light distribution for a tail light. The second function saved in the hologram is a depiction of the HELLA logo using a blue LED, which is positioned behind the hologram and illuminates the hologram area from an angle at the top. Here, the HELLA logo is positioned as a virtual picture several centimeters behind the hologram level. Using a hologram with several inscribed lighting functions offers innovative potential for designing signal functions and lamps. To save space, lenses or light guides with a hologram can be used for several lighting functions or additional lighting effects, such as a welcome function.

The boundaries of conventional optics have moved, softened, or even been completely resolved by holographic optics. The innovative design of signal functions, however, has to cope with challenging approaches, both with regard to the lighting technology calculation and design of diffractive and holographic optics, which until now has been unusual in the automotive area, as well as for manufacturing and integration from a process and production engineering point of view.

7 Coming/leaving-home functions/ new functions/eye catcher

In addition to the mandatory signal functions for vehicles, vehicle manufacturers are increasingly looking for new lighting functions and effects for a brand-typical appearance and to stand out from the competition. This work is focusing on coming/leaving-home functions, lighting functions, or illumination actions on the vehicle, which are activated when the vehicle is opened and closed and can only function when the vehicle is stationary and the engine is switched off. Legislation prescribes defined signal functions and colors for vehicle operations from which deviations often apply for coming/leaving-home functions. Animated lighting functions in the form of a running light or lighting functions in the headlamp, for example, which are briefly lit up in blue or another color, are particularly popular.

These also include door lights, which light up the road surface near the doors, providing lighting and orientation when entering and exiting the vehicle, to draw attention to say an uneven road surface, puddles, or areas of dirt. Simple door lights are often built into the undersides of the outside mirrors with the disadvantage that the area illuminated on the road surface moves as the door is opened.

The latest door lights with the innovative technology of a micro-lens array allow areas to be illuminated with a high depth of sharpness and high contrasts, even with very flat angles, in order to depict graphic patterns. This allows for installation in the vehicle's side doorstep with the benefit that the illuminated zone is fixed regardless of whether the door is opened and swiveled (Figure 16). A graphic on the illuminated zone is achieved using embedded masks (slides) in each of the individual micro-lens projectors, which are adjusted and overlapped using a multitude of micro-lens projectors in the micro-lens array to define the distribution of light density and depth of sharpness of the graphic depiction.

One signal function, which in addition to its role of indicating the vehicle's travel status to other road users, that can also be assigned an illumination task is the reversing light. By way of signal function, the reversing light has a rearward, white light to indicate that the vehicle is traveling backward and is, therefore, a source of danger for any traffic behind. At the same time, the reversing light can also illuminate the road surface to light up the area behind the vehicle for the driver when reversing the vehicle and/or maneuvering in the dark to give the driver greater peace of mind or provide a rear view camera with sufficient lighting. This lighting of the road surface is especially important if the vehicle does not have a sensory distance warning system or rear view camera. However, for stylistic reasons, the reversing light in many current rear combination lamps is still a pure signal function because it is integrated to be as small and inconspicuous as possible, leaving as much space as possible for the tail light, stop light, and direction indicator signal functions.

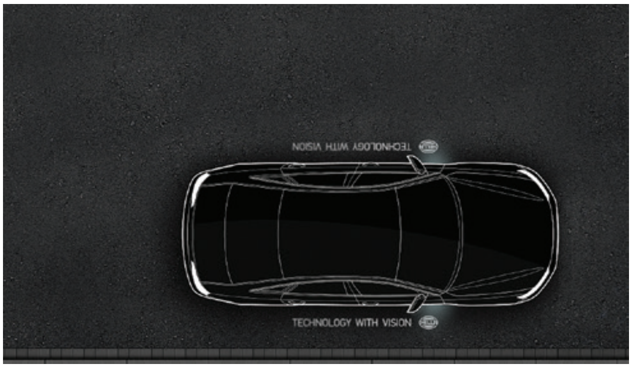

Figure 16: Entry light along the vehicle made by a light projection optic.

However, HELLA's innovation vehicle Lightron, presented 2012/13 to all OEM worldwide and equipped with innovative lighting technologies in headlamps and rear lamps [3, 8], pursues a different approach for its reversing light. Two-stage lighting intensity for use at day and night adjusts the light intensity to the prevailing requirements. During the day, there is simply a signal to indicate that the vehicle is moving rearward, whereas at night, a much more intense light provides this signal and also ensures good illumination of the road surface behind the vehicle. This illumination can be used for a rear view camera system or for direct visual orientation for the driver. A functional layout with a dual reflector system ensures that drivers behind the vehicle do not look straight into the bright spots of the LEDs because these are hidden behind the first reflector. As a new function in the rear lighting of vehicles, rear bend lighting operated together with the reversing light provides additional, sideways illumination of the road surface and surroundings and gives the vehicle driver much better lighting and, therefore, greater peace of mind when maneuvering and reversing, especially when looking in the outside mirror. Figure 17 shows the simulated light distribution of the reverse without additional side illumination (left) and with additional side illumination (right) in viewing direction to the rear (top) and in bird view (bottom). People or obstacles to the side of the vehicle and/or in the vehicle's corner region are detected much sooner thanks to the integration of rear bend lighting and/or sideways additional illumination. In contrast to front bend lighting, rear bend lighting is not defined as a licensable, independent function. The combination with the reversing light is, therefore, intended to ensure extra light distribution to the side in addition to the statutory light distribution of the reversing light.

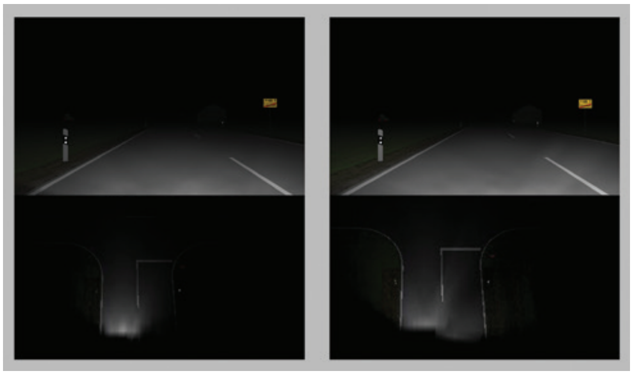

Figure 17: Light simulations of the reverse with/without additional side illumination.

Special features of future rear combination lamps and lighting functions also include providing the observer or potential purchaser in the showroom of car dealership with an unexpected, conspicuous, or particularly impressive lighting function. Such an eye catcher is already integrated in the rear combination lamp of the Lightron innovation vehicle (Figure 18). This eye catcher function supplements and supports the tail brake light, which is produced with a precise, narrow circular segment signature design, based on a second-generation EdgeLight light guide with an eroded, extremely uniform output surface. The light guide runs deep inside in an S-shape, similar to the neck of a bottle. This forces the 15 LEDs closer together and distributes them across a smaller diameter along the input zone of the light guide. The bottle neck-like contour has a positive effect on the blending of the light within the light guide, where even the fastening elements and holes in the light guide are not evident on the output surface.

As an eye catcher, a dynamic, ambient projection light is assigned to the tail brake light [8]. The functional principle is incredibly simple but extremely visible and technically superior (Figure 19). A printed film, similar to a slide with a grayscale graphic, is positioned inside a transparent PMMA cylinder, and a centrally located LED is shined through it. The light source projects the graphic onto a dull white reflector shell, which increases the size of the tail brake light and produces a depth effect, which can be consciously shaped and positioned by the design of the special graphics. However, when operating the vehicle, the observer only notices the special eye catcher function when the entire graphic light projection is run dynamically [8]. This is accomplished by making the PMMA cylinder rotate. The rotational speed of this feature depends on the engine speed of the vehicle. In addition to dynamic light projection, the advantage of this concept is the variability in the graphic. As a result, different vehicle equipment lines could be provided with particular graphics, such as a hybrid and a sport variant. The inserted film graphic can be eliminated by printing directly on the projection cylinder.

Figure 18: Rear lamp of the Hella innovation car Lightron.

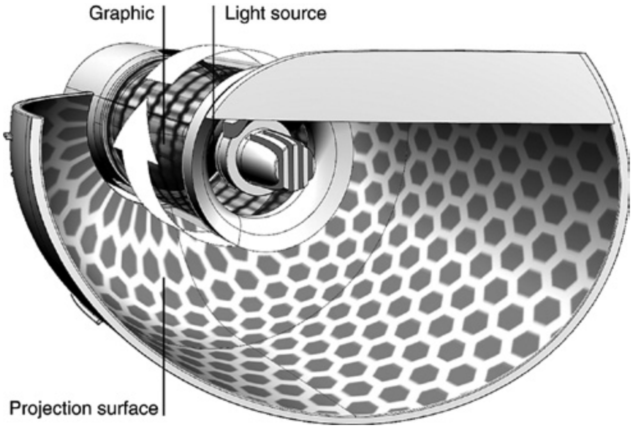

Figure 19: Principle of the light projection unit with rotating image.

8 Outlook

Rear lamps and the styling and design of integrated signal lights are very important for the styling of vehicles to reinforce the overall styling of the car, to demonstrate a brand-typical lighting signature and quality, and to deal with new technologies and innovative light appearances.

The marketing departments of vehicle manufacturers are increasingly focusing advertising on the headlamps and rear combination lamps of vehicles. New innovative technologies, high-quality light performance, or prominent design are just some examples of advertising messages.

These days, light is seen as a design element that embodies and depicts emotions and represents a brand message. The future development of signal functions will, therefore, be shaped by the further detailing of lighting systems, the precision of illuminating signatures, homogeneous lighting elements and surfaces, and the integration of innovative technologies. Using light to stage the vehicle, for example, when opening or closing the vehicle, will result in new applications and LED modules in all areas of the vehicle. Finally, this paves the way for a vehicle-wide lighting concept, which includes the interior lighting systems alongside the external lighting systems.

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Martin Mügge received a Dipl.-Ing. (FH) degree in Mechanical Engineering from the Gesamthochschule Kassel in 1990. He started working at the automotive supplier HELLA KGaA Hueck & Co. as optic-engineer for signal lights in the light lab. During optical development for series lamps about nine years he was involved in the introduction of the first LED-systems and the development of the first rear lamp with optic-free outer lens. In 1999 he focussed on predevelopment of lighting systems for rear lamps in the HELLA Lighting Systems GmbH in Paderborn. He also worked on light guide systems and close collaboration with Industrial Designers to create styling samples which led to some totally new series lamps. Back to the HELLA KGaA Hueck & Co. in 2009 he became a member of the predevelopment lighting department, responsible for signal lighting, styling samples and presentations to car manufacturing companies. Main tasks of his work are light guide systems, diffractive and holographic optics and laser for signal lights.

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Carsten Hohmann worked as a joiner before he studied Industrial Design at University of Applied Sciences in Darmstadt. He received the Dipl.-Designer (FH) degree in 2003 and started his work at HELLA Leuchten-Systeme GmbH, Paderborn as an industrial designer responsible for rear combination lamps. He moved to the lighting predevelopment of HELLA KGaA Hueck & Co., Lippstadt in 2009. Now he is responsible for predevelopment lighting concepts and the support of series development.