Advanced Automotive Interior Lighting and Exterior Displays

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ABSTRACT

Autonomous driving has a huge impact on cars. We present advanced solutions for interior "pixelated" lighting and exterior displays. Examples are visualization of driving mode by the steering wheel and information for other road users. Calibrated RGB LED systems provide the best solution in terms of optical quality and safety.

1 INTRODUCTION

Automotive interior lighting has become a major part of the customer experience. Fig. 1 top shows one of today's premium cars with interior lighting with selectable color. Future visions (Fig. 1 bottom) will take use of "pixelated" light as a single line or a low resolution display for advanced lighting effects and animations. Information visualization on the dashboard, like for warnings (yellow arrow) and steering wheel, require daylight readability.

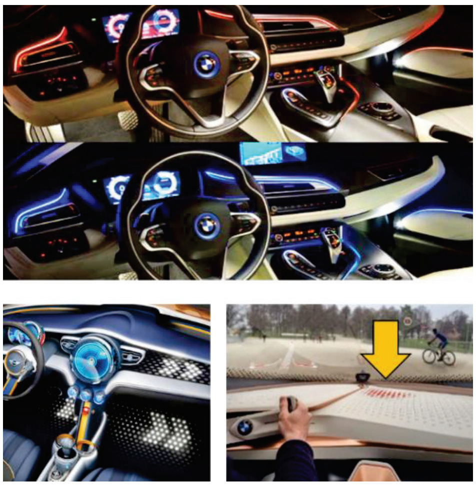

Fig. 1 Today's premium interior lighting (top), pixelated dynamic signage (bottom left) and daylight readable warnings (bottom right, arrow) for manual driving of level 3/4 autonomous cars. Source: BMW.

This paper describes the challenges and proposes solutions for advanced interior lighting and displaying information (interior and exterior) using up to 1,000's of RGB LEDs. Premium LED systems require temperature compensation, calibration (e.g. white point) and high data rate (larger than LIN). The safety of visualizing relevant information like autonomous driving mode is mandatory.

All these topics are only partially addressed by today's solutions. So we propose a new automotive RGB LED system which is calibrated for intensity & color and can be daisy-chained for 100's of LEDs. Security features provide enormous support toward ASIL functionality (risk classification scheme defined by ISO 26262).

Future cars will head towards autonomous (or automated) driving and can share as highly connected cars information via exterior displays to less connected, manual driven vehicles (e.g. traffic warnings) or inform others such as pedestrians.

2 NEW APPROACH FOR AUTOMOTIVE LEDS

In order to meet the requirements for advanced interior lighting, pixelated information and exterior displays, we developed within the ISELED alliance [1] a new approach for automotive RGB LEDs. The general challenges of RGB applications are briefly described and the implications for different applications pointed out.

RGB applications offer a high flexibility in terms of color tunability and gamut but at the cost of enhanced LED driving complexity especially when high color accuracy and stability is required like in an automotive environment. RGB LED characteristics (e.g. intensity, color and forward voltage) all depend on forward current and temperature and the behavior differs for each of the three colors. An overview of the most important dependencies is summarized in Figs. 2 - 4. Additional information can be found in corresponding datasheets like [2] and application notes (e.g. [3]).

The chart in Fig. 2 shows that especially red shows a large dependency of the intensity on temperature. This must be compensated in order to keep the coordinates of mixed colors within an acceptable range. The ISELED RGB LED offers the possibility to stabilize the red intensity with temperature by adjusting the Pulse-Width-Modulation (PWM) settings of the red chip as a function of the temperature according to a suitable Look-Up Table (LUT) that is loaded during the initialization procedure. The LUT contains 11 supporting points covering the range from -40°C to 105°C. This results in a very stable red intensity within the desired temperature range. The result is added to the graph in Fig. 2. In addition, the dominant wavelength λ_{dom} (color) of RGB LEDs depends noticeably on temperature (Fig. 3) and forward current I_f (Fig. 4); premium lighting has to deal with that.

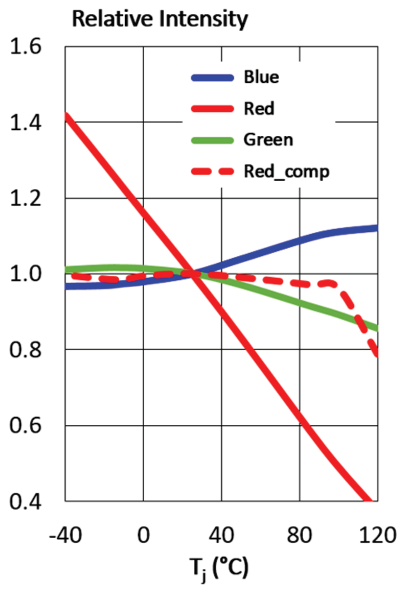

Fig. 2 Temperature characteristics of RGB LEDs.

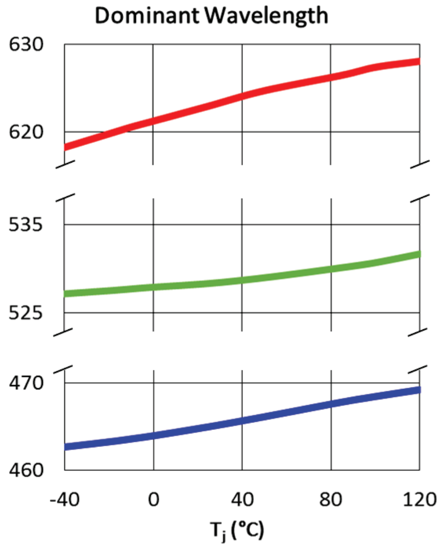

Fig. 3 Dependency of dominant wavelength from junction temperature of RGB LEDs.

Due to the dependency of the dominant wavelength on forward current I_f (Fig. 4), RGB LEDs are driven with constant current and dimmed by PWM. In principle this dependency would offer the possibility to "tune" the dominant wavelength by adjusting the forward current through the LED for blue and green. This would allow the use of a wider chip distribution within the product. For practical reasons and optimized overall system performance this feature is not used and the color accuracy of the RGB color points is assured with a narrow chip selection.

For automotive applications like a direct-lit "pixelated" light guide (Fig. 5 top) the requirements with respect to luminance and color uniformity are quite challenging. With the "traditional" calibration of the application, after the integration of LEDs, it is very hard to achieve sufficient results because the optical measurements with a luminance camera tend to be noisy (see luminance L over light guide position x, Fig. 5 bottom).

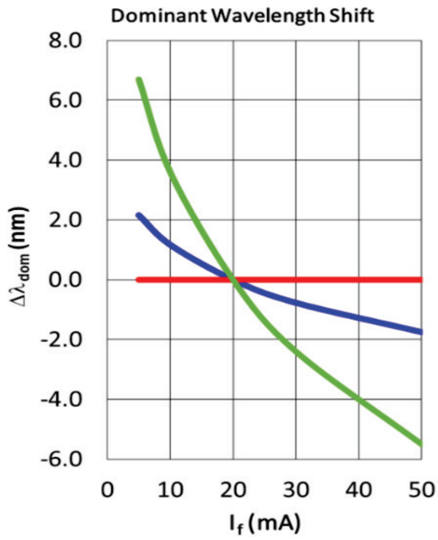

Fig. 4 Dependency of the dominant wavelength shift from LED forward current.

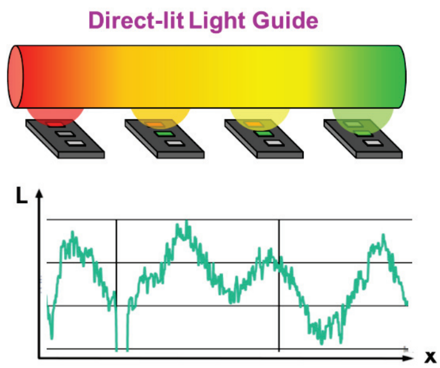

Fig. 5 Principle of direct-lit light guide and measured light output for white.

In order to overcome the challenges previously described, the ISELED smart RGB LED approach was established as a new standard (Fig. 6, [4]): RGB LEDs and an ASIC that includes LED driver, sensor, memory and controller functions are integrated into one small LED package. Each RGB LED is individually calibrated to 1,4 Cd @ D65 color point at the end of the production line. The calibration parameters for each LED are stored in the programmable memory of the ASIC. A sensor in the ASIC provides temperature feedback for the algorithm that stabilizes the red intensity over temperature (see Fig. 2). This procedure results in good color accuracy and stability in the application and easy color control for the user. The ISELED system (schematic block diagram and LEDs, Fig. 6) provides connectivity for up to 4,079 RGB LEDs in the systems. The controller enables a simple two wire interface

(2Mbit/s data rate) with a wide set of commands (addressing each RGB LED individually). On board diagnostics within the ASIC (e.g. read-back of LED current) are the fundamentals for fulfilling ASIL (automotive safety integrity level, ISO 26262, functional safety) requirements on system level.

Osram Opto Semiconductors offers two products within the OSIRE® RGB LED family that comply with the ISELED standard. The flat QFN based package with dimension of 4.6 mm x 3.3 mm x 0.7 mm includes all LED relevant automotive package features like solder inspection windows and a data matrix code (DMC) for traceability. There are two versions available with different chip arrangements within the optical cavity of the LED. KRTBI DVLM31.31 comes with a triangular chip arrangement and KRTBI DVLM32.31 with a linear chip arrangement.

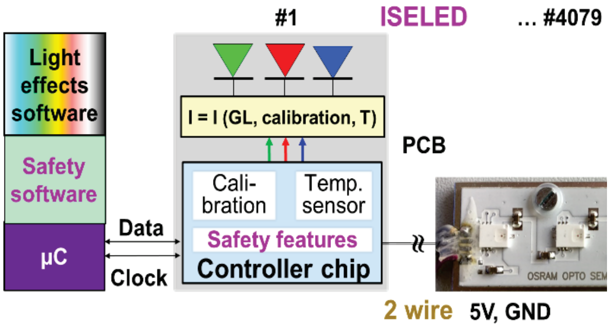

Fig. 6 ISELED smart RGB LED system with integrated LED driver and connectivity: Pre-calibration and T-sensor provide accurate and stable colors.

3 APPLICATIONS FOR THE NEW LED APPROACH

This section describes selected applications for the automotive optimized ISELED RGB LED system.

3.1 Advanced Steering Wheel and Pixelated Dynamic Interior Lighting

In order to perform highly automated driving (HAD) in compliance with upcoming legal requirements regarding driving status visualization, the integration of a light function into the steering wheel has multiple advantages under ergonomic and signal recognition aspects compared to e.g. instrument cluster. Fig.7 shows a steering wheel with a highly integrated RGB LED light system setup in the upper rim section and the simulation results regarding luminance distribution. The latter was required during the development process of the multi-component direct-lit optic to achieve the required light performance output, color mixing as well as homogeneity under daylight conditions (see image in false colors in Fig.7 right, verified by luminance measurements, [4]).

Due to the package restrictions in the steering wheel, the necessary light performance for daylight readability and high ASIL safety level requirements, there is no function failure in visualization of the driving status allowed. We took advantage of ISELED and their built-in safety features like real time read-back of each individual RGB LED in the system. Therefore, it feasible to continuously monitor the corresponding LEDs for light-up or off state. An example emphasizes that: If the autonomous mode is represented by green (G), all currents of RGB LEDs are read by the integrated controller. If any current is measured for the B or R LEDs, a failure is detected in real time in the supervising system. Vice-versa, if one or more currents of G LEDs are zero or smaller than set, this results in an error message. Tests and evaluation were successful.

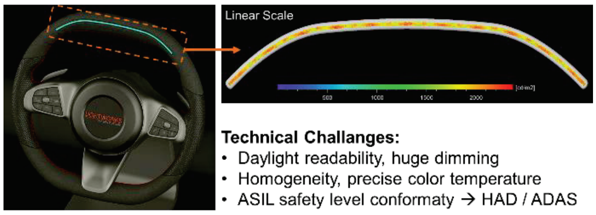

Fig. 7 Future steering wheel for visualization of driving state (manual, autonomous or take-over-request) and simulation of light output.

Fig. 8 shows a snapshot image of orchestrated light effects during a use case study. This integration was used for validation of the system including dynamic optical and electrical performance. This can be used for directional indication of ADAS warnings.

Fig. 8 Full color light effects (grey level, width, direction, speed, ramp …) by direct-lit "pixelated" light guide.

3.2 Exterior Light Elements & Displays

Exterior lighting (Fig. 9), besides rear and head lamps, becomes increasingly important and is currently only limited by legal regulations. Stylists and engineers of all OEMs explore the new lighting features. The ideas range from illuminated icons to fully pixelated display areas used for styling as well as for car to x communication.

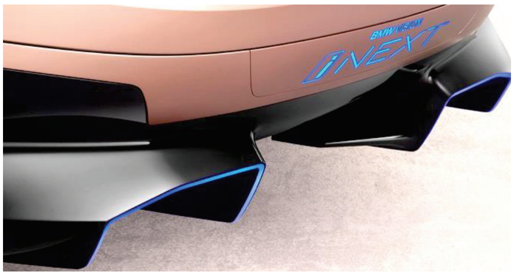

Fig. 9 Example of exterior lights, source BMW.

Fig. 10 shows examples of exterior displays from figures over text messages to (animated) icons. A pixel pitch of ~5 mm is a reasonable "first" compromise (later towards 2 mm) for observer distances larger than 5 m:

- 2 digits (figures, characters; left): Low resolution & fill factor: ~ 200 pixel, luminance of pixel ~20x display
- Characters, icons (center, right): Medium resolution & fill factor: > 1,000 pixel, luminance of pixel ~4x display

Fig. 10 Prototypes of exterior displays for autonomous cars: Front display with low resolution (left) and rear displays for characters (center) and icons (right, model car [5]).

As exterior displays must be readable in bright sunlight, the contrast ratio CR must be at least 3:1. CR must be defined for displays with low fill factor (see Fig. 9) via the effective ON luminance of the pixel area (pixel luminance + reflections from surface) and OFF luminance (for LEDs only reflections from surface):

$$CR = \frac{L_{ON}}{L_{OFF}} = \frac{L_{pixel\,ON} + L_{reflected}}{L_{reflected}} = \frac{L_{pixel\,ON}}{L_{reflected}} + 1$$

Sun-lit white clouds and buildings can reach typically 20,000 cd/m² and this value is treated for specular reflection. We assume a reflection coefficient of 0.05 (5%) for the black display cover material (Fig. 10 center) which includes some dirt. This results in $L_{reflected}$ = 1,000 cd/m² thus setting the effective (white) luminance for the total pixel area to 2,000 cd/m² for a CR = 3:1. For a fill factor of 20%, the luminance of the LED should be 10,000 cd/m² for white. An example for warnings in red for a typical RGB triple results in 5,000 cd/m² for red. However this must be examined further as we have to deal with ambient light.

Usually, the optical parameters of color displays are measured in CIE 1931 or 1976 and ΔE. However CIE Color Appearance Models (CIE CAM, e.g. [6]) describe the perception of exterior displays in bright sunlight better as e.g. simultaneous contrast sensitivity (background luminance including reflections), adaptation (surrounding luminance) and higher experienced luminance due to Helmholtz-Kohlrausch effect. This was used for theoretical validation of ISELED.

The typical observer - display geometries require only a portion (Fig. 11) of the half sphere (here only up to 45°) Depending on the scenario (pedestrian, cars at crossings, following car), (secondary) optics help to reduce power consumption and direct light into the typical observer cone. SMD LEDs show typical half intensity angles of ± 55°. As these displays are observed from 12:00, ϕ ranges from 0° to 180°. This results for pedestrians in about a threefold increase of luminance. A following car has only a tiny portion of the emission cone with $\theta < \pm 10°$ thus raising the effective luminance by more than 30x and enabling low fill factors. Such displays built with ISELED can be easily realized as up to 4,079 LEDs can be daisy chained with sufficient update time by two wire transmission.

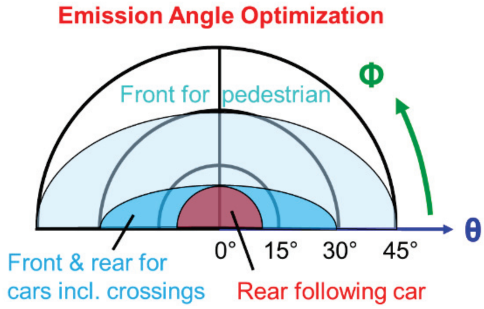

Fig. 11 Typical observer angular cones for three use cases. The luminance can be increased by optics or power consumption lowered.

4 SUMMARY

We have developed, prototyped and evaluated successfully a new approach of a RGB LED system for interior lighting and exterior displays for future automotive applications. Today's approaches have limits in terms of uniformity and safety or will result in higher cost. Our achievements are:

- ISELED RGB LED system: Validation of the system functionality under automotive environments for safety features and premium lighting requirements
- Daylight-readable LED steering wheel for visualization of the driving mode and ASIL functionality
- Direct-lit light guides for theater- and single line display-like lighting effects
- Requirements engineering and prototypes for exterior displays for information of other road users

Our findings help to implement new interior lighting and information functionality for various purposes in cars.

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