Lighting the Way

Development of the Bertrandt Full-LED Headlight Thermal Simulation and Design

By Kibriye Sercan, Michael Hage, Mario Dotzek and Eugen Tatartschuk, Bertrandt Group, Cologne , Germany

The style of a car is very much characterized by its lighting system. The final product is created by the collaboration between three areas of competence: Design, Thermal Management and Photometry in the pre-development phase. To show their expertize, Bertrandt engineers developed their own full-LED headlamp and exhibited it at the IAA 2013 in Frankfurt, Germany. The thermal analysis of the IAA exhibit was carried out using the thermal simulation software FloEFD™ from Mentor Graphics.

General Considerations

The creation of light inherently generates heat [1] [2]. The most common light sources nowadays are incandescent lamps and LEDs. Incandescent lamps are thermal radiators (black bodies) which emit a tiny fraction of energy in the visible spectrum. LEDs are semiconductors which release photons through the recombination process. Just as there are differences in the light creation processes, there are also different demands regarding the thermal management of the light sources. Incandescent bulbs need a minimum temperature for the filament to produce light. LEDs are "cold" emitters and require efficient cooling of the optically active junction layer to meet the requirements of service life and the emission spectrum. Compared to halogen bulbs, light-emitting diodes have a higher optical efficiency, lower heat generation and a longer service life. In addition, they provide designers with more creative freedom due to their smaller dimensions, directed light emission and greater freedom within the constraints of lighting legislation [3]. Given these advantages, the tendency towards using LEDs in the automotive industry is steadily growing. As a consequence, the demands on the LED lights are also higher. They are expected to offer higher performance

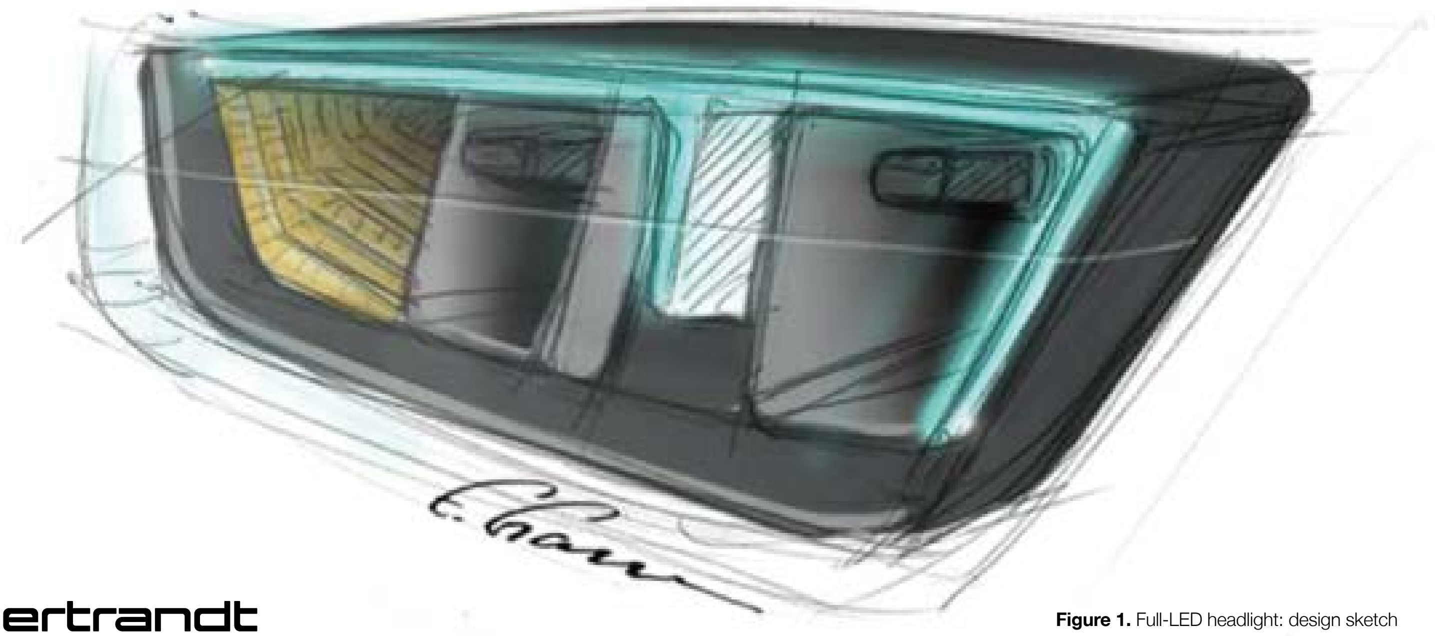

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Figure 1. Full-LED headlight: design sketch

while still providing a higher quality of light and be aesthetically more appealing than their halogen lamp counterparts. Additional degrees of freedom in the development of LEDs are created by the variety of types and their ability to operate over a wide range of currents, thus varying the light output, the service life and the power dissipated. The introduction of fans and heatsinks in headlight systems also presents developers with new challenges, as the luminous flux, which is very important for the lighting design, is highly dependent on optimum thermal conditions.

Requirements and Development Process

Bertrandt engineers wanted to develop a headlight for a lower mid-size vehicle without a standard-equipment AFS function in which the static cornering lights could be implemented at low cost by using fog lights. This meant that the photometric requirements for the low beams were higher. The static low beam was to illuminate the road as well as possible in every given situation. The luminous flux should be in the region of 600 lm, therefore the low-beam LED was to emit at least 1,000 "hot" lumen. In addition, the high-beam and daytime running light functions were to be a special design element (dimmed as a position light), and indicator lights were to be accommodated in the headlamp itself (see Figure 1). High and low beam were each to be achieved with a shovel reflector (the low beam mounted on the vehicle facing outwards to allow conversion for the North American market [4]). To increase the number of common parts, the same LED, an OSRAM OSTAR Headlamp Pro, was used for the high and low beam. For daytime running and turn indicator lights, several Advanced Power TOPLEDs were used.

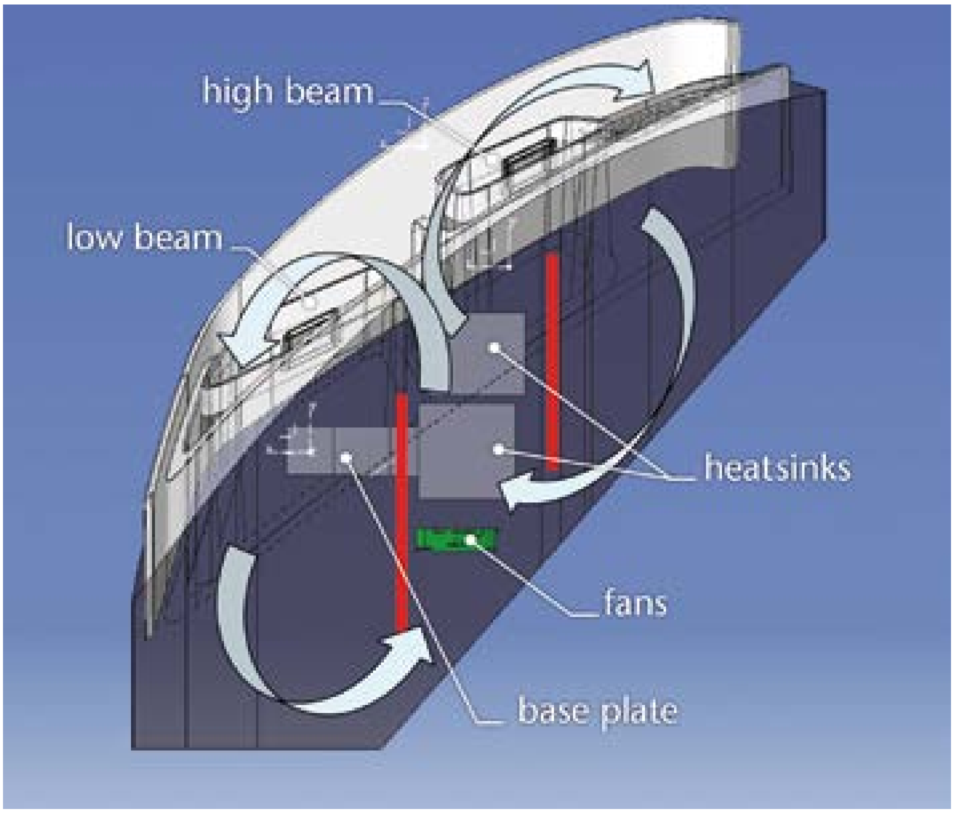

Figure 2. Concept representation of the intended airflow and simulated flow distribution in the headlight

In addition to the photometric considerations, a thermal system analysis was carried out. Two key scenarios were identified:

1. Low beam, high beam, turn indicator and position lights were activated for the most critical night time scenario, which was consequently also the scenario with the maximum power consumption.
2. Daytime running lights and turn indicator lights were activated simultaneously as the most critical day time scenario.

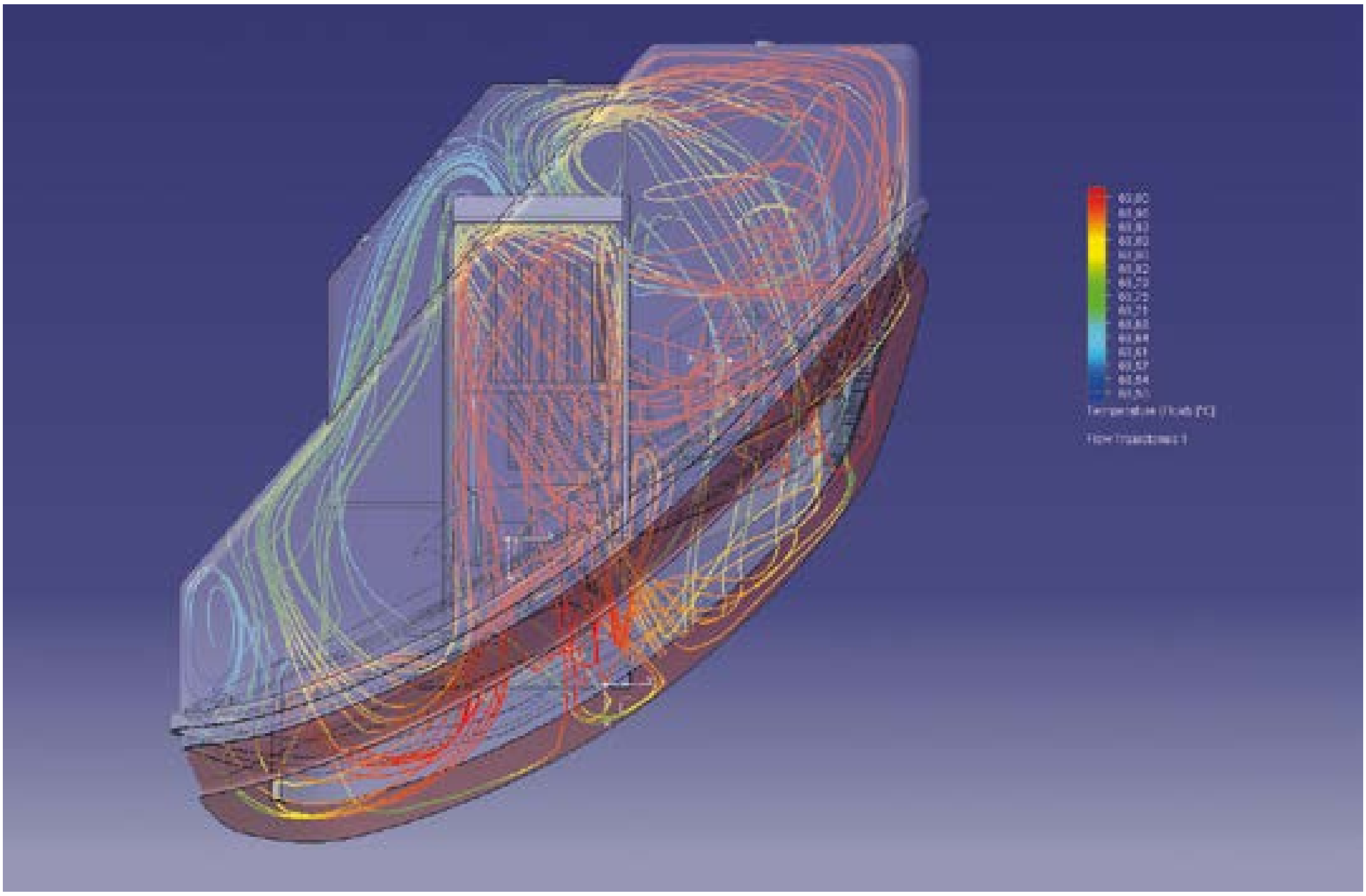

Figure 3. First airflow simulation without a cover frame. The circulations develop as planned. Part of the warm air slips through the cooling channel at the position where the base plate of the LED leaves a gap

In these two scenarios as a continuous condition, the junction temperatures of the LEDs should not exceed the maximum permissible values. A further aim was to direct the warm air from the main lighting functions (low and high beam) to the front of the cover frame, both to defog the lens and to cool the air in the lamp.

The development was carried out in the following steps:

3. Concept phase:
    - LED pre-selection
    - Heatsink positioning
    - Number of fans and possible positions
4. Dimensioning/layout:
    - Heatsink size and shape
    - Size of base plates
5. Adaptation of LED type
6. Design of the heatsink ribs and adaptation:
    - Size
    - Shape
    - Airflow direction
7. Air routing and cover frame
8. Fan selection

Through this process, which was partly iterative and partly connected with other disciplines such as lighting design, the developers succeeded in achieving the photometric objectives and the design of an efficient cooling system to attain the desired LED lifetime.

Cooling Concept

To meet the photometric requirements of the low beam, a powerful four-chip LED was chosen during the design phase. Based on the thermal resistance of the LED and estimates for the heatsinks, checks were run on whether the required luminous flux under the junction temperature of T = 150°C could be achieved. A particular challenge for cooling the low-beam LED is its position at the top of the headlight. With these design specifications, the low beam is deemed thermally more critical than the other functions. As a result of limited space in the upper housing portion, the LED was not placed directly on the heatsink, but had to be connected to the heatsink via a base plate. This resulted in additional thermal resistance, which was confirmed both by simulations and by analytical assessments. The decision was then made to move to the five-chip LED LE UW U1A5 01, which has a thermal resistance of 1.5K/W [5], because it could be operated with a lower current and achieve the same luminous flux. Since the natural convection was hampered by the heatsink shape and position, a fan was

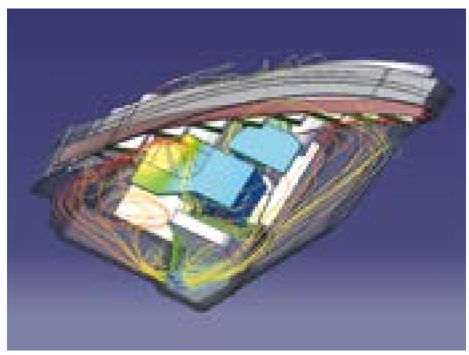

Figure 4. Thermal simulation with fully designed heatsinks and cover frame. Through several iterations and changes of the airflow guide, it was possible to design the airflow to be similar to the original plan. The base plates of the LEDs are wide enough to conduct the necessary amount of heat.

Figure 5. Photo of the final prototype.

utilized. This allowed good circulation of the air in the headlight, and a reduction in the size of the heatsinks (Figure 2).

The heatsink of the high beam was placed in front of the low beam heatsink, between the reflectors for the main lighting functions. Directly behind it, there is a fan that blows air through the two heatsinks in the vehicle's direction of travel. As a result, an air channel is created between the reflectors (Figure 3) which contributes to efficient cooling and air circulation. With the aid of Mentor Graphics' FloEFD™ 3D simulation software, the flow distribution was determined and the bezel geometry defined accordingly. The warm air was blown out of the heatsinks through an opening in the bezel below the centre section of the daytime running lights and against the cold lens, where the air cools down and simultaneously defogs the front lens. In two cycles, the cold air flows back behind the bezel and into the fan. The resulting cooling circuits are shown in Figure 2 (red lines indicate the air guide). It should be noted that two circuits are easier to control than one circulating around the entire headlight.

Using a parametric model of the heatsink and the FloEFD parametric study feature with post-processing [6], the heatsink fins were designed for the main lighting functions in order to ensure the most efficient cooling for a given airflow. The model was then completed for the signal light LED functions as well as their heatsinks. Based on the aerodynamic resistance of the system, an axial fan was chosen to work in conjunction with this system at its optimum operating point.

Results

Once the system was fully represented as a CAD model with the housing, lens, cover, air duct, fan, and heatsink, it was possible to run a simulation with precise LED parameters, a characteristic fan curve and boundary conditions in the two aforementioned scenarios. From these simulations, the operating current was calculated, which allowed an LED to operate below the critical temperature in typical conditions. All lighting functions were achieved at an ambient temperature of around 50°C at the lens and at 90°C on the housing in accordance with ECE regulations and performance requirements. This was also demonstrated with in-house measurements in continuous operation of the headlight [7].

Summary

Through regular consultation with the design department, production-ready road illumination was achieved with an almost unchanged aesthetic design of the headlight from the initial sketches to the finished prototype (Figure 5). With the direct integration of the simulation software into the CAD system CATIA V5, this process was significantly simplified and accelerated.

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