From Development to Start of Production

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Abstract

This paper highlights the complexity of an automotive LED module from initial concept design to the start of production. It shows that many modern tools are available to the designer even before any steel has been cut. Light and thermal simulation packages are invaluable to reduce design time and mould flow analysis highlights any potential problems during injection moulding of the parts. The problematic in the design of the light guide, the heart of an LED module, both during design and production phase is being discussed.

1. Customer Specification

Oshino Lamps develops the concept for a lighting module working closely together with their customer. When Jaguar Motors, for example, required a unique lighting solution for its new XF platform, it consulted with the company and used their expertise to turn an ambient lighting challenge into an ambient lighting reality. The automotive industry OEMs are increasingly trying to generate a "new mood" for the driving experience. This trend prompted Jaguar's desire for a stylish XF door-panel finish using decorative lighting effects.

Throughout the consecutive development phases the concept is developed step by step until start of production. The mode of operation, as is usual in automotive, thereby is construction from the outside to the inside. The customer will provide the assembly CAD package and specify his requirements. It is then the supplier's responsibility to make this requirement reality, thereby developing his own concept for the module package.

2. Design Concept

The housing of a lighting module, often made out of black plastic, usually holds a light guide and a pcb with electronics and light source. This housing is then fixed to the customer part by either screw or clip connection preventing at the same time any stray light. Image 1 shows a typical setup.

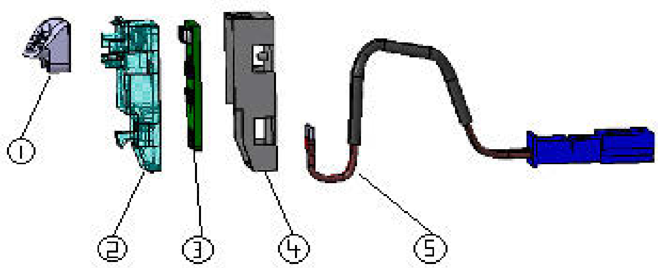


Image 1: Exploded view of a typical ambient lighting assembly consisting of lens (1), cap with integrated light guide (2), electronics pcb with light source (3), housing (4) and cable assembly (5)

Together with the light source the light guide is the heart of a light module. The desired illumination is realised through the geometry of the light guide which directs the light to the required area. The function of the light guide is either to bundle the light into a particular direction, disperse it (see image 2 for examples), or even mix the colours as is shown in image 3.

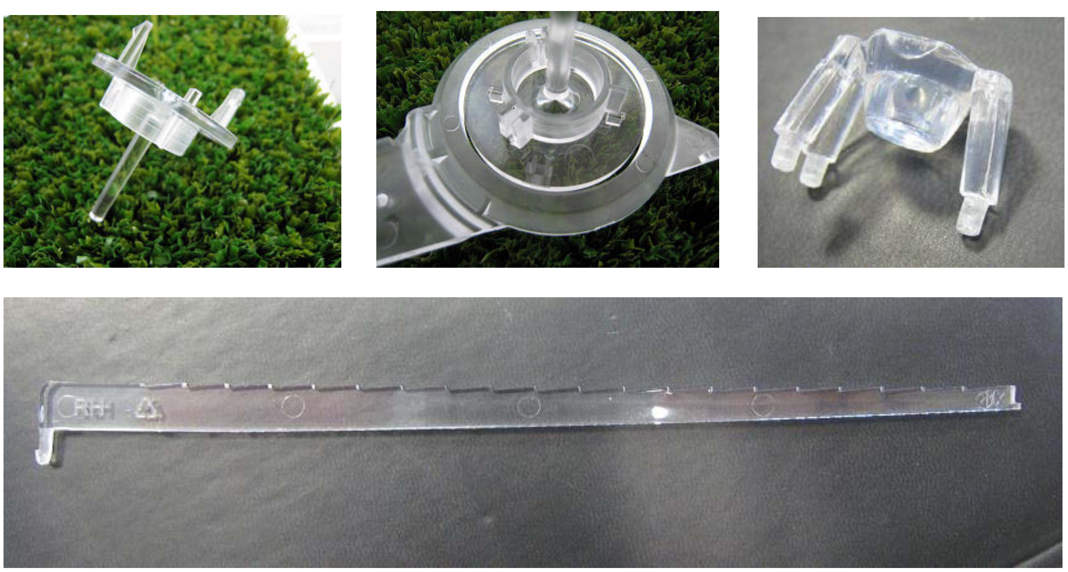
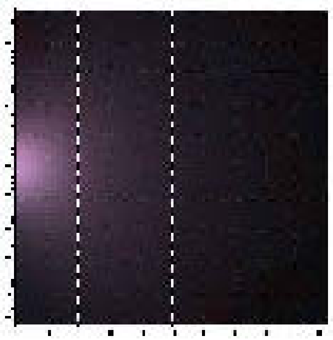


Image 2: Examples of light guides



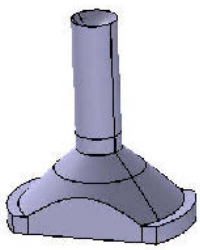
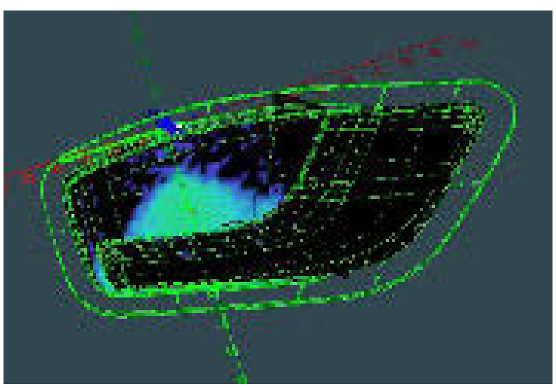
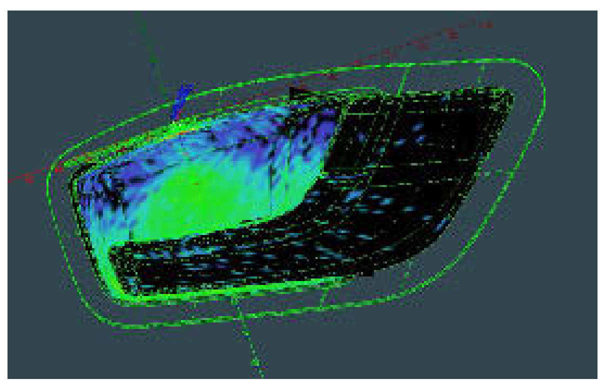


Image 3: Purple light output created by mixing colour output from a blue and a red LED within a light guide

Depending on the application either transparent materials, that allow light to be reflected according to the laws of physics, or light diffusion materials, that can disperse more or less light depending on the type of material utilised, are being employed. Image 4 shows by means of a CAX simulation how the choice of material influences the light output. With the clear PC lens, the output is much more focused while with the lens made out of PC with diffusing properties it is much more dispersed, illuminating a wider area.



Simulation with lens made out of PC clear



Simulation with lens made out of PC diffuser

Image 4: Effect of the use of diffuser material on light output

The polar diagram of an incandescent lamp can be emulated by an LED with the appropriate light guide. In the example shown in image 5, a traditional T10 lamp is replaced by an LED assembly with a lens in front. The function of the lens in this case is to reflect the light with a wider angle than that given by the LED with 120°. The difficulty thereby is that the light exit point has to be the same for the lamp as for the led/lens unit. If this is achieved, the led unit can then be utilised in a reflector in the same manner as an incandescent lamp.

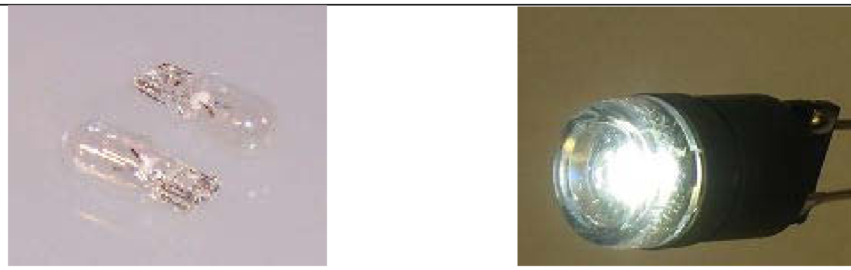


Image 5: Replacement of a T10 bulb with an LED / light guide assembly

3. Optical Design Work

The form and geometry of a light guide is designed with the aid of modern CAD and CAX programmes. The design of the light guide can either be carried out in the CAD system utilising the experience of the designer as well as the basic foundations of physics, or directly in the CAX system. Modern CAX programmes offer application tools for standard geometries like reflectors and lenses to aid the optimisation of the optical geometry. Oshino Lamps uses the CAX software Lucidshape. It is a reliable and highly effective ray tracing simulation software package, not only allowing the prediction of light solution results but also the reduction of time and resources needed to effectively create light solution designs. Image 6 shows how a typical light guide design could be started within Lucidshape. The basic geometry would be simulated, improved with iterative steps until the desired effect / light output has been obtained and the geometry then exported to the CAD system (Oshino Lamps uses Catia V5) to create a final, production suitable design. That final geometry is then re-imported into Lucidshape and a final light simulation check undertaken to ensure that any necessary extras, like fixing or location pins, have not had a negative impact on the light output.

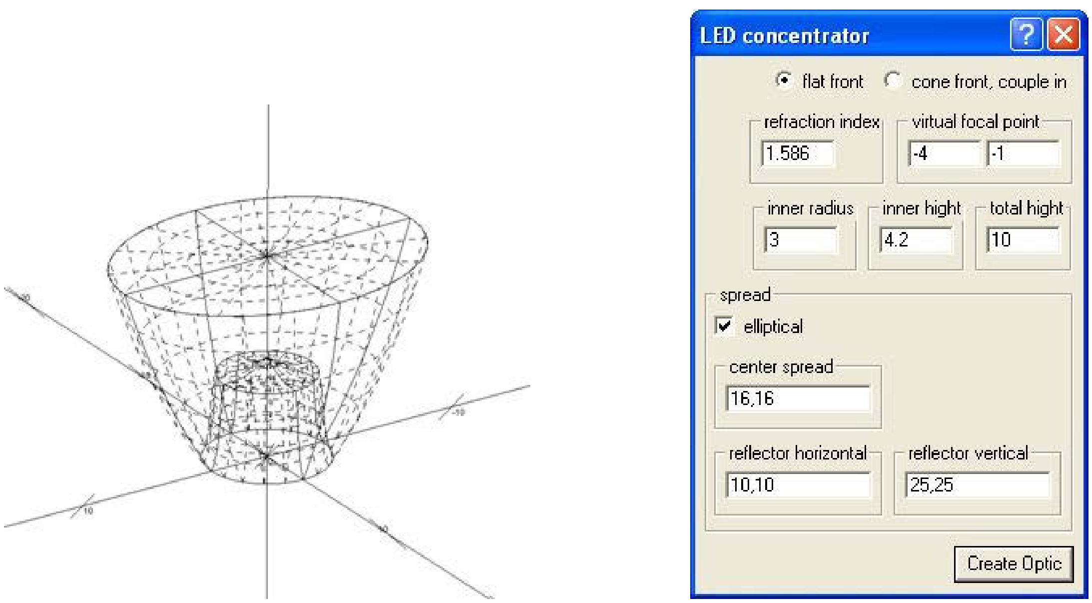


Image 6: Design of the basic lens geometry within Lucidshape with the aid of one of the application tools

In the LED module design for Jaguar, the opposite mode of development has been utilised. The basic shape was initially designed within the CAD system so that space limitations could be adhered to and the geometry then cross-checked in Lucidshape for correct light output. Again, this generally requires a few iterative steps. That way it was possible to accurately create an LED door panel theatre light system, which will be used across the XF platforms. By mixing two different LED colours in front of the light guide, it was not only possible to reduce the cost against a design with a 2 chip LED but also to allow specific colour mixing to satisfy Jaguar's chromaticity, luminance and uniformity requirements to illuminate the vehicles entire armrest. The Lucidshape software was used to model the precise LED and optics combination so that the brightest light was concentrated on the switch-pack and then the light gradually fades out past the door-grab pocket towards the rear of the armrest. In that way it was possible to achieve the subtle, ambient and yet eye catching lighting effect Jaguar desired.
Image 7 shows a typical concept presentation of the results as would be presented to the customer after initial concept design. The colour presentation on the below is such that red shows the brightest illumination.

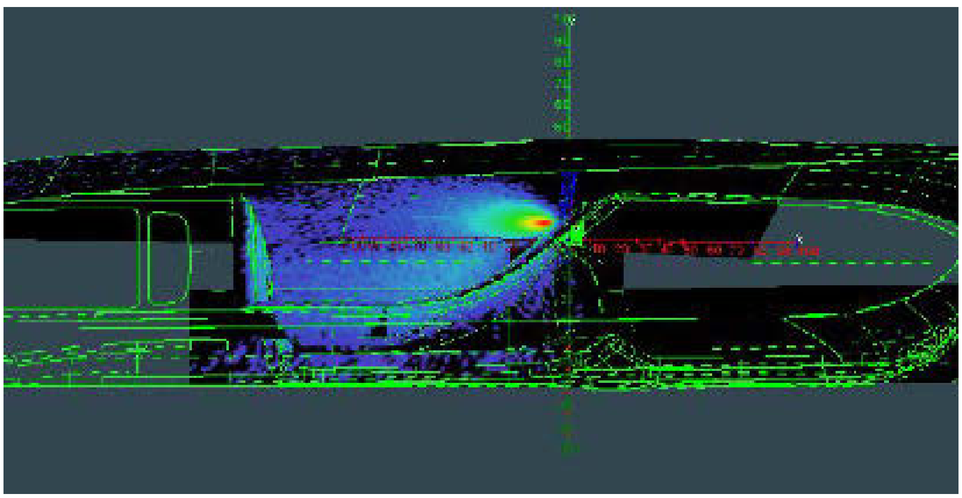
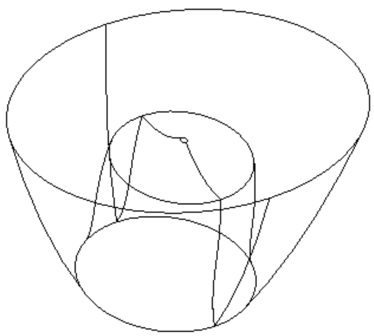


Image 7: Typical concept presentation of simulated light output

4. Mechanical Design

A usually necessary step and a further challenge for the designer is the fine tuning of the geometry without compromising the optics. Production orientated design is hereby the main requirement. For example, the optics will have to be given a framework or legs in order to be fixed to adjacent parts and to accurately locate the optics to the light source. Image 8 shows how the light guide develops during the engineering process. The LHS shows the basic part at the end of the simulation process with the light software whilst the RHS shows the same part after adding production essential items such as locating legs. As already mentioned above it is hereby necessary to repeat the light simulation and to double-check its results.



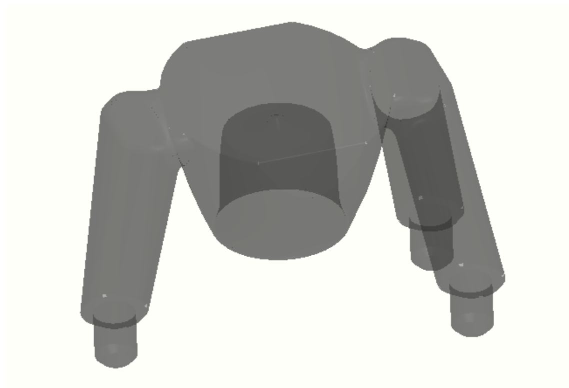


Image 8: Light guide after initial light simulation (LHS) and final production part (RHS)

Another contributing factor to the success of the light module is the positioning of the LED to the optics. Even small deviations in x, y, z direction can impact the light emission immensely and all tolerances of the complete system have to be taken into consideration. Image 9 shows the above light guide placed on a pcb. Here, placement of the LED is highly critical and the pcb/LED assembly will require positioning to a housing. This is typically done with dowels and in such a manner that tolerances will not be added up, as this would result in greater inaccuracies.

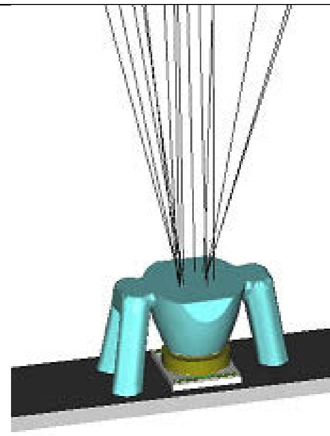


Image 9: Typical light guide positioning

Possible problem areas can be avoided early on with a production orientated design. One example of this is sink areas, caused by a varying material thickness, as this can have a negative impact on the light transmission. Image 10 shows the effect a sink mark can have on the light output. The light guide from image 8 has been simulated without a sink mark (LHS) and with a sink mark (RHS) and the impact can be seen clearly.

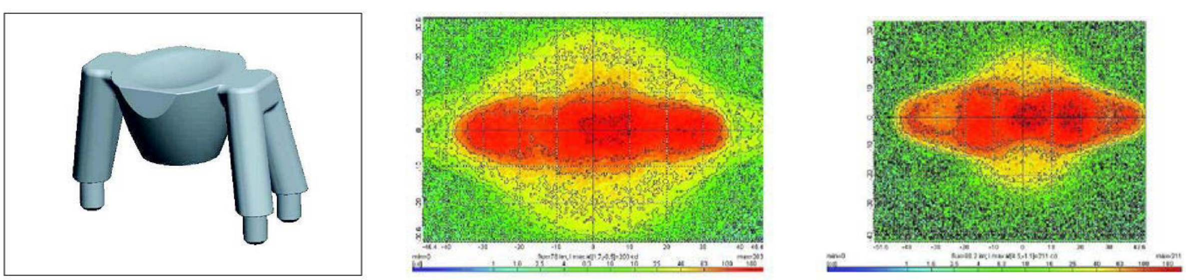


Image 10: Effect of sink mark on light output; LHS Simulation with a light guide without sink mark, RHS with sink mark

A very useful tool at pre-tool stage is Mould flow analysis. It can show the filling process during injection, thus identifying uneven plastic flow or potential sink areas. These can then be resolved either by a design change, if possible, or by implementing aids like vending points in the tool. Image 11 shows the injection process of a light guide at three stages. It can be concluded here that good tool vending points are necessary at the final filling stage as black burnt spots or sink areas can occur.

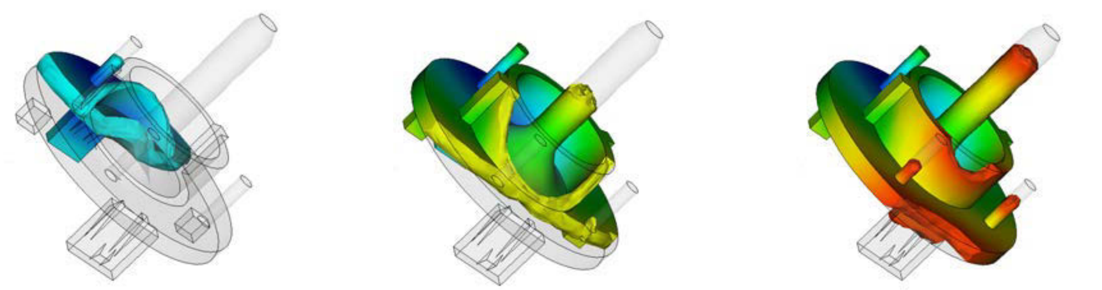


Image 11: Mould Flow Analysis on a light guide showing plastic filling stages with time

Image 12 shows a cut through the same light guide showing the expected material shrinkage. If a certain value is exceeded, the likelihood of bubbles is high and the light guide cannot be produced.

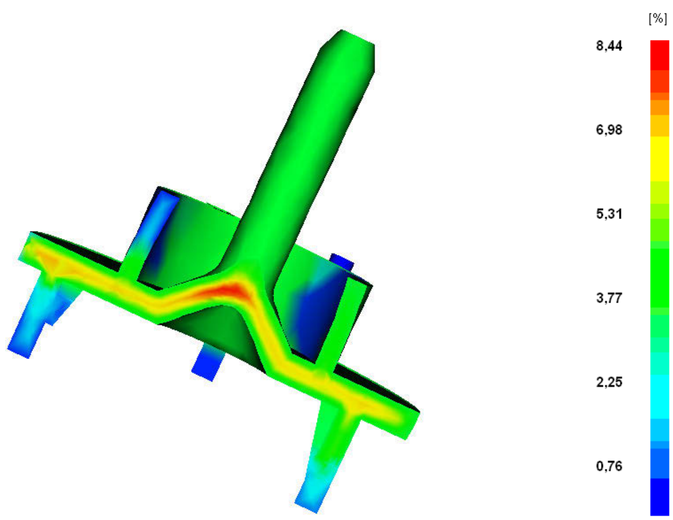


Image 12: Cut through a light guide simulated with mould flow analysis showing volume shrinkage

5. Thermal Management

Heat management is an important component in every lighting design. The current market requires an increased use of High Power LEDs for which good heat transfer management is necessary. With increased power the LED heats up much more which in turn lowers their efficiency up to the point of failure. At the same time, module spaces have not been increased making it more difficult to lead the heat away from the LED. Metal core pcbs, heat transfer polymers, heat transfer foils and potting compounds all aid to quickly disperse of the heat. Modern heat management simulation packages play an essential part in establishing a sufficient cooling system.

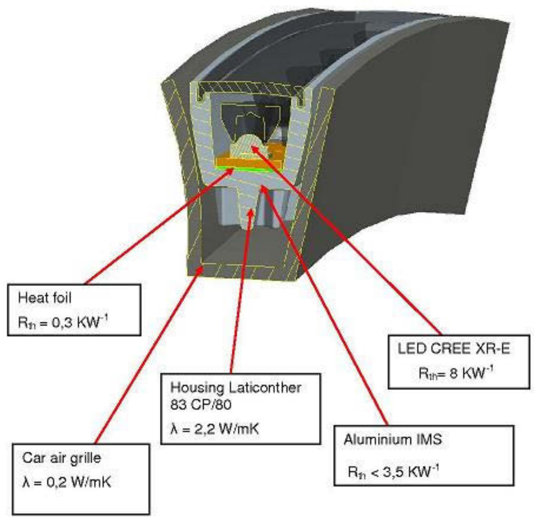


Image 13: Section through a daytime running lamp showing the individual parts required for thermal simulation

The simulation on a daytime running lamp (DRL) put into evidence that the initial case design was not efficient enough to extract the produced heat. The result showed case temperature levels close to 120-130°C which are higher than safe working temperatures (image 14; the five hottest spots show the area where an LED is placed below). In order to reduce the LED temperature, the heat conducting surfaces had to be enlarged. A common way is to add pins or fins (image 15). Image 16 finally shows the simulation result with pins added to the case of the DRL (pink spots as shown in the image). The LED temperature was thus lowered to about 50°C, a much safer temperature.

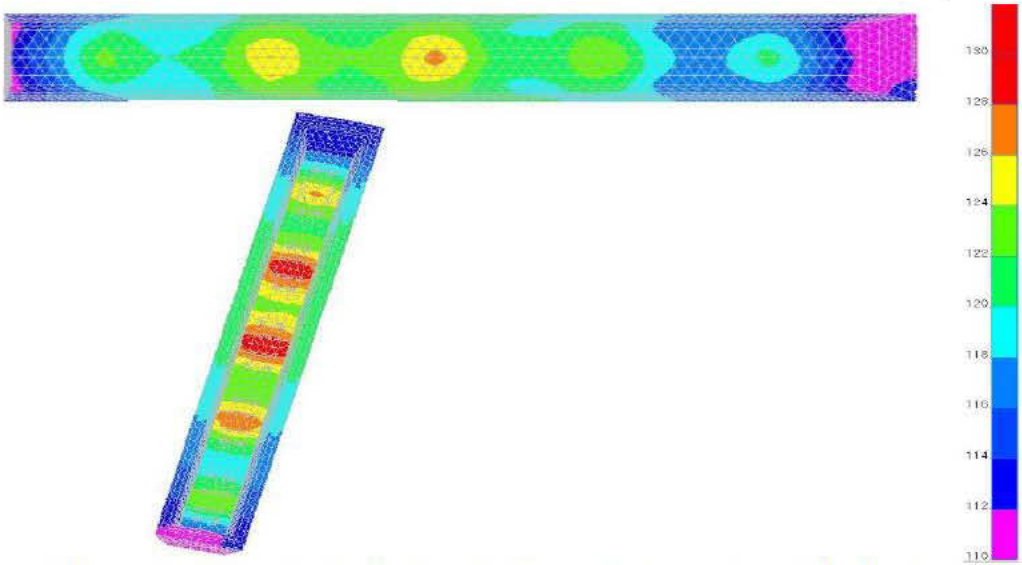


Image 14: Simulation of heat output on daytime running lamp design without pins

Image 15: Adding pins or fins to a case greatly increases the heat exchanging surfaces with minimal increase in height

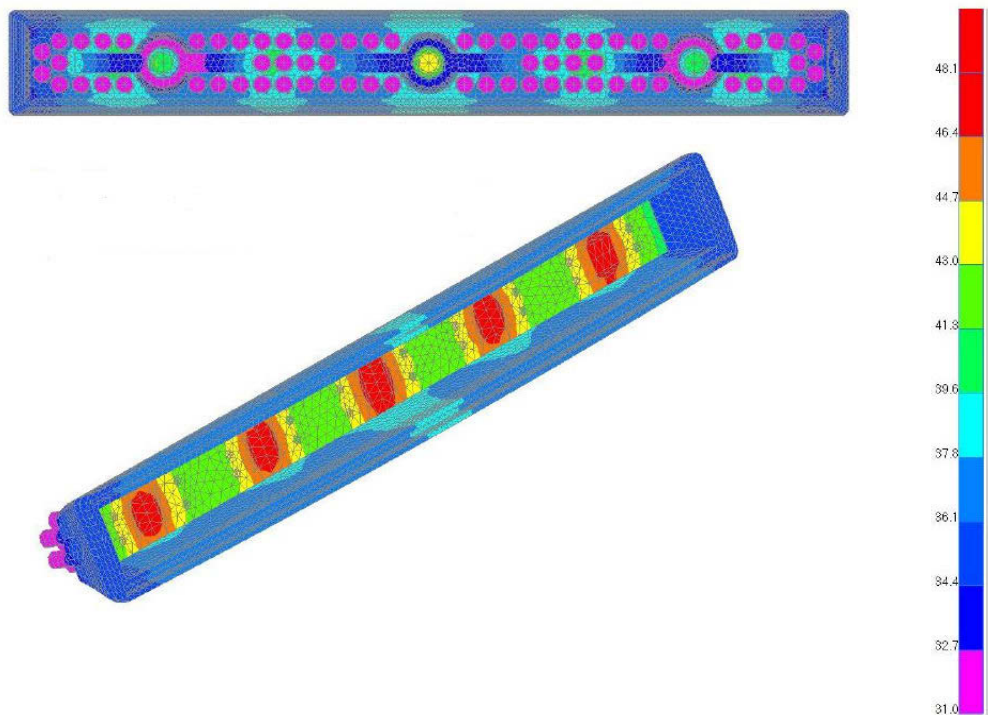


Image 16: Simulation of heat output on daytime running lamp design after the introduction of pins

6. Electrical Design

Current led applications are far from simple resistor-applications. Typical automotive applications require specific dimming and driving properties. Driving PWM signals from car electrical circuit and EMV/EMC requirements lead to more complicated and project individual pcb board design. Space and weight restrictions require small pcbs where again thermal problems are visible.
The adequate design of the electrical circuit and their thermal properties are necessary to end up with a reliable mass production. Thermal equipment is used to identify hot spots in order to minimize the thermal constraints for the led module. The design of the electrical circuit is as critical as the proper light guide design.

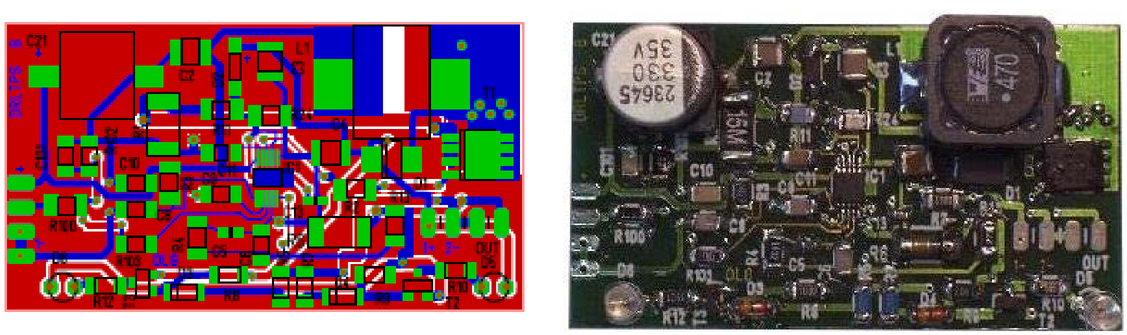


Image 17: Electrical design approach and final product

7. Production of the Part

Once the design has been agreed with the customer, tools are being machined and injection moulding of the parts ensues. It is thereby beneficial to work very closely with a local partner who has specialised in the injection moulding of light guides. As light guides are very often produced from clear material, one of the difficulties is the cleaning of the press between different projects. To avoid downtime by having to clean the barrel and related parts more thoroughly than would be the case when using similar products, one press will often be employed purely for the moulding of light guides.
Machine operating parameters are also critical so that the final product is clear and free from any discolouring.
Great toolmaking skills are required to have a finished product that resembles the CAD part exactly. As already outlined above, even smallest deviation can have a significant impact on the light output and distribution. Polishing surfaces can be used when requiring the surface to reflect the light, same as surfaces with a specified roughness can be utilised to disperse the light.

8. Final check and verification of all theoretical assumptions

As with all simulations, the results have to be verified with the final off tool parts by real measurements. Luminance flux can be measured with the aid of the Ulbricht-sphere (image 18 LHS), whilst colour and luminous density are measured with the luminance camera (image 18 RHS).
A thermographic camera (image 19) helps to verify the maximum temperature on the assembled parts. Respecting the thermal limits of the LED ensures product lifetime and lumen maintenance.

Image 18: Ulbricht-sphere and luminance camera

Image 19: Thermographic camera

[1] Literature Company Brochure "Oshino Lamps, Your Specialist for Illumination"

Many thanks to Jürgen Kanzler, KTF, for his contribution on the mould flow analysis and to Torsten Müller and Paco Bordonado, Oshino Lamps, for their support in providing some of the images.