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Integrated Automotive High-Power LED-Lighting Systems in 3D-MID Technology

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Proefschrift

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Werner THOMAS

Diplom-Ingenieur (FH), Ingolstadt University of Applied Sciences

geboren te Kösching, Germany

Dit proefschrift is goedgekeurd door de promotoren:
Prof.dr.eng. J.A. Ferreira
Prof.dr. J. Pforr

Samenstelling promotiecommissie:

Rector Magnificus, voorzitter
Prof.dr.eng. J.A. Ferreira, Technische Universiteit Delft, promotor
Prof.dr. J. Pforr, Ingolstadt University of Applied Sciences, Germany, promotor
Prof.dr. J.A. Cobos, Universidad Politécnica de Madrid, Spain
Prof.dr. techn. N. Seliger, Rosenheim University of Applied Sciences, Germany
Prof.dr. G.Q. Zhang, Technische Universiteit Delft
Prof.ir. L. van der Sluis, Technische Universiteit Delft
Dr. J. Popović-Gerber, Technische Universiteit Delft

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to my family

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Table of content

List of symbols

Latin Letters

A	Area	[m²]
A	Active Source	
A	Attenuation	
A_{active}	Surface area that contributes to radiation	[m²]
A_{back}	Back surface	[m²]
A_{bot}	Bottom surface	[m²]
A_{chip}	Chip area	[m²]
A_{front}	Front surface	[m²]
A_{plate}	Plate area	[m²]
A_{side}	Side surface	[m²]
A_{top}	Top surface	[m²]
B	Magnetic flux density	[T]
B	Width	[m]
B_{pk}	Peak magnetic flux density	[T]
C	Capacitance	[F]
C_{dg}	Drain gate capacitance	[F]
C_{ds}	Drain source capacitance	[F]
C_{gs}	Gate source capacitance	[F]
C_{in}	Input capacitance	[F]
C_{iss}	MOSFET input source capacitance	[F]
C_{out}	Output capacitance	[F]
C_{P}	Heat capacity of the fluid	[J/K]
C_{rss}	MOSFET output source capacitance	[F]
C_{x}	Branch capacitance	[F]
c_{i}	Inner diameter of vias	[m]
$c_{via\_3D\text{-}MID}$	Diameter of 3D-MID vias	[m]
D	Duty cycle	[%]
D	Diode	
Dr	Driver	
d_{trace}	Distance among circuit traces	[m³]
d_{via}	Distance between vias	[m]
E	Energy	[J]
F_{C}	Frequency response of C-filter	
F_{CL}	Frequency response of C-L-filter	
f_{e}	Effective frequency	[Hz]
f_{o}	Repetition frequency	[Hz]
f_{s}	Switching frequency	[Hz]
f_{mod}	Modulation frequency	[Hz]
h_{c}	Convection based heat transfer coefficient	[W/m²K]
$h_{inductance}$	Inductor height	[m]
h_{IRHS}	Height of Integrated Reflector Heat Sink	[m]
h_{hor}	Horizontal heat transfer coefficient	[W/m²K]
h_{vert}	Vertical heat transfer coefficient	[W/m²K]
I	Current	[A]

I_{avg}	Average Current	[A]
I_D	Diode Current	[A]
I_{dr}	Gate driver current	[A]
I_L	Current through inductance	[A]
I_{LED}	LED current	[A]
I_{Lp_x}	Current through primary winding of transformer x	[A]
I_{Ls_x}	Current through secondary winding of transformer x	[A]
I_n	Input current	[A]
I_{RMS}	Root mean square current	[A]
J	Current Density	[A/m²]
K_0	Core volume	[m³]
K_1	AC loss constant	
K_f	Frequency constant	
K_b	Flux density constant	
L	Inductance	[H]
L	Length	[m]
L_A	Parasitic anode inductance	[H]
L_{dx}	Parasitic drain inductance	[H]
l_{Cu}	Copper length	[m]
l_{IRHS}	Length of Integrated Reflector Heat Sink	[m]
L_K	Parasitic cathode inductance	[H]
L_{in}	Input inductance	[H]
L_{loop}	Parasitic loop inductance	[H]
L_o	Output inductance	[H]
L_s	Leakage inductance	[H]
L_{sx}	Parasitic source inductance	[H]
L_x	Branch inductance	[H]
M	Mutual inductance	[H]
M	Modulation signal	
N	Number of windings	
n_{branch}	Number of branches	
n_{cell}	Number of (converter-) cells	
n_{LED}	Number of LEDs	
P	Power	[W]
P_c	Core losses	[W]
$P_{conduction}$	Conduction losses	[W]
P_{conv}	Power dissipated by convective heat transfer	[W]
P_{LED}	LED power	[W]
P_{load}	Power of load	[W]
P_{loss}	Power loss	[W]
P_{rad}	Power dissipated by radiative heat transfer	[W]
P_{sw}	Switching losses	[W]
P_V	Magnetic core loss	[W]
Q	Heat dissipated by a source	[W]
Q	MOSFET	
q	Heat flux	[W/m²]
Q_{gd}	MOSFET gate charge	[C]
R	Resistance	[Ω]
R_{bx}	Balancing resistance	[Ω]
R_{ac}	Ac resistance	[Ω]
R_d	Diode resistance	[Ω]

R_{dc}	Dc resistance	[Ω]
R_{el}	Resistance of circuit trace	[Ω]
R_{dson}	On resistance of MOSFET	[Ω]
R_g	Gate resistance	[Ω]
R_{gate_dr}	Internal driver gate resistance	[Ω]
R_{loop}	Loop resistance	[Ω]
R_m	Magnetic resistance	[H^{-1}]
R_{max}	Maximum resistance	[Ω]
$R_{m\_air\text{-}gap}$	Magnetic resistance of air gap	[H^{-1}]
$R_{m\_ferrite}$	Magnetic resistance of ferrite	[H^{-1}]
R_{oper}	Temperature corrected resistance	[Ω]
R_{th_Cu}	Thermal resistance of copper (-layer)	[K/W]
$R_{th\_Cu\_spread}$	Thermal spreading resistance of copper	[K/W]
$R_{th\_interface}$	Thermal resistance of interface material	[K/W]
R_{th_IRHS}	Thermal resistance of Integrated Reflector Heat Sink	[K/W]
$R_{th\_IRHS\_ambient}$	Thermal resistance of Integrated Reflector Heat Sink to ambient	[K/W]
$R_{th\_j\_c}$	Junction to case thermal resistance	[K/W]
R_{th_LED}	Thermal resistance of LED package	[K/W]
R_{th_perp}	Perpendicular thermal resistance	[K/W]
R_{th_sub}	Thermal resistance of substrate	[K/W]
$R_{th\_sub\_ambient}$	Thermal resistance of substrate to ambient	[K/W]
R_{conv}	Convection resistance	[K/W]
R_{sp}	Thermal spreading resistance	[K/W]
R_{total}	Total resistance	[Ω]
R_{tot}	Total thermal resistance	[K/W]
s_x	Edge length	[m]
$T_{ambient}$	Ambient temperature	[K]
T_C	Time response C-filter	[s]
T_{CL}	Time response C-L-filter	[s]
t_{Cu}	Copper thickness	[m]
t_{if}	Current fall-time	[s]
T_j	Junction-temperature	[K]
t_{off}	Off-time	[s]
t_{on}	On-time	[s]
T_{max}	Maximum temperature	[K]
T_s	Switching period	[s]
t_{sub}	Substrate thickness	[m]
t_{vr}	Voltage rise-time	[s]
V	Voltage	[V]
V_{Cx}	Voltage of capacitor	[V]
V_D	Diode forward voltage	[V]
V_e	Core volume	[m^3]
V_g	Gate voltage	[V]
V_{in}	Input voltage	[V]
V_L	Voltage across inductance	[V]
V_{LED}	LED forward voltage	[V]
V_o	Output voltage	[V]
V_{out}	Output voltage	[V]
V_{plt}	MOSFET plateau voltage	[V]
V_{Rx}	Voltage of resistor	[V]
V_s	Voltage across power switch	[V]

V_{th}	Threshold voltage of MOSFET	[V]
V_x	Volume	[m³]
w_{Cu}	Copper width	[m]
w_{IRHS}	Width of Integrated Reflector Heat Sink	[m]
w_{window}	Width of magnetic core's winding window	[m]

Greek Letters

α	Angle	[°]
α	Aspect ratio	
α_{20}	Linear temperature coefficient	[1/K]
β	Expansion coefficient of the fluid	[1/K]
δ	Skin depth	[m]
ε	Permittivity	[F/m]
ε	Surface emission coefficient	
ε_r	Relative permittivity	
ε_r	Relative surface emission coefficient	
$\zeta_{relative}$	Relative volume utilisation factor	
η	Electrical efficiency	[%]
η_{LED}	Electrical LED efficiency	[%]
Θ	Magnetomotive Force	[AT]
$\Delta\ I$	Peak inductor current	[A]
$\Delta\ I_{LED\_max}$	Maximum branch current deviation	[%]
$\Delta\ I_{rel}$	Relative current deviation	[%]
$\Delta\ I_{rel\_simp}$	Simplified relative current deviation	[%]
$\Delta\ L$	Inductance deviation	[%]
$\Delta\ L_{loop}$	Change of parasitic loop inductance	[H]
$\Delta\ P_{LED\_max}$	Maximum branch power deviation	[%]
$\Delta\ P_{rel}$	Relative power deviation	[%]
ΔT	Temperature increase	[K]
ΔT_{LED}	Temperature increase of LED chip	[K]
ΔT_{22}	Time interval	[s]
Δt_{on}	Rise time	[s]
Δt_{off}	Fall time	[s]
ΔT_{trace}	Temperature increase of circuit trace	[K]
$\Delta\ V_{ds}$	Overvoltage at MOSFET	[V]
$\Delta\ V_{LED}$	LED branch voltage deviation	[V]
$\Delta\ v_o$	Output voltage deviation	[V]
Δx	Colour shift in x-direction chromaticity diagram CIE 1931	
Δy	Colour shift in y-direction chromaticity diagram CIE 1931	
Φ	Magnetic Flux	[Wb]
λ	Thermal conductivity	[W/mK]
λ_{Cu}	Thermal conductivity of copper	[W/mK]
λ_{IRHS}	Thermal conductivity of Integrated Reflector Heat Sink	[W/mK]
λ_{sub}	Thermal conductivity of substrate	[W/mK]
μ	Absolute viscosity of the fluid	[Ns/m²]
μ_0	Magnetic permeability of vacuum	[H/m]
μ_r	Relative magnetic permeability	
ρ_{20}	Specific electrical resistivity	[Ω mm²/m]

ξ	Damping ratio	
ρ	Fluid density	[kg/m³]
σ	Electrical conductivity	[S/m]
σ	Stefan-Boltzmann constant	[J/K]
$tan(\delta)$	Loss tangent	
$\psi_{component}$	Component volume	[m³]
$\psi_{total\_assembly}$	Total assembly volume	[m³]
ψ_{unused}	Total unused volume in the assembly	[m³]
ω	Angular frequency	[rad^{-1}]
ω_d	Angular frequency diode current	[rad^{-1}]

Acronyms

2D	Two-dimensional
3D	Three-dimensional
3D-MID	3D Moulded Interconnect Device
ac	Alternating current
CCC	Current Carrying Capacity
CCD	Charge Coupled Device
CCM	Continuous Conduction Mode
CTE	Coefficient of Thermal Expansion
dc	Direct current
DCM	Discontinuous Conduction Mode
DRL	Daytime Running Light
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FEM	Finite Element Modelling
IMS	Insulated Metal Substrate
IRHS	Integrated Reflector Heat Sink
LCD	Liquid Cristal Display
LCP	Liquid Crystal Polymer
LDS	Laser Direct Structuring
LED	Light Emitting Diode
MOSFET	Metal Oxide Field Effect Transistor
PA	Polyamide
PC	Phosphor coated
PC-ABS	Polycarbonate/Acrylonitrile Butadiene Styrene
PCB	Printed Circuit Board
PEEC	Partial Elements Equivalent Circuit
PEN	Polyethylene Naphthalate
PET	Polyethylene Terephthalate
PI	Polyimide
PMMA	Polymethyl Methacrylate
PPA	Polyphtalamide
PWM	Pulse Width Modulated
RMS	Root Mean Square
SEPIC	Single Ended Primary Inductor Converter
SMT	Surface Mount Technology
SSL	Solid State Lighting

1. Introduction

1.1. Background

Rising luminous fluxes of high-power LEDs as well as the growing energy consumption of lighting – 19 percent of the global energy production in 2006 [WT06] – have contributed to the widespread use of LEDs in modern lighting systems [St08]. Today, single LED-packages reach a light output that is competitive or even higher than those of incandescent- and compact-fluorescent-lamps, as illustrated in Figure 1-1. LED-arrays even surpass these values and achieve luminous fluxes of up to 9,000lm [Br11].

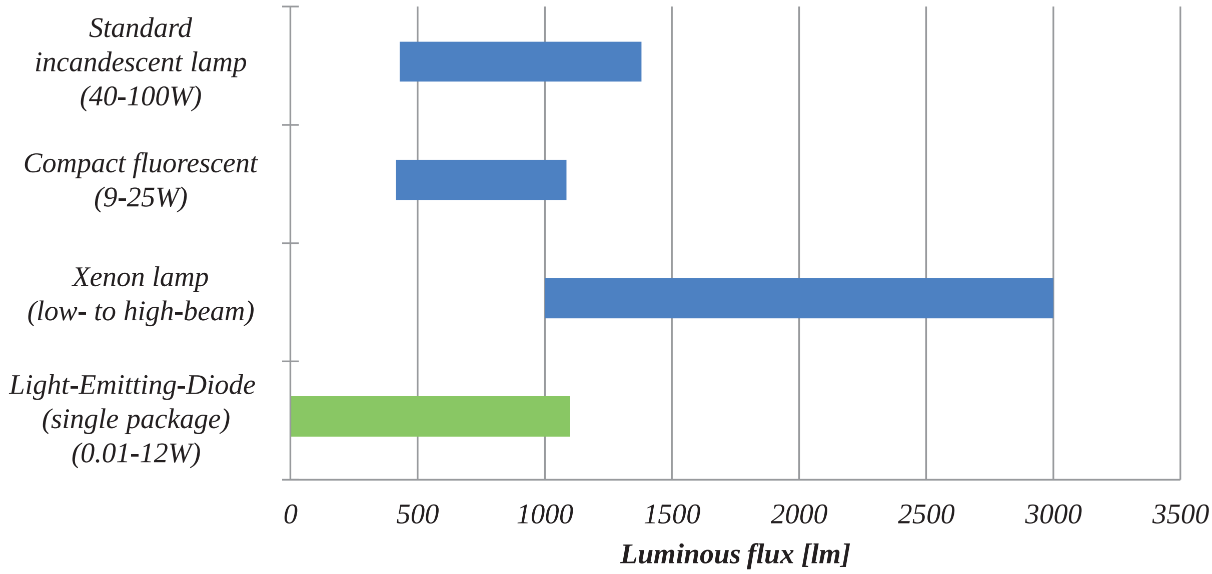


Figure 1-1: Total luminous flux of different light-sources derived from [WT06] with updated values for high-power LEDs [Os07], [Os08]

Increasing luminous efficacies, i.e. the emitted luminous flux per watt electrical power consumption, are another important reason for the growth of LED-lighting [Wh057].

The technological progress of LED-lighting can be seen from Figure 1-2, where a comparison of the luminous efficacy of different selected light sources is given. Currently, high-power LEDs achieve a maximum luminous efficacy of up to 157 lm/W, with a mean value of about 75 lm/W considering different power-classes [SSL11]. This is a factor 5 to 10 higher performance when compared to conventional incandescent- or halogen- lamps. Commercially available high-power LEDs can also compete with energy-saving- and fluorescent-lamps in terms of their luminous efficacy.

Furthermore, the general research goal for white high-power LEDs is set to reach 200 lm/W [SSL11] (single-chip LEDs), which is even higher than the efficacy of High-Intensity-Discharge lamps.

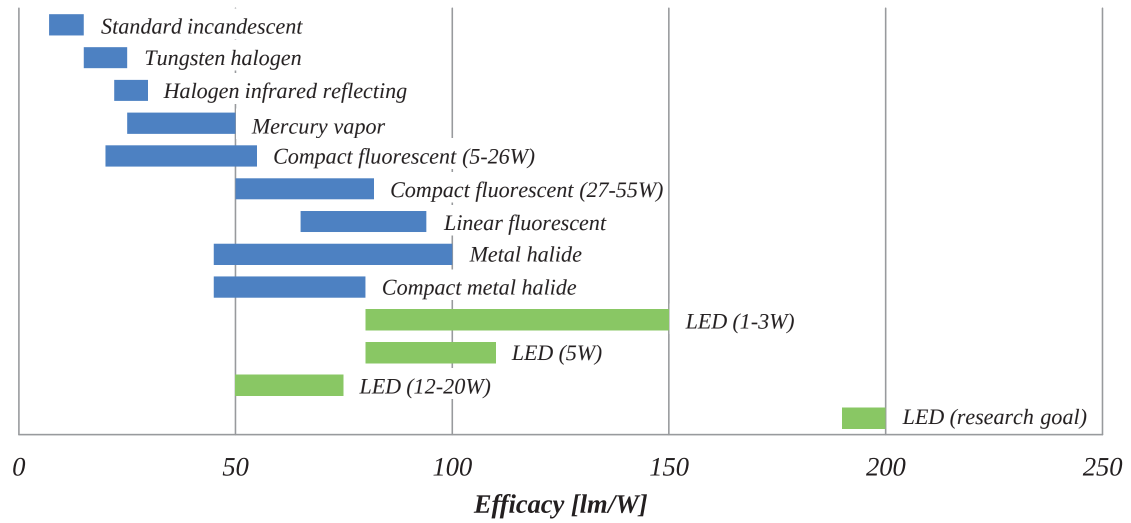


Figure 1-2: Luminous efficacy of selected light-sources derived from [AL03]with updated values for high-power LEDs [Os08], [Os07], [Ph07a], [Cr08b], [SSL11]

Another advantage of LEDs is their long lifetime which can reach a peak value of over 100,000 operating hours [Ph06] at optimal environmental conditions. Due to this, a multitude of lighting applications can be designed without considering maintainability. When combining this feature with the small geometrical dimensions of the LED-chips – a typical chip has an area of $A_{chip}=1\text{-}2mm^2$ – very compact or thin systems get possible.

These benefits as well as a wide range of available colours make LEDs and especially high-power LEDs the technology of choice for a multitude of applications. Besides, a large variety of customised lighting functions can be fulfilled by Solid-State-Lighting.

1.2. Applications of LED-lighting

LED-lighting applications comprise the automotive-sector, general-lighting and consumer electronics. These will be characterised in the following.

1.2.1. Automotive lighting

In the last years, LED exterior lighting has started to become a prominent innovation in automotive lighting. The beginnings have been already made in the 1990's with the introduction of the 'third stop-light' in LED-technology, where the fast turn-on behaviour of LEDs was used to decrease the reaction time of the following drivers [Ve06].

The use of complete LED taillights has been a further step to advance automotive exterior lighting. With the introduction of white light generated by LEDs and rising luminous fluxes, LED-based automotive front-lighting emerged and is already used in insular series applications today.

Besides to increased efficacies and lifetime, other technological benefits have contributed to the success of LED-lighting in automotive applications:

- The small footprint and height of LEDs allows new degrees of freedom in placing light elements and allows improved as well as complex three-dimensional lamp designs.
- LED-lighting systems often comprise a multitude of single LEDs, which can be individually arranged or electrically driven to enable new lighting functions highly exceeding the possibilities of conventional single and central light sources.

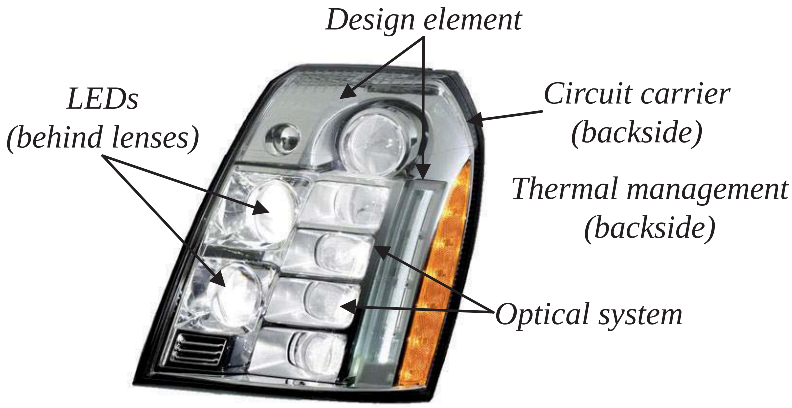
Figure 1-3 shows several examples of modern automotive LED-lighting systems which already benefit from the flexibility in lamp design obtained by the LED-technology. It is common to these solutions that the LEDs are spatially arranged in three-dimensions (*3D*) to create a more individual design of the day- and night-appearance of the automobile-front and -rear when compared to conventional halogen- or xenon-lamps. These systems will be called *3D LED-lighting systems* throughout this thesis.

(Source: Audi AG)

Figure 1-3: Trends in automotive exterior lighting: LED-lighting used as recognition feature to stand out from the competition and to differentiate model specific design

The arrangement of the LEDs is particularly used to underline the exterior shape of the automobile. The LED-design therefore provides a diversification in between the model-range of a car manufacturer. Furthermore, it is a recognition feature to stand out from the competitors.

Solutions with (advanced) *3D*-designs, however, require a complex assembly to mount and to electrically contact the LEDs in space that also comes at the cost of a large component count (Figure 1-4). Besides, conventional cooling solutions have to be adapted according to the desired *3D*-shape. Unfortunately, these aspects limit the design versatility that can be achieved in 3D LED-lighting systems and increase system costs when using state of the art assemblies. Therefore, the majority of contemporary automotive lamp designs are still focused on conventional shapes with single and central light source, as known for the past decades.



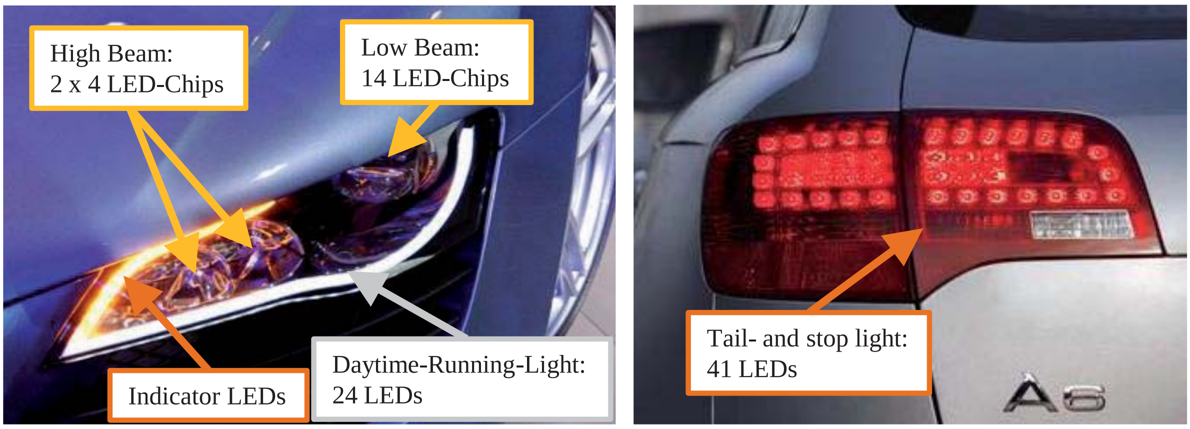
(Source: Cadillac)

Figure 1-4: Full-LED headlamp with limited *3D*-design

State of the art solutions for creating three-dimensional LED-lighting systems and their limitations will be discussed in detail in Chapter 2.

Environmental conditions and requirements

Automotive LED-lighting systems often consist of a multitude of LEDs that can have different power levels and colour values to perform lighting functions, like in stop-lights, day-time-running lights or even as low- or high-beam (Figure 1-5). The coloured and white LEDs are often located as clearly visible single light sources.



(Source: Audi AG)

Figure 1-5: Full LED-headlamp (left) and LED tail-lamp (right)

As the conventional 14V automotive electrical power net has a variable input voltage with typical values of V_{in} =*8V-17V*, a stable LED-brightness level has to be achieved over the entire input voltage range. Commonly, switched mode power converters are used to maintain and control the LED-brightness. When a large number of LEDs is used, a uniform brightness distribution is additionally required in order to maintain the required light output distribution as well as for optical reasons. In addition, brightness control is a key requirement in automotive lighting to provide basic lighting functions, e.g. day-time-running-lights are operated at night as position light which requires dimmed LED-operation. Finally, a high availability of the lighting system is required due to its security-related function. All these attributes define essential lighting functions, which require LED-drivers that are optimised towards automotive requirements.

3D LED-lighting systems further demand on solutions that allow the mechanical- and the electrical-connection of LEDs and LED-driver components in space to achieve the required design and functionality. As constructed space is limited in automobiles, the desired *3D*-shapes have to be realised without consuming excess space.

Harsh environmental conditions within the vehicle, with vibrations and shocks, amplify the requirements on the LED-lighting system. Furthermore, the LEDs and LED-driver components are excited to wide temperature ranges of -40°C to +80°C (up to +120°C in special cases) which requires an effective thermal management to keep component temperatures below critical values (Chapter 2). The heat dissipated by high-power LEDs increases temperature levels above environmental temperatures in the lamps. The electrical system should therefore operate at reduced losses when integrated in the lighting system.

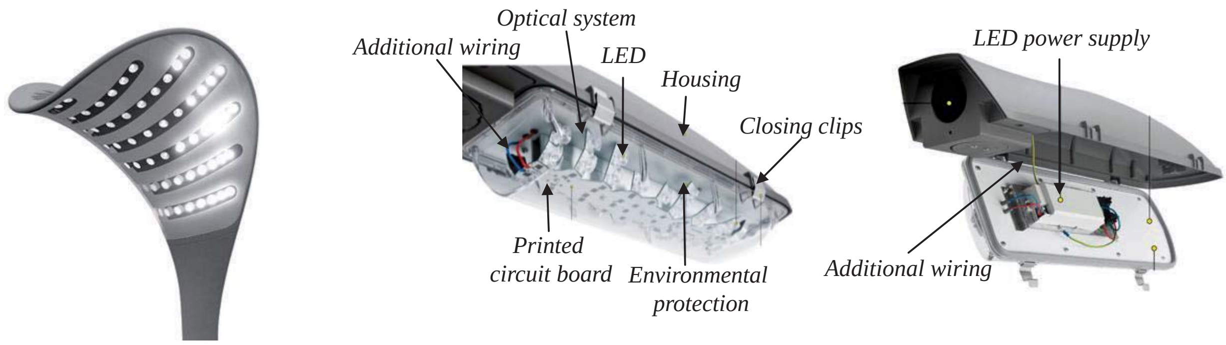
1.2.2. General lighting and consumer electronics

Next to the automotive environment, LED-lighting is increasingly used in general lighting and in consumer electronics. In the latter case, LEDs have been used as signal or control lights for decades, comparably to automotive (stop-) lighting. With rising luminous fluxes, however, also consumer articles emerged that contain high-power LEDs, e.g. in video projectors or in backlights of LCD-displays [Lu09].

The use of Solid-State-Lighting in general lighting has started to grow in the last few years. General lighting is considered in this thesis, as indoor- and outdoor-lighting, e.g. in street-lamps with LEDs that exhibit high luminous fluxes of 2,000-10,000 lumens [Ca09], [PT096], [Ow096]. The resolution of the European Commission for phasing out incandescent lamps and of lamps with a non-tolerable luminous efficacy [Eu08] further accelerated the demand on high-power LEDs as an alternative light-source in general lighting.

Like in automotive applications, in general lighting or in consumer electronics LEDs are not only used for reasons of saving energy and for lifetime considerations. Moreover, there are some applications that benefit from LEDs' small footprints and the ability to spatially arrange individual light sources. Figure 1-6 (a) shows an LED street lamp with a three-dimensional design as one possible example. In this lamp, the LEDs are used to create a completely new design which allows a diversification among other street lamps, which is comparable to the approaches in the automotive segment. Further, a three-dimensional LED-arrangement can also be used to obtain an improved brightness distribution on the street (Figure 1-6 (b)).

In contrast to the automotive sector, in consumer electronics or in general lighting, there is no general trend towards three-dimensional shaping of lighting systems, due to the wide span of applications, which neither require enhanced shaping possibilities nor need to save construction space.



(Source: Siteco GmbH) *(Source: Schréder GmbH)*

(a) *(b)* *(c)*

Figure 1-6: Three-dimensional shaped LED streetlamps

The absence of a simple solution for forming 3D LED-lamps and the high assembly complexity – with a large number of components (Figure 1-6 (b), (c)) – further contributes to the low number of applications, which benefit from a three-dimensional alignment of LEDs up to now.

Environmental conditions and requirements

General lighting solutions often comprise a multitude of high-power LEDs to meet the requirements on high luminous fluxes, as shown in Figure 1-6. Also consumer electronics, like the background illumination of flat-screen TVs, contains a large number of LEDs. A power electronic system is therefore required to maintain required LED-brightness-distribution and -control, e.g. for dynamic background illumination [WKM09]. Further, in 230 VAC mains application systems, galvanic isolation is required to decouple high input voltages from the LEDs. This is especially necessary when a compact lamp-design without extra LED-housing is desired. Hence, a power converter is required to transform high ac voltages into appropriate dc voltages for the LEDs.

Different environmental conditions, e.g. ambient temperatures, have to be considered in domestic applications, depending on indoor- or outdoor usage. In the vast majority of applications, the environmental impacts are significantly lower than in automotive LED-lighting. It is therefore assumed that most of the foregoing environmental conditions are also covered by the demands of automotive exterior lighting.

Thus, the automotive environment, with its conventional 14V automotive electrical power net, will be the considered environment in this thesis. However, special applications suitable for the mains will be commented throughout the work when applicable.

1.3. Requirements on three-dimensional LED-lighting systems

Progresses in the LED technology have led to a variety of applications in automotive- and general-lighting. Especially the field of automotive exterior LED-lighting uses the small footprint of LEDs and their characteristic as point light sources as key features to combine lighting tasks with design (Section 1.2).

Although automotive LED-lighting is at the leading edge regarding three-dimensional lighting solutions, the current construction of 3D LED-lighting systems is not optimised towards complex design requirements. Contemporary assemblies require a large number of construction parts to perform *3D*-contacting and -mechanical fixation of LEDs and their related power electronic LED-drivers.

Thus, the plurality of automotive LED-lighting systems is still focused on conventional designs of front- and tail-lights, as known for decades. The same limitation has been observed for the majority of LED-based general-lighting systems.

To improve 3D LED-lighting systems, the following target functions can be identified and should be addressed:

- *Spatial und mechanical functions:*
    - The lighting systems must be able to follow complex three-dimensional shapes to further improve the degrees of freedom in the lamp design. For this reason, the LEDs and the power electronics, for their electrical drive, require a *3D*-structure which fixes them.
    - Due to the requirement of reduced constructed space (automotive), the system should also be able to achieve the required *3D*-shape at a minimum of excess volume. Hence, solutions which allow a reduced construction height are desirable.
    - The systems should be built at a reduced number of components to reduce efforts in their spatial fixation. Furthermore, they must be robust against application specific environmental conditions, e.g. vibrations or maximum temperatures.
- *Electrical functions:*
    - In 3D LED-lighting systems, the LEDs and the power electronics must be electrically contacted in three dimensions and the appropriate signals have to be delivered to the spatially distributed LEDs.
    - The electrical drive has to ensure that a homogeneous brightness distribution is achieved among the LEDs, as they are often clearly visible as single light-sources. Here, LED specific requirements concerning temperature- and electrical-behaviour (Chapter 2 and 4) have to be observed.
    - As input-voltage levels can vary, the LED drive has the function to keep stable LED brightness levels over input voltage variations. Furthermore, the power electronics should provide a galvanic isolation when high (input-) voltages appear to separate them from the remaining system.
    - (Automotive) illumination requires high system availability. Therefore, the LED-driver should be able to maintain a high operational availability even at LED failures.

- *Thermal functions:*
  - An effective cooling of the used high-power LEDs and the power electronic components, especially for high power levels, is required and has to take care of the demand on high degrees of freedom in *3D*-design.

1.4. Problem description

The high versatility in placing individual and compact light sources is a key feature provided by LED-lighting technology. It allows an enhanced design flexibility which can skilfully be used to improve the appearance, but moreover to enhance functions of modern lighting systems, as introduced in Section 1.2. So far, the LED-technology's potential for improving three-dimensional designs is, however, insufficiently used in the vast majority of LED-lighting applications.

The physical realisation of contemporary LED-lighting systems requires a large number of components and is identified as the main hurdle for limiting the distribution of 3D LED-lighting systems. These systems comprise LED-drivers, *3D*-mounting and -contacting components as well as thermal management structures that have to be mounted and arranged in three-dimensions leading to high efforts and costs (Section 1.2).

A new approach is therefore needed for the realisation of 3D LED-lighting systems to decrease the number of components and to enhance the design versatility. This directly addresses the components which are necessary to fulfil spatial-, electrical- and thermal-functions, defined in Section 1.3.

Determining a new concept for the realisation of 3D LED-lighting systems requires the analysis of the current practice and evolution of 3D LED-lighting assemblies to identify the main technological boundaries as well as to derive requirements on future assemblies.

The main objective in this concept, and hence in this thesis, is to decrease the number of components of contemporary automotive LED-lighting systems and to enhance the design versatility in three-dimensions by integrating the functions provided by individual parts into one or more multifunctional components. This concept requires the investigation of the integration potential for the LED-driver, for the electrical- and spatial-contacting and for the thermal-management in the '3D multifunctional-component(s)'.

As a wide range of applications, with different spatial arrangements and power levels, exist for LED-lighting it is further required to provide techniques that derive the limitations and possibilities for the concept's electrical-, spatial- and thermal-design. These parameters can be used to determine the feasibility of prospective applications and to derive adapted designs.

1.4.1. Derived objectives

Analysing the foregoing problem description, the main objective of this thesis is to:

> *decrease the component number required in high-power 3D LED-lighting systems with power electronic LED-driver to reduce the complexity in the assembly and to increase the degrees of freedom in the design.*

To achieve this aim the following objectives have to be determined:

- Identification of the main reasons that limit enhanced designs of contemporary high-power LED-lighting systems by analysing the present practice of construction and the evolution towards 3D LED-lighting systems
- Determination of an approach to use the technology of 3D-Moulded Interconnect Devices (3D-MID) for enhancing the *3D*-design whilst decreasing the construction complexity of high-power LED-lighting systems with LED-driver by increasing the level of function integration
- Development of optimised LED-drivers with integrated lighting functions for a simplified 3D-MID realisation
- Determination of merits and limitations to mount and contact the LED-driver and the LEDs on the 3D-MID as well as to analyse influences of the 3D-MID technology on the spatial- and electrical- realisation of power-electronics
- Examination of the potential to integrate thermal management functions into the 3D-MID for low complexity systems and to derive a solution to enhance the power level of 3D-MID-based LED-lighting systems whilst maintaining high degrees of freedom

1.5. Thesis layout

Figure 1-7 visualises the layout of the thesis.

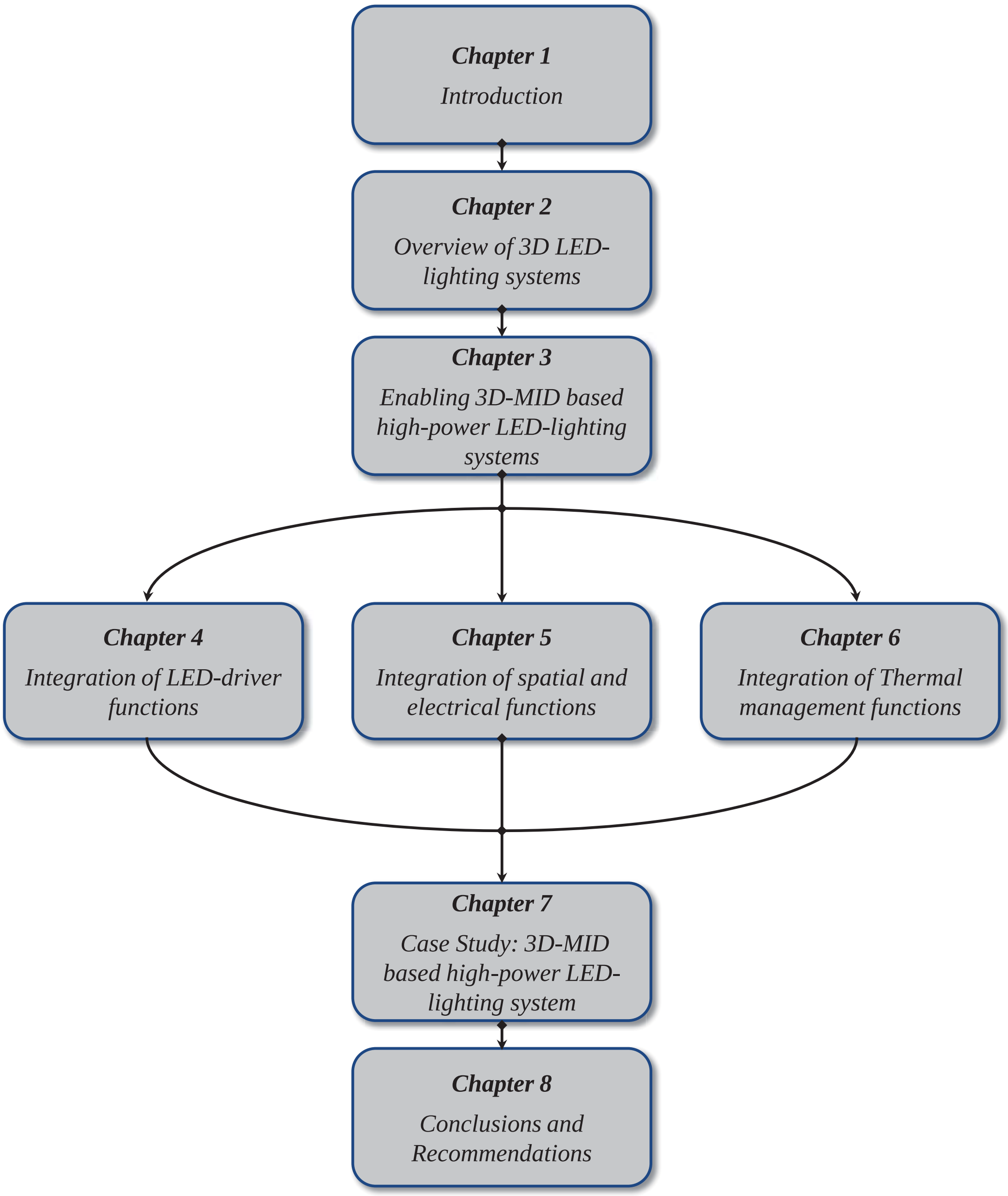


Figure 1-7: Thesis layout

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