

Conceptual Development of Automotive Forward Lighting System Using White Light Emitting Diodes

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ABSTRACT

This paper focuses on redesigning the headlamp subsystem functional architecture. The design involves meeting three major functional requirements: Achieving the lumen requirements according to Economic Commission for Europe (ECE) 324 regulations, Meeting the illumination pattern, and Maintaining the Light Emitting Diode's (LED) junction temperature at 90°C. White LEDs are considered in the design to satisfy the functional requirements due to their high lumen efficacy, compact size, and long life. These benefits, when compared to existing headlight systems benchmarked, present enough potential to warrant further conceptual virtual prototyping. The prototyping focused on solutions that allowed control of sizing and numbering of LEDs, illumination pattern limits, and temperature to achieve the multiple functions a dynamic headlight system. A primary challenge in this design is to maintain the LED's junction temperature within a recommended operational range. A conceptual design is presented with metal foam meta-material which act as both a heat exchanger to maintain the LED's junction temperature and a structural member. The metal foam design also exploits the environmental conditions of the vehicle operation to meet the desired functionality. An analytical thermal model is used to predict the LED's junction temperature, thus allowing for optimization of the metal foam constituent properties. A finite element model is developed to view the thermal affects of an LED on adjacent LEDs. The results of the finite element model

are used in conjunction with an optical analysis to determining any LED arrangement pattern restrictions and limitations. The number of LEDs required is derived from the lumen requirements set by ECE directive while including lumen deficiencies. Finally, the results of the individual model are integrated to meet the functional requirements of the headlamp subsystem.

PROJECT GENESIS

This project entails the redesign of a headlamp subsystem to incorporate the use of Light Emitting Diodes (LEDs) in place of existing High Intensity Discharge (HID) and halogen light sources. The motivation of the design originates from the numerous advantages and benefits for use of LED light sources.

USES OF LEDS IN VEHICLES – In the rear signal lamp sector, companies has successfully been using LEDs as light sources for more than ten years now, in high-mounted stop lamps, for example, or for tail light, stop light and direction indicator functions in combination rear lamps, such as in the case of the Volkswagen Golf Plus [1]. White LEDs have already been used for signal functions like positioning or daytime running lights [2]. The development of the first full LED headlamp appeared in the Auto R8, seen in Figure 1. For the first time, all light functions of a serial headlamp are being realized in LED technology, these are low and high beam, daytime running light, turn indicator and position light [2].



Figure 1: Audi R8 Headlight [3]

MOTIVATION – The motivation for using LED headlamps are their many advantages over existing headlight systems. LEDs, as a light source, generate completely new possibilities for headlamp shapes and arrangements [1]. Due to their high reliability, long operating life, fast response time and efficiency, LEDs are finding increasing use in automotive applications [4].

ADVANTAGES OF USING LEDS – There exists many advantages for using LEDs as a light source for vehicle headlamps. There are major benefits in terms of energy efficiency. For instance, in traffic lights, a red traffic signal head that contains 196 LEDs draws 10W versus its incandescent counterpart that draws 150W, estimating a potential energy savings ranging from 82% to 93% [5]. LEDs are projected to produce a much longer service life than their counterparts. A LED can maintain an operating life of 100,000 hours [6]. For this reason LEDs are ideal for hard-to-reach areas [5]. Other benefits of LEDs include [5]: no UV Emissions, durable and rugged, insensitive to shock, Lights instantly, can be

easily dimmed, silent operation, low-voltage power supply (increased safety), and small size provides high design flexibility.

HEADLIGHT SPECIFIC ADVANTAGES – Alongside the many advantages offered by LEDs, there exists many advantages unique to their use within headlamp systems. Figure 2 provides a tabulated list of LED advantages within the headlight market to justify their use as headlight alternatives.

Due to LEDs ability to easily change luminosity, transitioning from lit to unlit, they allow use in situations where light is needed for a short period of time or shifts and oscillations in luminosity are required. This modularity within an array of LEDs could substitute subsystems such as those which control dynamic motion (cornering and auto leveling). This removes the complexity of incorporating a dynamic system that requires use of a motor.

In terms of efficacy, the lumen output per Watt of power entering the system, LEDs have a significant advantage over alternative lighting systems. An LED is able to provide 160% the efficacy of an HID system. This reduces the energy constraint on the vehicle. This does not include energy savings from removing unneeded mechanical systems.

The operating life of an LED is unmatched, capable of maintaining operation for 100K hours. Incandescent lights, the closest performer, achieve a life span a third of LEDs. With a mileage of 300,000 kilometers in 15 years, the typical service life is 3000 to 7000 hours according to different OEMs [4]. Standard bulbs have lifetimes of approximately about 300 hours [4].

Advantage	Comment				Ref.
Design flexibility, modularity, and re-use of LEDs for different applications	- Unique night time identification, offers lit and unlit differentiation - Rears of cars already have innovative arrangement of LEDs				[7]
Reduces front-end overhang	- Depth of LED headlamp could reduce - Tighter turning circle, improved response to sharp bumps, better cornering				[8],[9]
Increased efficacy (lm/W)	LED	Incandescent	Fluorescent	HID	[9], [10] [11], [12]
	Up to 115	15	60	72	
Long lifetime (Hrs of operation)	LED	Incandescent	Fluorescent	HID	[6], [13]
	Up to 100K	30000	2000	3000	
High lumen maintenance	10% > HID				[6]
Comfort to human eye	Color temperature of 6000 K, Compare 4100 K – Xenon				[14]
Cool light	No heat transfer by radiation				[15]

Figure 2: Lighting Comparison

CONCEPTUAL DESIGN

The initial phase of design requires defining the system boundaries and the specifications the system must meet. These requirements came in part due to the regulation standards the LEDs are imposed to achieve, operational constraints provided by LED manufacturer, environmental constraints the system must take into consideration, constraints imposed by other subsystems within the vehicle, and client imposed constraints.

DESIGN OBJECTIVE – The objective of this project is to develop a concept that explores the use of LEDs as a light source for headlights. This requires developing a LED headlight concept that replaces the existing system in terms of functionality and meets the dynamic capabilities of standard headlight systems. This concept will require supporting evidence to demonstrate the LEDs ability to operate within the prescribed conditions.

CONCEPT EQUIPMENT – The LEDs used to realize the concept are the Cree XLamp 7090 XR-E LEDs, shown in Figure 3 [16]. The Cree XLamp 7090 XR-E LEDs were an appropriate selection as they were considered an efficient LED at the time of design conceptualization and technical specifications were provided by the manufacturer.

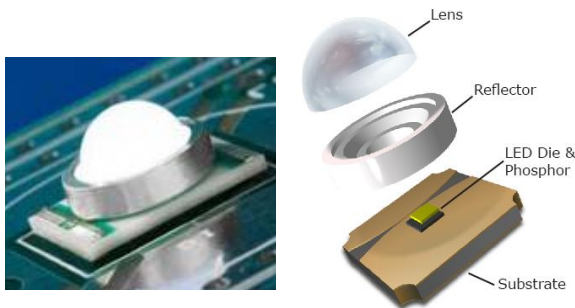


Figure 3: Cree XLamp7090XR-E [16]

REQUIREMENTS – The design of the LED headlight requires the consideration of many constraints. Each requirement was accounted for throughout the design process to ensure an suitable concept was developed. It is important to note that while constraints were imposed by the project client, these constraints are proprietary and cannot be disclosed.

Governmental – To ensure an appropriate and permissible system is designed, ECE (Economic Commission for Europe) regulations were referred to. ECE is an organization which adopted a uniform technical prescription for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions [17]. The ECE make use of a light intensity screen in which LEDs must meet prescribed illumination targets within different locations on the screen (ECE 324 / Rev 2/Oct'06 cl.6.3 [18]).

According to ECE requirements, the light source and the light intensity screen on which the light is illuminated are 25 meters apart. The screen, seen in Figure 4, is 4.5 meters long and 4.5 meters wide. The LED array considered during development was only concerned with high beam conditions. This was due to the additional lumen requirements needed to meet high beam conditions. The high beam requirements set forth by ECE do not impose any requirements on the vertical axis of the screen. The intersection point of the center line of the screen is referred to as H-V point. The screen is positioned so the longitudinal axis of the headlamp intersects with the H-V point. At the H-V point, a headlamp is allowed to have a maximum of 196 lux (measurement of light intensity per area). The requirements also enforce a minimum of 16 and 6 lux at distance of 1.125m and 2.25m from the HV point respectively.

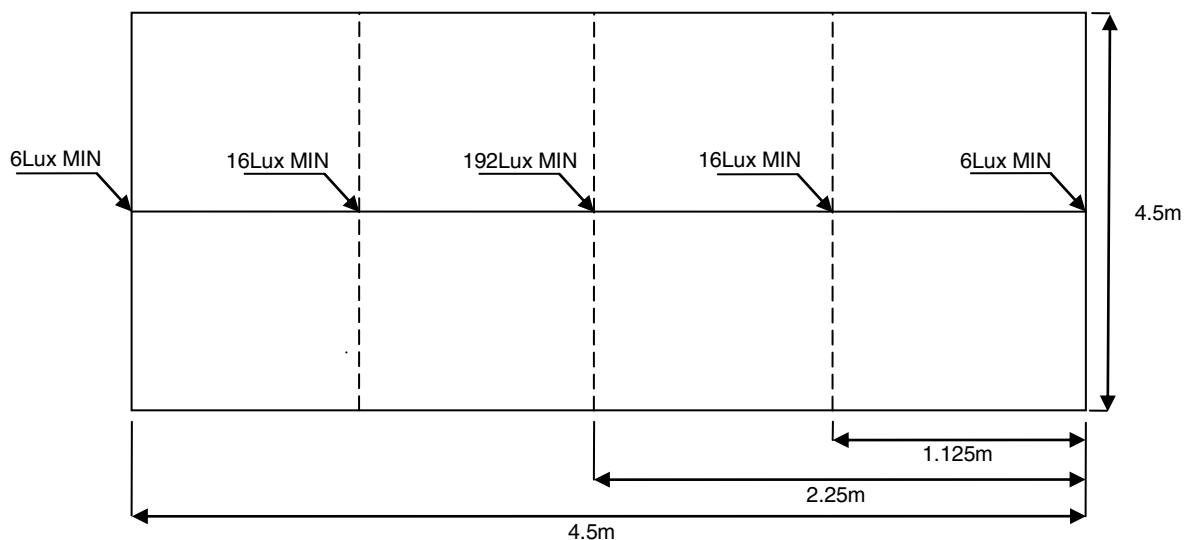


Figure 4: ECE High Beam Conditions Regulation Board [18]

Environmental – There are constraints put forth by the operational environment of the LED. This environment within the vehicle place energy, thermal, and dynamic constraints that must be considered to ensure proper functioning of the system. These requirements exist to ensure the system is able to operate as designed despite the external factors within a vehicle affect its operation.

The primary constraints on the LEDs performance are the effect of temperature on the photometric efficiency. The requirements primarily focus on the upper limit temperatures the LEDs are exposed to. The environment the LEDs are exposed to is illustrated in Figure 5. The LEDs selected to realize the concept have a maximum junction temperature of 90°C. While the LEDs are capable of operating at higher temperatures, there is a decrease in efficiency. The temperature of the ambient air is 50°C. This reflects the upper limit the design is approaching to ensure appropriate operation of the LEDs. The engine bay temperature is considered to be 105°C. However, the design assumes the LEDs will be insulated from the engine bay temperature through use of an interior headlamp shield.

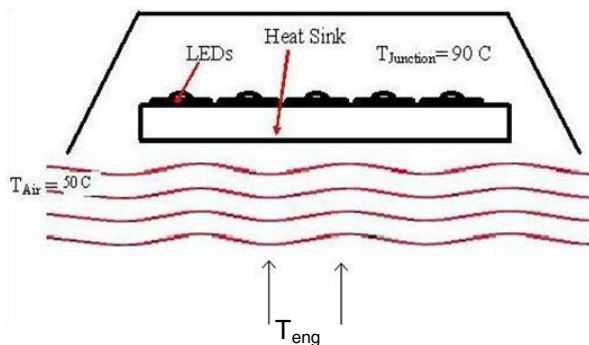


Figure 5: LED Environment

The LEDs must operate under the following required conditions: engine bay temperature is 105°C, environment temperature is -40 to 50°C, and output 2000 lumens per headlamp.

Operational – The LEDs used during the concept development phase imposed constraints to ensure operation within an efficient range. These constraints were provided by the manufacturer of the LEDs.

As seen in Figure 6, the Cree XLamp 7090 XR-E LEDs are capable of operating at currents up to 1000mA. 350mA is considered operation at normal output to avoid overload on the LED. However, the LEDs are well suited for increased current if thermal issues can be mitigated. For the concept, the LEDs were assumed to operate at 700mA. At 700mA, the photometric output of LEDs is approximately 170 lumens.

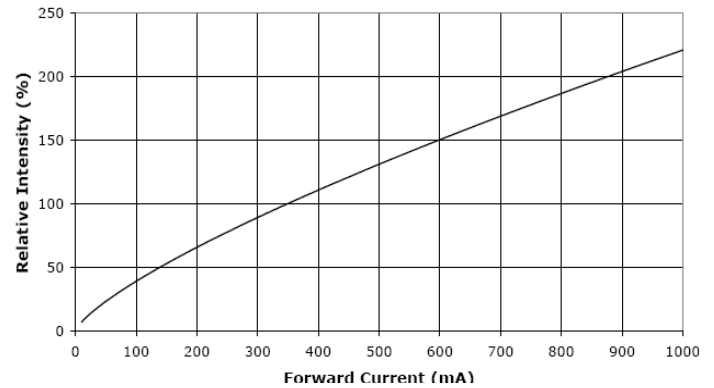


Figure 6: Intensity of LED with respect to Current [16]

It is important to note the intensity of 170 lumens (at 700mA) is performed a junction temperature of 25°C. However, the environmental constraints require operation at lower (-40°C) and higher (50°C) temperatures. As a result, it is important to view how temperature changes affect the photometric output. Figure 7 displays the junction temperature and its effect on the photometric output. As noted, at 25°C, the photometric output is 100%. At a junction temperature of 90°C, a 170 lumen white LED output is degraded to approximately 160 lumens. This information aids in determining the efficiency drop that will be encountered with temperature rise. This information will be used in addressing thermal issues and determining the number of LEDs required.

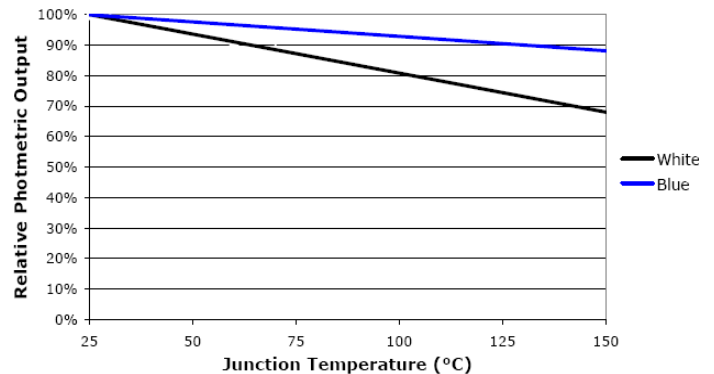


Figure 7: Photometric Output vs. Junction Temperature [16]

The LEDs will not operate on 100% efficiency in terms of power input to output. Approximately 90% of the power supplied to the LED is converted to heat, while the remaining 10% is used in providing light. In the case of the design, this translates to 3.35 Watts of the original inputted energy (3.5 Watts) transferring into thermal energy. For conservative measurements, an assumption that 100% of the input is converted to thermal energy, meaning the LED outputs 3.5 Watts of thermal energy.