# POWER LED EFFICIENCY FOR AUTOMOTIVE HEADLIGHTS

# *EFICIENȚA ENERGETICĂ A LED-URILOR PENTRU FARURILE AUTOMOBILELOR*

Costel-Ciprian RAICU[1], George-Călin SERIȚAN[2], Bogdan-Adrian ENACHE[3]

***Abstract:*** *This paper presents the different topologies for the main headlights driver for achieving a high electric power efficiency when power LED's are used. Different solutions of the buck-boost converters are analyzed to find the equilibrium between the functional flexibility of the vehicle system and the electrical efficiency of the unit. Simulations and data research are concatenated for achieving the optimal solution for the given problem.*

**Keywords**: headlights, LED, DCDC driver, efficiency.

***Rezumat:*** *Această lucrare prezintă topologiile diferite ale unităților de control pentru faruri, cu scopul atingerii unei eficiențe electrică ridicată, când sunt utilizate LED-uri. Soluțiile diferite pentru convertoarele buck-boost sunt analizate pentru a găsi un echilibru între flexibilitatea funcțională a sistemului de pe autovehicul și eficiența unității de control. Simulări și date din cercetări sunt concatenate pentru atingerea unei soluții optime pentru problema propusă.*

**Cuvinte cheie**: Faruri, LED-uri, modul DCDC, eficiență

## 1. Introduction

The automotive adoption of lighting-emitting diodes (LEDs), is generated due to their long lifetime, reliability, luminous and electrical efficiency, small packaging and environmental friendliness[1-4]. With advancements in light efficiency and the reduction of chromatic distortion, LED

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technology gained widespread adoption in the automotive industry. To ensure consistent and stable lighting, we need a reliable LED driver. The LED driver plays a critical role in determining the overall quality of lighting. Therefore, investing in high-quality LED drivers becomes crucial for the development and success of LED headlights and their performance[5]. On the other hand, power LEDs are still far from being an easy solution due to their drawbacks. One is their constant-voltage behaviour, they cannot be supplied from the direct current (DC) or alternating current (AC) input voltage directly. Hence, the need for an intermediary controller solution to limit the current, as in the case of the ballast used to limit the current on the high-intensity discharge(HID) lamps[6,7]. However, achieving high efficiency with power LEDs, can be done under strict operating conditions, some of which include low direct current and low junction temperature. All these constraints and gaps are pushing the boundaries for the power supply development that achieve the correct driving of LED-based headlights as an important research topic [8-13].

The driving unit is managing the conversion between the standard vehicle power supply of 14V up to the power LED string voltage, and is incurring losses due to thermal impact, EMC protection and switching phenomena. The headlights efficacy are depending on the driver topology and system design for control.

Headlights efficiency is rated at normal operating conditions, 25°C, and typically around 80%, where the efficiency of it, is the ratio between the input power in the LED loads on all channels and the output power from the power supply by the DCDC driver. Section 2 presents the driver unit under consideration and the different architecture model. Section 3, deals with the analysis and design of the proposed model. Section 4 the results and conclusions.

## 2. Driver unit for power LEDs

Headlights contain mainly 4 major components from an electrical perspective, the connectors, the driver unit, the harness and the LED's, in Figure 1 the architecture is presented.

Power LEDs to be active and generate luminous flux, require a higher voltage than 14V, and up to 50V, depending on the LED string topology. The intermediate voltage level approach is driving down the efficiency of the system, where the EMI filters required in the automotive equipment are having an impact and typically the full system may attain a maximum of 85%, which is considered good, given the constraints[14,15].

One advantage of adhering to a driver unit is the flexibility of using different LED loads with the same driver. The MCU will read the coded current of the application and adjust the current in the load. The headlights LEDs will vary in means of desired performance and luminous power. For low beams and High Beams, the total rated power is typically around 35W, whereas for the tail lights is 12W in the daytime running feature and around 3W in tail function.

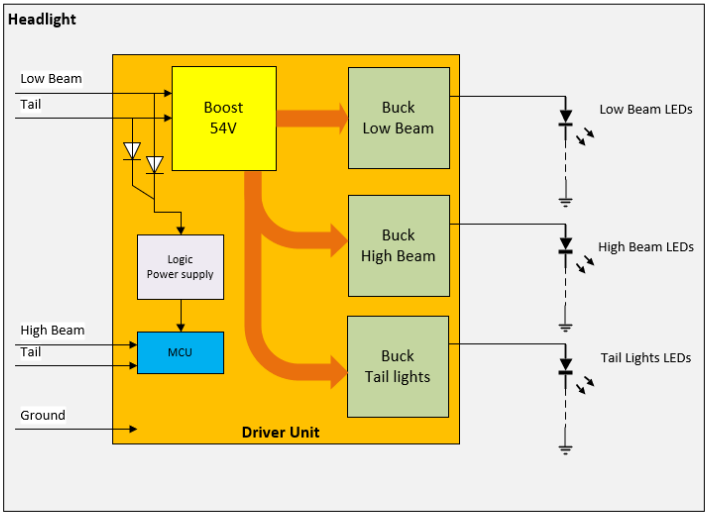



**Figure 1.** Headlight architecture synopsis

*2.1 LED loads parameters*

For the LED loads the architecture may be different, we chose a series topology for each channel with rated loads, in table 1.

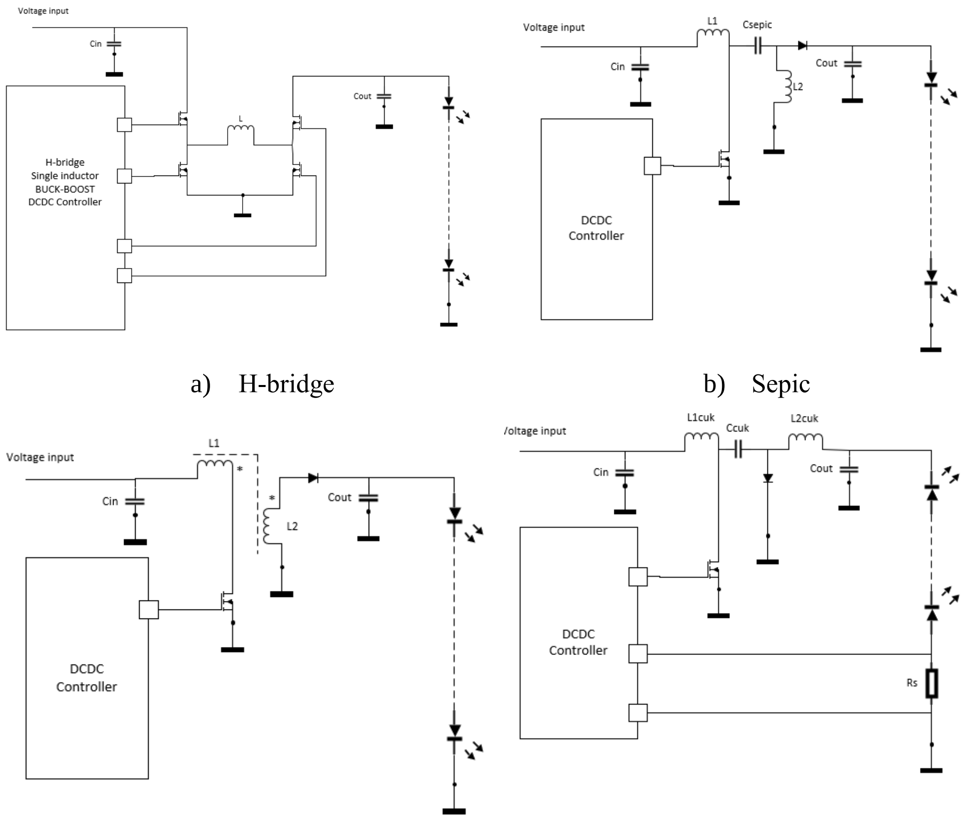
*Table 1:* ***LED load parameters***

| Function LED | Forward Current [A] | Forward Voltage [V] | Luminous flux [lm] | *Number of LED's | Electrical power [W] |
|---|---|---|---|---|---|
| Low Beam | 0.95 | 13.5 | 1280 | 3 | 38.4 |
| High Beam | 1 | 16.5 | 1600 | 1 | 16.5 |
| Tail light | 0.65 | 3.1 | 270-300 | 6 | 12 |
| NOTE: * Number of LED's is for one headlight. The LED's are multi-chip LED's for delivering the required luminous flux. | | | | | |

For a flexible approach designated for a wide spectrum of use, LED loads are of utmost importance to know ahead of the boundaries in which they will be chosen. For the rest of the paper, we will refer to this nominal choice.

### *2.2 Driver unit topologies*

Driver units are consistent in using a buck-boost topology driver, for raising the input voltage from the vehicle battery to the rated LED forward voltage, and maintaining the output voltage during input voltage variations to avoid flickering or function extinction. The solutions for the proper way of controlling the loads are diverse, beside the intermediary voltage level, in Fig.1, there are the h-bridge, sepic, cuk and flyback, some of the most used in the industry. In Figure 2, different topologies of the drivers are shown.




a) H-bridge b) Sepic

c) Flyback d) Cuk

**Figure 2**. Driver unit DCDC driver topologies

Given the nature of most topologies, where some specific components are needed to attain high-efficiency levels, the b), c) and d) have variable efficiency when loads are exchanged and not as designed, single value. For the automotive application, the LEDs usually are varying in characteristics due to process and binning.

For finding the best approach in means of efficiency the topologies and driving solutions will be verified, driver unit and control. LED string will remain in series, since in parallel or matrix, is common to have different values for the electrical characteristics, even if the same binning is chosen, and the light from one string will be usually higher than another.

## 3. Experimental results

For reference, we have chosen two synchronous rectifiers for an intermediary voltage level driver unit. To boost the LT3782A demo board and for buck the STEVAL-ILL089V1, in Figure 3.


a) Boost: LT3782A


b) Buck: STEVAL-ILL089V1

**Figure 3**. Evaluation boards for the intermediary buck-boost approach

The evaluation and testing were performed at room temperature with the following scenarios for better estimation during a full-day usage of the lights, in table 2 the configuration.

Efficiency was measured on 3 different voltage inputs, to assess the better point of behaviour, we use the schematic in figure 4 to measure the input and output currents and voltages across all lines, and in table 3 the associated results.

*Table 2: **Scenario of lights functions usage for efficiency calculation***

| Scenario | Tail Lights | Low Beam | High Beam |
|---|---|---|---|
| Day | 12 W – 100% usage | 38.4W - 10% usage | - |
| Night | 2.4W – 100% usage | 38.4W – 100% usage | 16.5W- 10% usage |

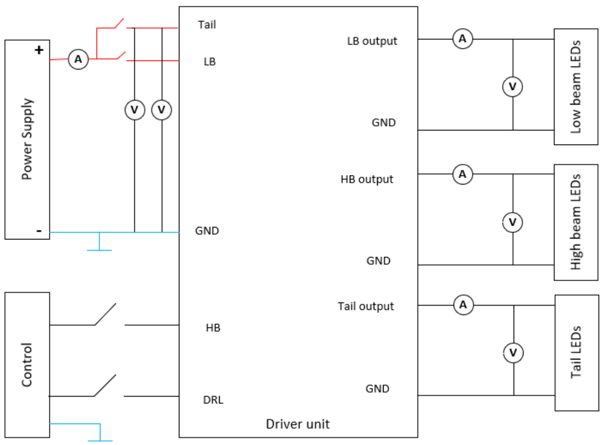



**Figure 4**. Electrical schematic for measuring the reference model efficiency

*Table 3: **Measured efficiency for the reference model***

| Scenario | Supply Voltage [V] | Raw Efficiency [%] | Average efficiency [%] | Total Efficiency [%] |
|---|---|---|---|---|
| Day | 12 | 73.2 | 76.2 | 78.45 |
| | 13 | 77.3 | | |
| | 14 | 78.1 | | |
| Night | 12 | 80.3 | 80.7 | |
| | 13 | 80.7 | | |
| | 14 | 81.2 | | |

The best efficiency was found during the night scenario, where the system worked at higher loads, given the supply voltage. The losses, from an architectural perspective, are due to the EMI filters and the step down from the 54V boost to the string voltages of high beam and tail lights.

For improved efficiency of the reference model, we would impose another topology for controlling the low beams and the high beams, using the same driving unit, in Figure 5, the adapted synoptic:

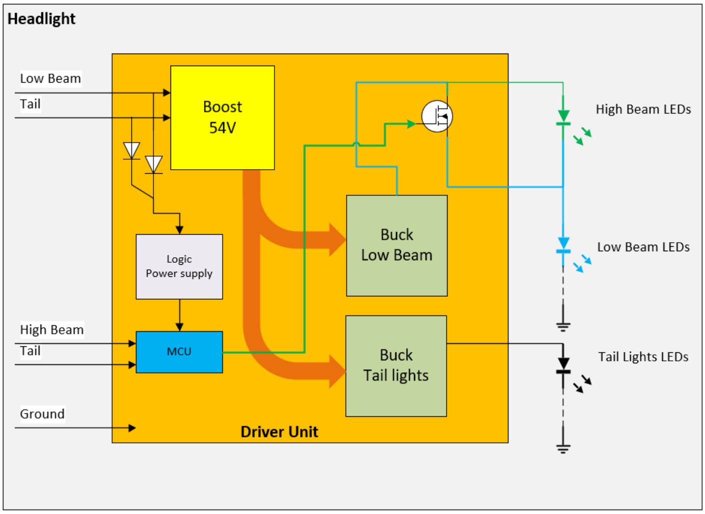



**Figure 5**. Reference model with improved synoptic

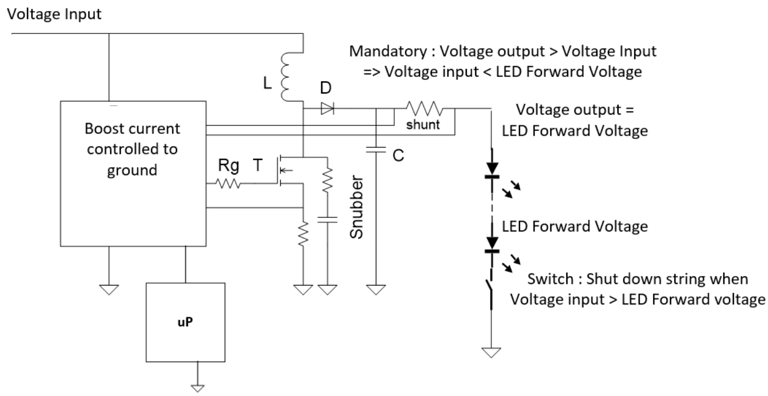
With the improved synoptic, the measurements were re-done, we used the same current forward current on both low beams and high beams and the results are reflected in table 4.

*Table 4: **Measured efficiency for adapted reference model***

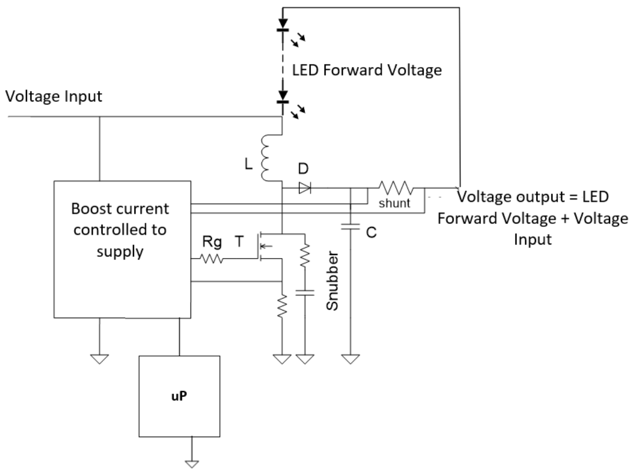
| Scenario | Supply Voltage [V] | Raw Efficiency [%] | Average efficiency [%] | Total Efficiency [%] |
|---|---|---|---|---|
| Day | 12 | 73 | 76 | 81.2 |
| | 13 | 77.1 | | |
| | 14 | 77.9 | | |
| Night | 12 | 85.3 | 86.4 | |
| | 13 | 86.7 | | |
| | 14 | 87.2 | | |

With the change in driving synoptic, the efficiency gain is at best 2.75%, but without a buck, simpler design.

Onward, we can see the drawback of a buck-boost topology with an intermediate voltage to achieve a high-efficiency gain. During the measurements, we see that given some specific scenarios as real life, sometimes, the outputs should be designed in such a manner to be adaptive for the required use-case. One such approach is using the h-bridge topology, where, we use for the day scenario a boost to supply control and for the night scenario a boost to ground, topologies for control in Figure 6.




a) Boost to ground




b) Boost to supply

**Figure 6**: H-bridge topologies for driving power LEDs

In this manner, the boost to ground, operates with LED forward voltage from 35V to 60V, whereas the boost to supply with a range between 5 to 35V. The H-bridge would work in both states boost and buck, as reflected in Figure 7.

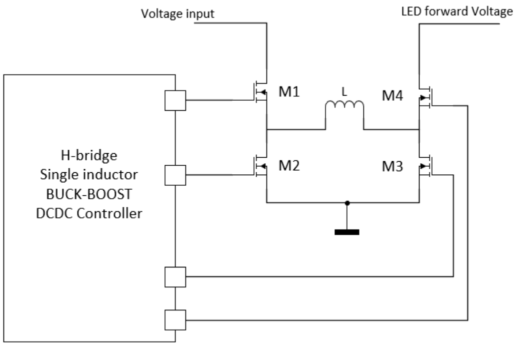



**Figure 7**: H-bridge topology and control for buck-boost

In table 5, the characteristics to control the buck or boost behaviour of the H-bridge, according to figure 7 markings for Mx, are described.

*Table 5:* ***H-bridge control logic to switch between the controlling states***

| | **Boost mode** | **Buck-Boost mode** | **Buck mode** |
|---|---|---|---|
| M1 | ON | PWM | PWM |
| M2 | OFF | PWM | PWM |
| M3 | PWM | PWM | OFF |
| M4 | PWM | PWM | ON |

Measuring the efficiency of H-bridge, with the same loads and controlling strategies and comparing it with the intermediate voltage level approach, we used the TLD5541-1QV Buck-Boost Driver, Figure 8.

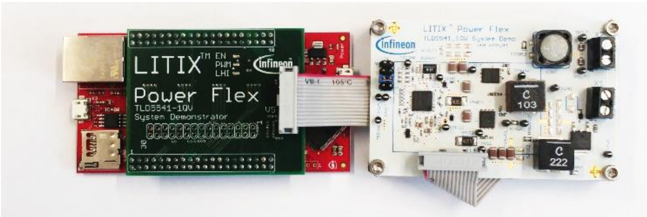



**Figure 8.** TLD5541-1QV Buck-Boost Driver

The efficiency measured with the H-bridege, according to different supply voltages, is shown in Figure 9.

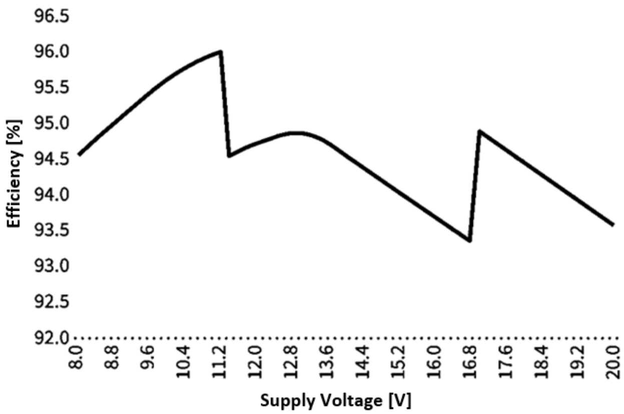



**Figure 9**. Efficiency of H-bridge according to different supply voltages.

We tested and retrieved the values of the H-bridge efficiency according to the same scenarios as for the adapted model (table 4), in table 6 the values found.

*Table 6: Measured efficiency for adapted reference model*

| Scenario | Supply Voltage [V] | Raw Efficiency [%] | Average efficiency [%] | Total Efficiency [%] |
|---|---|---|---|---|
| Day | 12 | 93.1 | 93 | 92.3 |
| | 13 | 93.3 | | |
| | 14 | 92.7 | | |
| Night | 12 | 91.5 | 91.6 | |
| | 13 | 92.1 | | |
| | 14 | 91.4 | | |

## 4. Conclusions

A topology of control was studied in this article for driving power LED’s with the best efficiency.

With the adaption of the controlling strategy of the high beam and low beam LED strings, we identified one solution to increase the efficiency, by 2.75%, and remove one buck driver. Under the consideration to use the same driving current for the LEDs.

Compared the models of intermediary voltage levels with the h-bridge with an increase in efficiency of 11.1%. These two models are the ones with the highest adaptability for the load-wide spectrum and will avoid dedicated changes of sensible components, from the driver unit, susceptible to the loads, like sepic, cuk and flyback.

The efficiency gains, even if may look reduced, for the automotive domain, can add-on benefits such as higher compliance with the regulations of CO2 targets and for the battery electric vehicles a longer driving range.

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