TOPOLOGY CONCEPT FOR DRIVING THE FRONT HEADLIGHTS LOW POWER LOADS

Costel Ciprian RAICU[1], George-Călin SERIȚAN[2]

LEDs changed the current design methods for vehicle lighting resulting in reliability and performance improvements. To increase their aesthetics, they become more complex with added electronics and functional enhancements. This paper aims at the problem of efficiency for the front lighting low power loads (LPL) and presents the advantages of topology manipulation to increase the overall system performance. The reference model, for the Daytime Running Lights (DTRL) and Turn Indicator (TI), was created using Matlab Simulink with available data from the specialised literature, as well as the targeted installed power. The reusability of the base topology was examined and compared with the literature data to have a baseline. The findings have shown an improvement when the linear driver for the TI was eliminated, achieving, in the end, an overall system efficiency increase of 5.75%, while maintaining the functionality and prospects to remove not needed components. In conclusion, by using the LPL loads in the same mechanical interface, and adapting the topology the overall system efficiency attained is 84.5%, compared to the literature topology of 78.75%.

Keywords: Daytime Running Lights, Turn Indicator, LEDs, DC/DC, LPL.

1. Introduction

In recent years, automobile and equipment manufacturers are dedicated to enhancing the efficiency of their products. The stringent requirements imposed by the regulation authorities to reduce the CO2 footprint are driving the system design and the architectures to be focused on electrical efficiency as a must-have requirement [1-3]. The lighting system which is fitted in every automobile has sustained major improvements over time, from incandescent bulbs towards today's semiconductor-based lighting sources, such as lighting emitting diodes (LEDs) or even Lasers[3-5].

The current front lighting systems contain five major features with the scope of supporting the automobile driver to perceive and be perceived safely. The features are categorized, from a power consumption perspective, in large and LPL, the first is the high beams (HB), low beams (LB) and fog lights (FL) with a required power usage between 25W to 35W, whereas the daytime running lights (DTRLs)

[1] PhD(c). Eng., Doctoral School of Electrical Engineering, The National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail: costel_ciprian.raicu@upb.ro
[2] Prof., Faculty of Electrical Engineering, The National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail: george.seritan@upb.ro

and turn indicators (TIs) between 10W to 15W [6-9]. Current specialized literature and research are focused on the improvement of the large power loads for the front lighting to increase their efficiency by above 80%, whereas for the low-power consumers, the efficiency is at around 70% [9-10].

In the headlights, to manage the activation and design of the feature when LEDs are used, static converters are employed to adapt the input voltage and current fluctuations to provide stable voltage and current into the loads to avoid flickering or damage to the components [4, 9-11].

Furthermore, the LPLs are used for safety, increased visibility and aesthetics reasons, the use of the DTRLs given the last regulations is to be active during the whole use of the automobiles [12-14], and with a low power efficiency is generating a bad fuel usage (for internal combustion engines) and shorter state of charge (SOC for electrical vehicles).

As highlighted above the low power loads are in dire need of making some improvements to the power efficiency while maintaining their design and scope. The analysis and optimization of the LPLs is one with a non-standard approach due to the different aesthetic designs of the automobile manufacturers.

In this research, we established the design considerations and an approach to how to optimize the low power load efficiency with the use of a dedicated topology, while using a single DC/DC driver to drive these loads. We employed a MATLAB Simulink analysis and compared the findings with the current market data, as well as maintaining the compliance of the design according to the ECE regulations R48 [15] and safety standards ISO26262 [16].

2. Front lighting aspects and current trends for automobiles

Front lighting with LED loads requires DC/DC converters to manage the stable electrical characteristics delivered into them. LEDs are current-driven devices, and their optical behaviour is linked with the driven current, as well as the optical performance. The DC/DC converters usage instead of the simpler linear converters, are linked with the LED requirements, which need to be driven with a voltage higher than the automobile voltage network of 14V [5-9]. For the features of LB and HB, the voltage required is between 24V and 36V, depending on the used topology, whereas for the DTRL, usually around 20V and for the TI below 9V [9, 17-19].

The topology and the use of LEDs are driving a considerable number of improvements when compared to incandescent bulbs, Table 1, the comparison between the two types of lighting sources for the front lighting.

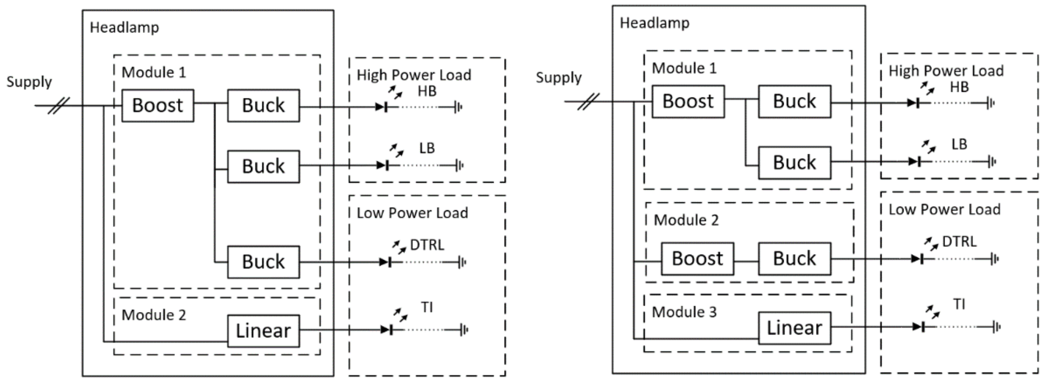
When compared to the previous traditional driving system for lighting, the LED-based loads are 37.2% more efficient, from an installed power perspective.

Table 1

Comparison between front lighting technologies' power usage requirements

Feature	Number of lamps	Total power requirements (W)	
		Incandescent bulb system	LED system
Low beam	2	112.4	108
High beam	2	127.8	68.8
Front Turn indicator	2	53.6	13.8
Daytime running lights	2	45.8	22.8
	Total	339.6	213.4

An electrical and electronic driving topology for the front lighting, based on LED usage, is diverse, and linked with the aesthetics of each automotive manufacturer; in Fig. 1 the typical topologies used are presented.



a) b)

Fig. 1. Front lighting topology - driver and loads [2, 5-9]

In most cases the topology used for driving the high-power loads, module 1 in Fig.1 a) and modules 1 and 2 in Fig. 1 b), use a boost driver to raise the voltage to the maximum rated voltage and dedicated buck drivers for each feature. The buck drivers are needed to adapt the boost output voltage to the LED required string forward voltage (*Vf*) to be active, the buck is used as well to adapt and prescribe the required forward current (*If*). For the topologies presented in Fig. 1, the control for the features can be with dedicated supply lines, signal lines or a communication network such as CAN (controller area network).

For the LPL, for example, the Turn Indicator, it uses a linear driver, since the required forward voltage on the LED loads is below 9V, hence no need for a dedicated cascaded DC/DC topology to be used. In other cases, from an aesthetic design need, the DTRL and TI are fitted in the same mechanical structure, and light guide, and they should never be active at the same time.

For the linear driver, the power efficiency can't be tunned due to the voltage functional area needed for normal behaviour, typically between 9 and 16V [4, 9], and since the lower end is closer to the LED string voltage, at that point the linear driver is the most efficient, but at the typical 14V, its efficiency is dropping at 70% [15, 18].

3. Low power loads topology analysis and simulations

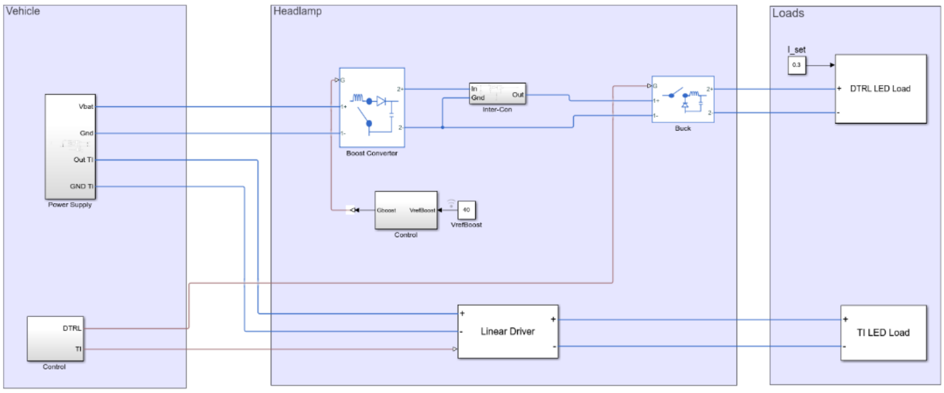
For the prospect of setting the analysis and establishing a comparison model, we designed the LPLs topology for the front lighting using the MATLAB Simulink program, according to Fig.1 b). The loads and requirements are imposed as in Table 2, the LEDs are installed in series.

Table 2

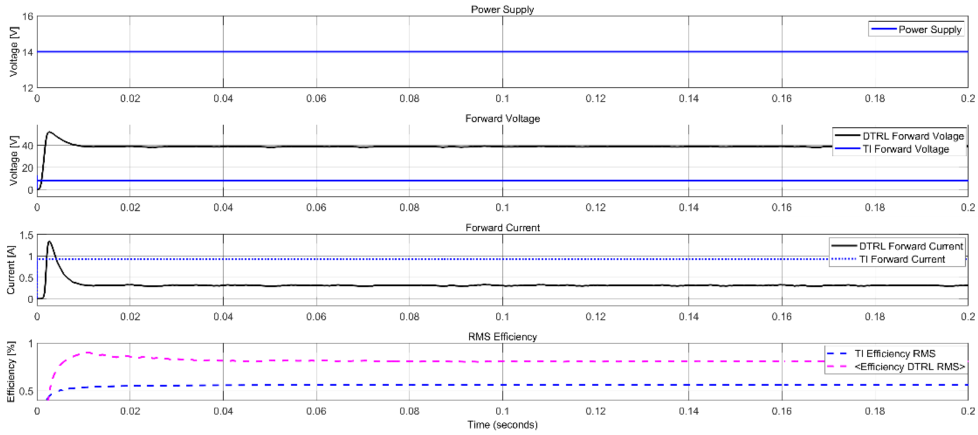
Low power load design factors

Feature	Number of LEDs	Number of LED strings	Forward current (mA)	Forward voltage (V)	Installed power (W)
Front Turn indicator	12	6	0.15	2.7	7.3
Daytime running lights	5	1	0.3	7.7	11.5
Total					18.8

The front lighting system topology simulation and results are highlighted in Fig. 2, according to the current typical market topologies.



a) MATLAB Simulink model for the front lighting



b) Electrical characteristics for the front lighting
Fig. 2. Analysis of the front lighting topology efficiency

We have found that the average efficiency with the DTRL using a cascaded converter of type boost to buck is around 80%, whereas, for the linear driver, the efficiency is around 55%. Furthermore, to catch the complete picture with this topology we evaluated the efficiency for different supply voltages, and we extracted the values in Table 3, based on the topology.

Table 3

Efficiency of the front lighting low power loads

Feature	Supply voltage (V)	Efficiency (%)
DTRL	9	81
	14	80
	16	82
TI	9	85
	14	55
	16	50

Given the required functionality area in the automobile industry, from 9 to 16V, where the lighting systems should work at their nominal characteristics, the linear strategy is best for the worst supply voltage due to the proximity of the voltage balancing. In the MATLAB design, we have an 8.1V for the LED string voltage, so the linear converter has better efficiency when supplied with 9V. On the other hand, the DTRL driver is consistent at around 80% efficiency for the whole spectrum of supply voltage, which makes it a better choice when the efficacity of the electrical parameters is discussed.

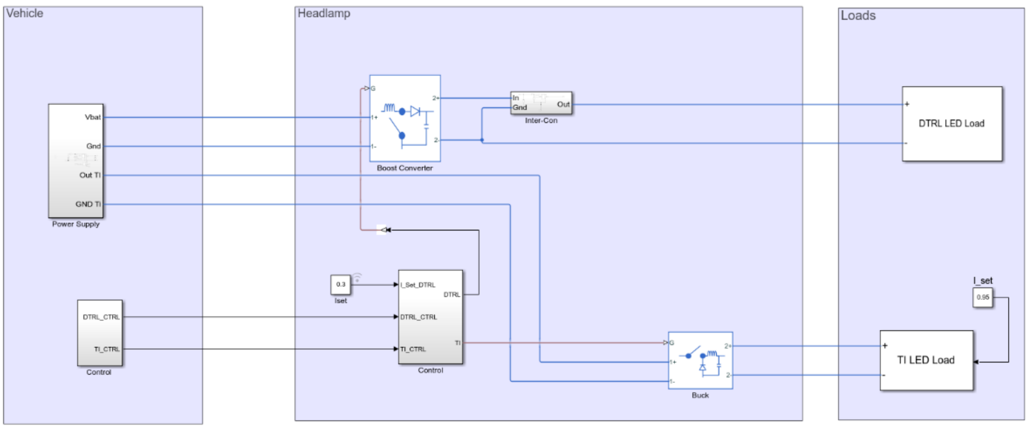
For the whole system when supplied with 14V, the overall efficiency is found to be 67%, when both features are active. On the other hand, if the system is evaluated based on the typical use case of the features to be active, for a driving cycle of 1 hour, the DTRL is active 100% of the time, while the TI is active only for 10% of the time. The adjusted system efficiency linked as well with the activation profile is, using Eq. (1), 78.75%.

$$\eta = \frac{\eta_{DTRL} \cdot 90 + \eta_{TI} \cdot 10}{100} \tag{1}$$

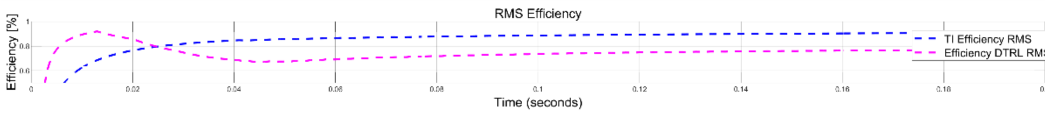
4. Topology improvements and low power load unification

Following the analysis and the results retrieved in Chapter 3, as well as the current market trends, we identified that the DTRL and TI may benefit greatly if both are using a DC/DC strategy. For example, many automobiles currently integrate the same mechanical interface, light guide, and both features and drivers are nearby.

The functionality perspective of the shared mechanical interface for the two features and the associated regulation is that when the TI is active the DTRL must be shut down [15-16]. Hence the overall system efficiency for these loads will decrease according to Eq. (1) if the same strategy is used. Given the simulations and prospects of efficiency improvements, keeping in mind the mentioned design perspective two possible topologies to increase the overall performance are studied. The first strategy would be to use the buck driver supplied by the vehicle network for the TI and for the DTRL a current controlled boost driver, hence reducing the overall system components while targeting the system efficiency improvements, the results are highlighted in Fig. 3.



a) Optimised MATLAB Simulink model for the front lighting

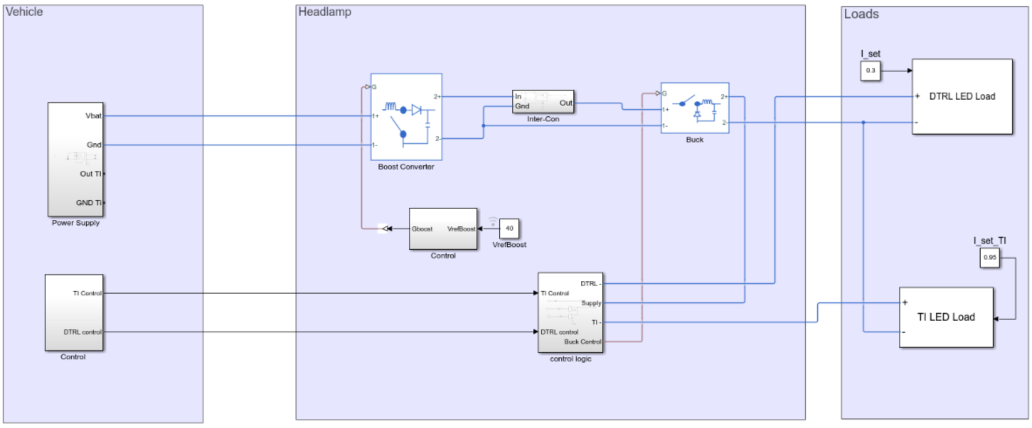


b) RMS Efficiency for DTRL and TI features

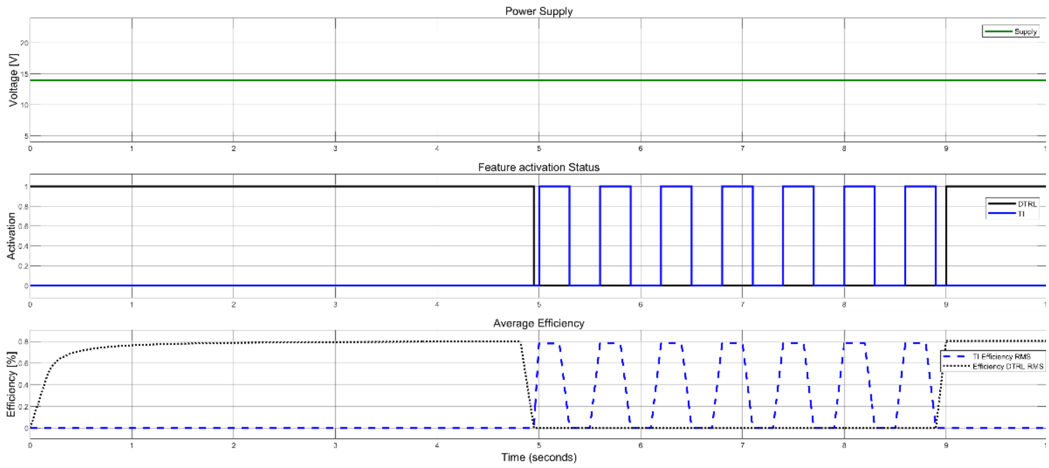
Fig. 3. Topology strategy one - analysis for the optimised front lighting efficiency

Based on the findings from the topology one, Fig. 3, the overall system efficiency achieves a cumulated value of 84%, whereas, with Eq. 1, we have an efficiency of 80.5%. The TI with the buck has achieved, 90% efficiency, while the DTRL with the boost rested at 80% efficiency.

The second topology strategy, reusing cascaded operation from Fig. 1 b), while powering the DTRL and TI from the buck, in cycles, since they can't be active at the same time is analyzed in Fig. 4.



a) Optimised MATLAB Simulink model for the front lighting



b) RMS Efficiency for DTRL and TI features

Fig. 4. Topology strategy two - analysis for the optimised front lighting efficiency

In the second topology, where both features couldn't coexist at the same time, we employed a longer simulation. The results highlighted in Fig 4 b), are showing the feature activation status in the second plot whereas the average efficiency of each feature is linked with their activation status in the third plot. With the integration of the control logic, which contains switches to select which feature should be supplied from the buck, in Fig 4. a), we managed to address the efficiency problem. With the DTRL we recorded an average efficiency during usage of 80%, while with the TI an average of 79%. Overall, the second system topology achieves an average efficiency of 80.5%.

Furthermore, we were not satisfied with this value and adapted, even more, the entire strategy, by matching the TI LED topology, to be in series, rather than parallel, hence the number of LED strings will be reduced to one from six, Table 2. Hence matching the overall forward voltage across the string to 32.4V, closer to the DTRL forward voltage, while matching the boost output voltage to the maximum string voltage of the two features, 39V. With this new strategy, we retained an efficiency increase of around 4% compared with the previous value and 6% compared with the initial model, linear and DC/DC from Fig 2, for the overall system, in Fig. 5.

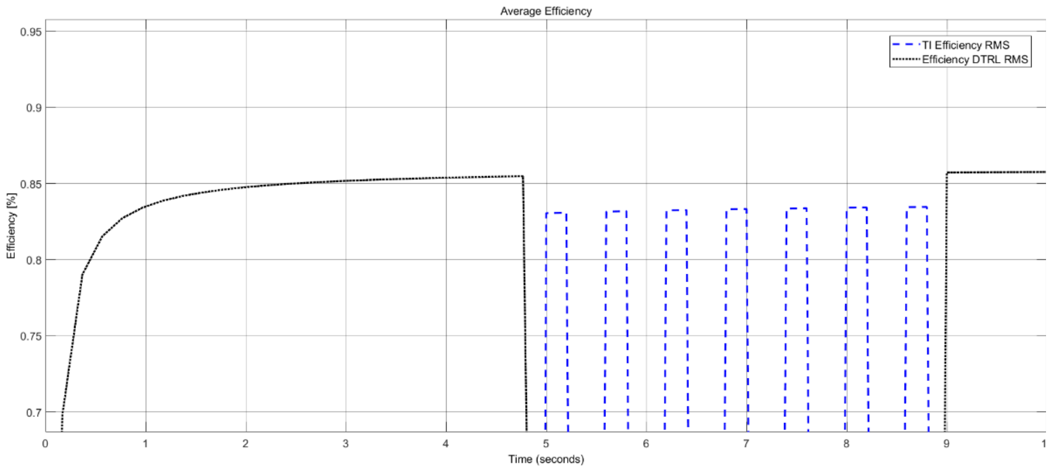


Fig. 5. Topology strategy two – efficiency optimisation

We maintained the same activation profile as used in Fig. 4, and the overall improvement was achieved, for both DTRL and TI. Given the usual losses, the DTRL is at its maximum potential given the used DC/DC concept, while the TI, is lagging due to higher losses, generated from the voltage difference between the boost output voltage and the TI load forward voltage.

5. Conclusions

This paper aims the efficiency demand for the low power loads used in the automotive industry for lighting equipment. The features targeted for which the efficiency was analyzed are some of the most used, hence the need to find the best equilibrium in means of power usage. We analyzed the current literature with the available data, and also analyzed and created models relevant to the market products. With the topology improvements, we highlighted the opportunity to decrease the number of components while not degrading the functional behaviour, remove the linear driver and share the buck driver between the loads.

The boost and buck cascaded topology for the low power loads of the front lighting system, is achieving an overall efficiency of 84.5%, an increase of 5.75% from the design found in the literature. While better control strategies may be employed to achieve higher efficiency potential, such as SEPIC or buck-boost, the flexibility of the used design shows the appeal of reusing the control topology with different loads, for different vehicle models, without changing the base design or the application custom tailored components.

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