Design of Automotive LED Driver Control Circuit

Borislav Georgiev Dyuzov and Emil Dimitrov Manolov

Abstract - **The paper discusses the results from investigation, analysis and design of LED driver control circuit for automotive electronics. The basic types LED connection circuits and current regulators are considered in order to choose the best solution. As a result, an enhanced LED driver control circuit is proposed and simulated.**

Keywords – **Light Emitting Diode, LED, LED driver, Automotive electronics, Switching regulators**

I. INTRODUCTION

The constantly increasing demands on the quality and reliability of the state-of-the-art vehicles lead to an enormous growth of the number and complexity of the electronic devices that are being used in them. These systems represent complex digital-analog, pulse and digital devices, which work under very heavy conditions – high voltages, electrical interference, vibrations, temperature changes in wide ranges, etc. [1]. This complicates the requirements to the automotive power systems.

Nowadays LEDs (Light Emitting Diodes) are very successful alternative to incandescent, halogen, and fluorescent lighting [2]. The most important LED's advantages are high efficient, long life-time and low cost. They are the reason for the increasing implementation of LED components in the automotive industry. The LED driver circuits are basic component of the LED systems [3]. These circuits are characterized with large variety in order to fulfill the requirements of the different consumers.

The paper presents the results from the conceptual design of LED driver control circuit for automotive electronics. To this aim, an investigation and analysis of the LED driver control systems is presented. The basic types LED control circuits and DC-DC converters are considered in order to choose the best solution. As a result, a LED driver control circuit, which fulfils the requirements of the automotive industry, is presented and analyzed.

II. PROBLEM STATEMENT

The increasing application of the LED systems in the vehicles is a reason for continuous investigations in the field of the automotive LED control systems and circuits.

Three types of connections of the LEDs are known in the practice: parallel, series and mixed (series-parallel).

The advantage of the parallel connection (Fig. 1) is that it does not require high voltage supply. The main

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disadvantage is the necessity of monitoring and control for each branch, which increases the current consumption and the number of the used additional components.

The series connection (Fig. 2) needs monitoring and control for only one branch, lower current from the battery and small number additional components, but it demands high voltage supply.
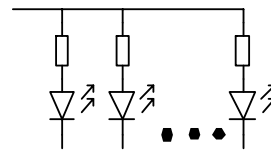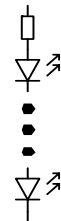

Fig. 1. Parallel connection   Fig. 2. Series connection

The mixed (series-parallel) connection combines the advantages and disadvantages of both described connections.
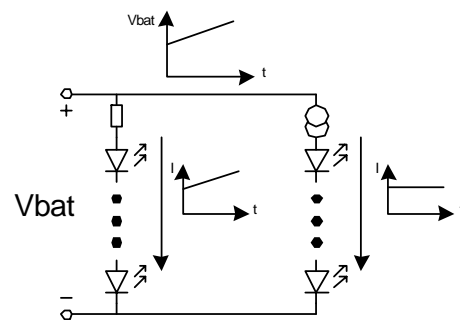

Fig. 3. Current control of LED string

As it is shown on Fig. 3 [4], the current control can be implemented by simple resistor or by current regulator. The limiting resistor is the most widely used solution in automotive electronics, up to now. The current regulator is used to compensate the variation of the LED forward voltage from device to device, the variation of the LED forward voltage with the temperature, and the wide range variation of the supply voltage in the vehicles.

The most important parameter, which determines what kind of current control is preferable, is the power dissipation. Resistor and linear current regulator are used for low bright LEDs with low current. The high bright LEDs (>1W) need higher currents. In this case the heat dissipation in the resistor or in the pass transistor of the linear current regulator will be too large. Then switch-mode current control is recommended. It can be implemented by using switching regulators. This type of regulators does not allow the pass transistor to operate in active region. The transistor alternatively saturates and cuts off, which ensures less power dissipation [5].

The switching regulators, which are the most appropriate for the implementation in the LED driver control, are based on boost and buck DC-DC converters [6].

The boost (step-up) regulator (Fig. 4) is used when the load voltage is always higher than the supply voltage.
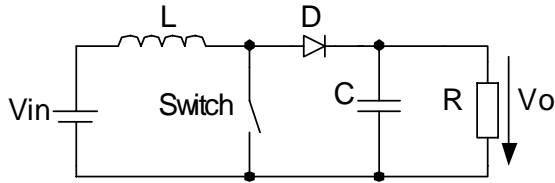

Fig. 4. The boost converter

The buck (step-down) regulator (Fig. 5) is used when the supply voltage is higher than the load voltage.
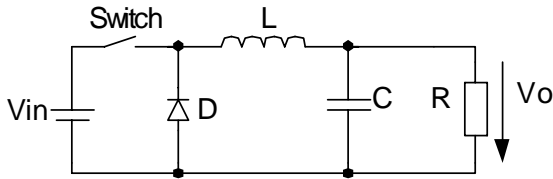

Fig. 5. The buck converter

Fig. 6 shows an example of LED string driver control. With boost converter we can increase voltage over LED string and control the flowing current. The most important condition is to keep current constant during LED string shining. To this aim, peak current control method is used. The advantages of this method are: good regulation of LED current over wide variations in input and output voltages; simple design (no feedback compensation is required); PWM dimming response of the converters is almost instantaneous.

Peak current controlled buck converters go into sub-harmonic oscillations at duty cycles over 50%. The result average output current drops, while the output ripples current increases.
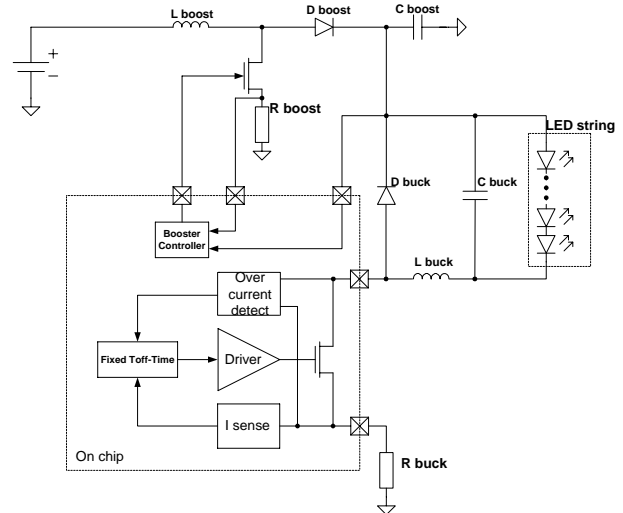

Fig. 6. Example of LED string driver control

To avoid this problem, an externally or internally slope compensation circuit needs to be added. The slope compensation circuit adds an upward slope to the current sense signal and the converter can be stabilized by varying the slope of the added ramp. This added ramp causes an error between the sensed current and the actual LED current.

Although this error could be compensated by appropriately changing the value of the sensing resistor, the converter's rejection of the input and output voltage variations will be significantly. Thus, changing the input or output voltage will significantly change the LED current, without additional feedback circuitry for regulating them. This makes the peak current controlled buck converter practically useless for the cases where the input voltage is less than twice the output voltage.
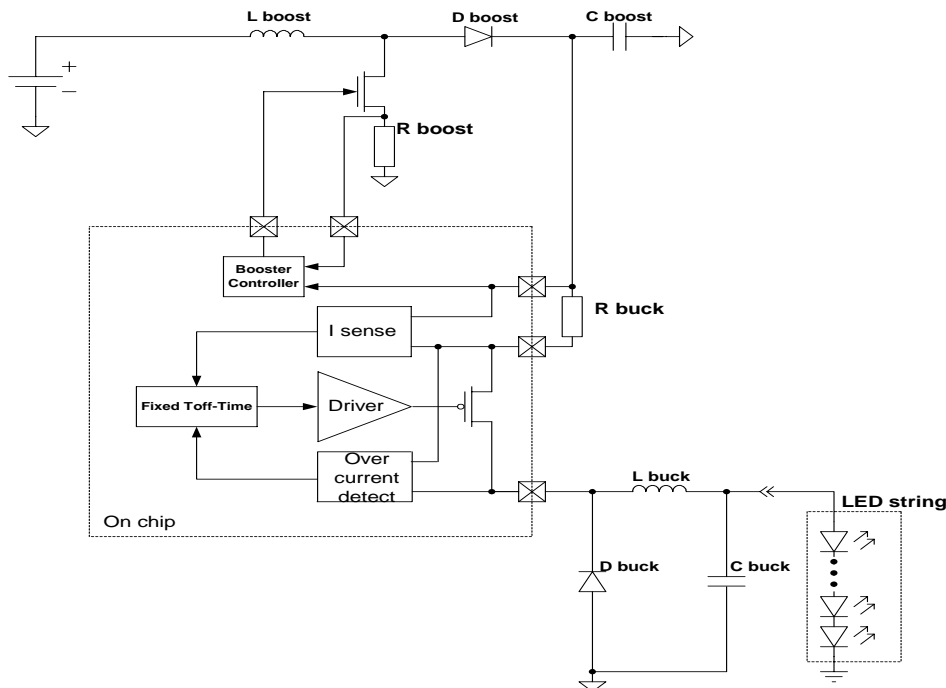

Fig. 7. The enhanced circuit

The problem can be overcome by changing the control method to constant off-time operation. In this case, the off-time is fixed by design, the on-time is based on the current sense signal and the switching time-period is adjusted to be equal to the on-time plus the off-time. This change will allow the converter to work with duty cycles greater than 50% and still have the advantages of the peak current controlled buck converter. In this case the block diagram and used method are easily applicable and suitable in automotive industry.

III. THE ENHANCED CIRCUIT

An example of the proposed peak current control circuit is shown on Fig.7. This circuit is appropriate in the case when the LED string is away from the board. The advantages are that the LED string is connected to ground (chassis) and that there is no need of feedback. The main disadvantages are the high voltage inside on the chip, and more area of silicon (big PMOS driver). This choice of current control is a compromise between external PMOS and frequency of operation, respectively the size and the cost of the external inductor.

In the discussed case, current floating through external sense resistor R_buck, passes through internal switch and after - through external inductor. As a result, the voltage over capacitor increases and current starts floating through LED string. Capacitor C_buck reduces voltage spikes over LED string. Current through sense resistor R_buck increases, and when reaches to a fixed value, the flag of the "I sense" block turns. After this moment the internal switch is off and the fixed T-off time is starting (see Fig. 8). When fixed T-off time is over, internal switch again is on.
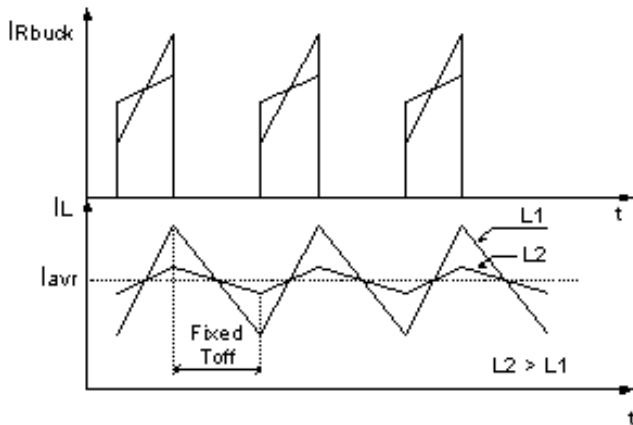

Fig. 8. Time-diagram of the LED driver circuit

This method of peak current control allows current through LED string to remain an average constant. To this aim, an appropriate value of the inductor should be chosen. It depends on the allowed current ripple through LED string. To define the value of the external inductor we have to know buck voltage and allowed ripple current thought LED string. T-off time will adjust inductor value.

$$L_{buck} = \frac{V_{buck}\, T_{off}}{\%_{ripple}\, I_{LED}} \tag{1}$$

$$I_{peak} = I_{LED} + \frac{V_{buck}\, T_{off}}{2\, L_{buck}} \tag{2}$$

The next step is to determine external buck (or sense) resistor as a function of the internal reference voltage.

$$R_{buck} = \frac{V_{ref}}{I_{peak}} \tag{3}$$

The external diode can be chosen according to the following two equations:

$$V_d = 1.5\, V_{boost} \tag{4}$$

$$I_d = I_{LED}\left(1 - \frac{V_{buck}}{V_{boost}}\right) \tag{5}$$

The last external component is the capacitor. This is an optional component and customer can put it, if it is needed.

$$C = \frac{I_{peak} - I_{LED}}{0.5\, f_{MAX}}\quad, \tag{6}$$

where

$$f_{MAX} = \frac{1 - V_{buck}/V_{boost}}{T_{off}} \tag{7}$$

The described methodology for calculation of the external components is clear and concrete and gives the customers freedom to choose and adjust their application according to the needed accuracy.

IV. EXAMPLE

A simple example with OSTAR LED string (V_nom=18.5V, I_led=0.7A, LED module per string =3) is developed by using above computing methodology.

For V_buck about three times higher than V_nom, assumed ripple current =20%, accepted T_off time=3.2μS, V_ref=0.2V and V_boost=66V, the obtained results are as follows: V_buck=55.5V, L_buck=1.27mH, I_peak=0.77A, R_buck=0.26Ω, V_d =83.25V, I_d=0.0525A.

The simulation schematic, which presents and proves the obtained results, is shown on Fig. 9. In this circuit ISENSE block is ideal comparator, TOFF_TIME block is ideal time source, PMOS transistor is replaced with ideal switch. The obtained results are shown on Fig.10 and Fig. 11.

Fig. 10 presents the current through the sense resistor and the LED string. Fig. 11 shows zoomed view of these results. The average value of the current is about 702.74mA, the peak of the current is 770mA (as it was predicted in the previous computations), and the minimum is about 634 mA. The ripple of the current is very close to the expected value of 20 %.

V. CONCLUSION

The paper presents the results from the design and investigation of the automotive LED driver control circuit.

To this aim - series, parallel and mixed types of connection of the LEDs are described and the current control of the LED string in contemporary vehicles is discussed. The basic LED drive circuits are investigated and the using of the switching regulator circuits is

motivated. An example of LED string driver control circuit is presented and its operation and disadvantages are shortly described.

An enhanced method and LED driver circuit, which avoid the defects of the existing circuits, are presented and analyzed. A simple methodology for calculation of the external components of the circuit is described. The methodology is clear and unambiguous.

An example for control of OSTAR LED string is developed by using this methodology. The circuit is simulated and the obtained results correspond completely to the preliminary assumptions and calculations.

The next step in the work is the application of the presented results in the design of integrated automotive LED driver control system.

VI. ACKNOWLEDGEMENT

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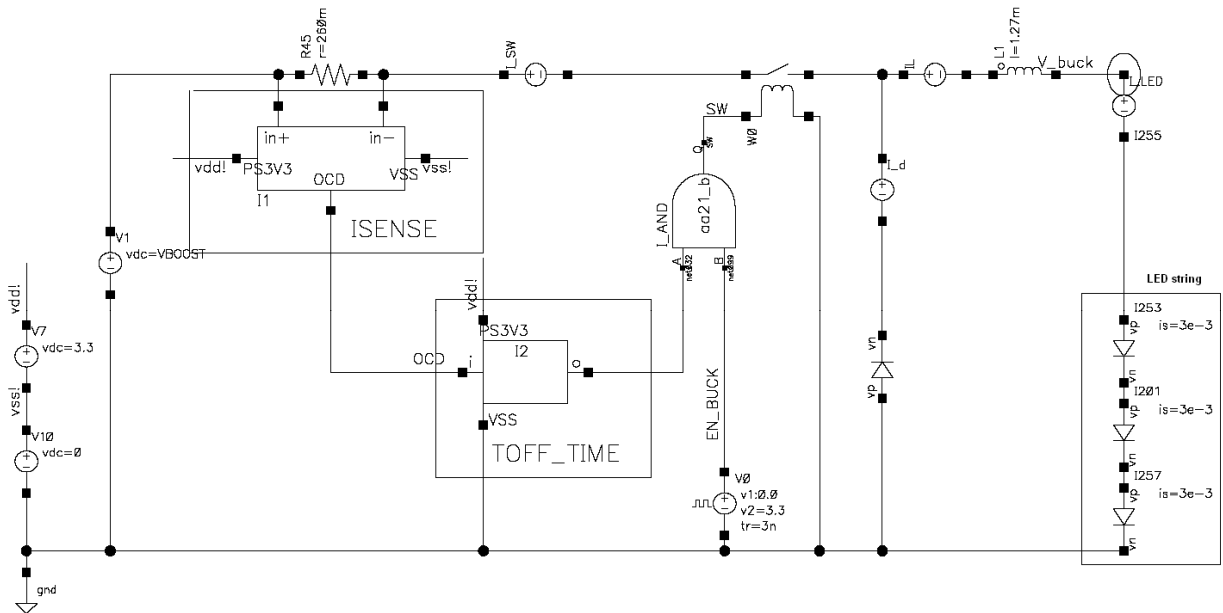http://www.supertex.com/pdf/app_notes/AN-H50.pdf

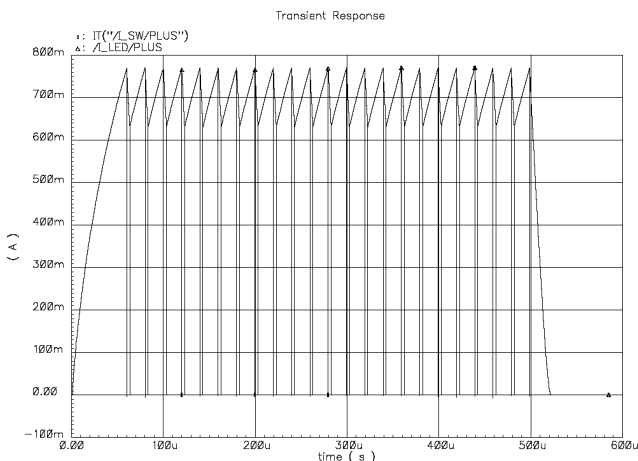Fig. 9. Circuit for simulation of the presented example
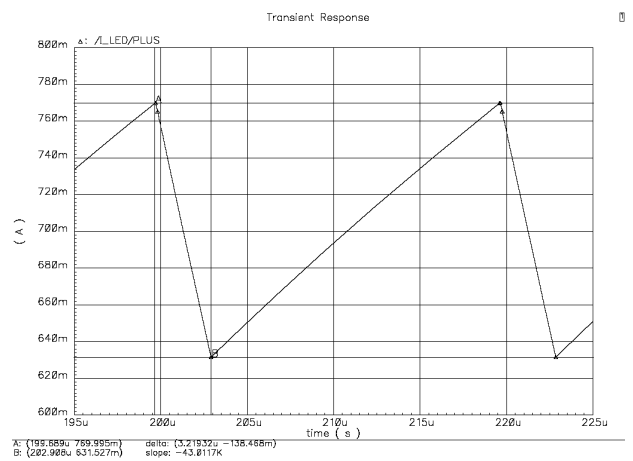

Fig. 10. Current through sense resistor and LED string

Fig. 11. Zoomed view of the current from Fig. 10