PWM Dimming Control for High Brightness LED Based Automotive Lighting Applications

Muhammad Wasif Umar[1], Norzaihar B Yahaya[2], Zuhairi B Baharuddin[3]
Department of Electrical and Electronic Engineering, Universiti Teknologi PETRONAS
32610, Bandar Seri Iskandar, Perak, Malaysia

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ABSTRACT

In recent years, the use of high brightness LEDs has become increasingly accepted as light sources in mainstream vehicles. However, LEDs are semiconductor devices having electrical characteristics completely different to the traditional lamps. The output luminous flux of an LED is determined by the forward current running through it. Therefore they cannot be powered directly from the automotive battery using the conventional driving techniques. They require specialized driving systems which can ensure the optimal flow of current through LEDs, while maintaining the required level of output luminous. This paper discusses the importance of luminous control for LED based lamps. A design example of boost type DC-DC switching converter with pulse width modulated (PWM) dimming control is presented. In the end, simulation has been presented using MATLAB/Simulink simulation package to ensure the system's performance within the desired parameters

Corresponding Author:

Muhammad Wasif Umar,
Department of Electrical and Electronic Engineering,
Universiti Teknologi PETRONAS,
32610, Bandar Seri Iskandar, Perak, Malaysia.
Email: cmwasif@yahoo.com

1. INTRODUCTION

Over the past few years, high brightness LEDs (HBLEDs) have become increasingly accepted as light sources in many applications but their use in auto industry has been on the rise [1]. Auto makers across the globe are adopting them for various lighting application especially for headlamps, as their light colour is very similar to daylight. In comparing with the traditional light sources (Halogen and HID), LEDs offer several potential advantages like about five times greater lighting efficiency, reduced energy requirement and many times greater lifetime [2-3]. These benefits have led to the consideration of high brightness LED sources for use in mainstream vehicles by all major car manufacturers and are seen as the future of automotive lighting.

However, LEDs are semiconductor light sources and due to their electrical characteristics are completely different to those of conventional lamps. They are current controlled devices as the output luminous flux of a LED is determined by the forward current running through it. Therefore, they cannot be powered directly from the automobile battery using the traditional driving techniques. Specialized driving circuits are required which can respond to the changing needs of the LED systems as their electrical properties change while maintaining the required level of luminance [4-6].

The possibility of controlling the luminous flux is getting very important feature of latest LED based lamps. It allows using them in energy-saving mode and creating different versions of illumination. This paper discusses about the importance of luminous control for LED driving applications. A PWM DC-DC boost test model using MATLAB Simulink environment has been developed to demonstrate the system's performance within the desired parameters. However, a physical implementation scheme for the system, using appropriate microcontrollers and digital sensors is also researched out and proposed for the future work.

2. LUMINOUS AND CURRENT CONTROL OF LEDs

In automobile lighting applications luminous control is often required to have different lighting levels, to extend the life of the electronic components in the driver and sometimes for aesthetics as well. The dimming of conventional light sources is well known due to many years of applications. Generally it is based on the control of the supply voltage but in case of LEDs, which are strongly nonlinear devices simple voltage control is not enough. Therefore, specialized drive schemes are needed which can ensure the optimal flow of current through LEDs while having dimming capabilities to maintain the uniform brightness.

As discussed previously that the flux generated by a high-power LED is a direct function of forward current running through it at constant temperature condition. Therefore, to achieve the uniform brightness simply voltage control is not satisfactory it is necessary to take into account two nonlinear relationships:

$$I_F = k_1 V_S \quad (1)$$

Where

I_F is the LED forward current

$$\phi = k_2 I_F \quad (2)$$

The above relationships describe the dependence between LED supply voltage V_S and its luminous flux ϕ. Hence the practical realisation of LED driving circuit with dimming ability depends on the assumed rule of LED luminous control. Two commonly used methods found in literature [7-9] for LED luminous control are:

A. *Amplitude Modulation*
B. *Pulse Width Modulation*

Each method has its own benefits and drawbacks, and so for each application it is important to identify the critical characteristics. Both these methods control the averaged current through a single LED or an array, by examining them in detail their advantages and disadvantages become evident.

2.1. Amplitude Modulation

Amplitude modulation involves the adjustment of cycle by cycle LED current to achieve the desired level of luminous flux. Typically, the LED drive current is adjusted by using a simple potentiometer or a current regulator circuit and thereby increasing or decreasing the output luminous flux. These control architecture regulate the LED current by simply adjusting the reference value of the current feedback as shown in Figure 1. The resistor R_S here is used to sense the voltage and subsequently to measure the LED current. This measured LED current is then used by a controller to adjust the output voltage and current of the dc-dc converter.

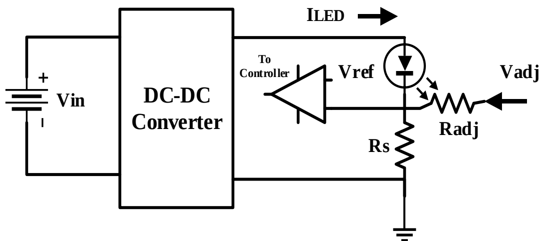

Figure 1. Amplitude Modulation dimming

Amplitude modulation can provide a simple and cost effective dimming solution to a single LED device but may not be able to deliver the best overall performance for an array of LEDs. As it leads to chromaticity (Quality of colour) shift as the drive current value varies due to variation in the characteristics of the different LEDs [9, 10].

2.2. Pulse width modulation dimming

As discussed earlier that not only the LED output luminous flux but its chromaticity also depends on the drive current. A small variation in LED drive current may cause a significant chromaticity shift particularly in an array configuration of LEDs. Therefore To maintain the required chromaticity, it is necessary to drive the LED systems at constant current. Pulse width modulation (PWM) provides the most convenient method for LED luminance control witout altering the current. Such systems regulate the output current by changing the duty cycle $d = T_{ON}/T_S$ or in other words, by varying the pulse width T_{ON} of a power switch (MOSFET) [11-13] as shown in Figure 2.

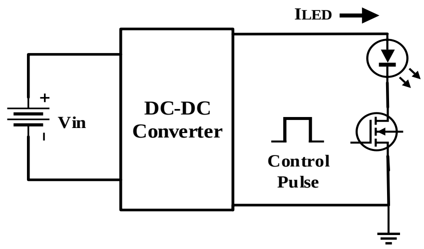

Figure 2. Pulse width modulation dimming

As a result, effective brightness B_{eff} of the LED under the PWM control follows the corresponding output current I_o is substituted by B_o , which is the LED brightness obtained at the continuous current I_o as shown below in Figure 3. The effective current (brightness) is obtained by multiplying the current (brightness) at the continuous mode by the duty cycle $d = T_{ON}/T_S$.

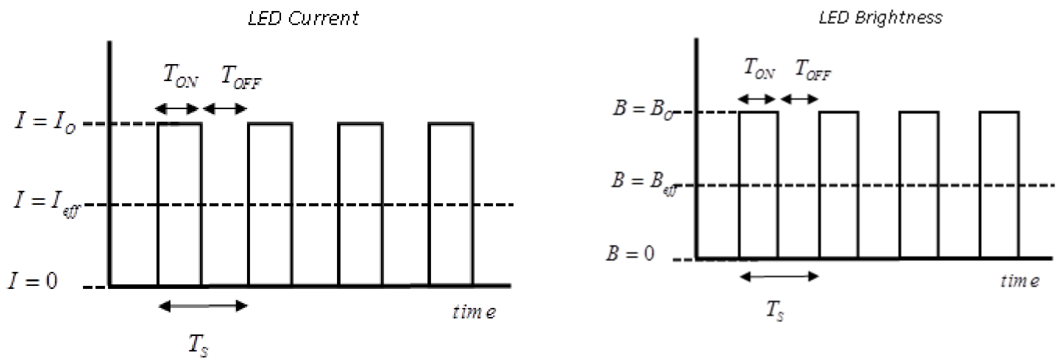

Figure 3. Illustration of the LED luminous control with PWM

Hence, chopped dc voltage produced at LED load can be represented as:

$$V_L = \frac{T_{ON}}{(T_{ON} + T_{OFF})V_S} = \frac{T_{ON}}{T_S V_S} = dV_S \tag{3}$$

Where

Chopping period, $T_S = T_{ON} + T_{OFF}$ and duty cycle $d = \frac{T_{ON}}{T_S}$

RMS value of output voltage

$$V_{ORMS} = \sqrt{d(V_S)^2} = \sqrt{d}V_S \tag{4}$$

RMS value of output current

$$I_{ORMS} = \sqrt{d\left(V_S/R_L\right)^2} = \sqrt{d}\left(V_S/R_L\right) \quad (5)$$

Power delivered to the LED load

$$P_{LED} = I_{ORMS} * V_{ORMS} = \sqrt{d}\left(V_S/R_L\right) * \sqrt{d}V_S = d\left(V_S^2/R_L\right)$$

Hence,

$$P_{LED} = kd \quad (6)$$

Therefore the expected light output is linearly proportional to the pulse duration of the PWM signal. Where constant k ,$\left(V_S^2/R_L\right)$ is constant as long as the dc source V_S is maintained constant.

3. DESIGN EXAMPLE

To verify the above theoretical predictions, a boost type DC-DC switching converter has been designed to demonstrate the proposed system. The output current of boost power stage is continuous or non-pulsating; hence boost topology is a viable option for constant current control in battery operated systems. The proposed converter is designed with the design specifications presented in [14] as shown below in Table 1.

Table 1. Specifications of Proposed Converter

Nominal input voltage *Vin (DC)*	12
Output voltage *Vo (DC)*	24
Switching Frequency *(kHz)*	50
Topology	Boost
Isolated/Non-Isolated	Non-Isolated

To achieve dimming, PWM scheme is adopted in which the LED load current is precisely controlled to a specific current level for cetain time, and zero current level for rest of the time in a low frequency on-off cycle which is 50kHz in this case.Therefore, the duty cycle of the dimming signal controls the average LED current and provides dimming.

For the LED load, we have assumed a high power LED automotive headlamp array with 8 LUXEON Rebel ES LEDs. As the drive voltage of an LED array is the sum of the forward voltages of all the LEDs present in it [1] therefore, in this case: $V_{F_{Total}} = 8\times3 = 24V$ (As typical $V_F = 3V$ for LUXEON Rebel ES LEDs @ 700mA) [15].Considering the automotive power system the nominal input voltage is 12V. Based on the above design parameters, Matlab/Simulink model is developed to simulate the dc dc boost converter's performance for both uncompensated and compensated conditions as shown in Figure 4.

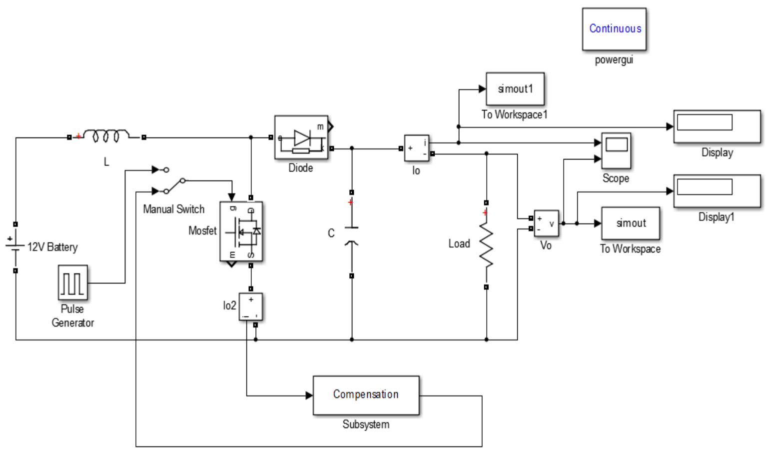

Figure 4. Matlab/Simulink model

4. RESULTS AND ANALYSIS

MATLAB Simulink environment has been used to demonstrate the system's performance within the desired parameters. The simulated responses of load current and output voltage for both uncompensated and compensated system are presented in Figure 5 and Figure 6 respectively.

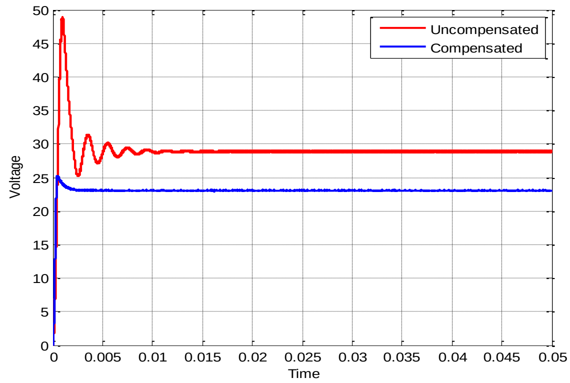

Figure 5. Output voltage

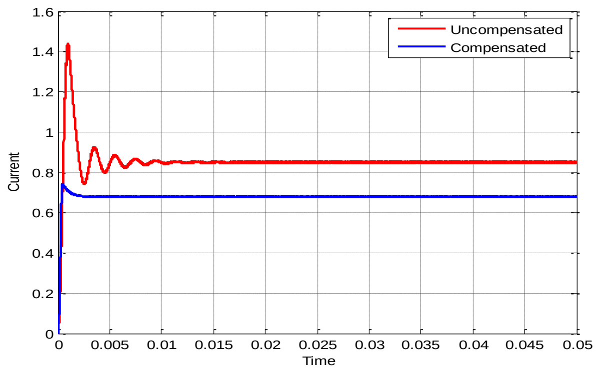

Figure 6. Output Current

The above responses show that the designed system is working well within the desired parameters for both uncompensated and compensated conditions. Furthermore we checked the PWM dimming control and its effect on output current for different duty cycle scenarios i.e for 25%, 50% and 75% as shown in Figures 8, 9 and 10 respectively. It can be seen easily the change in duty cycle gives different levels of output current hence providing different levels of brightness.

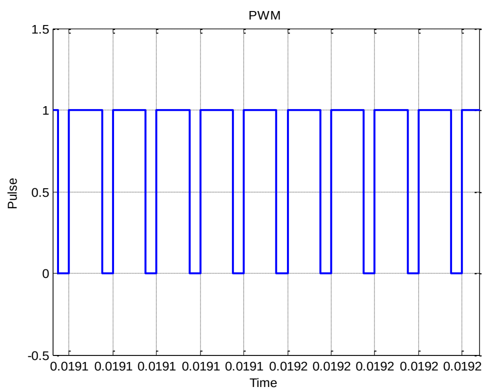

Figure 7. PWM signal

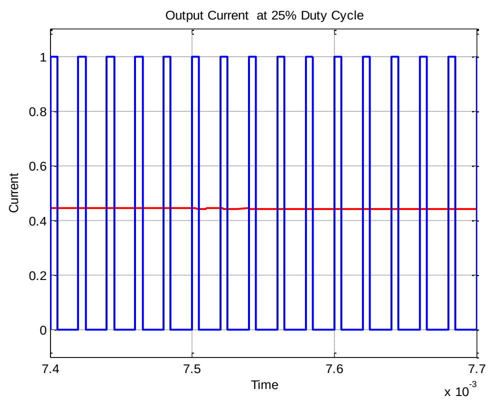

Figure 8. Output current at 25% of duty cycle

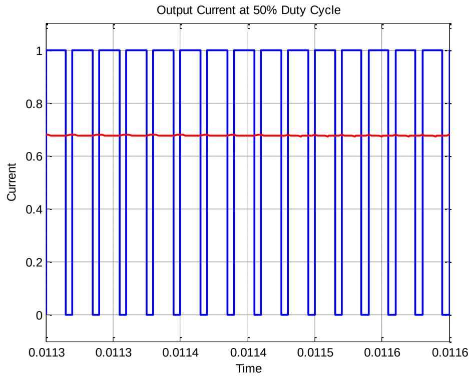

Figure 9. Output current at 50% of duty cycle

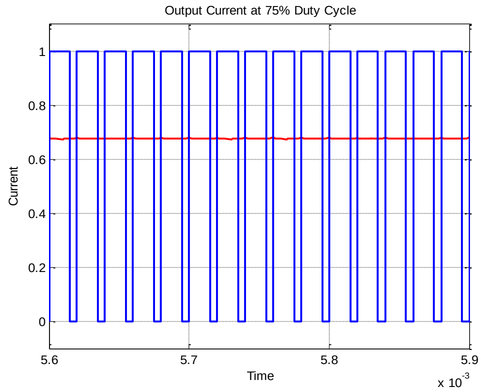

Figure 10. Output current at 75% of duty cycle

5. CONCLUSION AND FUTURE WORK

PWM technique has been adopted for luminous and current control of a high brightness LED based automotive lamp. A design example for DC-DC Boost converter is presented to obtain the required performance for the above mentioned application. MATLAB/Simulink simulation package has been used to verify the theoretical predictions. The results show that the proposed system works well for both uncompensated and compensated modes of operation. Physical implementation of this proposed control scheme can be realised by using digital power management technique with the help of appropriate microcontrollers and digital sensors and will be discussed in future work.

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BIOGRAPHIES OF AUTHORS

Muhammad Wasif Umar received his B.Sc in Electronics Engineering from Bahauddin Zakariya University, Multan, Pakistan in 2009. In 2011, he received his M.Sc in Control and Electronics from Teesside University, Middlesbrough, UK. From 2011 to 2013 he worked with different organizations in UK. He is currently working towards the PhD degree at Universiti Teknologi PETRONAS, Malaysia. His main research interests include DC-DC converters, switch-mode power supplies and their control techniques, high-brightness LED drivers and rapid control prototyping.

Nor Zaihar Yahaya was born in Lumut, Malaysia. He received his B.Sc degree in Electrical Engineering from University of Missouri-Kansas City, USA in 1996. After that he served 5 years in the industry in Malaysia. In 2002, he was awarded M.Sc in Microelectronics from the University of Newcastle Upon Tyne, UK. In 2011, he received Ph.D from Universiti Teknologi PETRONAS, Malaysia. His main teaching/research areas are the study of Solid State Electronics, Microelectronics & Devices, Power Electronics & Drives. He has published more than 70 papers in proceedings, journals and book chapter with several Patent and Copyright. Currently, he is actively working on projects related to power electronics/ renewable energy and for oil & gas/PETRONAS.

Zuhairi Baharudin is a faculty member in Electrical and Electronics Engineering Department at Universiti Teknologi PETRONAS, Malaysia. In 2010 he received his PhD degree from Universiti Teknologi PETRONAS. Currently he served as Associate Professor in the department. He had published many papers in the area of power systems and communications technology. His research interest includes forecasting, empirical modeling, renewable energy, artificial intelligence applications and communications technology.