DESIGN OF AN ELECTRONIC DRIVER FOR LEDS

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***Abstract* – This paper presents the design of a buck converter driving two Luxeon III Emitter LXHL-PW09 3W LEDs. A DALI protocol interface is also implemented to provide user interaction in dimming control. The aspects of PWM driving and the dependence of color and luminous flux with the junction temperature are also discussed. Laboratory results obtained with the proposed driver are presented covering the topics developed trough the paper.**

***Keywords* – LED driver, PWM, junction temperature, buck converter, DALI protocol.**

I. INTRODUCTION

In the past few years there has been an increased penetration of Solid State Lighting (SSL) into the lighting market, which is mainly based on the enhanced efficiency, energy savings and flexibility associated to this technology. Nowadays, SSL has been used in some niche applications as signaling, signage, traffic lights, automotive and architectural implementations. Some authors estimates that in a short future SSL will replace standard lamps used in general illumination.

The extended lifetime inherent to the Light Emitting Diode (LED) qualifies SSL to compete with other technologies in the market. However, there is a hurdle to overcome in order to make a coherent definition of this property for LEDs. In traditional lighting technologies the lifetime of a lamp is measured based on the expected time to failure of the light bulb. This procedure can not be applied for the LEDs lifetime characterization since there is a notable reduction in the output flux before the device fails. Instead, it is necessary to propose a method that quantifies the lifetime of SSL devices in a way that allows the consumer to make a clear comparison of this property among the innumerous available technologies. Some technical standards are currently being developed by IESNA to address this concern, e.g. IESNA LM18 regarding luminous depreciation and IESNA LM79 that deals with optical and electrical properties of the LEDs. In regard to security, SSL has the advantage of being operated at low voltage levels, when compared to other technologies. The electrical shock hazard is reduced when the driver is isolated from the electrical grid, which in the present study is obtained with the use of the electronic transformer, and also because there is no need of filament or gas tubes.

Another benefit associated to SSL is concerning environmental issues. It is well known that illumination represents a large amount of worldwide energy consumption, and that coal and petroleum burning is among the main sources of electrical energy. Thus, carbon emission would be reduced as SSL becomes widely adopted for general illumination. However, for a wide acceptance of SSL in applications where a stable white light is required, many challenges on driving techniques and color control have to be met. It is known that the chromaticity coordinates that characterizes the color emitted by a Light Emitting Diode (LED) are strongly dependent on its junction temperature. The ANSI C78.377A technical standard deals with the acceptable shifts in the chromaticity coordinates. Thus, a control regarding to this dependence or a method that stabilizes this temperature are a vital concern that has to be addressed.

Another issue to be considered is in regard to the junction temperature measurement. Since it is not practical acquiring this temperature directly, several procedures have been proposed as an effort to estimate it based on indirect measurements [1], [2] and [3].

In this paper a design of a structure to drive two Luxeon III Emitter LXHL-PW09 3W LEDs is presented, suitable for architectonic applications. These applications require chromaticity coordinates stabilization, even when employing dimming control. A picture of the LED used is shown in Fig. 1. A commercial electronic transformer is used to feed the driver from a 127V grid. To supply a DC voltage to the driver circuit a rectifier bridge and a smoothing capacitor are connected to the output of the transformer.

The main goal of this study is to propose a low-cost driver that is able to feed the LEDs from a 127V electrical grid. As an option, a Digital Addressable Lighting Interface (DALI) based control interface is presented in order to allow the user to adjust the dimming level of the LEDs.

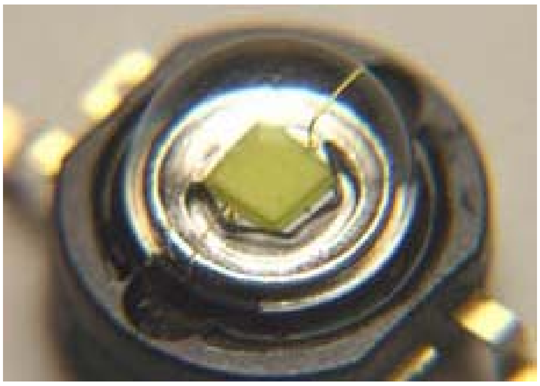

Fig. 1 - Detailed picture from a white LED Luxeon III Emitter LXHL-PW09.

II. INFLUENCE OF JUNCTION TEMPERATURE

During the SSL technology evolution many studies were made in order to investigate the influence of LEDs junction temperature in the emitted light characteristics. Their conclusions agree that the output flux and color are strongly dependent on this property. In general, the output flux is reduced as junction temperature increases, as shown in Fig. 2 [4].

The type of LED being considered also has influence on this analysis. Regarding the characteristics of the color emitted by the LED, there is a shift in the wavelength of the peak emission in the spectral power distribution (SPD), which leads to a shift in the chromaticity coordinates. Thus, an instable color point is achieved.

It became evident that the junction temperature has to be considered in a control scheme designed to stabilize the output flux and color. However, the measurement of this temperature is not trivial, since it is not practical to do this directly. Therefore, this measurement has to be taken indirectly, based on other LEDs characteristics.

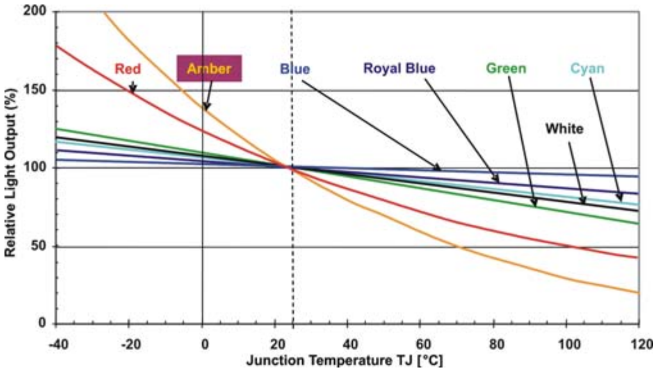

Fig. 2 - Relative output flux in function of junction temperature [4].

There are some references that describe methods to estimate this temperature. Some of them are based on spectral acquisition, which is not a good solution for most commercial products due to complexity and costs factors. It is also possible to estimate the temperature through forward voltage measurements [1].

In this paper no measurements are going to be taken in order to estimate the LEDs junction temperature. Instead, a method that allows dimming the LEDs and, at the same time, results in a reduced shift in the white color point and a stable output flux will be used. Details on this method are provided in section III.

III. PWM DRIVING METHOD

There are several methods to drive LEDs and control the output flux generated. It is possible to feed a LED with a DC current, where the output flux is proportional to its intensity, known as amplitude modulation (AM). An inconvenient of this approach is that the white color emitted by the LED is not stable, i.e. the chromaticity coordinates are shifted as the LED's forward current is varied [5]. Fig. 3 shows SPD change for PC (Phosphor Converters) white LEDs.

One way to reduce this color shift is to use PWM on LED driving. The LED is fed with pulsed low frequency constant amplitude current, in this way, when the LED is turned on its instantaneous forward current is always the same and its color point then kept constant. The lower boundary of this PWM frequency is given by the sensitivity of the human eye, values higher than 100Hz are normally tolerated with no perception of light flickering.

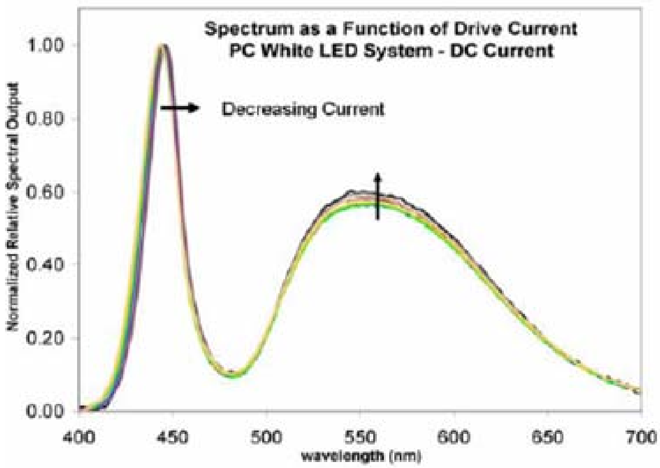

Fig. 3 – Influence of LED forward current in its SPD when dimmed by AM [5].

The direct consequence of employing PWM driving is that there is a reduced influence in the emitted light coordinates by the value of the forward current and the temperature effects on the luminous flux can now be compensated by adjusting the low-frequency PWM duty-cycle.

Fig. 4 presents a comparison between AM and PWM methods for dimming control, when employing RGB or PC white LEDs in the system. This figure shows the chromaticity point for a given PWM driving method and for a current level range of 10.5mA to 350mA. It is important to notice that the color shift due current level changes is reduced when PWM method is used [5].

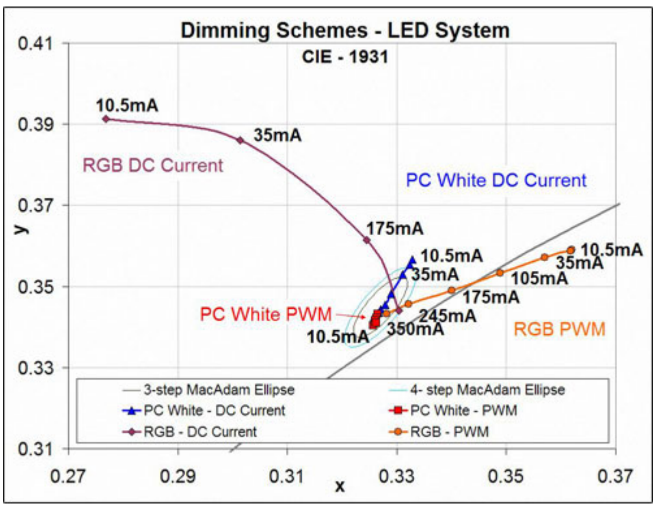

Fig. 4 – Chromaticity coordinates of the light emitted by RGB and PC white LEDs, considering both AM and PWM dimming methods.

In this work a buck converter is used to drive the LEDs, and the implementation of the PWM method discussed before is DALI-based. The driver circuit is detailed in section IV and a brief description of the DALI communication protocol is given in section V.

The desired waveform of the current in the LEDs array is shown in Fig. 5. The LEDs brightness may be controlled through the variation of the duty cycle D, since its average current is proportional to this parameter.

Another care that has to be taken is with the current slope in the LED. Whereas the driver proposed in this paper consists in a buck topology there is a limit for the derivative of the current in the inductor. Consequently, the time necessary for the current in the LED to reach the value I_p has to be considered when choosing the PWM operating frequency.

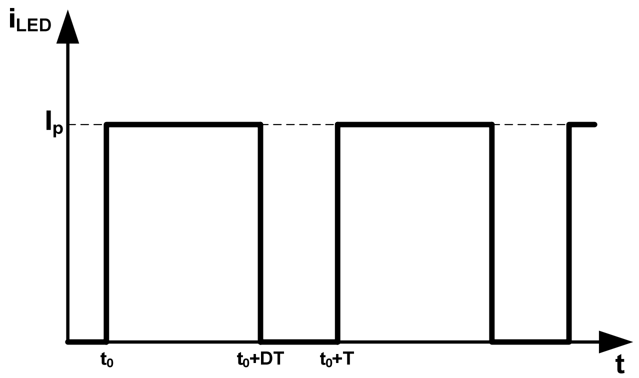

Fig. 5 - Desired current in the LED array.

Where:

T - PWM signal period.
D - PWM signal duty cycle.
I_p - Driving current when the LEDs are turned on.

IV. DRIVER CIRCUIT

DC-DC switching converters are a good choice for driver applications due its improved efficiency [6]. Moreover, this subject was broadly discussed in literature, there being many references describing DC-DC switching converters and their characteristics. In this paper, as previously mentioned, the driver circuit consists in a buck converter as shown in Fig. 6.

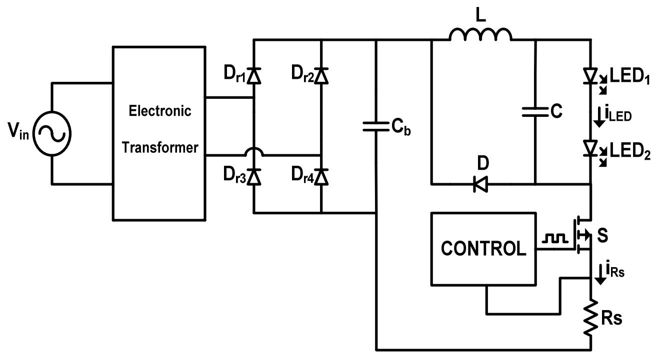

Fig. 6 - Driver structure.

A. Circuit Detailing

The inductance L is determined dealing with the trade-off between current slope and current ripple. As L value increases, the ripple in the current that flows through the inductor is reduced but, in counterpart, the derivative of this current becomes more limited. The same statement can be made in regard of choosing the capacitance C.

The sensing of i_{LED} is made through a resistor in series with the LED array. Any inductance present in this resistor will induce voltage peaks on the switch. Thus, a low inductance carbon resistor is chosen for this task. In addition, its resistance must be as low as possible, so low ohmic losses can be achieved.

With regard to the choice of the diodes for the bridge rectifier an extra care has to be taken, since there is a high frequency component in the output voltage of the electronic transformer. This fact leads to the necessity to choose fast rectifier diodes. The capacitance value of the bus capacitor C_b must be large enough to keep the voltage at the bus higher than 8.5V. In an undervoltage situation the IC shuts down by *under-voltage lockout* (UVLO) protection.

B. Current Control

Generally, the control of DC-DC converters is designed in view of output voltage stabilization, which derives from the nature of their usual applications. For LEDs, since the output flux is proportional to its forward current, the requirements change. This current has to be sensed and used as input of the control structure.

The control of the converter used in this paper is based on the integrated circuit (IC) UC3843. The IC operates in the current mode, in order to impose the current in the LEDs. The switching frequency is constant as described in the controller's datasheet [7], and its value is 180 kHz. The current in the LEDs is adjusted by its peak limitation, therefore only a small ripple is allowed in order to its average value to be correctly imposed by the control. The theorical current in the sensing resistor R_s and the command signal generated by the controller are shown in Fig. 7.

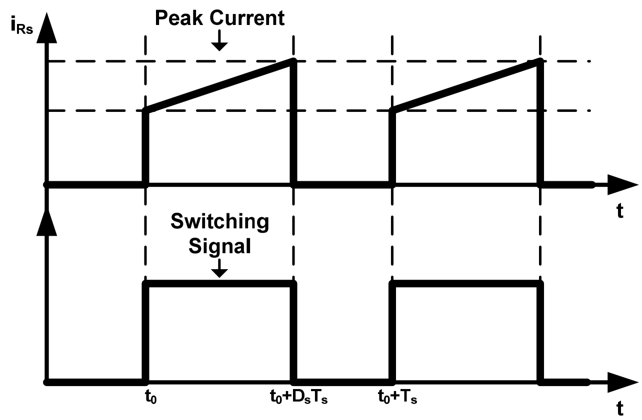

Fig. 7 - Current in the sensing resistor and switching signal.

Where:

T_s - Switching signal period.
D_s - Switching signal duty cycle.

V. THE DALI PROTOCOL

In the search for the systems with larger flexibility and functionality new tools and concepts are spread, among them the denominated *"intelligent management of the illumination"*. In this context, the DALI*(Digital Addressable Lighting Interface)* technology stands out as a data protocol and transport mechanism that was developed and specified by several manufacturers of lighting equipment [8]. The DALI protocol has been described in the fluorescent lamp ballast standard IEC 60929 under Annex E.

A typical DALI system consists of a master controller and their slaves. The master controller transmits instructions containing an address and a command for all the slaves through the electric interface. The slave units receive the instruction and the software determines if they can execute it. A master controller can contain up to 64 connected slave units, each one with an individual address (*Short Address*).

A. Communication Specification

The format of the communication is based on the code Manchester (*bi-phase*), where the bits are represented by the phases of transitions (usually the representation in terms of the level of the pulses is considered). The protocol uses asynchronous serial communication, half-duplex. The baud rate is of approximately 1.2 kHz, with period of 833.33 µs ± 10% for each bit.

The instruction (*forward frame*) of the master controller for the slave units is constituted of 19 codified bits: 1 start bit, 1 address byte, 1 data byte. The package of instructions finishes with 2 stop bits. The answer of the slave unit for the master controller (*backward frame*) is constituted of 11 bits bi-phases: 1 start bit, 1 data byte. The package of instructions finishes with 2 stop bits. The stop bit does not contain phase transition. Fig. 8 shows the format of the communication in the DALI protocol.

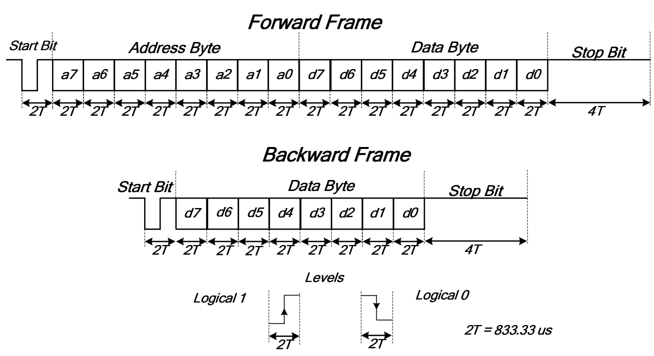

Fig. 8 - Format of Communication in the Protocol DALI.

B. Electrical Specification

The DALI communication is serial and it uses two wires for communicating in both directions. The voltage difference between the wires indicates if it is a high or low level. A voltage difference above 9.5 V (the upper limit is 22.5V) is a high level and a voltage difference less than 6.5 V (the lower limit is -6.5V) is a low level. The master unit communicates with the slave units by setting the level high or low according to DALI protocol. When no communication takes place the master unit keeps the level high. The slave unit responds to the master unit by setting the level high or low. A high level is simply achieved by not interfering with the high level set by the master unit. A low level is obtained by forcing a short circuit across the wires. This is possible, since the DALI standard states that the current supply for the DALI communication has to be limited to 250mA [8].

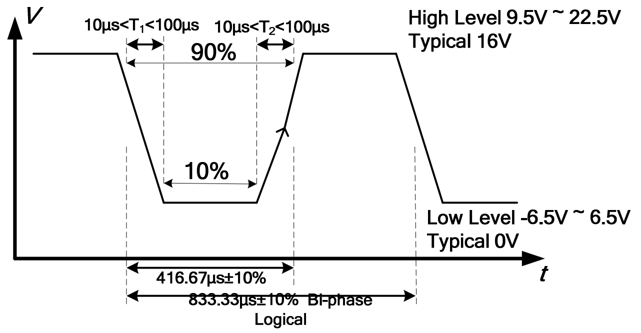

Fig. 9 - DALI electrical logical level.

Fig. 9 shows the times involved in the transitions with their respective tolerances and the voltage levels recommended by the norm.

C. The Implementation of the Hardware

The proposed system is presented in Fig. 10. It is important to remark that there are micro-controllers of 8-bits in the slave unit structure and in the master controller structure. As a consequence, it is necessary an electric interface to isolate and to adapt the voltage levels of the component at the levels of voltage of the bus stipulated by the norm.

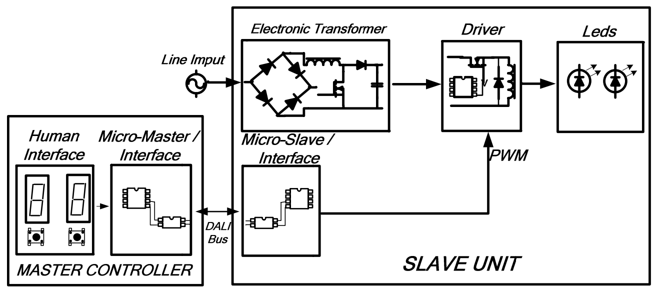

Fig. 10 - Hardware Implemented.

The data package containing an address and a command from the master controller is processed by the slave unit. If the correspondent address coincides with the address of the slave unit it will act in PWM, altering the illumination level.

VI. EXPERIMENTAL RESULTS

The driver proposed was mounted experimentally. Some acquisitions were made and the main waveforms are presented next.

Fig. 11 shows the current in the LEDs array. The system is operating at a dimming level of 40%. The PWM control frequency supplied by the DALI controller is 250Hz.

The detail of the current slope in the LEDs array is shown in Fig. 12. It is possible to verify that the waveform is close to a square wave. Thus, the inductance chosen is an acceptable value in regard to this condition. In order to complete the validation of this value, a ripple analysis in the inductor current is necessary. The detail of the current ripple in the inductor is shown in Fig. 13, where a ripple of about 4% is observed, which is completely acceptable for the purposes of this work.

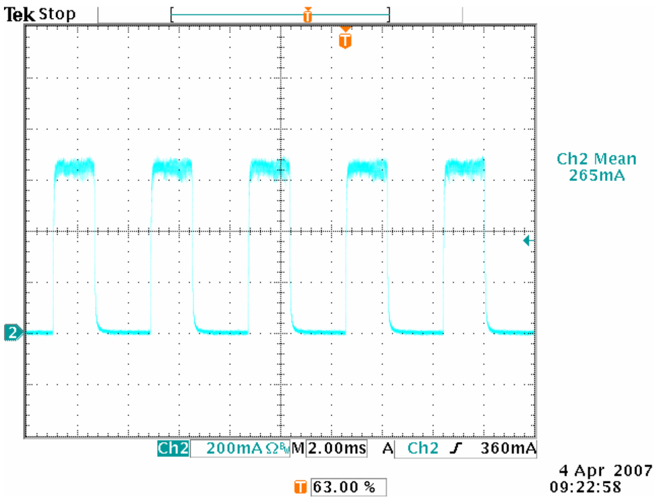

Fig. 11 - Current in the LEDs array.

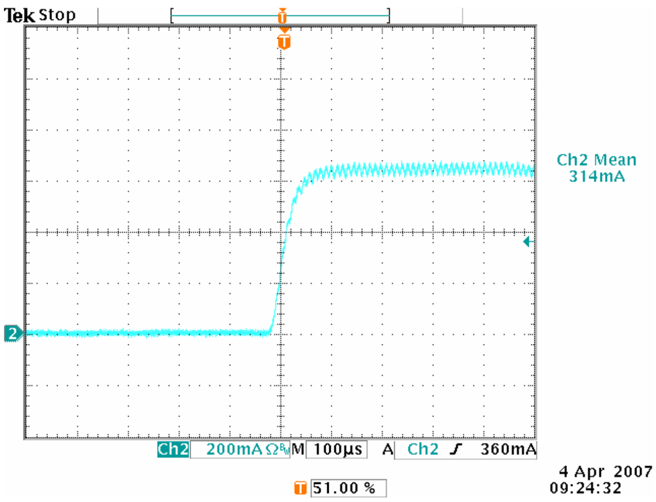

Fig. 12 - Slope detail in the inductor current.

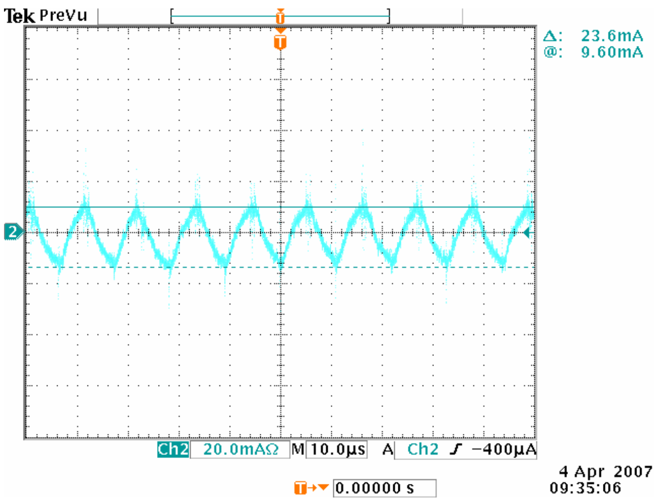

Fig. 13 - Current ripple in the inductor.

VII. CONCLUSIONS

In this paper a DC-DC buck converter was analyzed operating as a LED driver. The influences of the LEDs junction temperature in emitted light characteristics were discussed and some considerations made in order to reduce the fluctuations in output flux and to achieve a more stable color. A DALI interface was also designed to provide a user interactive dimming control to the system. The driver was mounted experimentally, validating the theoretical analysis made.

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