Advancing Towards Digital Control for Low Cost High Power LED Drivers

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***Abstract*— This paper describes a complete design and implementation of a low cost digital controller for a High Power LED driver. The main advantages of High Efficiency LEDs are their good luminosity, efficiency and long life. Due to these improved behaviour, the number of LED-based applications is increasing. Nowadays, the cost of digital processors is continuously decreasing, and the trend is that still lower costs will be achieved in the future. In addition, digital processors offer extra features, e.g. communication protocols, software protections, and so on. Therefore, this study has an increasing practical interest.**

Design guidelines for a LED based light supply with digital control are proposed. A prototype has been built and tested, and results are shown to validate the design approach.

I. Introduction

Initially, LEDs were used in signalizing applications, mainly as voltage indicators in electronic devices like TV, video, electronic targets, and so on.

Next, a new generation of High Efficient LEDs, known as Power LEDs, is changing the world of lighting systems. In most cases, Power LEDs could replace incandescent, halogens and fluorescent lamps. Main characteristics of Power LEDs are:

- Luminous efficiency. Last generation of Power LEDs have a luminous efficiency around 45 lm/W, with better performances than incandescent lamps (10 lm/W) or halogen lamps (20 lm/W). Luminous efficiency in Power LEDs has been triplicated in the last 2 years.
- Power LEDs operating life is longer than other types of light sources. The manufacturer guarantees a 30% light depreciation of emitted light after 100.000 hours [1],[2],[5],[6].
- Another advantage is the broad temperature operation range (-40 °C to 120 °C) and the low on-off times, around 100 ns.
- Finally, as it is well known, the use of LEDs is a good choice in lighting applications, because they do not need complex power topologies for working (unlike discharge lamps).

The costs of digital devices are continuously decreasing, thus allowing the practical use of Digital Signal Processors (DSPs) in lighting applications.

A prototype of a High Efficiency LED electronic driver has been built and tested. The prototype has been controlled by means of a DSPIC microcontroller. The advantages of digital control versus analogue control are widely known in the technical literature. Some advantages are the capacity of adding communication capability without extra circuitry and also the capability of control scheme re-design by means of software re-programming. In addition, digital calculations are very accurate because they don't have any direct physical magnitude dependencies (e.g. temperature). The main drawback of digital control is the discrete resolution of the Digital PWM. Therefore, a limit cycle could appear, and stability is not guaranteed. In order to avoid limit cycle conditions, some requirements must be fulfilled.

II. *Features of Power LEDs for the Prototype*

Altough the built prototype has been designed for a commercial LED, the obtained conclusions of this work are applicable to any kind of Power LEDs, because of the similar behaviour of these devices as power load.

The LEDs used in this work are type LXHL-PW01 from LUMILEDS. This diode is based in a blue LED (InGaN) chip, covered with a phosphor that absorbs some of the blue light and fluoresces with a broad spectral output, ranging from mid-green to mid-red (see Fig. 1). This diode is a 1W LED with a nominal voltage of 3.42 V at a nominal current of 350 mA. The luminous flux in this point is around 30 Lm (minimum value, with a maximum value of 45 Lm).

V_d – 3.42V $\quad$ Id_{AVG}– 350mA $\quad$ Id_{max}– 500mA

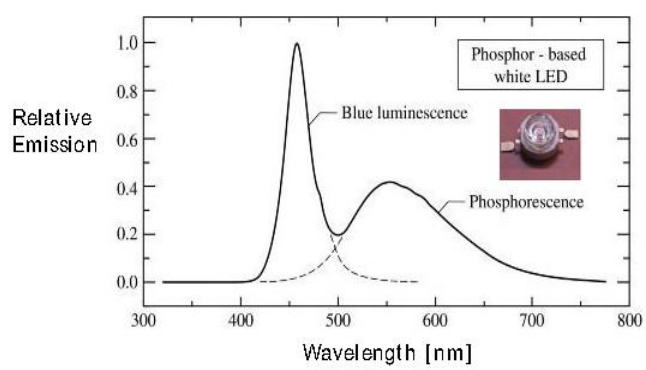

Fig. 1. Spectrum diagrams of white LED diodes

In this kind of LEDs, the thermal design is very important in order to ensure a good behaviour and low luminosity deprecation. The operating life of these LEDs is drastically reduced if they operate at high temperatures. This is the main problem in the design procedure of Power LED-based lighting sources.

The thermal design is not detailed in this paper, but accurate thermal design is exposed in references [5],[6]. The prototype has been designed to assure an operating temperature bellow 70 ºC.

III. Proposed Topology Basic Operation and Design

The power topology depends on the number of LEDs connected in series, and also on the input voltage. Usually, the ON voltage is high (around 3 V for white LEDs), therefore a topology that rises the voltage is appropriate (Boost, Buck-Boost, Forward, Flyback, and so on).

For this prototype galvanic isolation is not required, so the topology used is the boost converter. Fig. 2 shows this power topology. The boost is designed to operate in Continuous Conduction Mode (CCM).

Next, the design procedure of the power stage will be explained

A. *Design Procedure:*

- Step 1: The duty cycle (D) is determined from the input and output voltages. The microprocessor works with an internal oscillator of 64 MHz. With this clock, a switching frequency of 50 KHz could be achieved.

- Step 2: The magnetic devices are designed for operating in CCM, through all the power range. The capacitor is chosen to attain a low voltage ripple.

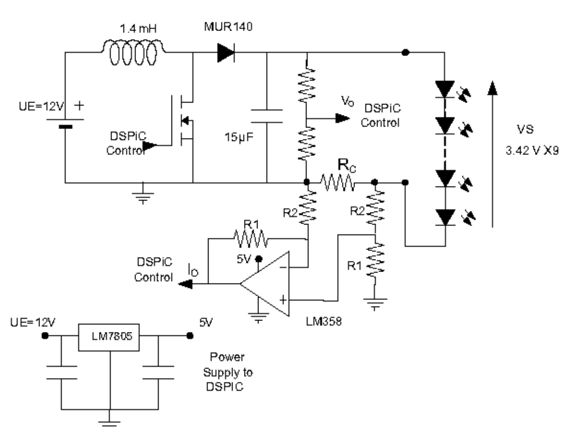

Fig. 2. Power Stage of LED diodes and DSPIC inputs

The inductor fulfils equation (1):

$$L \geq \frac{U_E D(1-D)}{2I_{D\min}} T \tag{1}$$

U_E is the input voltage, D is the duty cycle, T the switching period, I_{Dmin} is the minimum current diode and L is the inductance.

The voltage ripple is determined by the output capacitor, as detailed in eq. (2):

$$C = \frac{\Delta Q}{\Delta U_C} = \frac{I_{D\max} DT}{\Delta U_C} \tag{2}$$

I_{Dmax} is the maximum current through the load, and ΔU_C, is the voltage ripple through the load.

Magnetic designing of the inductor has been calculated using the program UM2T. An E12.6 magnetic core has been used.

- Step 3: For the appropriate selection of semiconductor we must consider the following:

  -A low threshold voltage transistor as IRFD024 is needed for controlling the MOSFET directly from the microcontroller. The power diode is a MUR140.

- Step 4: Designing the current control implies sensing the current through the load. For sensing the current a differential amplifier (LM358) has been chosen.

B. *Design Example:*

As a practical application, a nautical lamp has been designed. This ballast has 9 white power LEDs, which their featured had been mentioned before.

The nominal input voltage is 12 V. Thus, the duty cycle is obtained knowing the input and output voltage. As the output voltage depends on the power LEDs ON-voltage (3.42 V for white LUXEON LEDS with nominal current), thus U_S=3.42 x 9 = 30.79 V

This output voltage fixes the duty cycle. With this parameter the inductor and capacitor are chosen using (3).

$$U_S = U_E \frac{1}{1-D} \tag{3}$$

D = 0.61

The inductor for a current inductor ripple of 300 mA and a switching frequency of 50 KHz is (4):

$$L = \frac{U_E}{\Delta I_L} DT \tag{4}$$

L= 0.48mH

The current ripple through the load is filtered by a 15µF capacitor (C = 15µF).

Fig. 3 shows the nautical lamp with power LEDs. The PCB assembly plus the welding, work as a heatsink.

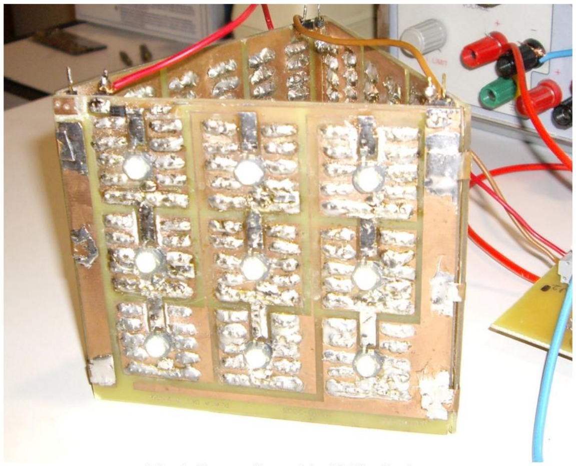

Fig 3. Lamp Based in LED diodes

IV. DIGITAL REGULATOR DESIGN

The microprocessor for the prototype is a low cost DSPIC 30F3010 from Microchip. The control scheme is a PI regulator, programmed with fixed point arithmetic (Q15 format). The system block diagram is shown in Fig. 4.

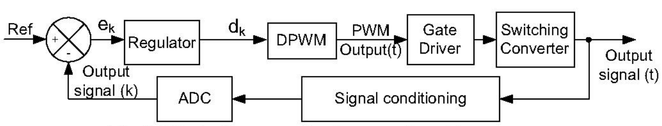

Fig 4. Block diagram of a discrete closed loop system

It is usual to design the sample frequency on ten times of the plant cut off frequency.

In the prototype, the cut-off frequency is obtained from the small averaged model around the nominal power operation point. The cut-off frequency is about 200 Hz, and it is shown in Fig 5. Therefore, a sample period of 250 μs is chosen.

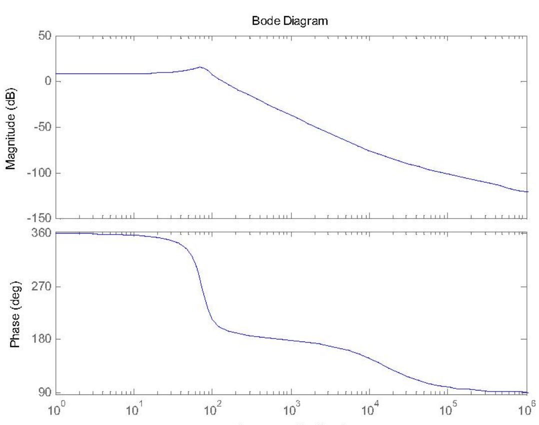

Fig 5. Bode plot of the small averaged model around the maximal power point

Proportional and integral constants are tuned using Ziegler-Nichols design criterion. In this application, simulation tools are used to choose optimal K_p and K_i.

Another typical problem of digital control is the limit cycle. To successfully avoid the limit cycle oscillation, the variation of the output voltage caused by one LSB change in the duty radio, has to be smaller than the analog equivalent of the LSB of the A/D converter. This topic is treated in reference [3].

This condition, for a boost converter topology is shown in (5):

$$n_{DPWM} \geq \text{int}\left[\log_2\left(\frac{1}{1-D}\left(\frac{V_{ref}}{V_{\max_{A/D}}}2^{n_{A/D}}+1\right)\right)\right] \quad (5)$$

In this application, the duty ratio is equal to 0.6 (60 %); $n_{A/D}$ equals 10 bits; $V_{maxA/D}$ is 5V; and $V_{ref}=A_d \cdot I_n$. In this last term, A_d is the differential gain (4.7), and I_n is the nominal current through the LEDs, hence $V_{ref}=0.25 \cdot 4.7=1.175V$. Thus, the number of PWM bits has to be equal or greater than 10 bits.

The worst case occurs when the maximum power operating point is reached. In that case, with a duty of 0.8 (80%), 10 bits are required for the DPWM.

The DSPIC30F3010 allows a DPWM resolution of 10 bits for a switching frequency of 50 Khz. Therefore, the minimal PWM resolution is fulfilled with this microcontroller.

V. EXPERIMENTAL RESULTS:

A prototype has been built in the laboratory, and the following results are obtained:

- The current regulation range is from 5 mA to 350 mA.
- The regulation range is shown in Fig. 6.
- The control loop stabilizes the ballast, and dimming is always possible with discrete current step of 5 mA.
- Experimental results have been satisfactory.
- The overall efficiency measured in the prototype reaches the 90%. Measurements are taken to validate the heating sink. Table I contains the measurement results.

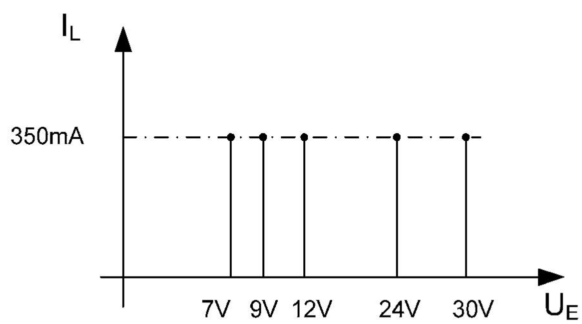

Fig 6. Regulation range Output current as a function of input voltage

The duty cycle variation is shown in Fig. 7. The range of variation is between 10% and 80%, as it could be shown

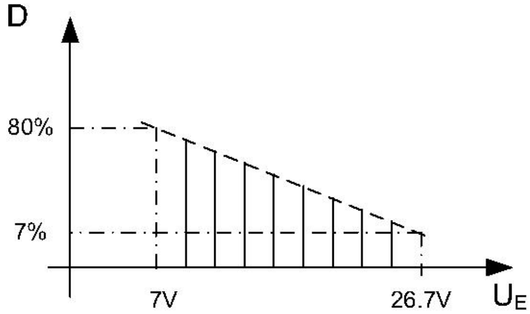

Fig. 7. Duty cycle as a function of output voltage for a nominal voltage

Fig. 8. shows the input voltage and duty cycle for an input voltage of 7V, and a nominal current of 250 mA.

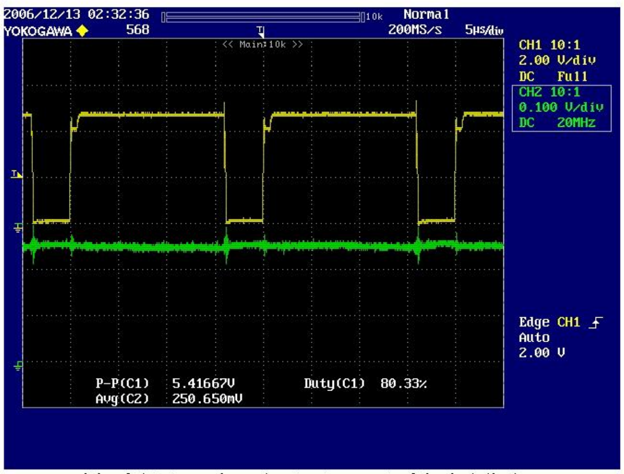

Fig. 8. Duty cycle and output current of the led diodes.

Current Id(mA)	Luminosity flux (Lm)	Heatsink temperature (C°)	Led temperature
5 mA	8 Lm	20°C	20°C
250 mA	155 Lm	45°C	55°C
350 mA	194 Lm	54°C	65°C

Table I: luminosity and temperature measurements (ambient temp. of 20°C)

VI. Conclusion and Future work

A High Power LED driver, with digital control, has been developed, designed, built and tested. Experimental results have been shown and they are very satisfactory.

The prototype allows the current regulation through the LEDs, with current steps of 1 mA if it is necessary.

Extra-features, as protocol communications, is direct from this applications. Also, dimming applications could easy have remote control with low cost hardware.

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