Design and Implementation of High Power LED Driver for Industrial Lighting

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ABSTRACT

One traditional low cost way of driving LED in electrical application uses a resistor in series with the LED device. Although this driving scheme is simple and inexpensive, it suffers from several disadvantages. The LED current can vary substantially over the battery voltage range even in normal operation of the device, thus affecting the brightness and reducing the service life of the lighting device. These problems are typically resolved by using constant – current linear requlators.Besides driving the LED at set current, these regulators can inherently protect from a reverse polarity application and block voltage transients up to tens of volts. Linear current regulators do not require input EMI filters and can yield inexpensive driver solutions. However, both the resistor and the linear regulators exhibit low efficiency. They may become impractical for driving high power LED loads due to the excessive heat dissipation. Therefore, switching power converters are needed for driving many signal and lighting LED devices. Hence high power LED driver is designed using IC LM3404 to achieve high efficiency with constant current and constant voltage output.

Keywords-LED driver,Buck-Boost converter,PWM dimming, Linear regulator

I. INTRODUCTION

The Design of power LED driver using IC LM3404 and buck-boost converter are used. The reason to design such a driver is to provide an efficient solution to the old method using a resistor in series to limit the current through the power LED because by using this method LED driver will have low efficiency at the typical power levels required for it to operate. But by using the LED driver, the input voltage can be adjusted to the correct level of voltage and supply the desired current for LED and also with this driver it will provide a more efficient solution for driving a high power LED and increase the efficiency of the power levels required for the LED to operate.

Typically boost converter is used in much electrical application for driving long strings of LED such as in instrument panel backlights and other lighting devices that require series connection of multiple LED. A typical boost converter can drive strings of LED having forward voltage in excess of 100 V. However, recent advances in the high-brightness LED technology have substantially increased the power ratings of a single LED package. LED current of 350mA, 700mA or even 1A are typical. Therefore, the number of series-connected LED in the string used in any lighting devices has become smaller. Despite its simplicity, the boost converter is suffering from a serious drawback in many of the electrical application systems where the supply line voltage can easily exceed the forward voltage of the LED string. Boost-buck converters can offer a solution for most of the higher-power lighting applications, including both exterior and interior lighting.

II. METHODOLOGY

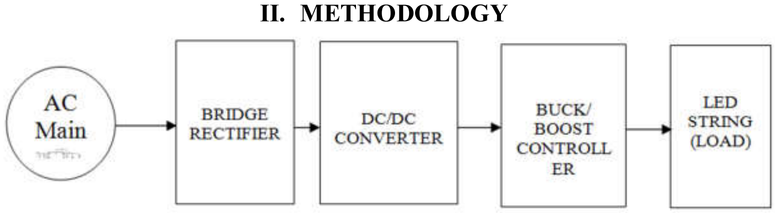

Figure 1: Block diagram of LED driver

Figure 1 shows the block diagram of LED driver. The idea of this paper is to present a design of system, that provides a more efficient solution for driving a high power LED by controlling the power LED current and the total amount of power feeding into the power LED by using IC LM3404. This system is designed to provide a more efficient solution for driving a high power LED and increase the efficiency of the power levels required for the power LED to operate.IC LM3404 is used to control the level of voltage so it can produce the desired power LED's current. It is controlled by setting the duty cycle of the PWM signal generated in the IC LM3404 at the average amount of time so that the power LED is energized. The PWM frequency is chosen high enough so that the power LED current is turned on and off at a rate that will not cause the human eye to detect flickering. Through this, the efficiency of the power levels required for the power LED to operate is increased.

A.HARDWARE DESCRIPTION

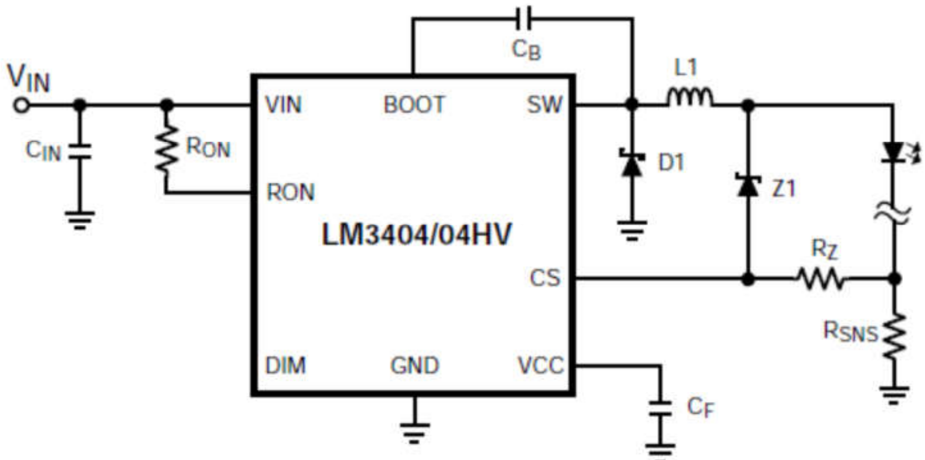

Figure 2: Circuit diagram of High power LED driver

Figure 2 shows the circuit diagram of LED driver. The LM3404 and LM3404HV devices are buck regulators with a wide input voltage range, low voltage reference, and a fast output enable and disable function. These features combine to make these devices ideal for use as a constant current source for LEDs with forward currents as high as 1.2 A. The controlled on-time (COT) architecture is a combination of hysteretic mode control and a one-shot on-timer that varies inversely with input voltage. Hysteretic operation eliminates the need for small-signal control loop compensation. When the converter runs in continuous conduction mode (CCM) the controlled on-time maintains a constant switching frequency over the range of input voltage. Fast transient response, PWM dimming, a low power shutdown mode, and simple output overvoltage protection round out the functions of the LM3404/ LM3404HV devices.

B.DESIGN REQUIREMENTS

Input voltage: 24 V ±10%

LED forward voltage: 7.1 V

LED current: 700 mA

Switching frequency: 400 kHz

C.DESIGN PROCEDURE

R_{ON} and t_{ON}: A moderate switching frequency is needed in this application to balance the requirements of magnetics size and efficiency. R_{ON} is selected from the equation for switching frequency as shown in equations.

$$R_{ON} = \frac{V_O}{1.34 \times 10^{-10} \times f_{SW}}$$

$$R_{ON} = 7.1 / (1.34 \times 10^{-10} \times 4 \times 10^{5}) = 132.5\ k\Omega$$

The closest 1% tolerance resistor is 133 kΩ. The switching frequency and on-time of the circuit can then be found using the equations relating R_{ON} and t_{ON} to f_{SW}, as shown in below equation.

$$f_{SW} = 7.1 / (1.33 \times 10^5 \times 1.34 \times 10^{-10}) = 398 \text{ kHz}$$
$$t_{ON} = (1.34 \times 10^{-10} \times 1.33 \times 10^5) / 24 = 743 \text{ ns}$$

Output Inductor

Because an output capacitor will be used to filter some of the AC ripple current, the inductor ripple current can be set higher than the LED ripple current. A value of $40\%_{P\text{-}P}$ is typical in many buck converters.

$$\Delta i_L = 0.4 \times 0.7 = 0.28 \text{ A}$$

With the target ripple current determined the inductance can be chosen:

$$L_{MIN} = \frac{V_{IN} - V_O}{\Delta i_L} \times t_{ON}$$

$$L_{MIN} = [(24 - 7.1) \times 7.43 \times 10^{-7}] / (0.28) = 44.8 \text{ µH}$$

The closest standard inductor value is 47 µH. The average current rating must be greater than 700 mA to prevent overheating in the inductor. Separation between the LM3404 drivers and the LED arrays means that heat from the inductor will not threaten the lifetime of the LEDs, but an overheated inductor could still cause the LM3404 to enter thermal shutdown.

The inductance of the standard part chosen is ±20%. With this tolerance the typical, minimum, and maximum inductor current ripples can be calculated:

$$\Delta i_{L(TYP)} = [(24 - 7.1) \times 7.43 \times 10^{-7}] / 47 \times 10^{-6} = 266 \text{ mA}_{P\text{-}P}$$
$$\Delta i_{L(MIN)} = [(24 - 7.1) \times 7.43 \times 10^{-7}] / 56 \times 10^{-6} = 223 \text{ mA}_{P\text{-}P}$$
$$\Delta i_{L(MAX)} = [(24 - 7.1) \times 7.43 \times 10^{-7}] / 38 \times 10^{-6} = 330 \text{ mA}_{P\text{-}P}$$

The peak LED/inductor current is then estimated:

$$I_{L(PEAK)} = I_L + 0.5 \times \Delta i_{L(MAX)}$$
$$I_{L(PEAK)} = 0.7 + 0.5 \times 0.330 = 866 \text{ mA}$$

In the case of a short circuit across the LED array, the LM3404 will continue to deliver rated current through the short but will reduce the output voltage to equal the CS pin voltage of 200 mV. The inductor ripple current and peak current in this condition would be equal to:

$$\Delta i_{L(LED\text{-}SHORT)} = [(24 - 0.2) \times 7.43 \times 10^{-7}] / 38 \times 10^{-6} = 465 \text{ mA}_{P\text{-}P}$$
$$I_{L(PEAK)} = 0.7 + 0.5 \times 0.465 = 933 \text{ mA}$$

In the case of a short at the switch node, the output, or from the CS pin to ground the short circuit current limit will engage at a typical peak current of 1.5 A. To prevent inductor saturation during these fault conditions the inductor's peak current rating must be above 1.5 A. A 47-µH off-the shelf inductor rated to 1.4 A (peak) and 1.5 A (average) with a DCR of 0.1 Ω will be used.

Using an Output Capacitor

This application does not require high frequency PWM dimming, allowing the use of an output capacitor to reduce the size and cost of the output inductor. To select the proper output capacitor, the equation from Buck Converters With Output Capacitors is re-arranged to yield the following equation

$$Z_C = \frac{\Delta i_F}{\Delta i_L - \Delta i_F} \times r_D$$

The target tolerance for LED ripple current is 100 $\text{mA}_{P\text{-}P}$, and a typical value for r_D is 1.8 Ω at 700 mA. The required capacitor impedance to reduce the worst-case inductor ripple current of 333 $\text{mA}_{P\text{-}P}$ is therefore:

$$Z_C = [0.1 / (0.333 - 0.1] \times 1.8 = 0.77\Omega$$

A ceramic capacitor will be used and the required capacitance is selected based on the impedance at 400 kHz:

$$C_O = 1/(2 \times \pi \times 0.77 \times 4 \times 10^5) = 0.51 \text{ µF}$$

This calculation assumes that impedance due to the equivalent series resistance (ESR) and equivalent series inductance (ESL) of C_O is negligible. The closest 10% tolerance capacitor value is 1 µF. The capacitor used must be rated to 25 V or more.

R_{SNS}: A preliminary value for R_{SNS} was determined in selecting i_L. This value must be re-evaluated based on the calculations for i_F:

$$R_{SNS} = \frac{0.2 \times L}{I_F \times L + V_O \times t_{SNS} - \frac{V_{IN} - V_O}{2} \times t_{ON}}$$

$t_{SNS} = 220$ ns, $R_{SNS} = 0.33\ \Omega$

Sub-1-Ω resistors are available in both 1% and 5% tolerance. A 1%, 0.33-Ω device is the closest value, and a 0.33 W. With the resistance selected, the average value of LED current is re-calculated to ensure that current is within the ±5% tolerance requirement. The average LED current can be found using following equation

$I_F = 0.2 / 0.33 - (7.1 \times 2.2 \times 10^{-7}) / 47 \times 10^{-6} + 0.266 / 2$

$= 706$ mA, 1% above 700 mA

Input Capacitor

Following the calculations from the Input Capacitor section, $v_{IN(MAX)}$ will be 24 V × 2%$_{P-P}$ = 480 mV. The minimum required capacitance is:

$C_{IN(MIN)} = (0.7 \times 7.4 \times 10^{-7}) / 0.48 = 1.1\ \mu F$

To provide additional safety margin the higher value of 3.3-µF ceramic capacitor rated to 50 V. Input rms current is:

$I_{IN-RMS} = 0.7 \times Sqrt(0.28 \times 0.72) = 314$ mA

Ripple current ratings for ceramic capacitors are typically higher than 2 A, more than enough for this design.

Recirculating Diode

The input voltage of 24 V ±5% requires Schottky diodes with a reverse voltage rating greater than 30 V. The next highest standard voltage rating is 40 V. Selecting a 40-V rated diode provides a large safety margin for the ringing of the switch node and also makes cross-referencing of diodes.

The next parameters to be determined are the forward current rating and case size. In this example the low duty cycle (D = 7.1 / 24 = 28%) places a greater thermal stress on D1 than on the internal power MOSFET of the LM3404. The estimated average diode current is:

$I_D = 0.706 \times 0.72 = 509$ mA

A Schottky with a forward current rating of 1 A would be adequate, however reducing the temperature rise in D1 . Power dissipation and temperature rise can be calculated as power dissipation is critical in this example. Higher current diodes have lower forward voltages, hence a 2-A rated diode will be used. To determine the proper case size, the dissipation

$P_D = 0.509 \times 0.3 = 153$ mW

$T_{RISE} = 0.153 \times 75 = 11.5°C$

C_B and C_F

The bootstrap capacitor C_B must always be a 10-nF ceramic capacitor. A 25-V rating is appropriate for all application circuits. The linear regulator filter capacitor C_F must always be a 100-nF ceramic capacitor, also 25-V rating.

Efficiency

To estimate the electrical efficiency, power dissipation in each current carrying element can be calculated and summed. Electrical efficiency, η, must not be confused with the optical efficacy of the circuit, which depends upon the LEDs themselves.

Total output power, P_O, is calculated as:

$P_O = I_F \times V_O = 0.706 \times 7.1 = 5$ W

Conduction loss, P_C, in the internal MOSFET:

$$P_C = (I_F^2 \times R_{DSON}) \times D = (0.706^2 \times 0.8) \times 0.28 = 112 \text{ mW}$$

Gate charging and VCC loss, P_G, in the gate drive and linear regulator:

$$P_G = (I_{IN\text{-}OP} + f_{SW} \times Q_G) \times V_{IN}\ P_G = (600 \times 10^{-6} + 4 \times 10^5 \times 6 \times 10^{-9}) \times 24 = 72 \text{ mW}$$

Switching loss, P_S, in the internal MOSFET:

$$P_S = 0.5 \times V_{IN} \times I_F \times (t_R + t_F) \times f_{SW}\ P_S = 0.5 \times 24 \times 0.706 \times 40 \times 10^{-9} \times 4 \times 10^5 = 136 \text{ mW}$$

AC rms current loss, P_{CIN}, in the input capacitor:

$$P_{CIN} = I_{IN(rms)}^2 \times ESR = 0.317^2\ 0.003 = 0.3\text{ mW (negligible)}$$

DCR loss, P_L, in the inductor

$$P_L = I_F^2 \times DCR = 0.706^2 \times 0.1 = 50\text{ mW}$$

Recirculating diode loss, P_D = 153 mW
Current Sense Resistor Loss, P_{SNS} = 164 mW
Electrical efficiency, $\eta = P_O / (P_O$ + Sum of all loss terms) = 5 / (5 + 0.687) = 88%
Temperature Rise in the LM3404 IC is calculated as:

$$T_{LM3404} = (P_C + P_G + P_S) \times \theta_{JA} = (0.112 + 0.072 + 0.136) \times 155 = 49.2°C$$

D.HARDWARE SETUP

Figure 3. Hardware setup of designed high power LED Driver

Table 1: Recommended Operating Conditions

		MIN	MAX	UNIT
Vin	LM3404	6	42	V
	LM3404HV	6	72	
Junction Temperature Range	LM3404	-40	120	°C
	LM3404HV	-40	120	

Table 2: Analysis of Result for Following Design Parameters

ID	TYPE	PARAMETER
D1	Schottky Diode	40 V, 2 A
Cf	Capacitor	100 nF 10%
Cb	Capacitor	10 nF 10%
Cin	Capacitor	3.3 µF, 50V
Rsns	Capacitor	1 µF, 25V
Ron	Resistor	0.33 Ω 1%

III. RESULTS

Table 3: Results of designed High power LED driver

Parameter	Theoretical	Practical	Unit
Input voltage	24	24	V
Output voltage	7.1	8.1	V
Output current	200	56	mA
Output power	5	4.5	W
Efficiency	88	85	%

Conclusion

This paper presents the design of a system that provides a more efficient solution for driving high power LED by controlling the power LED current and the total amount of power feeding into the power LED by using IC LM3404. This system is designed to provide a more efficient solution for driving high power LED and increase the efficiency of the power levels required for the power LED to operate. Hence it can be concluded that by using IC LM3404 high efficient power LED driver is designed and implemented.

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