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Small Form-Factor Driver for Power LEDs Powered with One Element Battery

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Abstract. The present paper is focused on designing small form-factor drivers for high-power LEDs, which are fed with one battery element. Standard power supply architectures are not suitable due to the design requirements and technical restrains imposed. The study evaluates power supply systems to solve the design case analyzing their advantages and drawbacks. In doing so it is introduced new power supply architectures of constant current drivers for LEDs that improve the performance of standard ones.

Keywords: Power supply, driver, LED, battery, Green Design.

1 Introduction

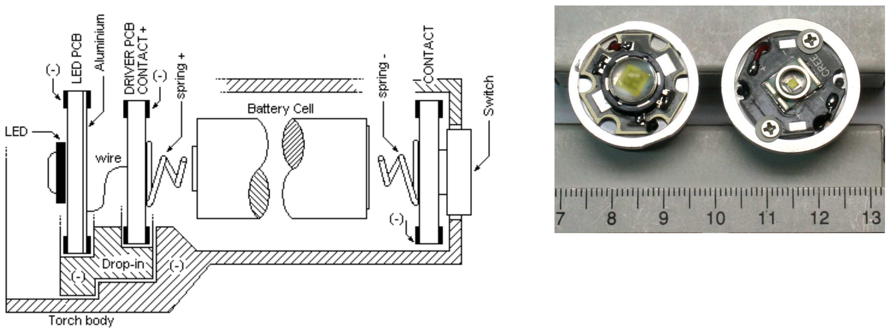
In the last few years LED lighting technology is becoming more and more popular. LEDs lighting has provided to be more efficient that the incandescent lamps, and it also requires less complicated electronics than fluorescent ballasts. Nevertheless, LED technology has certain disadvantages, but the benefits it provides are far superior, that is the reason of its penetration in many industrial sectors, like consumer electronics, automotive industry and even in military applications.

The key issue in any LED lighting system is its power driver. So far, the power supply system employed conditions system performance and its energy efficiency. There are two main lines to face this technical issue; linear regulation and switched regulation [1]. The first option is employed whenever a robust solution is required and when the available room for electronics is not a constraint; this is the case of the automotive industry. Nevertheless, manufactures are introducing switched regulator architectures, as they provide more features and better efficiency, which benefits, among other issues, the thermal compensation and handling, although reliability is reduced. On the other hand, unless switched regulation introduces electromagnetic interferences [2], it is suited whenever small size and efficiency are required over wide-range power source voltages.

Based on the article reference framework, the present work is entitled to research, and design, switched power supply architectures for power LEDs that meet the following technical requirements:

- High efficiency, (Green Design).
- Small form-factor, around 20 mm diameter.
- One Lithium element power source.
- Constant LED drive current without large capacitor.
- Constant current drain from battery without large capacitors.
- Polarity reversal protection

Fig. 1 illustrates the block diagram of target application that fulfils the enumerated requirements. The figure represents consumer electronics torch; the mechanical arrangement is only for didactic purposes, and it does not mean to be the best design approach but it is a widespread arrangement.



(a) (b)

Fig. 1. (a) Block diagram of a power LED torch feed with a one battery element. (b) Detail of the electronics dimensions (courtesy of Barbolight S.A.).

2 State of the Art

Before starting to describe our proposal, it is enlightened perform a briefly study of the following issues, for they help to understand and characterize the technical challenges designing small form factor drivers for power LEDs fed with one battery element:

- Power LEDs characteristics.
- Battery specifications and types.
- Protection electronics and thermal balance.
- Power converters architectures.

Power LEDs. To illustrate the technical requirements that power LEDs impose, it has been taken as reference the Seoul LED model W724CO. Fig. 2 and Table. 1 summarizes its characteristics and parameters. The data that provides Fig. 2 and Table 1 show that LED forward voltage is a function of the forward current, consequently, to guaranty a uniform luminous flux it is required an average constant led current over time. This current is discontinuous or continuous, but not constant, for it has ripple, so filtering capacitors are required to smooth current discontinuities or to reduce the ripple range. Besides, many manufacturers include Zener diodes to protect the LED against ESD, (electrostatic discharge), which limits the range of feasible power supply architectures.

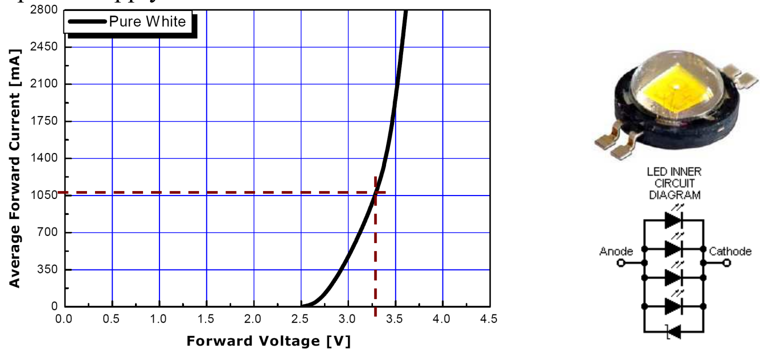


Fig. 2. W724CO de Seoul, $V_F = 3,6$ V@2,8 A, $I_{LED\ nominal} = 1,4$ A, $I_{LEDmax} = 2,8$ A [3].

Table 1. Electrical characteristics at IF=2,8 A and TA = 25ºC, and absolute maximum ratings of model W724CO of Seoul [3].

Parameter	Symbol	Value Min.	Value Typ.	Value Max.	Unit
Forward Current	I_F	-	2800	-	mA
Forward Voltage	V_F	-	3,6	4,2	V
	$V_F@I_F$=1400 mA	-	3,3	-	V
Power Dissipation	P_d		11,8		W
Thermal Resistance	R_θ		3		ºC/W
Junction Temperature	T_j		140		ºC
Operating Temperature	T_{opr}	-40		+85	ºC

Battery. Batteries could be primary or secondary, i.e., not rechargeable or rechargeable, respectively [4]. Due to the characteristics of the target application; voltage supply level, size and weight; the battery technologies more suitable, among others, are the following:

- Niquel-Metal-Hydrite (NiMH) and Niquel-Cadmium (NiCd), both require fuse.
- Ion-Lithium and Ion-Lithium-Polymer, both need a protection circuit and fuse.

No matter the type, their basic equivalent circuit is made of its internal resistance, R_{IN}, usually of low-value, and depends on the technology, tenths of milliohms for 1 Ahour capacity Ion-Lithium battery. It also includes a protection circuit, mandatory for safety requirements, which is made of the resistance of the fuse and a couple of Mosfets. Thus, batteries have a maximum current drain pulsed and discontinuous, overcoming these ratings or operating at discontinuous current will introduce unacceptable losses in their equivalent internal resistance, reducing the energetic efficiency of the electronics. To illustrate this behaviour battery manufacturers provide cell voltage as a function of the discharge capacity, Fig. 3.

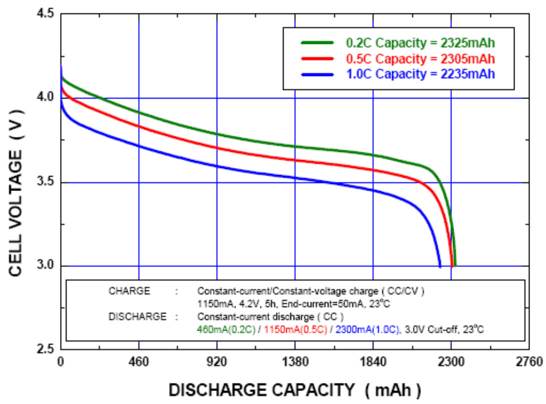


Fig. 3. Detail of the discharge capacity versus voltage of a LG Chem Ion-Lithium battery model ICR18650 with an internal resistance 80 mΩ and 45 g weight.

Protection circuits and thermal requirements. The family of battery cells used in the application conditions the amount and type of protection required. Unless, all the batteries require a fuse, (better if resettable), and some electronics to avoid polarity inversion; Lithium type requires an under-voltage protection circuit or low battery unplug circuit. Besides, as the power LED generates a substantial amount of heat it is mandatory to include a high temperature disconnection circuit, typically over 60ºC.

Power converters. Being LED lighting technology widespread the manufactures of IC power converters have developed many architectures to help designers and application integrators. The key issues to search for are; high current drive to feed the LEDs properly, type of converter, voltage operation to manage low-battery levels, and high-switching frequency to reduce the size of inductors and capacitors.

The following table provides selection of power converters that may be suitable for 1,4 A LED lighting system with a battery voltage range between 2,4 V and 6,6 V. The data show that there are not specific ICs that cover all the requirements; high power, low voltage and small size, not to mention temperature shutdown and polarity reversal protection.

Table 2. Selection of commercial power converters for a 1,4 A LED lighting systems with a battery voltage range between 2,4 V and 6,6 V.

Manufacturer	Model	Type	I_{MAX} (A)	Voltage range (V)	Freq. (kHz)
ON semicon.	NCP3065	Buck	1,5	3 - 40	250
Intersil	ISL97801	Boost/buck	1	2,7 - 16	-
Richtek	RT8271	Sept-down	2	4,75 -24	1200
Texas Instru.	TPS62110	Sept-down	1,5	3,1 - 17	1400
Intersil	EL7515	Step-Up	0,65	1,8 - 13,2	1200
Zetex	ZXLD1322	Step-Up	0,7	2,5 - 15	-
Linear	LT3757	SEPIC	2	2,9 - 40	1000
MPS	MP1517	Boost	4	2,6 - 25	-
Analog Devices	ADP1111-5	Boost	1,5	2- 30	72
Texas Instru.	TPS63000	Buck-boost	1,2	1,2 - 5,5	-

3 Objective

The main objective of the research work is: present and describe new power supply architectures for high power LEDs feed with one battery element and reduced dimensions, which have constant input and output current. Doing so, it is guarantied maximum battery energetic efficiency and, at the same time, constant LED luminous flux.

4 Technical alternatives

Based on the characteristics of target applications it has been analysed four main power supply architectures and its variants [5].

Buck converter (V_{OUT}<V_{IN}). First alternative is a buck converter. It requires an input voltage greater than the output voltage, which is not always available. There are two main Buck configuration alternatives that fit the target application, Fig. 5; none of them is affected by LED protection Zener diodes. Unless both provide constant LED current, the input current they drain from the battery is always discontinuous, this reduces the energetic efficiency and may lead to false low battery detections. Also, the first circuit depictures in Fig. 5 employs a P-type switch, which has a higher R_{ON} resistance, increasing energy losses. If the switch is replaced by an N-type one, R_{ON} is lower, at is shows the right schematic of Fig. 5, the performance is maintained but the electric and thermal contacts are attached to the positive pole of the battery.

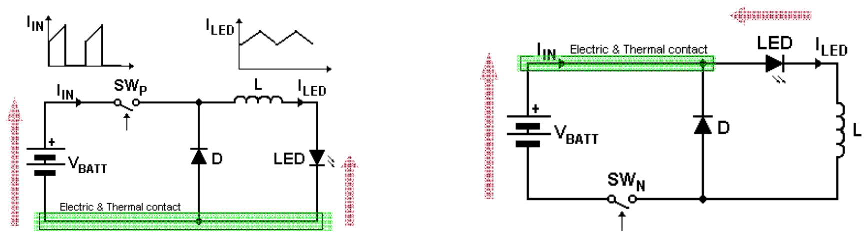
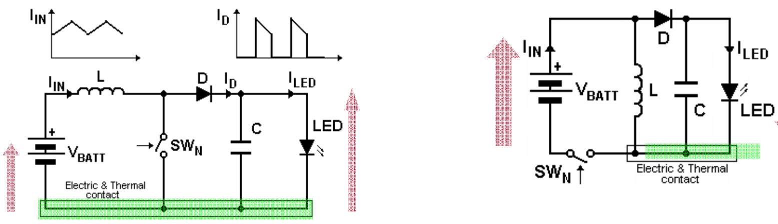


Fig. **5**. Buck converter power supply alternatives with V_{OUT}<V_{IN}

Boost converter (V_{OUT}>V_{IN}). In order to manage supply input voltages lower than the output voltage, it is possible to employs Boost configuration. The basic architectures are represented in Fig. 6. The main drawback they present is that, in spite off the input current remains continuous, the current trough the LED does not. Also, the second circuit of Fig. 6 has the thermal contact in the positive pole of the battery.

Buck-Boost or Inverter (|V_{OUT}|>or<|V_{IN}|). The reasoning line leads to the inverter configuration, Fig. 7, consequently; input voltage range is not a restraint as the output voltage could be greater or lower [6]. On the other hand, the input and output currents are discontinuous. Moreover, the first alternative requires a P-type switched, meanwhile; the second one, which has a N-type one, has its thermal contact attached to the positive pole of the battery.



(a) $V_{OUT}<V_{IN}$ (b) $|V_{OUT}|>$ or $<|V_{IN}|$

Fig. 6. Boost converter power supply alternatives with $V_{OUT}>V_{IN}$.

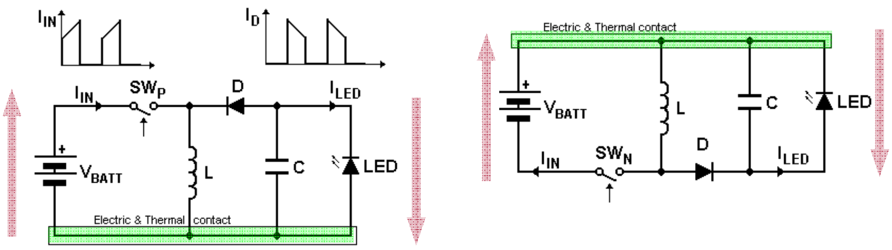


Fig. 7. Inverter power supply alternatives with $|V_{OUT}|$ > or < $|V_{IN}|$.

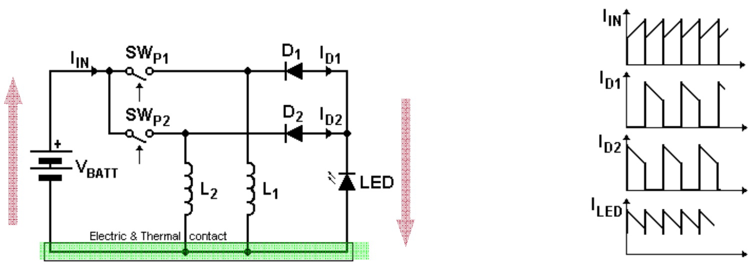


Fig. 8. Bi-phase inverter and current waveforms.

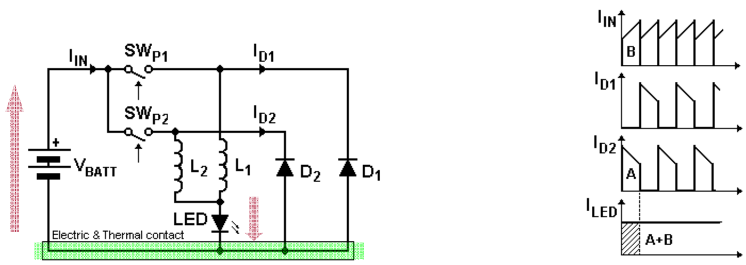


Fig. 9. Bi-phase inverter with constant LED current and current waveforms.

Bi-phase Inverter. All the previous architectures are feasible, but overcome their flaws lead to introduce the architecture represented in Fig. 8, a bi-phase inverter. With the bi-phase arrangement, the input and output currents are constant. The Fig. 8

represents the basic architecture and its current waveforms. This circuit could be further improved with the schematic represented in Fig. 9. The current waveforms show that the LED current becomes truly constant. The main drawback of the circuit is that this architecture requires two inductors, which occupy PCB area, unless it is possible to reduce inductors value and size increasing the switching frequency.

6 Results and Conclusions

In order to verify the behaviour of the technical architectures proposed, the inverter has been tested. Fig. 10 shows an example of one simple inverter made of discrete components. The waveforms provided show that, in spite of the inductance current, I(L1), is continuous, the input and output currents, I(D1), are discontinuous. It is also provided the efficiency figure, approximately a 75%. This value of efficiency could be further improved replacing the Schotcky diode by a Mosfet. Consequently, it seems adequate to introduce a new driver architecture to cope with the technical issues that standard ones left unsolved: the bi-phase inverter.

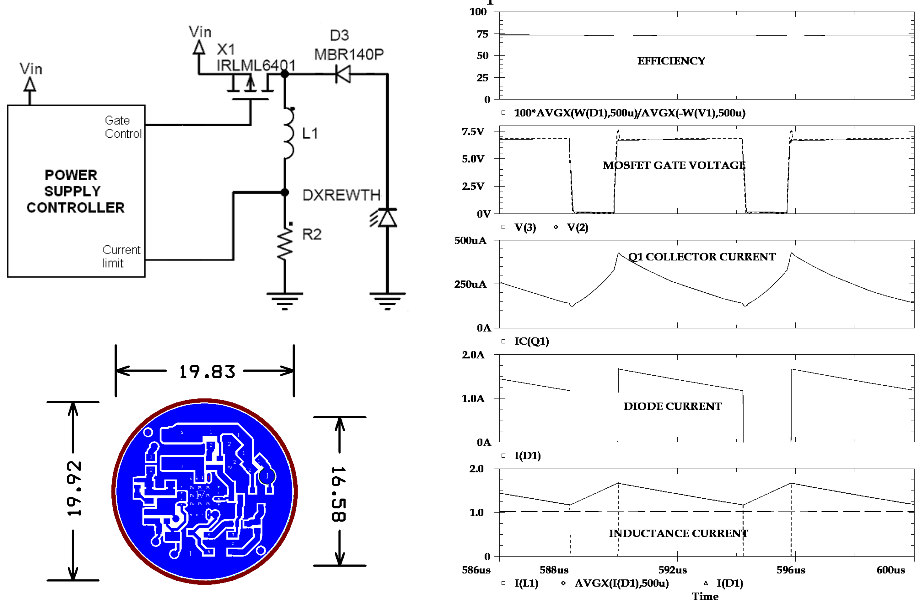


Fig. 10: Discrete inverter architecture, top layer PCB implementation and waveforms at nominal battery voltage for CREE power LED model DXEWTH.

The Table 3 compares the small form factor power LED drives identified in the research work as alternatives. It also summarizes the research results that are summarized in the following conclusions.

Despite Buck converter is commonly used in drivers for power LEDs battery powered, it has some drawbacks due to its basic architecture: the LED driver current is discontinuous, and, for input voltages lower than the output voltage, the LED luminosity starts to decay as the converter works out of regulation.

Meanwhile, Boost converters allow managing input voltages below the output voltage range, at expenses of discontinuous led current and an eventual increase of the input voltage above the output that leads the driver out of regulation.

Inverters, on the contrary, could manage input voltages higher or lower than the output, but have discontinuous input and output currents.

As long as the basic converters architectures do not provide continuous currents, it is presented new architectures that meet all the requirements: the bi-phase inverter and its variant that, theoretically have a truly constant LED current, instead of simply continuous. Unless, it may appear that the bi-phase inverter is the best alternative, it requires two inductors, which, eventually, will increase the required PCB area to develop the driver. Furthermore, the bi-phase architecture evaluated, instead of standard PFM or PWM control schemes, requires a variable frequency control that will be describe in future works.

Table 3. Summary of basic power LED driver architectures powered with one battery cell..

Type	Body connexion	Switch	I_{OUT}	I_{IN}	V_{OUT} / V_{IN}
Buck	(-)	P	continuous	discontinuous	$V_{IN}>V_{OUT}$
Buck variant	(+)	N	continuous	discontinuous	$V_{IN}>V_{OUT}$
Boost	(-)	N	discontinuous	continuous	$V_{IN}<V_{OUT}$
Boost variant	(+)	N	discontinuous	continuous	$V_{IN}<V_{OUT}$
Inverter	(-)	P	discontinuous	discontinuous	$\|V_{IN}\|><\|V_{OUT}\|$
Inverter variant	(+)	N	discontinuous	discontinuous	$\|V_{IN}\|><\|V_{OUT}\|$
Bi-phase inverter	(-)	P	continuous	continuous	$\|V_{IN}\|><\|V_{OUT}\|$
Bi-phase inverter alternative	(-)	P	**constant**	continuous	$\|V_{IN}\|><\|V_{OUT}\|$

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