Implementation of compact low cost linear LED drivers to replace boost converters for backlighting applications in portable products.

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Abstract

High quality backlighting has become an important selling feature when it comes to portable products. LEDs are widely used to address backlighting applications in cell phones and PDAs. Nevertheless, LEDs need to be driven properly to ensure optimal performance and long life. Designing and implementing an effective driver allows designers to obtain all the benefits of LEDs and still be cost effective.

This paper discusses an innovative approach for implementing low cost linear LED drivers to replace conventional boost converters. The considerations for the design and implementation of the linear solution are discussed. The advantages and disadvantages of the proposed low cost solution are compared to the boost solution.

Introduction

LED technology is widely used for backlighting applications in the majority of today's portable products. Strong requirements such as low power consumption, low quiescent current, reduced PCB area and maximum battery life are driving LED power management solutions to become highly integrated. System designers are facing significant challenges as they must consider many LED power management options when designing LED drivers for portable devices such as PDAs and cell phones.

Meeting the overall design requirements of longer battery life in the smallest PCB area at the lowest cost would not be possible to achieve without integrated LED power management solutions.

This article will describe and explain the design considerations for implementing a highly integrated linear LED driver to replace a conventional boost converter for backlighting applications in PDAs or cell phones.

Lithium-Ion (Li-Ion) battery

Li-Ion batteries fall into the secondary battery family category. Secondary batteries can be used repeatedly after recharging, and they differ from primary batteries mainly because primary batteries cannot be re-used once they are discharged. Another distinction of secondary batteries from primary batteries is that secondary batteries have the capability of discharging high currents.

One of the most important considerations for a Li-Ion battery is to maintain the charge and discharge cut-off voltages within the acceptable levels. Exceeding these limits could result in cell damage or explosion. Therefore special attention should be given to this particular point since they have very narrow tolerances between acceptable and non-acceptable levels. Figure 1 shows a graph with the typical voltage definitions.

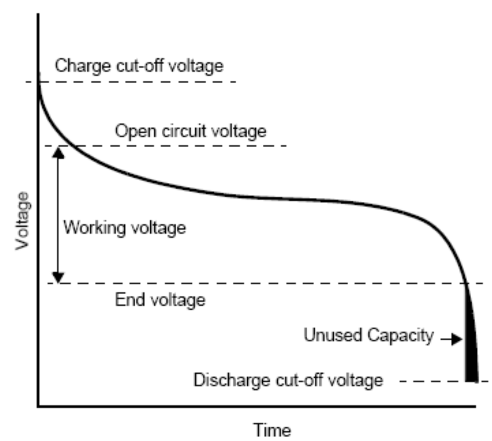

Figure 1 – Li-Ion battery typical voltage definitions

The typical nominal voltage of a Li-Ion battery cell is between 3.6 V and 3.7V. For portable devices such as cell phones and PDAs, the typical battery voltage range of operation is from 4.2V down to 3.2V for the graphite type, and as low as 2.7V for the coke type. For the graphite battery type, the voltage starts at 4.2V when it is fully charged and decreases to 3.2V, where the system typically enters into deep sleep until the battery is recharged. The battery will be discharged at a given discharge rate which depends on the amount of current taken from the battery over a period of time. The discharge rate is usually defined in terms of the battery's capacity and is called the "C Rate Specification". Figure 2 shows a typical Li-Ion battery discharge curve for the two different kinds.

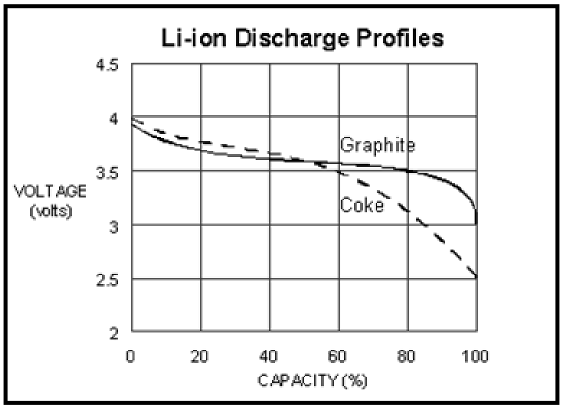

Figure 2 – Li-Ion battery typical discharge curves

As shown in figure 2, the graphite Li-Ion battery shows a much flatter discharge profile. This is the main reason why it is more widely used in today's portable products. The self-discharge characteristic for the two types of Li-Ion batteries is about 1/10th of that for nickel metal-hydride batteries (NiMH).

<u>LED backlighting for cell phones and PDAs.</u>

LED backlighting in cell phones and PDAs is usually addressed with low power LEDs (100mW). Typical LED current values are between 15mA and 25mA with forward voltages (Vf) between 3.0V to 3.4V depending on each LED manufacturer.

For PDA's display backlighting, four of these LEDs are typically used while for cell phones only one or two are used.

Boost converters and charge pumps are the most common solutions for LED backlighting in today's portable products. However, boost converters seem to be the preferred option as they offer higher efficiency and lower voltage operation than charge pumps.

<u>The boost converter solution.</u>

Boost converters provide high efficiency (typically 85%), accurate current regulation (±5%) and the ability to drive several LEDs in series from the battery voltage. However the circuit design can be complex since several external components are required (inductor, freewheeling diode, capacitors and sense resistor) in addition to the controller IC. Other important shortcomings of boost converters are EMI generation, PCB area and elevated cost. Figure 3 shows a schematic diagram of a typical boost converter to drive LEDs in portable applications.

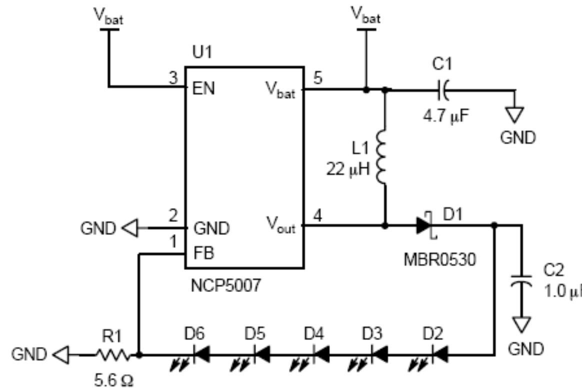

Figure 3 – Typical boost converter circuit to drive LEDs in portable applications.

A standard Li-Ion battery provides the supply voltage to the boost circuit which can be configured for different output voltages and LED currents according to the application needs.

The boost converter of figure 3 operates from input voltages between 2.7V & 5.5V, and can provide as high as 22V of output voltage and 1W of output power. The LED current is set through the R1 resistor (R1=200mV/ILED) and dimming is achieved by applying a PWM signal to the enable pin.

The overall efficiency of this boost converter when driving four 20mA LEDs in series is around 85% average. Figure 4 shows a graph of the overall efficiency versus battery voltage.

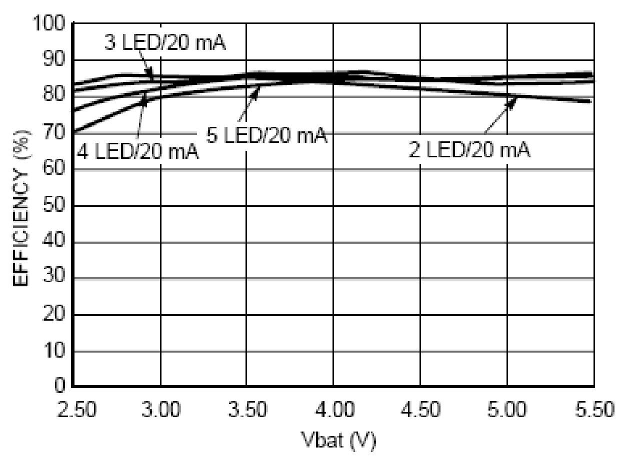

Figure 4 – Overall efficiency vs battery voltage (Iout=20mA, L=22 uH)

The efficiency goes down when the battery voltage is lower than 3.5V but it stays at 85% for the most part.

The low cost linear LED driver solution.

For applications with high input/output voltage difference, low efficiency and heat generation are the two biggest shortcomings of using linear regulators versus switching regulators. These two things prevent the usage of linear devices in many applications, specially in those with low power consumption requirements.

However, for the case of PDAs and cell phones, the option of using linear LED drivers to address backlighting applications does not imply low efficiency. This is because the input/output voltage difference is usually small. Figure 5 shows how a linear low voltage drop-out (200mV) LED driver such as the NUD4301 device can be implemented to address backlighting applications.

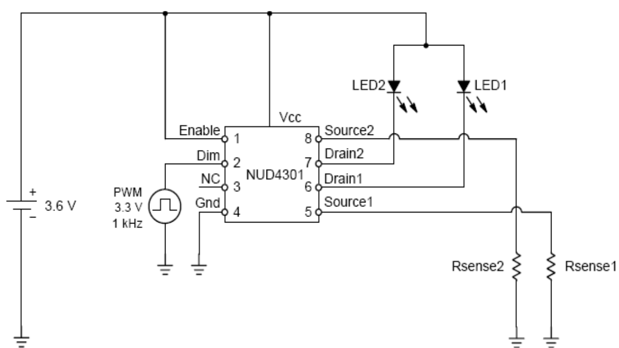

Figure 5 – Typical circuit configuration of the NUD4301 device to drive two LEDs.

As shown in figure 5, the LEDs are connected directly to the battery and it is known that they usually have a forward voltage range between 3.0V and 3.4V. This indicates that 200mV of voltage overhead will be available when the Li-Ion battery reaches its nominal voltage of 3.6V. The 200mV of voltage drop is enough for operating the NUD4301 device and generating the necessary sense voltage across the sense resistors to regulate the LED current.

The driver's efficiency is calculated as follows:

$\%Eff = [(V_{LED} \times I_{OUT}) / (V_{in} \times (I_{OUT} + I_{bias}))] \times 100$

However for calculation purposes, the Ibias can be disregarded because it is very low (200nA, enable low) compared with the total I_{OUT} (40mA for both LEDs). Then, the efficiency equation becomes:

$\%Efficiency = [(V_{LED}) / (V_{in})] \times 100$

The worst case for efficiency is when the Li-Ion battery is fully charged (4.2V) and the forward voltage of the LEDs is at the lower end of the distribution (3.0V):

%Efficiency = 3.0V / 4.2V = 71.4%

This efficiency number of 71.4% may not be as high as desired. However as shown in figure 2, the battery voltage does not stay at 4.2V for long. Therefore the efficiency will become higher as the battery reaches its nominal voltage of 3.6V. For this case, the driver's efficiency is:

%Efficiency = 3.0V / 3.6V = 83.3%

If we do the same efficiency calculations but now for the upper end value of the LED forward voltage (3.4V), the efficiency for fully charged and nominal battery voltage will increase significantly:

%Efficiency (fully charged) = 3.4 / 4.2 = 80.9%

%Efficiency (nominal) = 3.4 / 3.6 = 94.4%

Through the previous calculations, it is possible to see that linear LED drivers (NUD4301) can provide equivalent or higher efficiency than boost converters for specific battery conditions. Table 1 shows a side by side comparison of the overall efficiency for the boost converter and linear LED driver (NUD4301) when driving two 20mA LEDs. This table was made for specific conditions of battery and LED voltages.

	VLED = 3.0V		VLED=3.2V		VLED=3.4V	
	Linear	Boost	Linear	Boost	Linear	Boost
Vbatt	%Efficiency	%Efficiency	%Efficiency	%Efficiency	%Efficiency	%Efficiency
3.2V	93.7	83.0	n/a	83.0	n/a	83.0
3.6V	83.3	85.0	88.8	85.0	94.4	85.0
4.2V	71.4	84.0	76.2	84.0	80.9	84.0

Table 1 – Side by side efficiency comparison table for the linear solution (NUD4301) versus the boost converter solution.

There is a specific case where the efficiency calculation does not apply for the linear driver (NUD4301), and that is when the LED voltage is equal or greater than the battery voltage.

When this happens, the driver will not be in the regulation mode but will be in the saturation mode because there is not enough voltage across the driver to operate it ($V_{drop}=V_{batt} - V_{LED}$). This will cause the LED current to drop and thus the LEDs to dim. Figure 6 illustrates how the I_{LED} current behaves when the circuit of figure 5 is used to drive the LEDs for battery voltages between 3.2V and 4.2V.

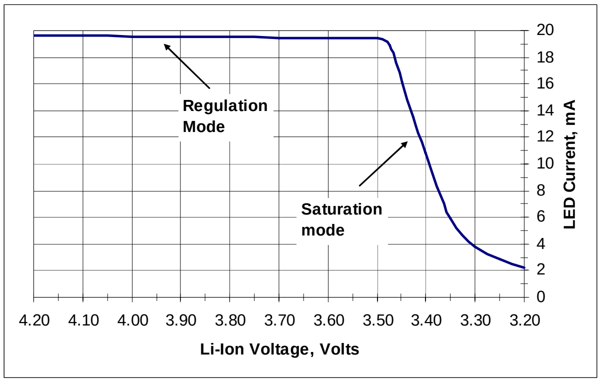

Figure 6 – NUD4301 typical line regulation (LED characteristics, Vf=3.3V@20mA)

The graph of figure 6 was generated using LEDs with forward voltage characteristics of 3.3V@20mA. Therefore, if different LEDs are used with different forward voltage characteristics the I_{LED} behavior will change.

As shown in figure 6, the linear driver (NUD4301 device) keeps the LED current constant until the voltage drop across itself is less than 200mV ($V_{drop}=V_{batt} - V_{LED}$). When the battery voltage further discharges to 3.4V, the battery capacity will have been consumed by 90% (see figure 2) and at this point the LED current (and therefore the light intensity) will drop to around 50% of its original value.

Although one may think that it would not be desirable to have the LEDs dimmed for battery voltages lower than 3.5V, it may not be as big of an issue as it looks. This is because the graphite Li-Ion battery's voltage stays above 3.5V 80% of the time (see figure 2) and therefore the LEDs will be lighted properly 80% of the time as well.

Conclusion

As explained in this article, there is no reason to be concerned about utilizing linear LED drivers (NUD4301 or similar) to address LED backlighting applications in portable products.

The option of using linear devices should not be eliminated before validating if it is really necessary to use an extra boost converter and inductor to improve the system efficiency by just a small percentage

Using any type of boost converter to drive LEDs will imply increasing the area of the PCB, the design cost and the EMI issues. For the contrary, a linear device such as the NUD4301 device is inexpensive, small, ease of design and the lowest EMI generator. Not to mention that it can provide higher efficiency than boost converters for specific conditions of battery and LED voltage.

References

[1] Carlos Martinez, Yossi Drori and Joe Ciancio, "Smart Battery Primer", July 11, 2005.

[2] BENCHMARQ, "Using NiMH and Li-Ion Batteries in Portable Applications", April 1995. (Copyright 1999, Texas Instrument Incorporated)

[3] ON Semiconductor datasheets, NCP5007 and NUD4301 devices.