Powering LEDs from Coin Cell Batteries

Coin cell lithium batteries are popular in small devices such as alarm clocks, watches, meters, test equipment, medical devices and wireless doorbell chime buttons. These batteries are suitable for powering a single low power LED to be used for backlighting an LCD display in low light conditions or driving an indicator LED for a short duration.

Lighting a single low power LED at a low current of 3mA from a 3V (nominal) lithium battery requires a boost converter to step-up the battery voltage to between 3V and 4V. A boost converter typically draws a larger amount of current during power-up causing a momentary drop of the coin cell battery voltage which could affect the operation of the device. For this reason, the use of dedicated LED drivers compatible with coin cell battery applications is recommended.

Coin Cell optimized LED Drivers

Fig. 1 shows an application circuit with a single LED powered from a coin cell battery using a charge pump LED driver. The coin cell battery can be modeled as an ideal 3V power supply with a series resistance or an output impedance (Rs). For a small CR2032 type lithium battery, the impedance of a new battery is fairly high and typically around 10 to 20 Ω. As the battery discharges over time, the impedance will increase further and could exceed 100 Ω at end of life.

When the LED driver is powered-up by transitioning the enable input (EN pin) from low to high, the LED driver starts to ramp-up the output voltage and charges the two flying capacitors, and most importantly, the output capacitor, to its nominal voltage of 3V to 4V depending on the LED forward voltage characteristics. This momentarily causes a higher input current (inrush) to be supplied by the battery. Fig. 2 shows the power-up waveforms when the driver is first enabled, showing the input current and the battery voltage transient. The LED driver input current peaks at about 10mA (Fig. 2).

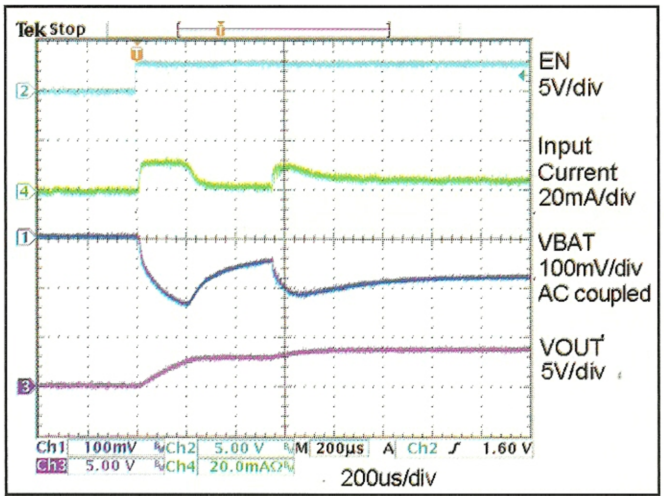

Fig. 2: Power-up waveform of coin cell optimized LED driver

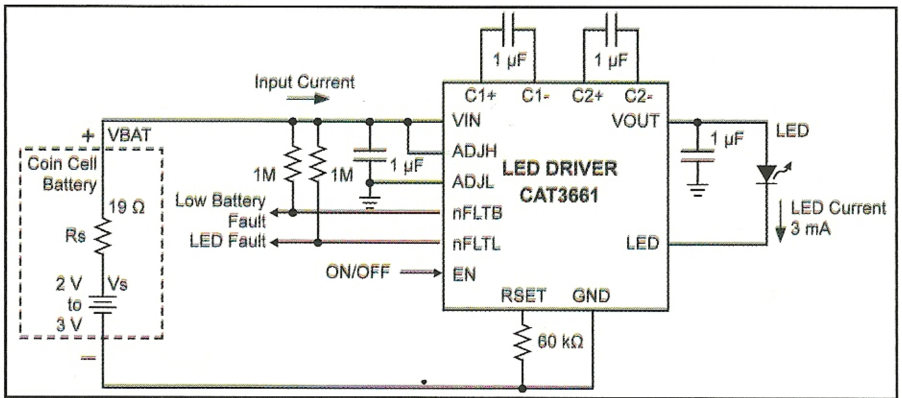

Fig. 1: LED powered by coin cell battery and charge pump LED driver

Let's compare the input current of a "regular" LED driver with a peak current at about 50mA, much higher than the 10mA with the low power LED driver. On the regular driver, the battery voltage drops momentarily by as much as 500mV compared to only 140mV for the low power driver. On a 3V battery, a 500mV drop is significant and even more critical as the battery discharges. By limiting the maximum input current to about 3.3 times the LED current (3.3 x 3mA = 10mA), the CAT3661 guarantees operation for much lower battery voltages, so that the battery can be used over a longer period and not require replacement so frequently.

The battery output impedance Rs can be estimated by looking at the waveform on Fig.2 and calculating the ratio between the VBAT voltage drop and the input current in a steady state portion of the curve (on the right side): Rs = VBAT drop / input current = 80mV / 4.2mA = 19Ω.

To extend battery life, the LED driver solution should also minimize the battery current consumption when the LED is on. Using a new CR2032 cell battery and driving a single LED at 3mA continuously, the input current and the battery voltage was monitored over a lifetime of about 22 hours until the battery was fully discharged (VBAT equal 1.9V) as shown in Fig. 3.

The ON Semiconductor Quad-ModeTM LED driver charge pump includes various modes of operation: 1x, 1.33x, 1.5x and 2x, where the boost ratio (output/input voltage) varies. For a typical LED forward voltage of around 2.9V, the LED driver will initially operate in 1.33x mode and transition to the 1.5x mode as the battery discharges. The mode change is visible in the coin cell battery discharge profile in Fig. 3. In the 1.33x mode, the input current

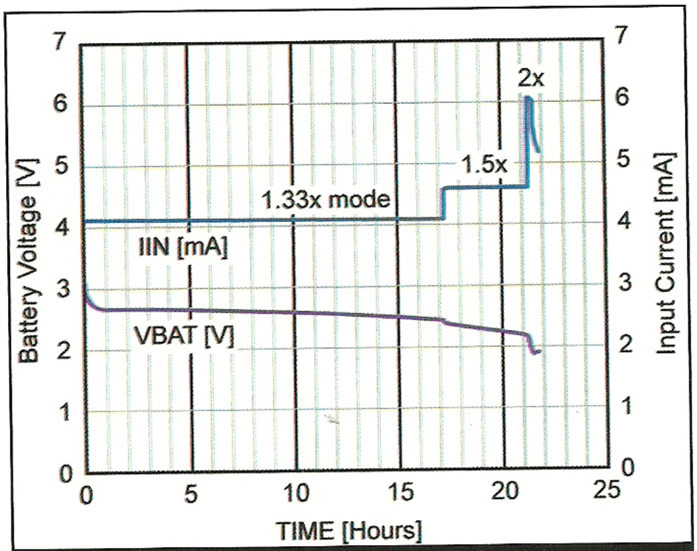

Fig. 3: CR2032 Coin Cell Discharge Profile

is equal to 1.333 times the LED current plus the quiescent current of 0.2mA (or a total of 1.333 x 3mA + 0.2mA = 4.2mA). While in the 1.5x mode, the battery input increases to 1.5 times the LED current (or 1.5 x 3 + 0.2 = 4.7mA). Eventually, the charge pump enters the 2x mode where the input current peaks to about two times 3mA (or 6mA). At that time, the discharged battery output impedance is so high that it causes the battery voltage to drop down to 1.9V forcing the driver into shutdown. If we compare the supply current between the 1.33x and the 1.5x mode, there is a 10 percent saving by staying in 1.33x mode. So fractional charge pumps with a 1.33x mode, such as the Quad-ModeTM CAT3661, provide higher efficiency compared to the traditional 1.5x charge pump mode only, and therefore extend battery life.

The CAT3661 charge pump LED driver minimizes the number of external components to four small 1µF ceramic capacitors, providing a very compact solution in a 3 mm by 3 mm package. It is compatible with low input voltages down to 2.0V needed to cover the coin cell battery range.

In case the LED is shorted or disconnected, the low power driver incorporates built-in protection modes. If the LED is shorted, the driver senses a small voltage differential (less than 1V) between the VOUT pin and the LED pin, and limits the output current to about 5µA. The driver enters a very low-power standby-mode, limiting drain on the battery. In case the LED is disconnected, the output VOUT rises until it reaches a high-voltage of about 4.5V, the driver disables the LED channel until the LED becomes reconnected. In both cases, the driver outputs an LED error flag by pulling down the open-drain nFLTL pin. The nFLTL pin can be connected to a microcontroller I/O pin to acknowledge the LED error.

Battery voltage monitoring is also handled by the low power driver by setting an adjustable low battery voltage threshold using external resistors connected to the ADJH and / or the ADJL pins. As soon as the battery voltage falls below the threshold, an error flag is activated by pulling low the nFLTB pin (open-drain). The battery voltage detection is achieved internally through a resistor divider connected to a voltage comparator. The driver will still continue to operate normally and regulate the LED current, even below the low voltage trip point. Once the VIN pin voltage reaches the under-voltage lockout (UVLO) threshold of about 1.9V, the IC will enter a "zero" current shutdown mode. The nFLTB pin can be connected to the microcontroller to recognize and process low battery voltage conditions. With the ADJH pin tied to VIN and ADJL pin tied to GND, as shown on Fig. 1, the low battery trip point is set to 2.4V.

Conclusion

The use of low power LED drivers to guarantee both input current limiting and high-efficiency gives the designer the ability to drive a low power LED at constant current even from a small coin cell battery. This opens up new applications for illuminated backlight and indicator LEDs by improving the user interface for various handheld devices. Coin cell battery lifetime impact can be minimized. The overall solution preserves board space and improves functionality by adding voltage monitoring, and the illumination makes the end-product more appealing and user-friendly. ■

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