SEMTECH

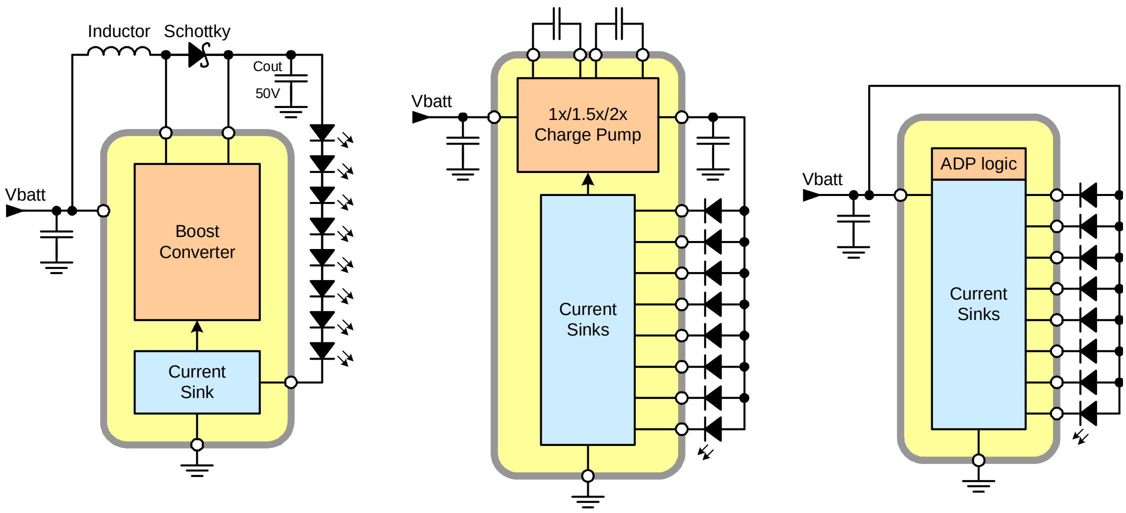
POWER MANAGEMENT PRODUCTS

Application Note

Automatic Dropout Prevention Enables Current Sink Backlighting for High-End Handheld Devices

Advances in mobile phones have transformed them from simple telephones to data communicators. An integral part of phones today is the color LCD. As handset data capability has increased, display size has grown, too. Today's handheld electronics typically include a color LCD with white LED backlighting. Power is provided from a single-cell Li-Ion rechargeable battery that operates in the 3.2V to 4.2V range. White LEDs typically require a forward voltage of 3.4V at 20mA – a common current setting for LED backlight designs. Because the battery voltage range and the white LED forward voltage overlap, most LED driver solutions include a circuit to boost the battery voltage to a higher level before feeding the LEDs with constant current. The two most common system designs are the boost converter topology (see figure 1a) and the charge pump topology (see figure 1b).

A third approach - the current sink topology (see figure 1c) - has been gaining acceptance, especially in low-end devices. Improvements in white LED technology resulting in lower forward voltages have made this an attractive and more cost effective alternative to boost converter topologies. One weakness of this approach is that the current sink regulators may lose regulation (called "drop out") under weak battery conditions. A new Semtech invention called Automatic Dropout Prevention (or ADP for short) eliminates the negative effects of dropout when using current sinks. It also provides the added benefits of reducing external components, eliminating switching noise, and extending battery life. These benefits make current sink LED drivers an attractive design approach even for high-end handheld devices.



a) Boost Converter Topology b) Charge Pump Topology c) Current Sink Topology

Figure 1 - White LED Backlight Driver Design Topologies

Why is a current sink topology attractive?

The current sink topology provides several advantages when compared to boost converter and charge pump topologies. A boost converter requires large external components, including an inductor, Schottky diode, and a 50V-rated output capacitor. Boost converters are inductor-based switching regulators, so they cause electro-magnetic interference (EMI) and ripple on their input and output lines that may contaminate adjacent circuits. Charge pumps produce less EMI due to the lack of an inductor, but they cause ripple on their input and output lines similar to the boost. Charge pumps also require multiple external capacitors, making component placement and routing difficult. Both the boost converter and the charge pump offer very similar overall efficiency. However, both experience their worst efficiency when the battery is near the end of life and weak, resulting in an accelerated decay of battery life.

The current sink topology only requires a single low-voltage capacitor at its input. There are no switching circuits to cause input/output ripple and EMI. Overall average efficiency is better than boost converters and charge pumps, and the efficiency peaks when the battery is near the end of life and weak. Later in this article, battery run-down tests will demonstrate the increased efficiency and battery life. Table 1 shows a comparison of the benefits of each LED driver approach, with green highlight indicating best performance, yellow indicating average performance, and pink indicating worst performance.

Table 1 - Comparison of Selection Parameters for LED Driver Topologies

	LED Boost	**LED Charge Pump**	**LED Current Sink**	
Chip Size	Small	Medium	Small	
Solution Size	Large	Medium	Small	
External Components				
Cin	Small	Small	Small	
Inductor	Large	None	None	
Schottky Diode	Small	None	None	
Flying Caps	None	Small	None	
Cout	Medium (50V)	Small	None	
System Cost	Medium (most external components)	Medium (external components + added die size)	Smallest (small die, no external components)	
Noise				
EMI	Yes	Low	No	
In/Out Ripple	Yes	Yes	No	
# of Wires to LEDs	Low	High	High	
Efficiency	High	High	Higher	
Dropout Issues	None	None	Yes	None with ADP
Battery Current at weak battery condition	High	Higher	Low	

What are the negative effects of current sink dropout?

For current sinks without ADP, there are three negatives that effect display quality under dropout conditions:

1. Regulation Accuracy – a current sink will not have enough headroom to regulate a steady current in its LED. Instead the current sink will act as a low-valued resistor, and LED current and brightness will reduce. Fortunately, the human eye responds logarithmically, so a substantial amount of dimming can be tolerated.
2. LED Current Matching – the current sinks will not have enough headroom to regulate and match the currents across the individual LEDs. LED forward voltage varies from LED to LED, making the mismatch appear even worse than expected. This will cause some brightness variations across the display. The light-guide and diffuser can mask much of the matching problem, so this problem can be tolerated to some extent, especially in low-end products.
3. Power Supply Ripple Rejection – the current sinks do not have enough headroom to reject line transients on the battery voltage as different system-loads are enabled and disabled. This will cause the display brightness to flicker and will be very noticeable to the human eye. Handheld devices like cell phones can see large changes in battery voltage of as much as 500mV as the transmitter and other high-current functions are enabled and disabled, causing the supply to the LEDs to vary widely while activated. This is the most serious problem because it results in a low-quality display appearance for the end product, causing damage to a manufacturer's reputation.

By preventing dropout, the ADP function solves the above problems, especially problems two and three.

How does Automatic Dropout Prevention work?

The ADP circuitry monitors each current sink simultaneously to avoid dropout in any of them. When any current sink is approaching dropout, a signal is sent to the digital logic to reduce the current setting for all the backlight LEDs by one setting. After a time delay, the current sinks are checked again, and if the near-dropout condition persists the current setting is reduced one more step. This continues until all of the current sinks have sufficient headroom to regulate their current at the reduced current setting. Figure 2 illustrates how this works in a system of eight white LEDs with different current-voltage curves as the battery supply decays. Note that when the display backlighting is disabled and re-enabled, the setting reverts back to the original programmed setting. If ADP needs to reduce the current settings again to maintain proper regulation, the process will repeat until the largest regulation current is found.

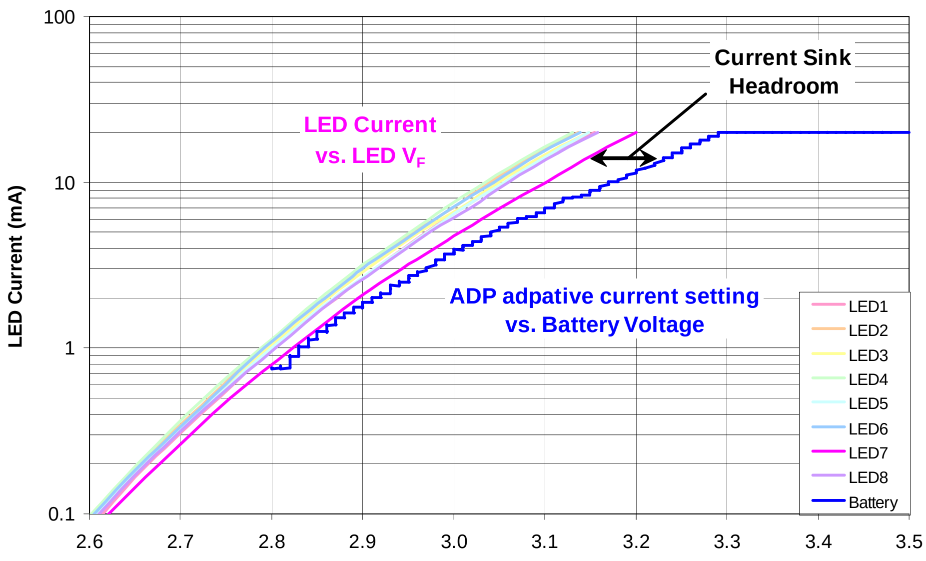
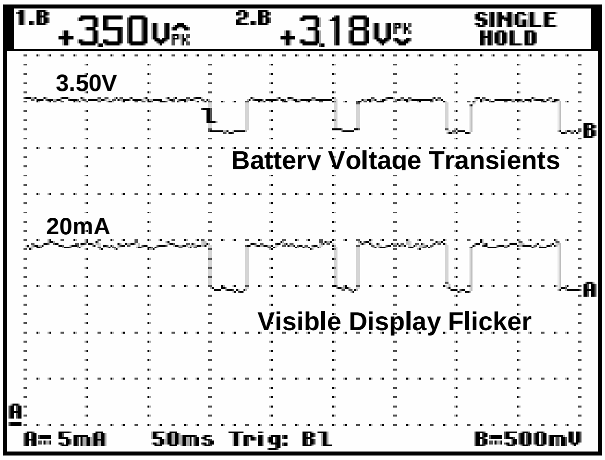


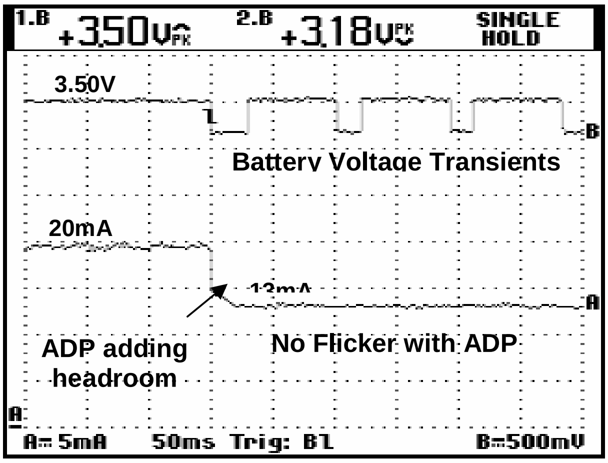
Figure 2 - ADP Profile as Battery Voltage Decreases (8 LED system)

The ADP function takes advantage of the LED forward voltage characteristic, as seen in Figure 2. As the current setting is reduced, the LED forward voltage (V_F) also reduces. At a given battery voltage, this V_F reduction leaves more headroom for the current sinks to regulate accurately. Regulation headroom and LED-to-LED current matching are maintained in this way.

To prevent flicker, ADP only reduces the current setting. Once the setting is reduced, it is not increased until the current sinks are disabled and enabled again. This operates like a valley detector for ripples on the battery voltage. Figure 3 shows how battery voltage ripple can cause display flicker without ADP and how ADP removes the flicker. In Figure 3a, the changes in LED current translate in changes in LED brightness, which appears as flicker. In Figure 3b, the single change in current shows that ADP removes the variability in the output current by reducing it once to a lower, but still bright level.



a) Line-Transient without ADP



b) Line-Transient with ADP

Figure 3 – LED Current and Voltage Waveforms (a) without ADP and (b) with ADP Active

As mentioned previously, it is necessary to reset the ADP function in order to restore the normal current setting after recharging the battery or after turning off a large system load that was pulling the battery voltage down. This is accomplished by either of the following:

1. Disabling and re-enabling the LED drivers
2. Disabling and re-enabling the ADP function

How much overlap is there between the battery voltage and the LED V_F?

In the past, the current sink topology was not used because the LED V_F was much higher than it is today. When white LEDs were first introduced into handset backlighting, the typical distribution of white LED V_F was centered at 3.5V at 20mA and the usual datasheet maximum specification was 4.0V at 20mA (see Figure 4). Boost converters or charge pump circuits were developed to drive white LEDs when the Li-ion battery voltage dropped below the V_F of the LEDs. Today's white LEDs are much improved with a typical V_F of 3.1V and a maximum specification over temperature in the range of 3.4V to 3.5V. This makes the current sink topology more attractive for systems with Li-ion batteries.

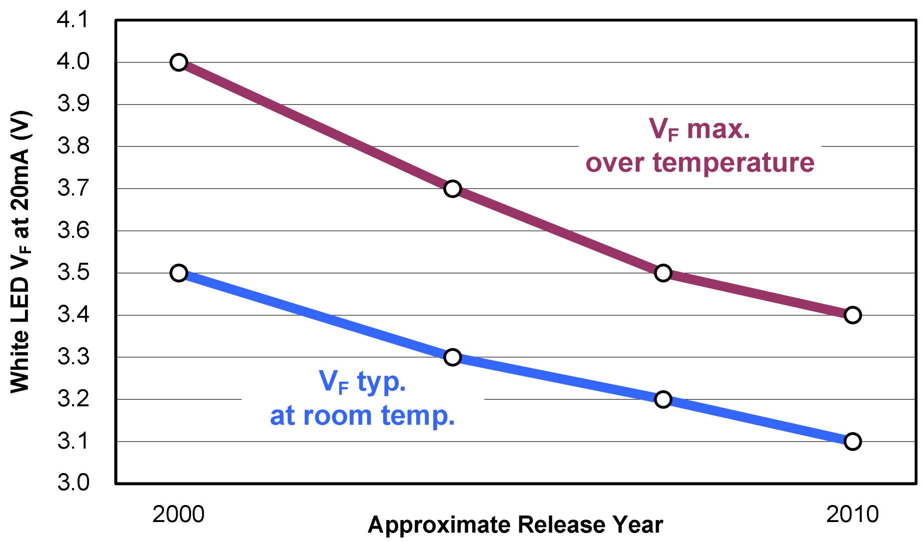


Figure 4 - LED Forward Voltage Trends over Time

Modern Li-Ion batteries have not only improved in their energy density, but have also flattened out their voltage curves and reduced their output resistance (see Figure 5). For most handheld devices, the end-of-life battery voltage is set in the 3.4V to 3.2V range.

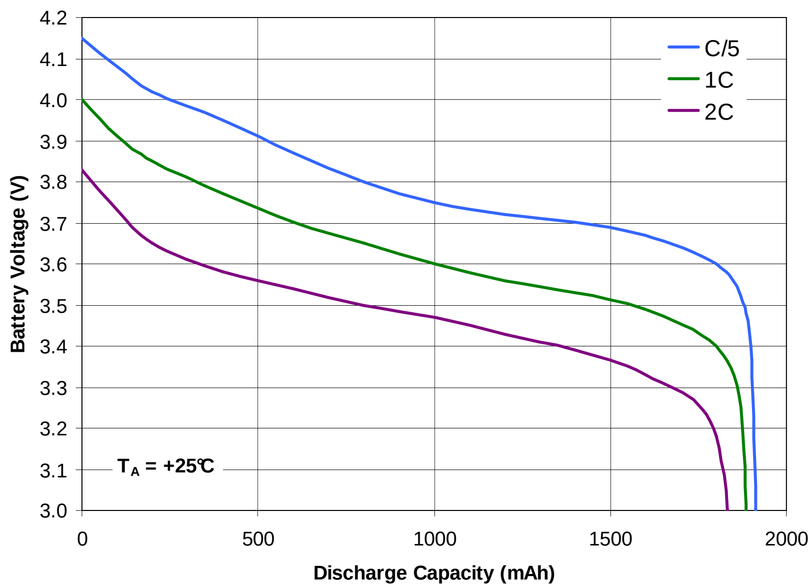


Figure 5 - Li-ion Battery Discharge Curves

Because of these improvements in battery capacity and white LEDs, ADP will usually only be needed during heavy-load events when battery capacity is low. This is true when the ambient temperature is at room temperature or hot temperatures. At cold temperatures, however, ADP plays a much bigger role. Batteries become much weaker at cold temperature (see Figure 6), and the LED V_F increases slightly as well (see Figure 7). Under cold conditions, the ADP function is critical to prevent flicker issues when using a current sink topology.

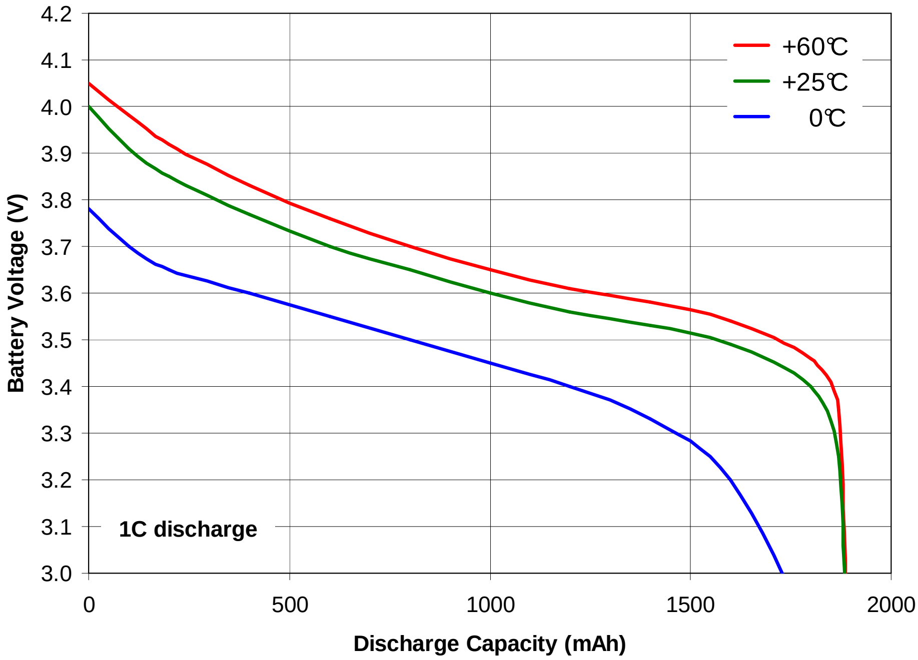


Figure 6 – Li-ion Battery Discharge Curves vs. Temperature

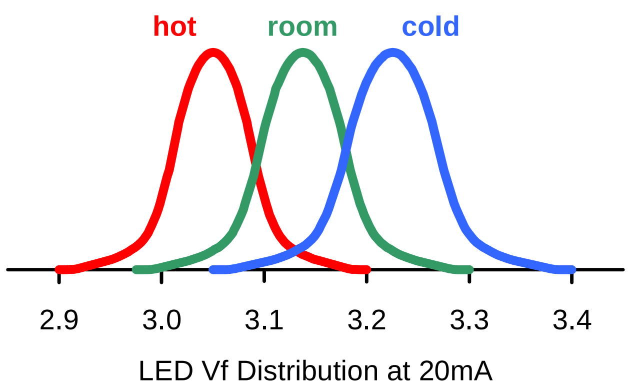


Figure 7 - LED Forward Voltage (V_F) Distribution Shifts vs. Temperature

How will ADP perform with a real battery discharge test?

In practice, most handheld devices disable operation when the battery reaches 3.2V to 3.4V. This leaves very little overlap between the supply voltage and the VF of the LEDs. ADP is ideal for such cases because it will only need to reduce the battery current when the battery is discharged to very low capacity. The current setting is gradually reduced as the battery voltage decays and dropout is detected, dimming the display while reducing the battery load current. The resulting battery discharge voltage curve, battery load current curve, and LED current setting can be seen in Figure 8.

Figure 8 compares the performance of a current sink topology with ADP (using the SC668 with eight LEDs and 20mA/LED setting) with the same data for a high-performance LED boost converter (using the SC4538 to the same eight LEDs and 20mA/LED setting). The data collected for this comparison graph was taken using a 900mAh single-cell Li-ion cellular phone battery as the input supply. To make a fair comparison, the same battery was fully charged to precisely the same level and then allowed to rest for the same amount of time.

It is easy to conclude from the curves in Figure 8 that the current sink with ADP significantly extends battery life when compared to the boost converter. The curves show that the boost converter is more efficient during the first two hours of discharge, but the current sink is more efficient during the next four hours and draws less total battery current. During the last phase of discharge when the battery is almost depleted, the boost increases the battery current exponentially to maintain full display brightness, discharging the battery even more quickly than at higher voltages. In contrast, the current sinks with ADP gradually dim the LEDs, reducing the loading on the weak battery, and extend the battery life for up to an hour.

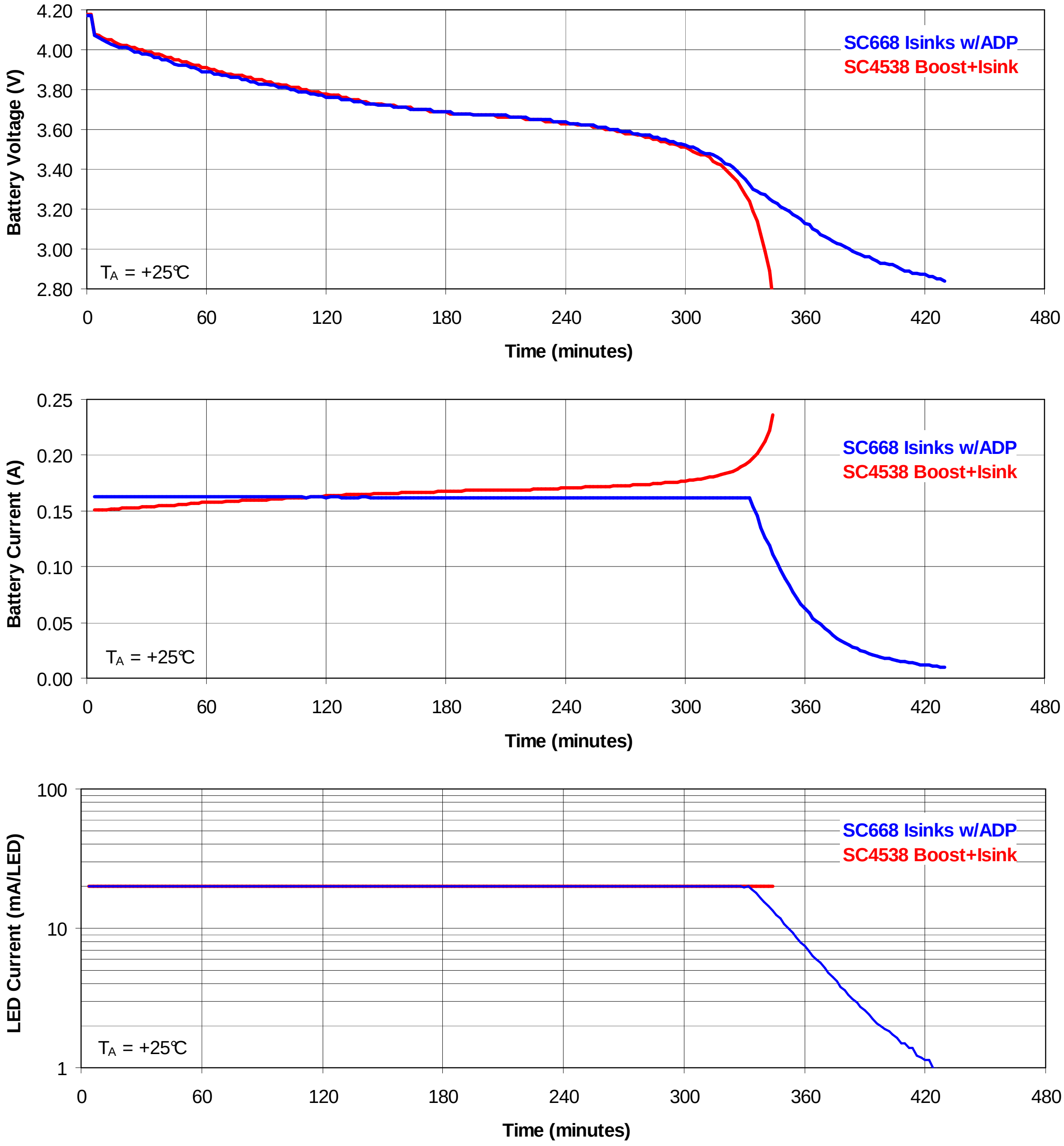


Figure 8 – Comparison of ADP to Boost Converter LED Driver

8 LEDs at 20mA/LED, Room Temperature

How about a run-down test at cold?

The same battery run-down tests were performed at 0℃ ambient temperature. The results of these tests are shown in Figure 9. At cold temperatures, the battery is weaker and the LED V_F is higher. Under these conditions, the differences in battery life are even more dramatic because ADP takes effect sooner in the discharge. While the boost converter needs to boost to a higher level sooner, ADP can maintain an acceptable brightness level and reduce the load on the cold battery, extending battery life even more.

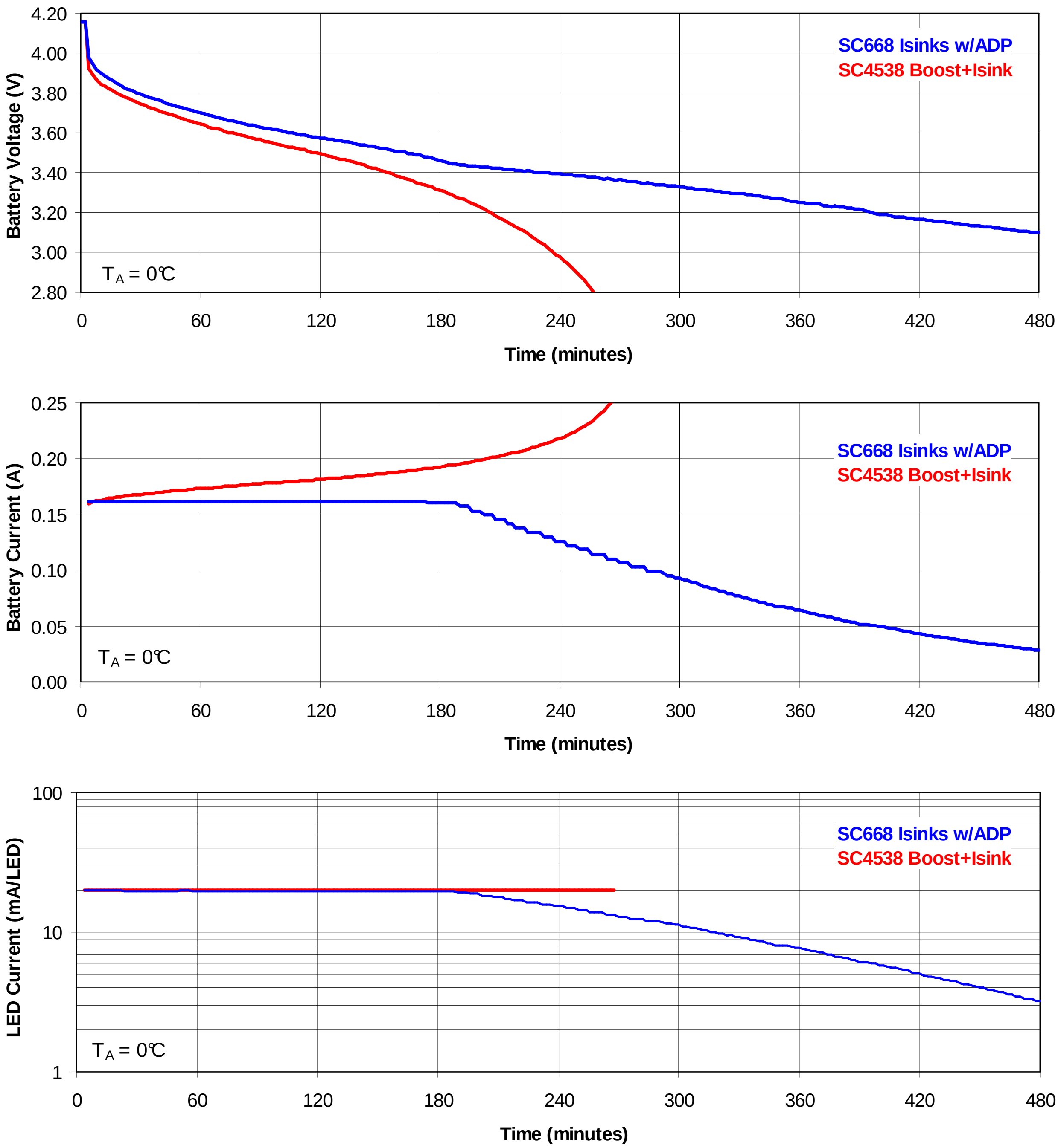


Figure 9 – Comparison of ADP to Boost Converter LED Driver

8 LEDs at 20mA/LED, T_A = 0°C

How dim is too dim?

The key design trade-off that is raised by the results in Figures 8 and 9 focuses on battery life vs. display brightness. System designers need to consider the weak battery condition and decide if it is it better to maintain backlight brightness and accelerate the battery decay or to extend the battery life and have a gradually dimmer display. The answer to this question ultimately depends upon how much dimming is tolerable. Fortunately the human eye response is logarithmic, so a fair amount of dimming can occur before it is noticeable to the average user. To demonstrate, a digital SLR was used to photograph a smartphone display that was dimmed from 20mA/LED to 3mA/LED in six nearly logarithmic steps (see Figure 10). Manual exposure was used so that each image is accurately portrayed for its brightness. Every individual will have their own opinion about how much dimming is acceptable, but the fact that ADP performs this dimming as gradually as the battery voltage decays helps mask the fact that dimming is occurring at all.

Figure 10 – Comparison of an LCD with Different Backlight Levels

The ADP function and implementation are proprietary to Semtech Corporation, and a US patent application has been filed. Figure 11 shows a typical schematic using Semtech's SC667 or SC668, the world's first LED drivers to integrate the ADP function. These ICs also integrate an ambient light sensing and control circuit, an internal digital-effects engine, a PWM dimming interface with digital low-pass filter for content-adaptive brightness control, multiple low-noise regulators for peripheral power, and an I^2C serial interface to facilitate system microprocessor control. The SC668 provides eight current sinks while the SC667 provides seven current sinks and an interrupt request indicator signal to tell the host processor when an ambient light threshold has been crossed. Both devices are available in the 3x3x0.6mm MLPQ package to minimize PCB area and optimize thermal performance.

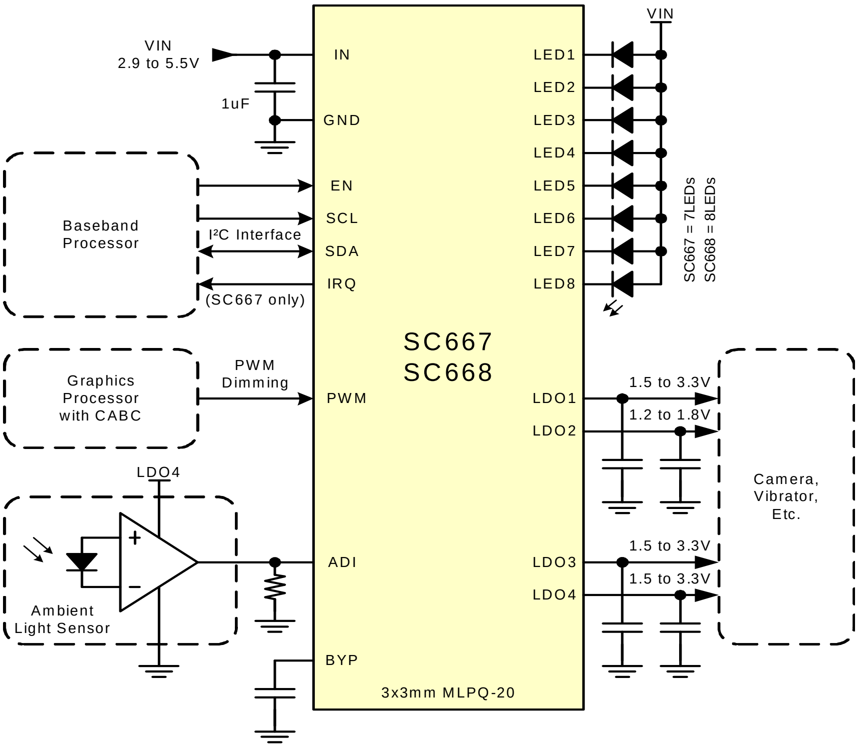


Figure 11 – SC667/668 Typical Application Circuit

ADP provides a very attractive backlight driver solution for high-, mid-, and low-end handheld devices. The current sink is efficient, creates no noise, and uses minimal space and external components. ADP enhances the current sink to prevent all dropout issues, such as regulation accuracy, LED-to-LED mismatch, and ripple-rejection/flicker. An additional benefit is that a current sink with ADP reduces battery loading and increases battery life especially when the battery is weak. In backlight applications, ADP offers a simple, cost-effective, high performance alternative to the traditional boost and charge pump LED drivers commonly used in handheld applications.

Important Notice

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