Multi-Channel WLED Driver Solution in Single-Cell, Li-Ion Battery Applications by AAT1451/1405/1407 and AAT3110

Introduction

The white LED backlight is very popular in notebook, portable DVD/TV, iPad and similar applications. Larger display screens need greater number of WLEDs to meet their requirement of brightness. General industry consensus is to adopt a step-up converter to drive WLEDs in series with several strings from Li-ion battery.

Panel sizes of 7 inch to 10 inch usually use 24~36 WLEDs in a 4~8 WLEDs in series, 4~6 strings in parallel, configuration for the backlight with 20mA to 30mA maximum WLED current. How to use a multi-channel WLED step-up power management IC to drive so many WLEDs with only a single Li-ion battery as input power is a key design consideration for such applications.

This document gives a solution for the single cell Li-ion battery backlighting application using AAT1451/1405/1407 and AAT3110 to drive the WLEDs. AAT1451/1405 plus AAT3110 is used to drive 6series-4parallel (6S4P) to 8series-4parallel (8S4P) and AAT1407 plus AAT3110 is employed to drive 4series-6parallel (4S6P) to 6series-6parallel (6S6P) configurations. AAT3110 is not required when the system is powered by a 2 cell Li-ion battery. AAT1451/05/07 can be powered directly by the 2 cell Li-ion battery in such applications.

Application Solution

Figure 1 shows the solution structure of the WLED driver by multi-channel WLED boost in Li-ion battery application using AAT1451/05/07 and AAT3110. The battery provides the power to the inductor and AAT3110. The AAT3110-5.0 outputs 5V for AAT1451/05/07.

Figure 1: Solution Structure for Multi-channel WLED Backlight in Li-ion Battery Application
AAT3110, a charge pump device, delivers up to 100mA with three small capacitors, to the voltage regulated output. AAT1451 is a step-up converter white LED driver for netbooks, notebook computers, monitors and portable TVs. It provides a high voltage output to drive multiple strings of series WLEDs. Four precision current sinks can provide constant current drive for up to 44 white LEDs depending upon WLED forward voltage. The WLED current, up to 30mA per string, is set by a single external resistor for a total output current capability of 120mA. External PWM signal is used to dim the WLED. For more detailed information on AAT3110 and AAT1451, please refer to their datasheets.

Figure 2 shows the multi-channel WLED backlight solution in Li-ion battery application with AAT1451 and AAT3110.

AAT1405 and AAT1407 have similar function, structure and driving capability compared to AAT1451. AAT1405 integrates a boost (step-up) converter and provides 45V output for driving series WLEDs. Four precision current sinks are programmable up to 30mA per string through one external RSET resistor, supporting up to 44 white WLEDs at 120mA total output current. AAT1407 integrates a boost (step-up) converter and provides up to 45V output for driving series WLEDs. Six precision current sinks are programmable up to 30mA per string through one external RSET resistor, supporting up to 66 white WLEDs at 180mA total output current.
Multi-Channel WLED Driver Solution in Single-Cell, Li-Ion Battery Applications
by AAT1451/1405/1407 and AAT3110

Figure 3 and Figure 4 show the application solutions using AAT1405 with AAT3110 and AAT1407 with AAT3110.
Design Considerations

The number of WLEDs in the application is determined by the WLED forward voltage, the required maximum LED current, the Schottky diode forward voltage and the output voltage capability of the boost. We will discuss them one by one in this section.

WLED I-V Curve

Whether a WLED backlighting solution is good or not is not only determined by the WLED driver, but also by the selected WLEDs. AAT1451/1405/1407 are specifically intended for driving WLEDs. These devices are suitable to drive most types of WLEDs with forward voltage specifications typically ranging from 2.2V to 4.7V, depending upon supply voltage. WLED applications may include mixed arrangements for display backlighting, keypad display, and any other application that needs a constant current sink generated from a varying input voltage. Since the FB1 to FB4 constant current sinks are matched within 2% with negligible supply voltage dependence, the constant current channels will be matched regardless of the specific WLED forward voltage ($V_F$) levels. The low dropout current sinks in the AAT1451/1405/1407 maximize performance and make them capable of driving WLEDs with high forward voltages.

In the past, the forward voltage of WLED was usually specified around 4V. With the WLED manufacturing technology continuing to improve, the forward voltage has decreased. Currently, there are many WLEDs available with typical forward voltages ($V_F$) in the 2.8 to 3.6V range. The typical I-V curve is shown in Figure 5, the typical forward voltage in the figure is specified to be 3.2V at 20mA.

![Figure 5: WLED I-V curve of RS-0805UW](image)

Schottky Diode I-V Curve

Figure 6 shows the Schottky diode (SS16L) I-V curve. When WLED is in 4 strings and its current is 30mA, the Schottky diode current is 120mA. Under these condition, the forward voltage is 350mV.

DISCONTINUED
Multi-Channel WLED Driver Solution in Single-Cell, Li-Ion Battery Applications
by AAT1451/1405/1407 and AAT3110

**V\textsubscript{OUT} Calculation**

As mentioned above, WLED has a 3.26V typical forward voltage \( V_F \) when \( I_{LED} \) is 30mA. The Schottky diode (DS1) has a typical 0.35V forward voltage \( V_D \) at 120mA forward current. With the sink voltage of feedback 0.5 to 0.9V \( V_{FB} \), we may calculate the required \( V_{OUT} \) which the LED driver needs to output using the following formula:

\[
V_{OUT} = n \cdot V_F + V_{FB}
\]

Where \( n \) is the quantity of WLEDs.

So, for 8 WLEDs in series (8S), the boost output needs to be 27V to obtain 30mA for each WLED as shown by the calculation below.

\[
V_{OUT} = 8 \cdot 3.26V + 0.5\sim0.9V = 26.58\sim26.98V
\]

The actual \( V_{OUT} \) is limited by the switching duty cycle \( D \), \( V_{INV} \), Schottky diode forward \( V_D \) and the boost internal NMOSFET \( V_{DS} \).

\[
(V_{BAT} - V_{DS}) \cdot D = (V_{OUT} + V_D - V_{BAT}) \cdot (1-D)
\]

So,

\[
V_{OUT} = \frac{(V_{BAT} - V_{DS}) \cdot D}{(1-D) + V_{BAT} - V_D}
\]

The maximum switching duty cycle of the three products is 90%. If \( V_{BAT} = 2.7V \), \( V_{OUT} \) can be calculated according to the above equation:

\[
V_{OUT} = \frac{(2.7 - 0.5) \cdot 0.9}{(1-0.9) + 2.7 - 0.35} = 22.15V
\]

With battery voltage decreasing, the \( V_{DS} \) will increase. Here, we assume that \( V_{DS} \) is 0.5V.

So, under 2.7V \( V_{BAT} \), the solution cannot drive 8S WLED with max 30mA each. If \( V_{BAT} = 3.3V \), \( V_{OUT} \) is 28.15V. Then under 3.3V \( V_{BAT} \), the solution can drive 8S WLED with max 30mA each.
Measurement Result

WLED 6S4P (6Series-4Parallel)
For 6S4P WLEDs, there is a total of 24WLEDs as the load. After changing PWM dimming duty and varying the battery voltage, we obtain the measurement results shown in Figure 7. The WLED current changes linearly with PWM dimming duty and can get up to 30mA LED current at full PWM dimming duty.

![LED Current vs PWM Dimming Duty for 8S4P](image)

**Figure 7: I\textsubscript{LED} vs PWM Dimming Duty for 6S4P Configuration**

Figures 8 shows that for 6S4P, the WLED maximum current is 30mA in the V\textsubscript{BAT} range of 2.7V to 4.2V.

![LED Current vs VBAT for 6S4P](image)

**Figure 8: I\textsubscript{LED} vs V\textsubscript{BAT} for 6S4P Configuration**

The curves show that the WLED current can get to 30mA under any battery voltage from 2.7V to 4.2V. So these three products are suitable for the application when the WLED arrays are 6S4P.
**Multi-Channel WLED Driver Solution in Single-Cell, Li-Ion Battery Applications**

**by AAT1451/1405/1407 and AAT3110**

**WLED 8S4P (8Series-4Parallel)**

For 8S4P, 32WLEDs, when the battery voltage is 2.7V, with the increase of PWM dimming duty, WLED current increases until the PWM dimming duty equal to about 80%. When the switching duty gets to its maximum value (90%), WLED current will not increase. See Figure 9.

**Figure 9: I_{LED} vs PWM Dimming Duty for 8S4P Configuration**

Figures 10 shows that when the battery voltage is less than 3.2V, the WLED current cannot get to 30mA as derived earlier.

**Figure 10: I_{LED} vs V_{BAT} for 8S4P Configuration**

DISCONTINUED
Multi-Channel WLED Driver Solution in Single-Cell, Li-Ion Battery Applications
by AAT1451/1405/1407 and AAT3110

WLED 6S6P (6Series-6Parallel)
In a 6S6P configuration, there are 36 WLEDs as the load. Therefore, AAT1407 is used because it has 6 channels for current sink. When the battery voltage drops from 4.2 to 2.9V, WLED current will not change anymore, and when the battery voltage is less than 2.9V, the IC will get into over-temperature protection (OTP) mode because of the increased internal power dissipation.

Figure 11 shows the maximum WLED current is 30mA during the whole battery voltage range from 2.9V to 4.2V.

Conclusion
The solutions using AAT1451, AAT1405 and AAT1407 with AAT3110 meet the application requirements for single-cell, Li-Ion battery to drive 24~36 WLEDs with 30mA maximum LED current. The maximum WLED current is limited by the maximum switching duty cycle for some combinations of array at low battery voltage.

The table below summarizes the details about the solutions using these products.

<table>
<thead>
<tr>
<th>AAT1451/AAT1405 + AAT3110</th>
<th>Maximum WLED current up to 30mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration (Number of WLEDs)</td>
<td>V\textsubscript{BAT} = 2.7~4.2V</td>
</tr>
<tr>
<td>6S4P (24 LEDs)</td>
<td>OK</td>
</tr>
<tr>
<td>7S4P (28 LEDs)</td>
<td>I\textsubscript{LED}=28mA at V\textsubscript{IN}=2.7V</td>
</tr>
<tr>
<td>8S4P (32 LEDs)</td>
<td>I\textsubscript{LED}=23mA at V\textsubscript{IN}=2.7V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AAT1407 + AAT3110</th>
<th>Maximum WLED current up to 30mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration (Number of WLEDs)</td>
<td>V\textsubscript{BAT} = 2.7~4.2V</td>
</tr>
<tr>
<td>4S6P (24 LEDs)</td>
<td>OK</td>
</tr>
<tr>
<td>5S6P (30 LEDs)</td>
<td>OK</td>
</tr>
<tr>
<td>6S6P (36 LEDs)</td>
<td>OTP at V\textsubscript{IN}&lt;2.8V</td>
</tr>
</tbody>
</table>
Multi-Channel WLED Driver Solution in Single-Cell, Li-Ion Battery Applications
by AAT1451/1405/1407 and AAT3110

Copyright © 2012 Skyworks Solutions, Inc. All Rights Reserved.

Information in this document is provided in connection with Skyworks Solutions, Inc. ("Skyworks") products or services. These materials, including the information contained herein, are provided by Skyworks as a service to its customers and may be used for informational purposes only by the customer. Skyworks assumes no responsibility for errors or omissions in these materials or the information contained herein. Skyworks may change its documentation, products, services, specifications or product descriptions at any time, without notice. Skyworks makes no commitment to update the materials or information and shall have no responsibility whatsoever for conflicts, incompatibilities, or other difficulties arising from any future changes.

No license, whether express, implied, by estoppel or otherwise, is granted to any intellectual property rights by this document. Skyworks assumes no liability for any materials, products or information provided hereunder, including the sale, distribution, reproduction or use of Skyworks products, information or materials, except as may be provided in Skyworks Terms and Conditions of Sale.

THE MATERIALS, PRODUCTS AND INFORMATION ARE PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND, WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE, INCLUDING FITNESS FOR A PARTICULAR PURPOSE OR USE, MERCHANTABILITY, PERFORMANCE, QUALITY OR NON-INFRINGEMENT OF ANY INTELLECTUAL PROPERTY RIGHT; ALL SUCH WARRANTIES ARE HEREBY EXPRESSLY DISCLAIMED. SKYWORKS DOES NOT WARRANT THE ACCURACY OR COMPLETENESS OF THE INFORMATION, TEXT, GRAPHICS OR OTHER ITEMS CONTAINED WITHIN THESE MATERIALS. SKYWORKS SHALL NOT BE LIABLE FOR ANY DAMAGES, INCLUDING BUT NOT LIMITED TO ANY SPECIAL, INDIRECT, INCIDENTAL, STATUTORY, OR CONSEQUENTIAL DAMAGES, INCLUDING WITHOUT LIMITATION, LOST REVENUES OR LOST PROFITS THAT MAY RESULT FROM THE USE OF THE MATERIALS OR INFORMATION, WHETHER OR NOT THE RECIPIENT OF MATERIALS HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

Skyworks products are not intended for use in medical, lifesaving or life-sustaining applications, or other equipment in which the failure of the Skyworks products could lead to personal injury, death, physical or environmental damage. Skyworks customers using or selling Skyworks products for use in such applications do so at their own risk and agree to fully indemnify Skyworks for any damages resulting from such improper use or sale.

Customers are responsible for their products and applications using Skyworks products, which may deviate from published specifications as a result of design defects, errors, or operation of products outside of published parameters or design specifications. Customers should include design and operating safeguards to minimize these and other risks. Skyworks assumes no liability for applications assistance, customer product design, or damage to any equipment resulting from the use of Skyworks products outside of stated published specifications or parameters.

Skyworks, the Skyworks symbol, and "Breakthrough Simplicity" are trademarks or registered trademarks of Skyworks Solutions, Inc., in the United States and other countries. Third-party brands and names are for identification purposes only, and are the property of their respective owners. Additional information, including relevant terms and conditions, posted at www.skyworksinc.com, are incorporated by reference.