Texas Instruments

Application Report
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Optimizing Li-ion Power Pack Performance

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ABSTRACT

Power packs or power banks are used to extend run time for mobile devices like smart phones, tablets, and gaming systems. As the cell capacity nears the end of a charge, the cell chemical impedance increases, thus causing the apparent cell voltage to fall. Because the cell is powering a boost converter to provide the 5-V rail, the current increases further to deliver the same power to the load. This increase results in less total capacity being delivered to the load. .

The TPS2511 is a great solution for power banks and can support charging a wide variety of devices including iPads®, Galaxy Tablets™, smart phones, and portable gaming systems.

The TPS3700 is a low quiescent current (I_Q) window comparator IC that has user-settable overvoltage and undervoltage thresholds with independent outputs. These can be used to set a high current mode when then the cell is at full capacity and a lower current mode on the TPS2511 as the cell voltage falls.

This document shows how the TPS3700 combined with the TPS2511 helps maximize the amount of capacity that can be used, while minimizing heat in the power bank.

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1 Introduction

The TPS2511 is a sophisticated, dedicated, charging port controller with a programmable current limit, load droop compensation, and short-circuit current limiting. This device integrates autodetect logic to automatically configure and negotiate with the connected device to provide the correct charging current. Figure 1 shows the block diagram.

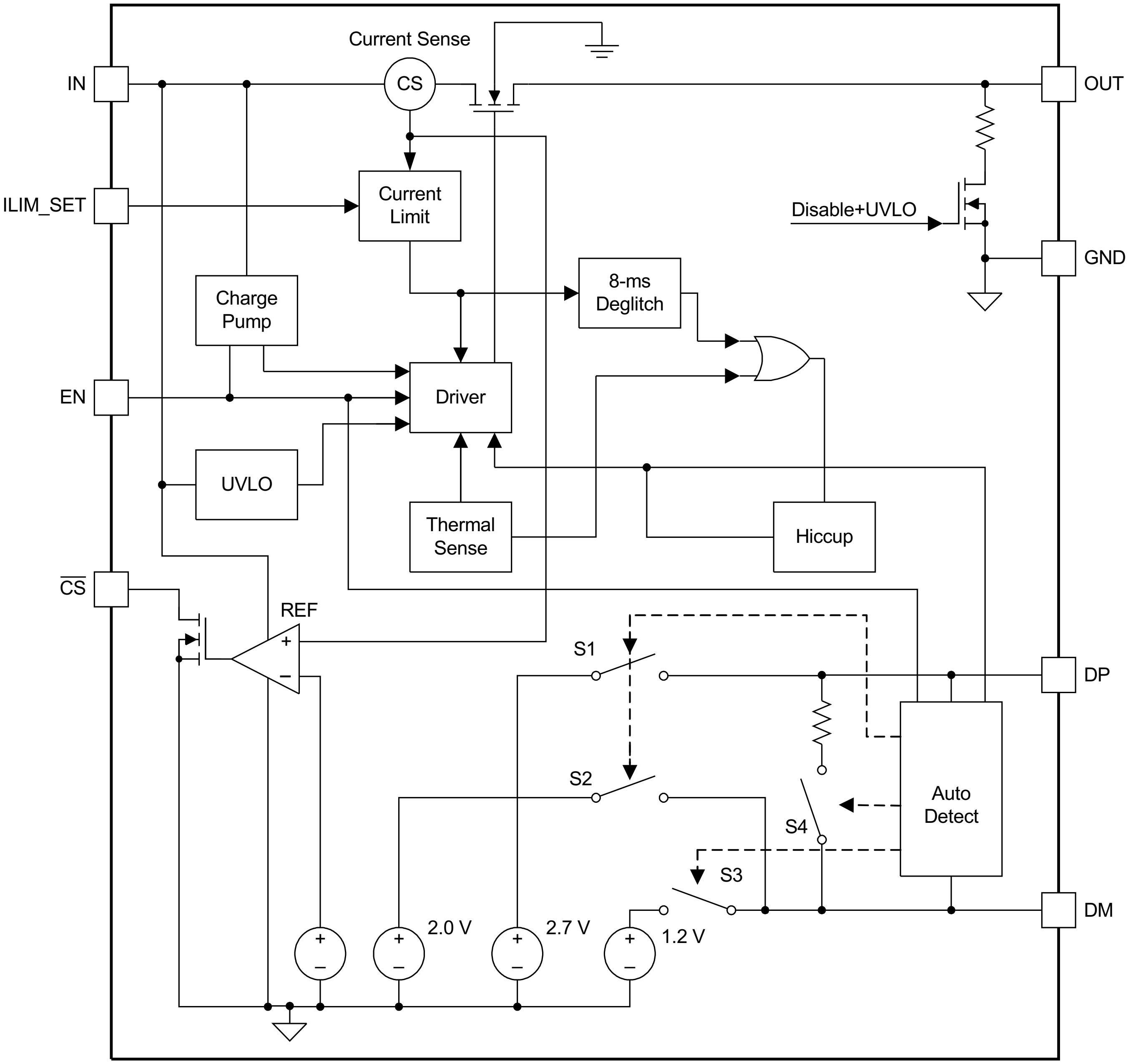

Figure 1. TPS2511 Block Diagram

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The TPS2511, shown at the top of Figure 1, has an embedded N-channel pass switch and internal current limit. The ILIM_SET pin is used to program the current limit. The EN pin enables the device. Because USB cables have an intrinsic parasitic resistance, there is a IR voltage drop from the charging side to the load. Therefore, the voltage at load may be too low to properly charge the battery at higher charging currents. The TPS2511 uses designed-in voltage droop compensation to compensate for this low voltage. When the load current exceeds 1.2 A, the $\overline{CS}$ pin is pulled low, which is used to pull down on the feedback network of the dc-dc converter providing the 5-V rail. This pull-down results in the dc-dc converter raising its output voltage to compensate for the IR voltage drop in the USB cable. This mode of operation is required to meet *Made-for-iPad* requirements.

The TPS3700 is a window comparator with independent undervoltage and overvoltage thresholds and outputs. This device can operate with VDD ranging from 1.8 V to 18 V. If the voltage at the INB– pin rises above the 400-mV threshold, the OUTB pin is pulled low. Correspondingly, if the INA+ pin falls below the 400-mV threshold, the OUTA pin is pulled low. Because this device is designed as a window comparator, the OUTA and OUTB pins are open-drain outputs and can be either tied together or used independently. Figure 2 shows the TPS3700 block diagram.

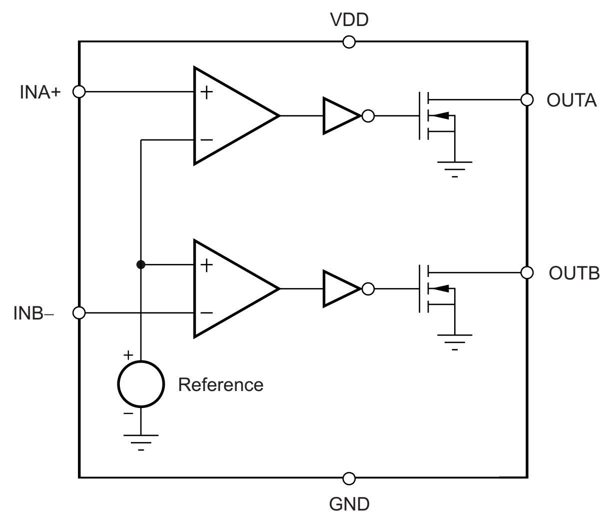

Figure 2. TPS3700 Block Diagram

The intended operation of the TPS3700 is to validate that the input voltage (V_{IN}) is in a proper range before enabling the system; for example, 4.75 V < V_{IN} < 5.25 V. Because the two inputs and outputs can be configured independently, they can be used in the power-bank application to maximize capacity.

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2 Basic Power Bank Structure

Figure 3 shows a very basic block diagram of a power-bank solution. Here, the input voltage may come from either an ac adapter or a USB port. This voltage is used to charge the *1SnP* configuration of Li-ion cells (where *1S* means one series cell and *nP* can be *n* cells in parallel). A battery charger is required to properly charge the cell and a boost converter solution is required to supply 5 V to the USB port. The TPS2511 negotiates with the end device so that it can charge with the proper charging voltage and current.

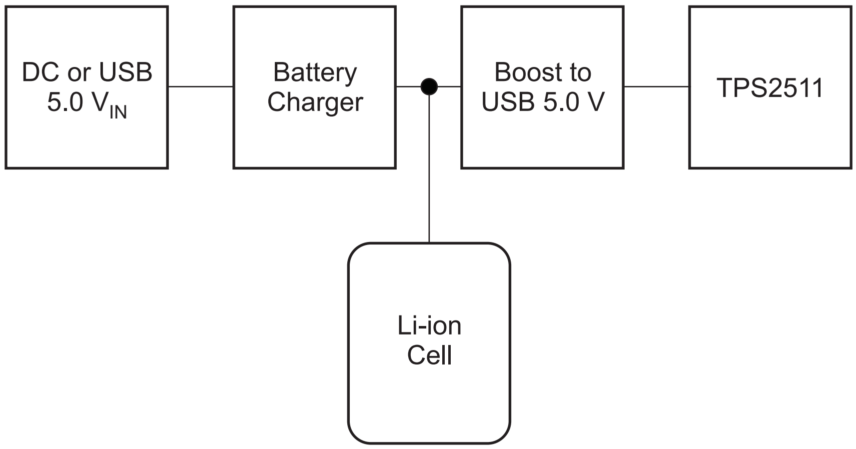

Figure 3. Basic Power Bank Block Diagram

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3 Supporting Dual-Current Limits with the TPS3700

The circuit in Figure 4 shows how the TPS3700 can use the cell voltage to determine the charging current at the load. Additionally, if the battery voltage falls below a set threshold, the TPS3700 can shut down the boost converter completely.

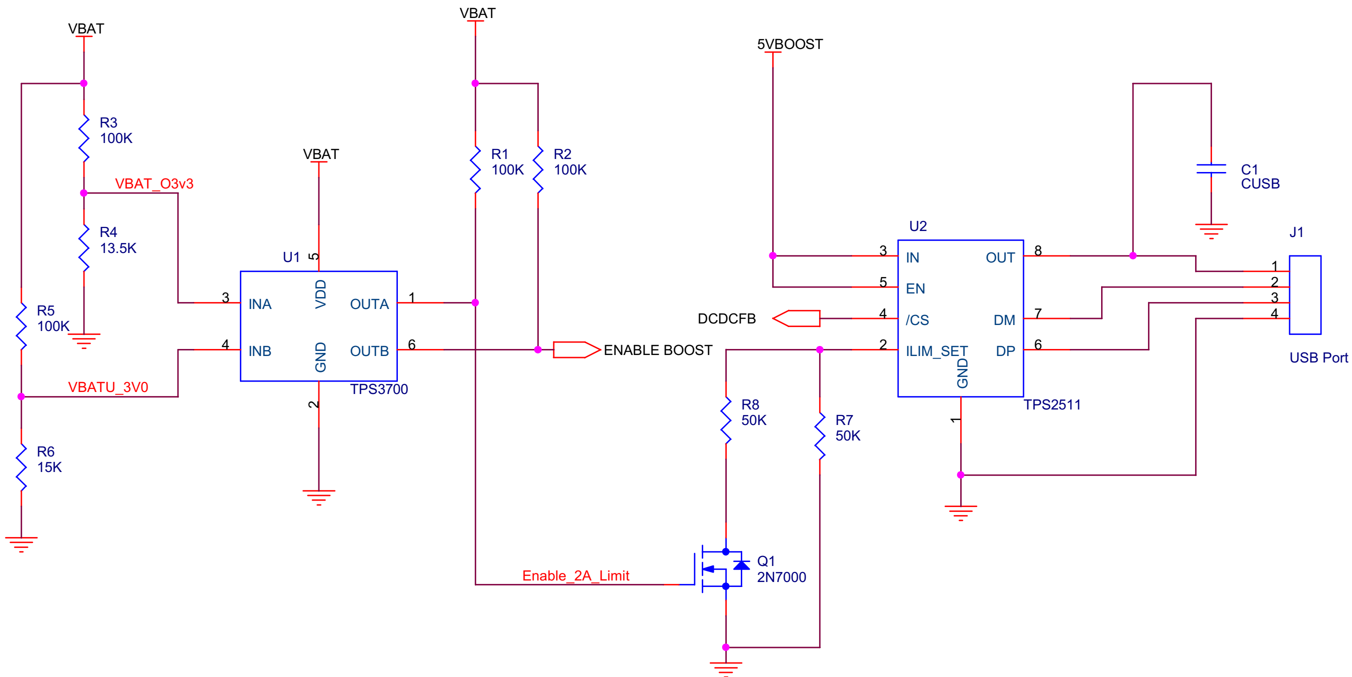

Figure 4. Dynamically Adjusted Current Limit Based On Battery Voltage

In Figure 4, R5 and R6 set the effective undervoltage lockout (UVLO) for the boost converter. With these resistor values, if the voltage were to fall below ~3.0 V, the boost converter is disabled. The voltage threshold (V_{ITP}) is set using Equation 1:

$$V_{ITP} = 0.4\ \text{V} \times \left(\frac{R5 + R6}{R6} \right) \tag{1}$$

The threshold for enabling (or disabling) the higher charge current is set using the same equation, but substituting R3 for R5 and R4 for R6. When the INA input of the TPS3700 rises above the reference threshold, the output of the OUTA pin becomes high impedance and is pulled up to VBAT. When VBAT is greater than the programmed threshold voltage (~3.36 V in this example), the output of OUTA is pulled high. This high state drives the gate of the 2N7002 and changes the current limit from ~1 A to ~2 A. Therefore, while the cell is discharging, and after VBAT falls below ~3.36 V, the current limit falls to ~1 A. The current limit of the TPS2511 is set by Equation 2:

$$I_{LIM} = \frac{51128}{R_{EFF}}$$

where R_{EFF} = either the 50-kΩ resistor or the parallel combination of R7 and R8. (2)

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4 Benefits of Changing Current Limit

Adjusting the charging current limit has two benefits in the power bank application. The first benefit is simply that more of the battery capacity can be delivered to the load. There are two reasons for this; first, there is a fixed impedance of any cell. For example, a typical 18650 Li-ion cylindrical cell usually has a fixed internal impedance of around 80 mΩ. So, as the boost switch current increases from maybe 3 A to say 5 A, the cell physical voltage drops from 240 mV to around 400 mV. There is also the chemical impedance that is inherent in the discharge reaction of the cell itself. As the cell is nearing the end of its charge capacity, this reaction rate slows and therefore the apparent output voltage is reduced as shown in Figure 5.

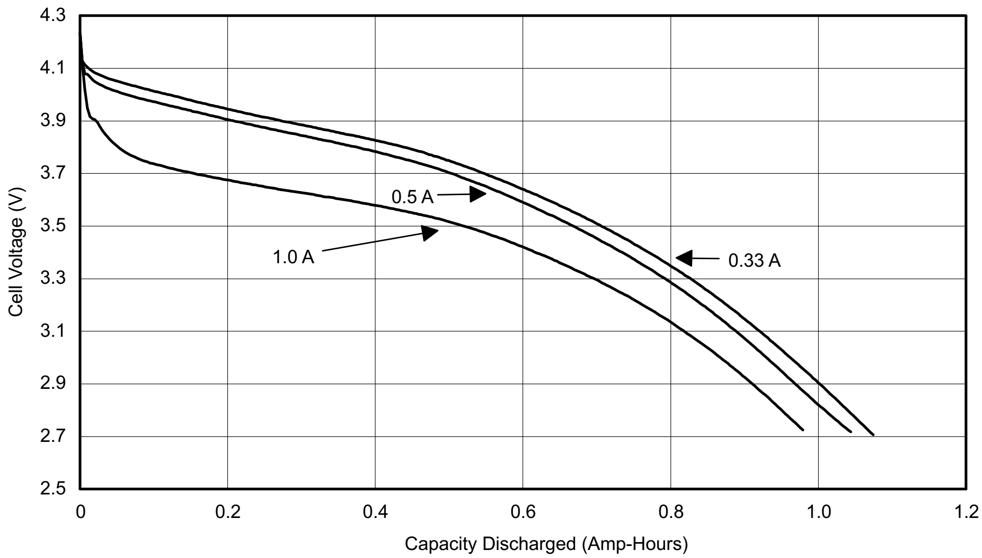

Figure 5. Apparent Voltage vs Discharge Rate

The second benefit of reducing the discharge current when the battery is at lower voltage is simply heating. The efficiency of the boost converter decreases as the switch current increases. As the power bank application is generating 5V for a constant load, the switch current increases as the battery voltage decreases. This translates into diminished conversion efficiency and more heat or power loss in the application.

5 Conclusion

To extend the run time of portable devices, power packs or power banks want to deliver power to the load as efficiently as possible to all know devices. The TPS2511 is a very popular solution for universal chargers as well as power banks. When coupled with the TPS3700 as a voltage based discharge current controller the power bank can deliver more of the cell capacity to the application. This is accomplished by reducing the current limit of the TPS2511 as the cell voltage diminishes to realize more of the real capacity in the cell.

6 References

1. TPS2511 data sheet, SLUSB18, Texas Instruments
2. TPS3700 data sheet, SBVS187B, Texas Instruments
3. Using NiMH and Li-ion in Portable Applications, SLUA015, Texas Instruments

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