Application Report
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Flash Battery Charging Pushes the Boundary of Charging Current

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ABSTRACT

With the development of battery technology and the requirements for electronic products with a longer running time, battery capacity continues to increase. To maintain the existing charging time with increased battery capacity, fast-charging technology is one of the preferred features for smartphones. Existing chargers are divided into linear charger and switching charger. The linear charger is used in small, current-charging applications, such as wearable equipment, because of its lower cost. The linear charger costs less, but the efficiency is also lower, limiting the charging current. The switching charger is used in applications where higher-charging current is required. Texas Instruments is the pioneer of fast-charging devices and has several families of switching chargers that can provide up to 4-A or 5-A current, such as the bq2419x and the bq2589x series. The charging current is limited by the heat generated from the power conversion. The case temperature of the equipment is tied to the user experience, and the temperature inside the case has impact on the life of the electronic products. The power loss must be further reduced to push the boundary of the charging current.

This application report focuses on a new system solution called *flash charger for smartphone battery charger solution*, which can further improve charging efficiency with less power loss so that battery charging with up to 7 A can be achieved.

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1 The Concept of Flash Charging

The operation principles of a flash charger are similar to a linear charger. The difference is that the linear charger has a fixed input voltage, while the flash charger has a variable input voltage. The linear charger regulates the switch as a variable resistor between the input and the output so the output voltage is regulated, while the flash charger has a variable input voltage. The input voltage is regulated to the level of V_{BAT} + I × R, where I is the battery charging current and R is the resistance between the input source and the battery cell. A comparison of the two systems is shown in Figure 1 and Figure 2. There is only conduction loss in the flash charging solution.

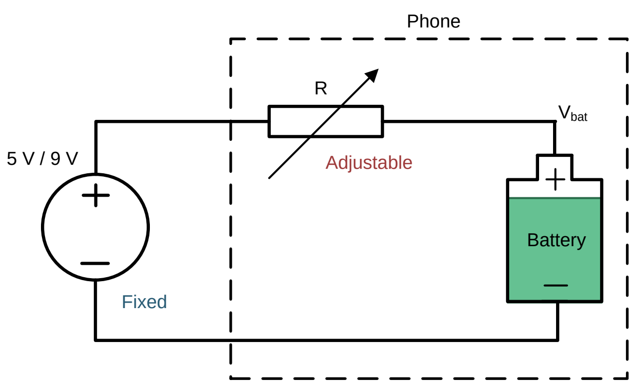

Figure 1. Simplified Linear Charger Solution

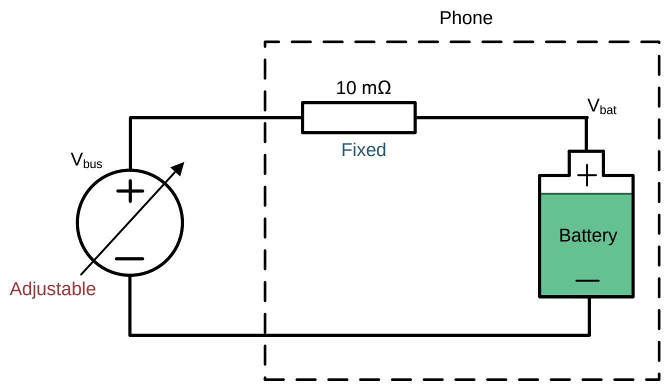

Figure 2. Simplified Flash Charger Solution

When the value of R and the battery voltage are known, the charge current can be controlled by adjusting the voltage drop from V_{BUS} to V_{BAT}.

Compared to the linear charger, the major loss component is removed from the charger. Compared to the switching charger, there is only conduction loss without high-frequency switching loss or inductor loss in the power circuit, so the flash charger is more efficient than a switching charger. The power loss in an enclosed phone affects the user experience, so the maximum charging current is based on the charging efficiency to satisfy the loss budget requirement. In this condition, higher charging current can be achieved under the same loss budget than typical switching charging solutions.

Another major difference is that the flash charger does not need an inductor. A low-profile, high-current, and low-loss inductor is another major hindrance for high-current battery charging.

The flash charger is a system-level solution. The output voltage of the adaptor is adjustable based on the battery voltage and charging current, so the traditional 5-V or 9-V adapter could not be used. The 5-V or 9-V adaptor should be replaced by a specific adaptor that can adjust the output continuously. This replacement will increase the complexity and the cost of the total solution.

2 Integrated Flash Charging Solution

Based on the introduction and analysis in Section 1, TI has developed a series of flash battery-charging solutions, the bq2587x, to achieve more charging current up to 7 A in practical application. This is the first generation of a flash battery-charging solution on the market.

Flash battery charging is a total solution that can be seen in Figure 3. It has two low $R_{DS(on)}$ field-effect transistors (FET) in the power circuit to reduce the conduction loss. The purpose of using two back-to-back FETs instead of one FET is to avoid the backflow from the battery to the adapter side.

Besides the power circuit, the bq25870 integrates a high-precision 10-bit analog-to-digital converter (ADC) to sample voltages and currents while detecting the charging status.

For such flash battery-charging solutions, the protection function is important because the adaptor charges the battery directly without a converter to buffer the voltage spike. Compared to the regular voltage and current protections, the bq25870 has a smarter function called LDO mode to realize the overvoltage protection (OVP) or overcurrent protection (OCP) without disabling charging directly. For example, there is a voltage spike on the adaptor voltage which will induce surge charging current. The first response for this IC is to increase Q1 and Q2's equivalent impedance immediately to regulate the charging current to isolate the spike from the battery. During this period, Q1 and Q2 operate at LDO mode, producing more conduction loss. LDO mode is a transient protection which cannot stay for a long time. The second response is to reduce the adaptor voltage to get Q1 and Q2 out of LDO mode as soon as possible to get less power dissipation. The IC will not enter into LDO mode under the following conditions:

1. The voltage drop from V_{BUS} to V_{BAT} exceeds the threshold. The heat dissipation for Q1 and Q2 has positive correlation with the voltage drop from V_{BUS} to V_{BAT} in LDO mode. The flash charger does not initiate LDO mode under this condition to avoid generating too much heat.
2. The V_{BUS} or I_{BUS} exceeds the overvoltage or overcurrent protection thresholds. The last level of protection is the traditional OVP and OCP. When the IC detects that the input voltage, battery voltage, or input current charging current exceeds the protection threshold, it will turn off the FETs to ensure the safety for the entire system.

The IC can also control the external input OVP FET Q_0. Taking the OVP FET outside the IC can reduce total solution cost comparing integrating OVP FET into the chip.

Alternatively, to increase the compatibility for a flash battery-charging solution with a traditional constant voltage adaptor, TI's fast battery-charging solution IC such as the bq25892 can be used together with the bq25870 to provide up to 5-A charging when a voltage-adjustable adaptor is unavailable.

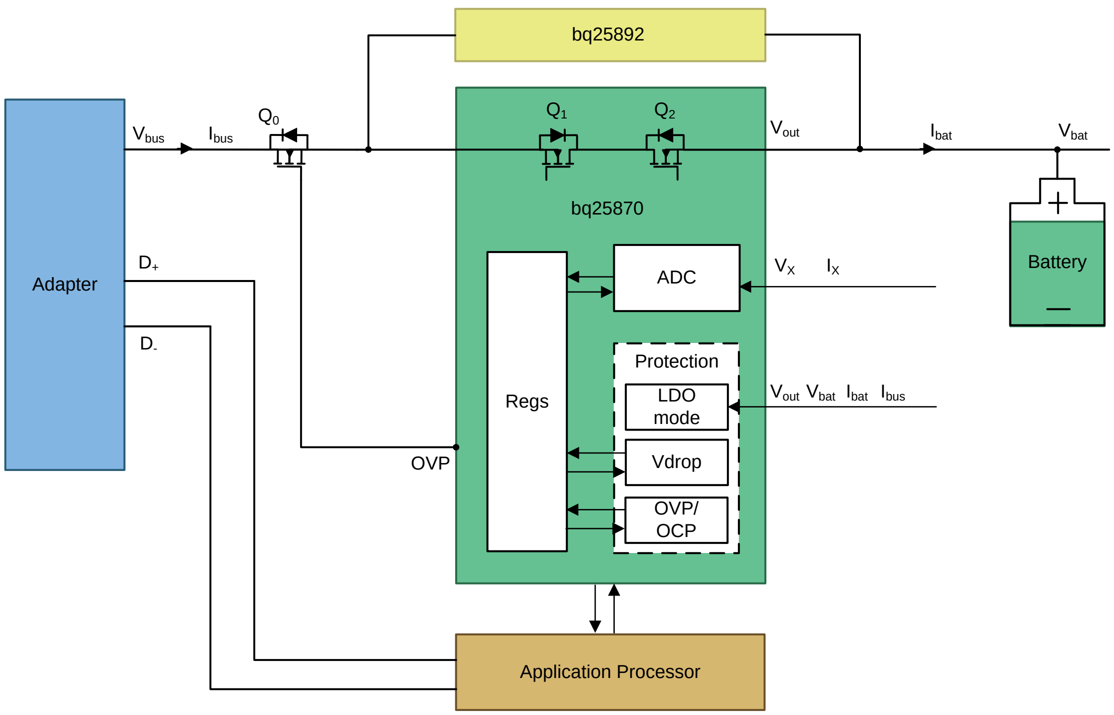

Figure 3. TI's Integrated Solution for Flash Charging

3 Verification With Experiment

In this section, typical operations of flash charging solution based on the bq25870 are tested and verified.

Figure 4 shows the response to I_{BAT} regulation (LDO mode). The flash charger works as it does normally without fault until t1 when there is a decrease on system load current. I_{BUS} also decreases and V_{BUS} has a slight increase due to the circuit impedance, which results in the charging current being greater than regulated value. After 400 µs (typical), the I_{BAT} regulation loop begins to respond by increasing Q1 and Q2's equivalent impedance to control the charging current to the set value. The simplified circuit for response at t1 and t2 can be seen in Figure 5 and Figure 6. Different LDO modes, including I_{BUS} regulation, I_{BAT} regulation, V_{OUT} regulation, and V_{BAT} regulation, work similar.

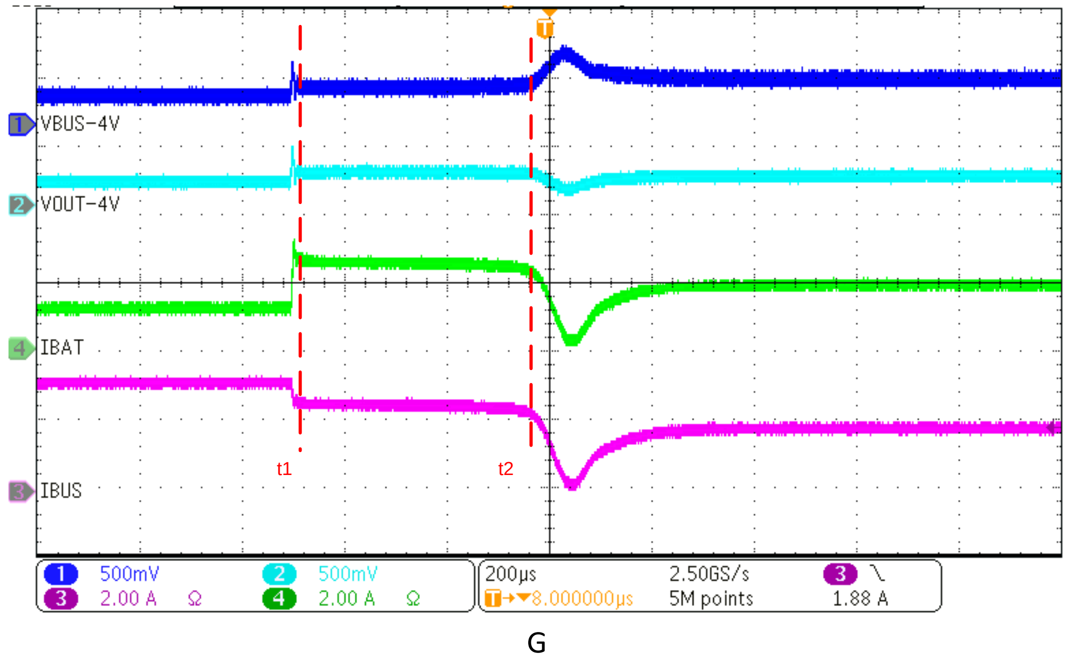

Figure 4. I_{BAT} Regulation Waveform

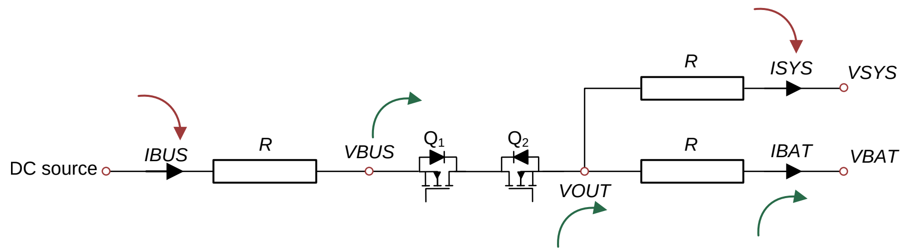

Figure 5. Simplified Circuit at t1

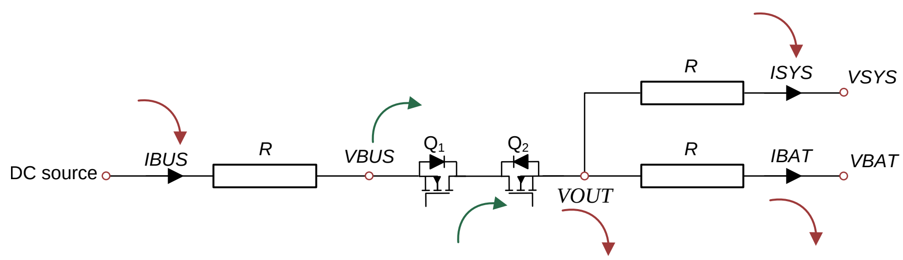

Figure 6. Simplified Circuit at t2

Figure 7 shows the I_{BUS} OCP waveform. From the waveform, we can see that I_{BUS} increases due to the slowly-increased V_{BUS} and hitting the I_{BUS} OCP threshold. Both Q1 and Q2 shut down immediately to protect the battery and the whole system. In this experiment, the other OVP and OCP are disabled except for I_{BUS} OCP in case confusion is caused by multiple protections potentially being triggered. The operation principle for different OVP and OCP are similar.

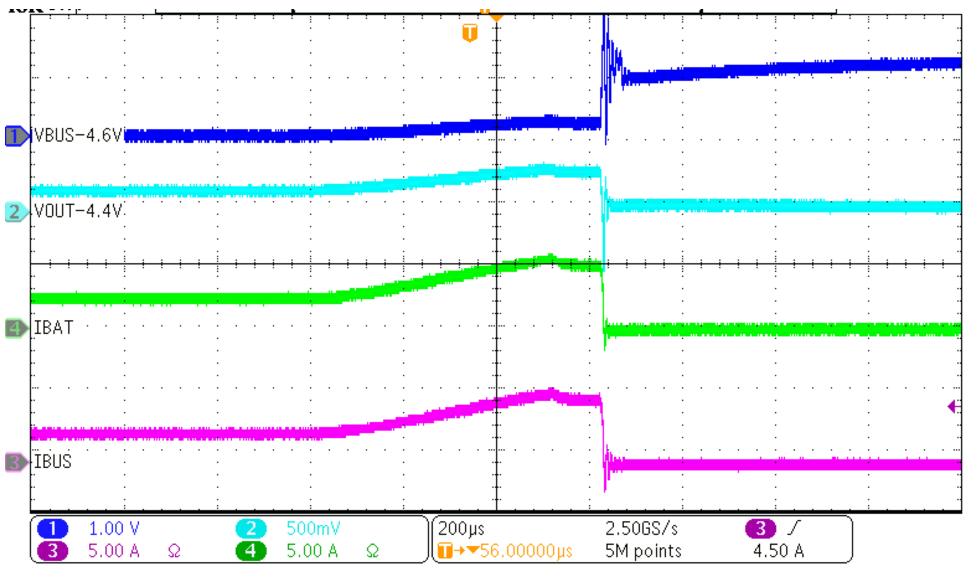

Figure 7. I_{BUS} OCP Waveform

Figure 8 shows the loss comparison of a typical switching charger, bq24196, and a flash charger, bq25870. For the same 1.2-W loss budget, the switching charger can achieve 2.8-A charging current, and flash charging can achieve 6.2-A charging current in an enclosed phone case. From the experiment results, we can see that the boundary of charging current will be pushed by flash battery charging solutions.

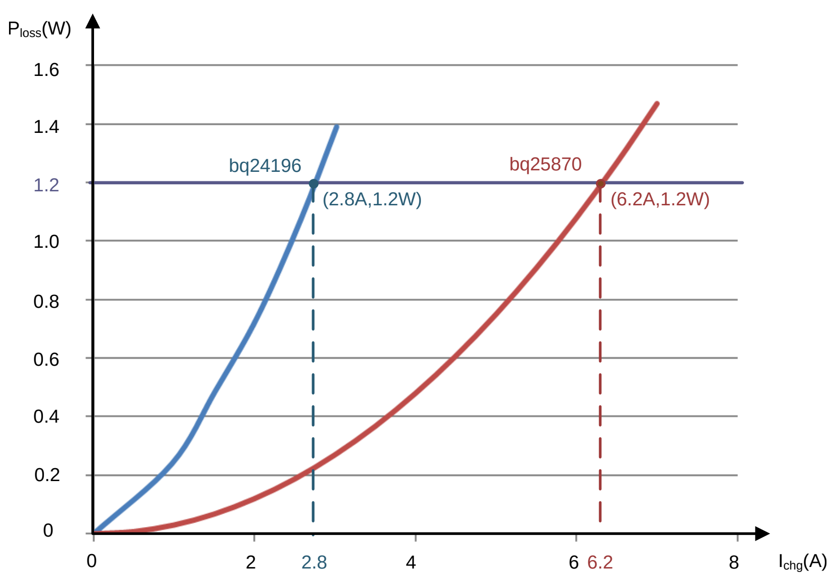

Figure 8. Power Loss Comparison Between Switching Charger and Flash Charger

4 Summary

Most of the battery-charging solutions for smartphones are a switching charger integrated with a Buck converter. However, the efficiency constraint of a switching charger limits the boundaries for charging-current development. Texas Instruments developed flash battery-charging solutions, bq2587x, which can improve the battery-charging efficiency and increase charging current. The voltage-adjusted adaptor charges the battery directly without a converter to limit the power dissipation. Only conduction loss is dissipated in the smartphone without any switching loss or inductor loss. The LDO mode combined with traditional overvoltage and overcurrent protection can ensure the safety for the battery-charging system. The flash battery charging solution, bq2587x, can provide up to 7 A charging current with 96% efficiency along with faster, cooler charging and a longer device lifetime.

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