ABSTRACT
Super Cap is becoming very popular in many applications since its unique feature like more recharge cycle, better transient capacity, simpler charger management and less environment pollution. Typical multi-cell Cap in series requires buck boost topology to charge from empty to full when \( V_{IN} \) is below 5 V. BQ25703A is good device which can perform quick charging, power path and protection function in single chip. This paper discusses how to use it and some considerations in real application.

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1 Typical Application Requirements

1.1 Application Example

- $V_{IN}$: 4.5~5.5 V. // Power source current limit is 0.5 A for USB and 2 A for Adaptor.
- CAP: Two cell in series. //25F/2.7 V for single cell.
- $V_{BAT}$: 0 V — 4.8 V. // CAP from empty(0V) to full ( $V_{CHG} = 4.8$ V).
- $V_{SYS}$ range: 2.8 V~4.8 V. // $V_{sysmin} = 2.8$ V, $V_{CHG} = 4.8$ V.
- Cell balancer function. // 10 k Resistor in parallel with each Cap cell for passive balance.
- Power path function. // When ultra-low $V_{BAT}$ and connect to AC, system start up instant.
- $V_{IN}$ DPM function. // Protect $V_{IN}$ from big drop when reach current limit.
- Cap OVP threshold: 5.2 V ( MAX to 5.4 V ). // Hardware OVP protection.
- Charge time: USB $V_{IN}$ 120 s / Adaptor $V_{IN}$ 30 s. // From $V_{sysmin}$ to $V_{CHG}$.
- Working temp: -40~65 °C ( up to 85 °C )

1.2 Test Equipment

- Agilent E3644 A 5 V / 3 A Power supply
- Tektronix MSO4054 Oscilloscope
- Agilent 34401 A Multi-meter
- TI BQ25703A EVM Board
- EV2400 USB to any board
- TI Battery Management Studio software
- Nesscap Two cell 25 F Super Cap
2 Super Cap Charger Based on BQ25703A

2.1 BQ25703A Key Features

Figure 1. Buck Boost Charger With BQ25703A

BQ2570x series provide the flexibility for different application option, which shows as Table 1.

Table 1. BQ2570x Series Buck Boost Charger

<table>
<thead>
<tr>
<th></th>
<th>BQ25700A</th>
<th>BQ25703A</th>
<th>BQ25708</th>
<th>BQ25710</th>
<th>BQ25713</th>
<th>BQ25713B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>SMBus</td>
<td>I2C</td>
<td>SMBus</td>
<td>SMBus</td>
<td>I2C</td>
<td>I2C</td>
</tr>
<tr>
<td>Device Address</td>
<td>09h</td>
<td>6Bh</td>
<td>09h</td>
<td>09h</td>
<td>6Bh</td>
<td>6Ah</td>
</tr>
<tr>
<td>VAP for IMVP9</td>
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<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pass Through Mode</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>OTG Mode</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>OTG Voltage Range</td>
<td>4.48 V — 20.8 V</td>
<td>4.48 V — 20.8 V</td>
<td>N/A</td>
<td>3 V — 20.8 V</td>
<td>3 V — 20.8 V</td>
<td>3 V — 20.8 V</td>
</tr>
</tbody>
</table>
Table 1. BQ2570x Series Buck Boost Charger (continued)

<table>
<thead>
<tr>
<th></th>
<th>BQ25700A</th>
<th>BQ25703A</th>
<th>BQ25708</th>
<th>BQ25710</th>
<th>BQ25713</th>
<th>BQ25713B</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTG Voltage Resolution</td>
<td>64 mV</td>
<td>64 mV</td>
<td>N/A</td>
<td>8 mV</td>
<td>8 mV</td>
<td>8 mV</td>
</tr>
<tr>
<td>Charging Voltage Resolution</td>
<td>16 mV</td>
<td>16 mV</td>
<td>16 mV</td>
<td>8 mV</td>
<td>8 mV</td>
<td>8 mV</td>
</tr>
</tbody>
</table>

BQ25703A key features list below make it good single chip solutions for two cell super cap buck boost charger with full addition function.

- Large \( V_{IN} \) range: 3.5 V ~ 24 V.
- Buck-boost controller flexible for Multi-cell charging (Li-ion or CAP).
- NVDC power path – Instant-On with deeply discharged CAP.
- High charge current up to 6 A.
- DPM function against power source overload.
- High efficiency and Low Battery Quiescent Current
- IC Safety OVP/OCP/OT protection and integrated comp for flexible protection.
- High accuracy voltage (0.5%) and current regulation (2%).
- Integrated AMP/ADC to monitor charge status easily.

### 2.2 Typical Charging Profile

![Typical Charging Profile with Pre-Charge and Fast-Charge](image)

**Figure 2. Adapter Charging Profile with Pre-Charge and Fast-Charge**

**Setup and Software Configure:**

- * Chose Power supply is adapter 4.5 V ~ 5.5 V / 3 A.
- * Using \( R_{sr} = 5 \, \Omega \) for this example.
- * Set \( CELL\_BATPRESZ \) for 1 Cell start up.
- * Power up. This would automatically enable 256 mA wake up charging current for 30 min. (128 mA for 10 m\( \Omega \)); \( V_{SYS} \) would keep 3.58 V default value.
- * Set \( I_{CHG} = 0 \, A \) (REG0x03/02) would stop wake up charging. And wait software configure.
- * Set \( V_{SYS\_MIN} = 2.8 \, V \) (REG0x0D/0C), \( V_{SYS} \) would change from to 2.8 V immediately.
- * Set \( V_{BAT} = 4.8 \, V \) (REG0x05/04). Full voltage of two cell cap. One cell can set up to 5 V.
- * Check the \( I_{LIM\_HZ} \) when higher \( I_{CHG} > 2 \, A \). Or disable \( I_{LIM\_HZ} \) pin to set input current limit. (REG0x33/32


bit 7=0)

- Set $I_{CHG} = 2.048 \text{ A (REG0x03/02 = 1.024 \text{ A for 10 m\(\Omega\))}}$ would start charging.

2.3 Speed Up Pre-Charge Stage

With the default setting, the pre-charge current is about 384 mA for 10 m\(\Omega\), the charge time from empty to full would reach up to above 100 s. This pre-charge current is fixed in device, two methods we can take to increase it and speed up charge process.

1) Use smaller $R_{sr} = 2 \text{ m\(\Omega\)}$.

Compared with 10 m\(\Omega\), the pre-charge current would increase by 5 times which up to 1.9 A. When fast stage set to 2 A (REG: 0.4 A for 10 ohm), the charging time from empty to full would about 20 s.

![Figure 3. $R_{sr} = 2 \text{ m\(\Omega\)}$](image)

2) Disable LDO Mode

The main reason why pre-charge current small is IC working in LDO mode to key $V_{sysmin}$ when ultra low battery voltage. Disable LDO mode can increase the pre-charge current but this would lose regulate high $V_{sysmin}$, and the current is controlled by $V_{sr}$, $V_{BAT}$ and Cap internal resistance. The charge time would reduce to 40 s.

![Figure 4. LDO Mode](image)  ![Figure 5. Bypass Mode](image)  ![Figure 6. Disable LDO Mode](image)
2.4 **USB 0.5 A Charge**

Some power supply current capacity is low, like USB 2.0 of computer which only have 0.5 A current limit. In these case, when high current charge process would make the $V_{IN}$ drop out and system crashed. Two method can be taken to avoid $V_{IN}$ big drop.

1) **Reduce Precharge Current and Fast Charge Current**

Suggest using large $R_{sr} > 5 \text{ m} \Omega$ to limit the pre-charge current below 0.5 A.

$$\text{Min}(R_{sr}) = 10 \text{ m} \Omega \times \frac{2.8 \text{ V} \times 384 \text{ mA}}{5 \text{ V} \times 0.5 \text{ A} \times 0.9} = 4.7 \text{ m} \Omega$$

(1)

Set $I_{CHG} < 0.4 \text{ A}$ to limit fast charge current below 0.5 A

Below is $R_{sr} = 5 \text{ m} \Omega$ and $I_{CHG} = 0.4 \text{ A}$, which could maintain $V_{IN}$ keep 5 V not drop.

2) **Use Integrated DPM Function**

Figure 12 shows when DPM enabled and $I_{IN}$ is reach up to 0.5 A, the charge current would reduce quick to maintain $V_{IN}$ not drop. DPM function can make full use of any power source supply and avoid system crashed when input power is limited.

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**Figure 9. USB Charging with Lower Current**

**Figure 7. 1 A Fast Charge**

**Figure 8. 0.4 A Fast Charge**

**Figure 10. Without DPM**

**Figure 11. With DPM**

**Figure 12. Charger with $V_{IN}$ DPM Function**
2.5 Cell Passive Balance

Cell balance function is important when mismatch between cells since manufacture and long term running. This could prevent one cell over charge while the other under charge to improve the life cycle of the super cap. Active balancer performance and efficiency are good while the control is complicated and cost is high. Passive balancer is simple and lower cost with tradeoff efficiency.

For 10 K ohm parallel resistance, there would be about 250 µA sell loss current. But compared with a typical 0.5 A current system, this small trickle can be ignored. For longer standby time or lower system current, suggest higher parallel resistance. The test waveform is as Figure 4 which shows cell voltage match well each other when charging.

Figure 15. Passive Cell Balance Function

Figure 13. Passive Balance circuit example

Figure 14. Additional OVP circuit with HIZ
2.6 Hardware OVP Protection

BQ25703A have integrated Battery Overvoltage Protection (BATOVP). The BATOVP threshold is 104% (1 s) or 102% (2 s to 4 s) of regulation voltage set in REG0x05/04().

But in some case, when wrong high V\textsubscript{CHG} setting or software control crashed, you need a additional way to protect OVP protection. BQ25703A have one internal comparator which is very suitable for addition protection like OVP, OCP and thermal protection. One method is using HIZ mode to disconnect V\textsubscript{IN} when OVP. External control to cut off BATFET is another method to consider.

3 Summary

BQ25703A is a good device as buck boost charger for super cap application. Its NVDC power path, DPM function can make system works smarter and not add any cost. Additional feature like hardware OVP and passive balancer make solutions safer in real system.

4 References

- 1. Texas Instruments, SLUSCU1A, BQ25703A product datasheet.
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