Extracting maximum power from an adapter without overload using the bq2589x battery charger ICO feature

ABSTRACT
To maximize the output power of any adaptor to charge battery, the bq2589x family of battery chargers includes the Input Current Optimization (ICO) feature. This application explains how the ICO feature configures the charger input current limit to the maximum allowed in order to avoid overloading the charger input power source.

Contents
1 Background ................................................................................................................... 1
2 Operation ..................................................................................................................... 2
3 Summary ...................................................................................................................... 6

List of Figures
1 Effective input current limit set by VINDPM (VINDPM_ILIM) ................................................ 2
2 Graphical representation of ICO during operation ............................................................. 3
3 Automatic ICO detection after increase in charge current with V(BAT) > VMINSYS .............. 3
4 Automatic ICO detection after increase in charge current with V(BAT) < VMINSYS .............. 4
5 Forced ICO Detection With V(BAT) > VMINSYS ............................................................ 5

List of Tables
1 Current Limit Registers .................................................................................................. 6

Trademarks
All trademarks are the property of their respective owners.

1 Background
Wall adapters used to power portable electronic devices come in a variety of voltage and current ratings. Most battery chargers inside the portable devices include one or more fast response feedback control loops to prevent the charger from pulling too much current from their wall adapter, thereby collapsing it. One such loop is the input current limit dynamic power management (IIINDPM) loop. The designer, through external resistor, I2C register, or the charger D+/D- circuitry automatically sets a predetermined value for the amount of input current the charger is allowed to pull from the adapter. The charger dynamic power path management circuitry then distributes this input power to the system load and uncharged battery, reducing charge current if necessary to provide the demanded dc or transient system load. In the event the adapter cannot provide its rated output current or because of highly resistive connections from the source to the charger, the charger input pin voltage droops. This could also happen when an adapter unknown to D+/D- detection (for example, a 3rd party adapter) is attached and the charger sets the IIINDPM setting too high. When this happens, the second feedback loop, input voltage input dynamic power management or VINDPM, activates and reduces the charge current to prevent the charger from crashing the adapter as highlighted in Figure 1.
Extracting maximum power from an adapter without overload using the bq2589x battery charger ICO feature

At startup, the charger sets a default VINDPM threshold (for example, 600 mV below the unloaded input voltage). The host software can change the INLIM or VINDPM voltage thresholds via I 2 C anytime. If the input voltage droop is due to highly resistive connections, then allowing the charger’s VINDPM loop to continuously be in control and regulate the charger input voltage to prevent further droop is acceptable. If, however, the droop is due to adapter overload, reducing the charger’s input current limit to a level where the adapter is not in overload is preferable. More detail about IINDPM and VINDPM can be found using the SLUA400.

The bq2589x ICO circuitry identifies and sets the maximum (optimal) current the charger can pull from the adapter without collapsing the adapter.

2 Operation

If the bq2589x EN_ILIM bit (REG00[6]) is set, then the actual input current limit is the lower of the value set by the ILIM pin resistor or as reported by the IDPM_ILIM registers (in other words, the ILIM pin resistor clamps the maximum input current limit value). The remainder of the application note assumes EN_ILIM = 0 which results in the IDPM_ILIM reporting the actual input current limit in use.

With ICO disabled (REG02[4] = 0) or until the ICO algorithm has optimized the input current limit, the ICO_OPTIMIZED bit (REG14[6]) = 0 indicating optimization is disabled or in progress. The IDPM_ILIM register (REG13[0:5]) reports the same value as configured in the IINLIM register (REG00[0:5]) by the D+/D- algorithm (bq25890, bq25895) or PSEL bit (bq25892, bq25896) at startup, or by host software.

If ICO is enabled, the charger waits for the first VINDPM event to occur, that is, for the desired system plus charge current power to exceed the power source output power capability, and reports ICO_OPTIMIZED bit (REG14[6]) = 0, meaning ICO optimization is in progress. When V(BAT) > VMINSYS and a VINDPM event has occurred, the ICO algorithm does the following:

- Reduces IDPM_LIM register, the charger maximum allowed input current, to 500 mA then
- steps up the current limit until the input voltage drops to VINDPM threshold then
- lowers the IDPM_ILIM register slightly below the point where VINDPM is reached.
- The ICO_OPTIMIZED bit is set to 1.
Figure 2 is a graphical representation of the ICO algorithm list above. It is assumed that the system load or charge current increases at the point where the VBUS voltage is no longer at the adapter voltage (VADPTR).

![Graphical representation of ICO during operation](image)

Figure 2. Graphical representation of ICO during operation

Figure 3 is a scope shot of ICO in action on a board with 0.5-Ω input resistance from a 6-V supply, 5.3-V VINDPM threshold. The charge current increases from 1 A to 4 A causing the input voltage to droop to VINDPM and triggering and ICO.

![Scope shot of ICO in action](image)

Figure 3. Automatic ICO detection after increase in charge current with V(BAT) > VMINSYS
When \( V(\text{BAT}) < V_{\text{MINSYS}} \), the battery voltage may be too low to supplement a large system load if the charger buck converter is limited to 500 mA and then ramped up by the ICO algorithm. Therefore, when \( V(\text{BAT}) < V_{\text{MINSYS}} \) and a VINDPM event occurs, the ICO algorithm works simpler by:

- setting the input current equal to the IINLIM register value (which is clamped to a lower value by the VINDPM control loop), then
- stepping down the current limit until the charger exits VINDPM control.
- The IDPM_ILIM register is updated to this input current limit value and
- the ICO_OPTIMIZED bit is set to 1.

**Figure 4** is scope shot of this on the same board but with a \( V(\text{BAT}) < V_{\text{MINSYS}} \).
The input current limit remains optimized and will not automatically run the ICO detection algorithm again unless the following occurs:

- another VINDPM event or
- IINLIM register changes or
- VINDPM_OS register (when FORCE_VINDPM=0) changes or
- VINDPM register (when FORCE_VINDPM=1) changes

In addition, for the bq25890/5x parts with D+/D-, if DCP/HVDCP adapter is detected at startup, the ICO algorithm automatically runs.

The host software can also force ICO detection using the FORCE_ICO bit (REG09[7]) or toggling the ENable_ICO (REG02[4]) bit, which defaults to 1. As shown in Figure 5, when forcing detection, the ICO detection algorithm first disables charge for 10 ms and applies a 10 mA sink on BAT, in order to determine whether V(BAT) is greater than or equal to VMINSYS, and then precedes as previously described.

![Figure 5. Forced ICO Detection With V(BAT) > VMINSYS](image-url)
3 Summary

A charges VINDPM loop is the last line of defense in preventing the charger from collapsing its input source, i.e. adapter. While the charger is fully capable of indefinitely regulating its input current limit using the VINDPM loop, running a wall adapter in an overload state is unhealthy for the adapter. The designer sets the input current limit register, either through external ILIM resistor or IINLIM register to match the adapter rated current. In the event of malfunctioning adapters or highly resistive adapter cables, the bq2589x ICO circuitry finds the charger optimal input current limit setting for maximum power extraction without adapter overload. Table 1 summarizes possible cases for input current limit registers.

<table>
<thead>
<tr>
<th>TEST CONDITIONS</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapter</td>
<td>Max ILIM Per Pin Resistor</td>
</tr>
<tr>
<td>Case 1</td>
<td>5 V at 3 A</td>
</tr>
<tr>
<td>Case 2</td>
<td>5 V at 1.5 A</td>
</tr>
<tr>
<td>Case 3</td>
<td>5 V at 3 A</td>
</tr>
<tr>
<td>Case 4</td>
<td>5 V at 3 A</td>
</tr>
</tbody>
</table>
## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

### Changes from A Revision (February 2018) to B Revision

<table>
<thead>
<tr>
<th>Change Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Changed the third paragraph in Section 2</td>
<td>2</td>
</tr>
<tr>
<td>• Changed list item From: Reduces IDPM_LIM to 500 mA then To: Reduces IDPM_LIM register, the charger maximum allowed input current, to 500 mA then</td>
<td>2</td>
</tr>
<tr>
<td>• Changed paragraph From: &quot;In order to ensure that the system...&quot; To: &quot;When V(BAT) &lt; VMINSYS, the battery voltage...&quot; in Section 2</td>
<td>4</td>
</tr>
<tr>
<td>• Changed text From: &quot;0 – ICHG doesn’t require 3.25 A input To: 0 – ICO in progress because ICHG does not require IBUS = 3.25 A in the ICO Status Register column of Table 1</td>
<td>6</td>
</tr>
</tbody>
</table>

### Changes from Original (August 2016) to A Revision

<table>
<thead>
<tr>
<th>Change Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Changed 3.25 A to 3 A in the Case 4 Actual Input Current Limit column of Table 1</td>
<td>6</td>
</tr>
</tbody>
</table>
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2019, Texas Instruments Incorporated