1 Features

- Fully Compliant USB Charger
  - Selectable 100-mA and 500-mA Maximum Input Current
  - 100-mA Maximum Current Limit Ensures Compliance to USB-IF Standard
  - Input-Based Dynamic Power Management ($V_{IN}$-DPM) for Protection Against Poor USB Sources
- 28-V Input Rating with Overvoltage Protection
- Integrated Dynamic Power Path Management (DPPM) Function Simultaneously and Independently Powers the System and Charges the Battery
- Supports up to 1.5-A Charge Current with Current Monitoring Output (ISET)
- Programmable Input Current Limit up to 1.5 A for Wall Adapters
- System Output Tracks Battery Voltage
- Battery Disconnect Function with SYSOFF Input
- Programmable Pre-Charge and Fast-Charge Safety Timers
- Reverse Current, Short-Circuit, and Thermal Protection
- NTC Thermistor Input
- Proprietary Start-up Sequence Limits Inrush Current
- Battery Charge Voltage, $V_{BAT}$:
  - bq24076 - 4.4 V (typ)
  - bq24078 - 4.35 V (typ)
- Status Indication – Charging/Done, Power Good

2 Applications

- Smart Phones
- Portable Media Players
- Portable Navigation Devices
- Low-Power Handheld Devices
- Portable Gaming
- Headsets
- Wearables
- Home Automation
- Portable Medical

3 Description

The bq2407x is a family of integrated Li-Ion battery linear chargers with system power path management functionality targeted at space-constrained portable applications. The devices operate from either a USB port or an AC adapter and support charge currents up to 1.5 A. The input voltage range with input overvoltage protection supports unregulated adapters. The USB input current limit accuracy and start up sequence allow the bq2407x to meet USB-IF inrush current specifications. Additionally, the input dynamic power management ($V_{IN}$-DPM) prevents system crashes because of incorrectly configured USB sources and maximizes the power available from the adapter.

The bq2407x features dynamic power path management (DPPM) that powers the system while simultaneously and independently charging the battery. The DPPM circuit reduces the charge current when the input current limit causes the system output to fall to the DPPM threshold; thus, supplying the system load at all times while monitoring the charge current separately. This feature reduces the number of charge and discharge cycles on the battery, allows for proper charge termination and enables the system to run with a defective or absent battery pack.

Device Information

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bq24076</td>
<td>VQFN (16)</td>
<td>3.00 mm × 3.00 mm</td>
</tr>
<tr>
<td>bq24078</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application Circuit

[Diagram of the bq2407x application circuit]
Table of Contents

1 Features ................................................................. 1
2 Applications .......................................................... 1
3 Description ............................................................. 1
4 Revision History ..................................................... 2
5 Description (continued) ............................................ 3
6 Device Comparison Table ........................................ 3
7 Pin Configuration and Functions ............................... 4
8 Specifications .......................................................... 5
   8.1 Absolute Maximum Ratings ................................. 5
   8.2 ESD Ratings ..................................................... 5
   8.3 Recommended Operating Conditions ..................... 6
   8.4 Thermal Information .......................................... 6
   8.5 Dissipation Ratings ........................................... 6
   8.6 Electrical Characteristics .................................... 7
   8.7 Typical Characteristics ..................................... 9
9 Detailed Description ............................................... 11
   9.1 Overview ..................................................... 11
   9.2 Functional Block Diagram .................................. 12
   9.3 Feature Description ........................................ 13
9.4 Device Functional Modes ..................................... 24
10 Application and Implementation .............................. 26
   10.1 Application Information .................................... 26
   10.2 Typical Application ......................................... 26
11 Power Supply Recommendations .............................. 31
12 Layout ................................................................. 31
   12.1 Layout Guidelines .......................................... 31
   12.2 Layout Example ............................................. 32
   12.3 Thermal Considerations .................................. 33
13 Device and Documentation Support .......................... 34
   13.1 Device Support .............................................. 34
   13.2 Related Links ............................................... 34
   13.3 Receiving Notification of Documentation Updates .... 34
   13.4 Community Resources ..................................... 34
   13.5 Trademarks ................................................ 34
   13.6 Electrostatic Discharge Caution ......................... 34
   13.7 Glossary ...................................................... 34
14 Mechanical, Packaging, and Orderable Information ....... 34

4 Revision History

Changes from Original (October 2017) to Revision A

• Changed $I_{\text{IN}}$ Test Conditions From: $T_J = 85^\circ C$ To: $T_J < 85^\circ C$ in the Electrical Characteristics table ......................... 7
5 Description (continued)
Additionally, the regulated system input enables instant system turn-on when plugged in even with a totally discharged battery. The power-path management architecture also lets the battery supplement the system current requirements when the adapter cannot deliver the peak system currents, thus enabling the use of a smaller adapter.

The battery is charged in three phases: conditioning, constant current, and constant voltage. In all charge phases, an internal control loop monitors the IC junction temperature and reduces the charge current if the internal temperature threshold is exceeded. The charger power stage and charge current sense functions are fully integrated. The charger function has high accuracy current and voltage regulation loops, charge status display, and charge termination. The input current limit and charge current are programmable using external resistors.

6 Device Comparison Table

<table>
<thead>
<tr>
<th>PART NUMBER (1) (2)</th>
<th>V\text{OVP}</th>
<th>V\text{BAT(\text{REG})}</th>
<th>V\text{OUT(\text{REG})}</th>
<th>V\text{DPPM}</th>
<th>OPTIONAL FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>bq24072</td>
<td>6.6 V</td>
<td>4.2 V</td>
<td>V\text{BAT} + 225 mV</td>
<td>V\text{O(\text{REG})} - 100 mV</td>
<td>TD</td>
</tr>
<tr>
<td>bq24073</td>
<td>6.6 V</td>
<td>4.2 V</td>
<td>4.4 V</td>
<td>V\text{O(\text{REG})} - 100 mV</td>
<td>TD</td>
</tr>
<tr>
<td>bq24074</td>
<td>10.5 V</td>
<td>4.2 V</td>
<td>4.4 V</td>
<td>V\text{O(\text{REG})} - 100 mV</td>
<td>ITERM</td>
</tr>
<tr>
<td>bq24075</td>
<td>6.6 V</td>
<td>4.2 V</td>
<td>5.5 V</td>
<td>4.3 V</td>
<td>SYSOFF</td>
</tr>
<tr>
<td>bq24076</td>
<td>6.6 V</td>
<td>4.4 V</td>
<td>V\text{BAT} + 210mV</td>
<td>V\text{BAT} + 100 mV</td>
<td>SYSOFF</td>
</tr>
<tr>
<td>bq24078</td>
<td>6.6 V</td>
<td>4.35 V</td>
<td>V\text{BAT} + 210mV</td>
<td>V\text{BAT} + 100 mV</td>
<td>SYSOFF</td>
</tr>
<tr>
<td>bq24079</td>
<td>6.6 V</td>
<td>4.1 V</td>
<td>5.5 V</td>
<td>4.3 V</td>
<td>SYSOFF</td>
</tr>
</tbody>
</table>

(1) For all available packages, see the orderable addendum at the end of the data sheet
(2) This product is RoHS compatible, including a lead concentration that does not exceed 0.1% of total product weight, and is suitable for use in specified lead-free soldering processes. In addition, this product uses package materials that do not contain halogens, including bromine (Br) or antimony (Sb) above 0.1% of total product weight.
7 Pin Configuration and Functions

### Pin Functions

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAT</td>
<td>I/O</td>
<td>2, 3 I/O</td>
<td>Charger Power Stage Output and Battery Voltage Sense Input. Connect BAT to the positive terminal of the battery. Bypass BAT to VSS with a 4.7-μF to 47-μF ceramic capacitor.</td>
</tr>
<tr>
<td>CE</td>
<td>I</td>
<td>4 I</td>
<td>Charge Enable Active-Low Input. Connect CE to a high logic level to suspend charging. When CE is high, OUT is active and battery supplement mode is still available. Connect CE to a low logic level to enable the battery charger. CE is internally pulled down with approximately 285 kΩ. Do not leave CE unconnected to ensure proper operation.</td>
</tr>
<tr>
<td>CHRG</td>
<td>O</td>
<td>9 O</td>
<td>Open-Drain Charging Status Indication Output. CHG pulls to VSS when the battery is charging. CHG is high impedance when charging is complete and when charger is disabled. Connect CHRG to the desired logic voltage rail using a 1kΩ-100kΩ resistor, or use with an LED for visual indication.</td>
</tr>
<tr>
<td>EN1</td>
<td>I</td>
<td>6 I</td>
<td>Input Current Limit Configuration Inputs. Use EN1 and EN2 control the maximum input current and enable USB compliance. See Table 2 for the description of the operation states. EN1 and EN2 are internally pulled down with ≅285 kΩ. Do not leave EN1 or EN2 unconnected to ensure proper operation.</td>
</tr>
<tr>
<td>EN2</td>
<td>I</td>
<td>5 I</td>
<td>Adjustable Current Limit Programming Input. Connect a 1100-Ω to 8-kΩ resistor from ILIM to VSS to program the maximum input current (EN2=1, EN1=0). The input current includes the system load and the battery charge current. Leaving ILIM unconnected disables all charging.</td>
</tr>
<tr>
<td>IN</td>
<td>I</td>
<td>13 I</td>
<td>Input Power Connection. Connect IN to the external DC supply (AC adapter or USB port). The input operating range is 4.35 V to 6.6 V (bq24076 and bq24078). The input can accept voltages up to 26 V without damage but operation is suspended. Connect bypass capacitor 1 μF to 10 μF to VSS.</td>
</tr>
<tr>
<td>ISET</td>
<td>I/O</td>
<td>16 I/O</td>
<td>Fast Charge Current Programming Input. Connect a 590-Ω to 8.9-kΩ resistor from ISET to VSS to program the fast charge current level. Charging is disabled if ISET is left unconnected. While charging, the voltage at ISET reflects the actual charging current and can be used to monitor charge current. See Charge Current Translator for more details.</td>
</tr>
<tr>
<td>OUT</td>
<td>O</td>
<td>10, 11 O</td>
<td>System Supply Output. OUT provides a regulated output when the input is below the OVP threshold and above the regulation voltage. When the input is out of the operation range, OUT is connected to VBAT except when SYSOFF is high. Connect OUT to the system load. Bypass OUT to VSS with a 4.7-μF to 47-μF ceramic capacitor.</td>
</tr>
<tr>
<td>PGOOD</td>
<td>O</td>
<td>7 O</td>
<td>Open-drain Power Good Status Indication Output. PGOOD pulls to VSS when a valid input source is detected. PGOOD is high-impedance when the input power is not within specified limits. Connect PGOOD to the desired logic voltage rail using a 1-kΩ to 100-kΩ resistor, or use with an LED for visual indication.</td>
</tr>
<tr>
<td>SYSOFF</td>
<td>I</td>
<td>15 I</td>
<td>System Enable Input. Connect SYSOFF high to turn off the FET connecting the battery to the system output. When an adapter is connected, charging is also disabled. Connect SYSOFF low for normal operation. SYSOFF is internally pulled up to VBAT through a large resistor (approximately 5 MΩ). Do not leave SYSOFF unconnected to ensure proper operation.</td>
</tr>
<tr>
<td>Thermal Pad</td>
<td>–</td>
<td>–</td>
<td>There is an internal electrical connection between the exposed thermal pad and the VSS pin of the device. The thermal pad must be connected to the same potential as the VSS pin on the printed circuit board. Do not use the thermal pad as the primary ground input for the device. VSS pin must be connected to ground at all times.</td>
</tr>
<tr>
<td>TMR</td>
<td>I</td>
<td>14 I</td>
<td>Timer Programming Input. TMR controls the pre-charge and fast-charge safety timers. Connect TMR to VSS to disable all safety timers. Connect a 18-kΩ to 72-kΩ resistor between TMR and VSS to program the timers a desired length. Leave TMR unconnected to set the timers to the default values.</td>
</tr>
</tbody>
</table>

---

*Not to scale*
8 Specifications

8.1 Absolute Maximum Ratings\(^{(1)}\)

over the 0°C to 125°C operating free-air temperature range (unless otherwise noted)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_i) Input Voltage</td>
<td>IN (with respect to VSS)</td>
<td>–0.3</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>BAT (with respect to VSS)</td>
<td>–0.3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>OUT, EN1, EN2, CE, TS, ISET, PGOOD, CHG, ILIM, TMR, ITERM, SYSOFF, TD (with respect to VSS)</td>
<td>–0.3</td>
<td>7</td>
</tr>
<tr>
<td>(I_i) Input Current</td>
<td>IN</td>
<td>1.6</td>
<td>A</td>
</tr>
<tr>
<td>(I_O) Output Current (Continuous)</td>
<td>OUT</td>
<td>5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>BAT (Discharge mode)</td>
<td>5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>BAT (Charging mode)</td>
<td>1.5(^{(2)})</td>
<td>A</td>
</tr>
<tr>
<td>Output Sink Current</td>
<td>CHG, PGOOD</td>
<td>15</td>
<td>mA</td>
</tr>
<tr>
<td>(T_J) Junction temperature</td>
<td>–40</td>
<td>150</td>
<td>ºC</td>
</tr>
<tr>
<td>(T_{stg}) Storage temperature</td>
<td>–65</td>
<td>150</td>
<td>ºC</td>
</tr>
</tbody>
</table>

\(^{(1)}\) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability. All voltage values are with respect to the network ground terminal unless otherwise noted.

\(^{(2)}\) The IC operational charging life is reduced to 20,000 hours, when charging at 1.5A and 125°C. The thermal regulation feature reduces charge current if the IC’s junction temperature reaches 125°C; thus without a good thermal design the maximum programmed charge current may not be reached.

8.2 ESD Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{(ESD)}) Electrostatic discharge</td>
<td>Human body model (HBM), per ANSI/ESDA/JEDEC JS-001(^{(1)})</td>
<td>(\pm1500)</td>
</tr>
<tr>
<td></td>
<td>Charged-device model (CDM), per JEDEC specification JESD22-C101(^{(2)})</td>
<td>(\pm500)</td>
</tr>
</tbody>
</table>

\(^{(1)}\) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

\(^{(2)}\) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.
8.3 Recommended Operating Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range</td>
<td>V_in</td>
<td>IN voltage range</td>
<td>4.35</td>
<td>26</td>
<td>V</td>
</tr>
<tr>
<td>Operating voltage range</td>
<td>V_in</td>
<td>IN operating voltage range</td>
<td>4.35</td>
<td>6.4</td>
<td>V</td>
</tr>
<tr>
<td>Input current, IN pin</td>
<td>I_IN</td>
<td>I_in</td>
<td>1.5</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Current, OUT pin</td>
<td>I_OUT</td>
<td>I_OUT</td>
<td>4.5</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Current, BAT pin (Discharging)</td>
<td>I_BAT</td>
<td>I_BAT</td>
<td>4.5</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Current, BAT pin (Charging)</td>
<td>I_CHG</td>
<td>I_CHG</td>
<td>1.5</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Junction Temperature</td>
<td>T_J</td>
<td>T_J</td>
<td>–40</td>
<td>125</td>
<td>°C</td>
</tr>
<tr>
<td>Maximum input current programming resistor</td>
<td>R_LIM</td>
<td>R_LIM</td>
<td>1100</td>
<td>8000</td>
<td>Ω</td>
</tr>
<tr>
<td>Fast-charge current programming resistor</td>
<td>R_SET</td>
<td>R_SET</td>
<td>590</td>
<td>8900</td>
<td>Ω</td>
</tr>
<tr>
<td>Termination current programming resistor</td>
<td>R_TERM</td>
<td>R_TERM</td>
<td>0</td>
<td>15</td>
<td>kΩ</td>
</tr>
<tr>
<td>Timer programming resistor</td>
<td>R_TMR</td>
<td>R_TMR</td>
<td>18</td>
<td>72</td>
<td>kΩ</td>
</tr>
</tbody>
</table>

(1) The IC operational charging life is reduced to 20,000 hours, when charging at 1.5A and 125°C. The thermal regulation feature reduces charge current if the IC’s junction temperature reaches 125°C; thus without a good thermal design the maximum programmed charge current may not be reached.

(2) Use a 1% tolerance resistor for R_SET to avoid issues with the R_SET short test when using the maximum charge current setting.

8.4 Thermal Information

<table>
<thead>
<tr>
<th>Thermal Metric</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction-to-ambient thermal resistance</td>
<td>R_JA</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-case (top) thermal resistance</td>
<td>R_JC(top)</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-board thermal resistance</td>
<td>R_JB</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-top characterization parameter</td>
<td>ψ_JT</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-board characterization parameter</td>
<td>ψ_JB</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-case (bottom) thermal resistance</td>
<td>R_JC(bot)</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.

8.5 Dissipation Ratings

<table>
<thead>
<tr>
<th>Package</th>
<th>R_JA</th>
<th>R_JC</th>
<th>Power Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGT</td>
<td>39.47°C/W</td>
<td>2.4°C/W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T_A</th>
<th>POWER RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 25°C</td>
<td>2.3 W</td>
</tr>
<tr>
<td>= 85°C</td>
<td>225 mW</td>
</tr>
</tbody>
</table>

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.

(2) This data is based on using the JEDEC High-K board and the exposed die pad is connected to a Cu pad on the board. The pad is connected to the ground plane by a 2 x 3 via matrix.
8.6 Electrical Characteristics

Over junction temperature range (0°C ≤ Tj ≤ 125°C) and the recommended supply voltage range (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVLO</td>
<td>Undervoltage lock-out</td>
<td>VCC: 0 V → 4 V</td>
<td>3.2</td>
<td>3.3</td>
<td>3.4</td>
</tr>
<tr>
<td>ITH</td>
<td>Hysteresis on UVLO</td>
<td>VCC: 4 V → 0 V</td>
<td>200</td>
<td>300</td>
<td>mV</td>
</tr>
<tr>
<td>ILIM</td>
<td>Input power detection threshold</td>
<td>Input power detected when VCC &gt; VBAT + ILIM</td>
<td>55</td>
<td>80</td>
<td>130</td>
</tr>
<tr>
<td>ILIM</td>
<td>Hysteresis on ILIM</td>
<td>VCC = 3.6 V, VIN: 3.5 V → 4 V</td>
<td>20</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>VBSUP1</td>
<td>Deglitch time, input power detected status</td>
<td>Time measured from VCC: 0 V → 5 V 1 μs</td>
<td>1.2</td>
<td>ms</td>
<td></td>
</tr>
<tr>
<td>IBSUP1</td>
<td>Input overvoltage protection threshold</td>
<td>VCC: 5 V → 7 V</td>
<td>6.4</td>
<td>6.6</td>
<td>6.8</td>
</tr>
<tr>
<td>IBSUP1</td>
<td>Hysteresis on OVP</td>
<td>VCC: 7 V → 5V</td>
<td>110</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>IBSUP1</td>
<td>Input overvoltage blanking time (OVP fault deglitch)</td>
<td>Time measured from VCC: 11 V → 5 V with 1 μs fall-time to PGOOD = LO</td>
<td>1.2</td>
<td>ms</td>
<td></td>
</tr>
<tr>
<td>QIC</td>
<td>Input overvoltage recovery time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| QUIESCENT CURRENT | | | | |
|-------------------|-----------------|-----|-----|-----|------|
| IBSUP1(LOW)       | Sleep current into BAT pin | ILIM = LO or HI, input power not detected, No load on OUT pin, Tj = 85°C | 4.1 | 7 | μA |
| IBSUP1            | Standby current into IN pin | EN1= HI, EN2=HI, VIN = 6 V, Tj < 85°C | 39 | 50 | μA |
| IBSUP1            | Active supply current, IN pin | EN1= LO, VIN = 6 V, no load on OUT pin, VIN: 3.6 V, RBAT ≥ 8 kΩ | 91 | 200 | mΩ |
| ILIM              | Maximum input current | EN1 = HI, EN2 = LO | 2.2 | mA |
| ILIM              | Maximum input current | EN2 = HI, EN1 = LO | 95 | 100 | mA |
| ILIM              | Programmable input current limit range | EN2 = HI, EN1 = LO, ILIM ≤ 8 kΩ to 1.1 kΩ | 200 | 1500 | mA |
| IBSUP1(LOW)       | OUT pin voltage regulation | VCC > VOUT + ILIM(OUT), VCC ≥ 3.2 V | 3.31 | 3.41 | 3.51 | V |
| IBSUP1            | Maximum input current | EN1 = LO, EN2 = LO | 90 | 95 | 100 | mA |
| ILIM              | Output voltage threshold when input current is reduced | EN2 = LO, EN1 = X | 450 | 475 | 500 | mA |
| IBSUP1            | Output voltage threshold when charging current is reduced | VCC: 125mV | 300 | 475 | mV |
| IBSUP1            | Exit battery supplement mode | VCC: 3.6 V, RBAT = 1.5 kΩ, RLOAD = 10 Ω → 2 Ω | 1500 | 1610 | 1720 | mA |
| IBSUP1            | Battery charge voltage | | 1500 | 1525 | 1720 | mA |
| IBSUP1            | Short-circuit detection threshold, power-off | | 8.8 | 8.8 | 9 | V |
| IBSUP1            | Short-circuit detection threshold, power-on | | 0.8 | 0.9 | 1 | V |
| IBSUP1            | Recovery time, supplement mode short circuit | | 60 | ms |

| BATTERY CHARGER | | | | |
|----------------|-----------------|-----|-----|-----|------|
| IBAT           | Source current for BAT pin short-circuit detection | VCC: 5 V | 4 | 7.5 | 11 | mA |
| IBATSC          | BAT pin short-circuit detection threshold | VCC: 5 V | 1.6 | 1.8 | 2 | V |
| VBATSC          | Battery charge voltage | | 4.358 | 4.4 | 4.44 | V |
| VBATSC          | Pre-charge to fast-charge transition threshold | | 4.31 | 4.35 | 4.39 | V |
| IBSUP1(LOW)     | Deglitch time on pre-charge to fast-charge transition | | 25 | ms |
| IBSUP1(LOW)     | Deglitch time on fast-charge to pre-charge transition | | 25 | ms |
Electrical Characteristics (continued)

Over junction temperature range (0° ≤ Tj ≤ 125°C) and the recommended supply voltage range (unless otherwise noted)
8.7 Typical Characteristics

\(V_{IN} = 6 \text{ V}, \) \(EN1=1, \) \(EN2=0, \) bq24078 application circuit, \(T_A = 25^\circ \text{C}, \) unless otherwise noted.

**Figure 1. Thermal Regulation**

**Figure 2. Dropout Voltage vs Temperature**

**Figure 3. Dropout Voltage vs Temperature No Input Supply**

**Figure 4. bq24078 Output Regulation Voltage vs Battery Voltage**

**Figure 5. bq24078 Output Regulation Voltage vs Temperature**

**Figure 6. bq24076 Output Regulation Voltage vs Temperature**
Typical Characteristics (continued)

$V_{IN} = 6\, \text{V},\, \text{EN1}=1,\, \text{EN2}=0,\, \text{bq24078\, application\, circuit},\, T_A = 25^\circ\, \text{C},\, \text{unless\, otherwise\, noted.}$
9 Detailed Description

9.1 Overview

The bq2407x devices are integrated Li-Ion linear chargers and system power path management devices targeted at space-limited portable applications. The device powers the system while simultaneously and independently charging the battery. This feature reduces the number of charge and discharge cycles on the battery, allows for proper charge termination and enables the system to run with a defective or absent battery pack. This feature also allows instant system turn-on even with a totally discharged battery. The input power source for charging the battery and running the system can be an AC adapter or a USB port. The devices feature Dynamic Power Path Management (DPPM), which shares the source current between the system and battery charging, and automatically reduces the charging current if the system load increases. When charging from a USB port, the input dynamic power management \(V_{\text{IN}}\)-DPM circuit reduces the input current if the input voltage falls below a threshold, thus preventing the USB port from crashing. The power-path architecture also permits the battery to supplement the system current requirements when the adapter cannot deliver the peak system currents.
9.2 Functional Block Diagram
9.3 Feature Description

9.3.1 Undervoltage Lockout (UVLO)

The bq2407x family remains in power down mode when the input voltage at the IN pin is below the undervoltage threshold (UVLO).

During the power down mode the host commands at the control inputs (CE, EN1 and EN2) are ignored. The Q1 FET connected between IN and OUT pins is off, and the status outputs CHG and PGOOD are high impedance. The Q2 FET that connects BAT to OUT is ON. (If SYSOFF is high, Q2 is off). During power down mode, the \( V_{OUT(SC2)} \) circuitry is active and monitors for overload conditions on OUT.

9.3.2 Power On

When \( V_{IN} \) exceeds the UVLO threshold, the bq2407x powers up. While \( V_{IN} \) is below \( V_{BAT} + V_{IN(DT)} \), the host commands at the control inputs (CE, EN1 and EN2) are ignored. The Q1 FET connected between IN and OUT pins is off, and the status outputs CHG and PGOOD are high impedance. The Q2 FET that connects BAT to OUT is ON. (If SYSOFF is high, Q2 is off). During this mode, the \( V_{OUT(SC2)} \) circuitry is active and monitors for overload conditions on OUT.

Once \( V_{IN} \) rises above \( V_{BAT} + V_{IN(DT)} \), PGOOD is driven low to indicate the valid power status and the CE, EN1, and EN2 inputs are read. The device enters standby mode if (EN1 = EN2 = HI) or if an input overvoltage condition occurs. In standby mode, Q1 is OFF and Q2 is ON so OUT is connected to the battery input. (If SYSOFF is high, FET Q2 is off). During this mode, the \( V_{OUT(SC2)} \) circuitry is active and monitors for overload conditions on OUT.

When the input voltage at IN is within the valid range: \( V_{IN} > UVLO \) AND \( V_{IN} > V_{BAT} + V_{IN(DT)} \) AND \( V_{IN} < V_{OVP} \), and the EN1 and EN2 pins indicate that the USB suspend mode is not enabled [(EN1, EN2) ≠ (HI, HI)] all internal timers and other circuit blocks are activated. The device then checks for short-circuits at the ISET and ILIM pins. If no short conditions exists, the device switches on the input FET Q1 with a 100mA current limit to checks for a short circuit at OUT. When \( V_{OUT} \) is above \( V_{O(SC1)} \), the FET Q1 switches to the current limit threshold set by EN1, EN2 and \( R_{ILIM} \) and the device enters into the normal operation. During normal operation, the system is powered by the input source (Q1 is regulating), and the device continuously monitors the status of CE, EN1 and EN2 as well as the input voltage conditions.
Feature Description (continued)

![Startup Flow Diagram](image)

**Figure 13. Startup Flow Diagram**
Feature Description (continued)

9.3.3 Overvoltage Protection (OVP)

The bq2407x accepts inputs up to 28 V without damage. Additionally, an overvoltage protection (OVP) circuit is implemented that shuts off the internal LDO and discontinues charging when $V_{IN} > V_{OVP}$ for a period long than $t_{DGL(OVP)}$. When in OVP, the system output (OUT) is connected to the battery and PGOOD is high impedance. Once the OVP condition is removed, a new power on sequence starts (see Power On). The safety timers are reset and a new charge cycle will be indicated by the CHG output.

9.3.4 Dynamic Power-Path Management

The bq2407x features an OUT output that powers the external load connected to the battery. This output is active whenever a source is connected to IN or BAT. The following sections discuss the behavior of OUT with a source connected to IN to charge the battery and a battery source only.

9.3.4.1 Input Source Connected (ADAPTER or USB)

With a source connected, the dynamic power-path management (DPPM) circuitry of the bq2407x monitors the input current continuously. For the bq24076/78, OUT is regulated to 210 mV above the voltage at BAT. When the BAT voltage falls below 3.2 V, OUT is clamped to 3.41 V. This allows for proper startup of the system load even with a discharged battery. The current into IN is shared between charging the battery and powering the system load at OUT. The bq2407x has internal selectable current limits of 100 mA (USB100) and 500 mA (USB500) for charging from USB ports, as well as a resistor-programmable input current limit.

The bq2407x is USB IF compliant for the inrush current testing. The USB specification allows up to 10 μF to be hard started, which establishes 50 μC as the maximum inrush charge value when exceeding 100 mA. The input current limit for the bq2407x prevents the input current from exceeding this limit, even with system capacitances greater than 10 μF. The input capacitance to the device must be selected small enough to prevent a violation (<10 μF), as this current is not limited. Figure 14 demonstrates the start-up of the bq2407x and compares it to the USB-IF specification.

![USB-IF Inrush Current Test](image)

The input current limit selection is controlled by the state of the EN1 and EN2 pins as shown in the EN1/EN2 Settings table in Pin Configuration and Functions. When using the resistor-programmable current limit, the input current limit is set by the value of the resistor connected from the ILIM pin to VSS, and is given by the equation:

$$I_{IN,MAX} = K_{ILIM}/R_{ILIM}$$

(1)

The input current limit is adjustable up to 1.5 A. The valid resistor range is 1.1 kΩ to 8 kΩ.
Feature Description (continued)

When the IN source is connected, priority is given to the system load. The DPPM and Battery Supplement modes are used to maintain the system load. Figure 16 illustrates examples of the DPPM and supplement modes. These modes are explained in detail in the following sections.

9.3.4.1.1 Input DPM Mode ($V_{IN}$-DPM)

The bq2407x utilizes the $V_{IN}$-DPM mode for operation from current-limited USB ports. When EN1 and EN2 are configured for USB100 (EN2=0, EN1=0) or USB500 (EN2=0, EN1=1) modes, the input voltage is monitored. If $V_{IN}$ falls to $V_{IN-DPM}$, the input current limit is reduced to prevent the input voltage from falling further. This prevents the bq2407x from crashing poorly designed or incorrectly configured USB sources. Figure 15 shows the $V_{IN}$-DPM behavior to a current limited source. In this figure, the input source has a 400-mA current limit and the device is in USB500 mode (EN1=1, EN2=0).

![Figure 15. $V_{IN}$-DPM Waveform](image)

9.3.4.1.2 DPPM Mode

When the sum of the charging and system load currents exceeds the maximum input current (programmed with EN1, EN2, and ILIM pins), the voltage at OUT decreases. Once the voltage on the OUT pin falls to $V_{DPPM}$, the bq2407x enters DPPM mode. In this mode, the charging current is reduced as the OUT current increases in order to maintain the system output. Battery termination is disabled while in DPPM mode.

9.3.4.1.3 Battery Supplement Mode

While in DPPM mode, if the charging current falls to zero and the system load current increases beyond the programmed input current limit, the voltage at OUT reduces further. When the OUT voltage drops below the $V_{BSUP1}$ threshold, the battery supplements the system load. The battery stops supplementing the system load when the voltage at OUT rises above the $V_{BSUP2}$ threshold.

During supplement mode, the battery supplement current is not regulated (BAT-FET is fully on), however there is a short circuit protection circuit built in. Figure 31 demonstrates supplement mode. If during battery supplement mode, the voltage at OUT drops $V_{O(SC2)}$ below the BAT voltage, the OUT output is turned off if the overload exists after $t_{DGL(SC2)}$. The short circuit recovery timer then starts counting. After $t_{REC(SC2)}$, OUT turns on and attempts to restart. If the short circuit remains, OUT is turned off and the counter restarts. Battery termination is disabled while in supplement mode.
9.3.4.2 Input Source Not Connected

When no source is connected to the IN input, OUT is powered strictly from the battery. During this mode the current into OUT is not regulated, similar to Battery Supplement Mode, however the short circuit circuitry is active. If the OUT voltage falls below the BAT voltage by 250 mV for longer than $t_{DGL(SC2)}$, OUT is turned off. The short circuit recovery timer then starts counting. After $t_{REC(SC2)}$, OUT turns on and attempts to restart. If the short circuit remains, OUT is turned off and the counter restarts. This ON/OFF cycle continues until the overload condition is removed.

9.3.5 Battery Charging

Set $CE$ low to initiate battery charging. First, the device checks for a short-circuit on the BAT pin by sourcing $I_{BAT(SC)}$ to the battery and monitoring the voltage. When the BAT voltage exceeds $V_{BAT(SC)}$, the battery charging continues. The battery is charged in three phases: conditioning pre-charge, constant current fast charge (current regulation) and a constant voltage tapering (voltage regulation). In all charge phases, an internal control loop monitors the IC junction temperature and reduces the charge current if an internal temperature threshold is exceeded.

Figure 17 illustrates a normal Li-Ion charge cycle using the bq2407x:
In the pre-charge phase, the battery is charged at with the pre-charge current ($I_{PRECHG}$). Once the battery voltage crosses the $V_{LOWV}$ threshold, the battery is charged with the fast-charge current ($I_{CHG}$). As the battery voltage reaches $V_{BAT(REG)}$, the battery is held at a constant voltage of $V_{BAT(REG)}$ and the charge current tapers off as the battery approaches full charge. When the battery current reaches $I_{TERM}$, the CHG pin indicates charging done by going high-impedance.

Note that termination detection is disabled whenever the charge rate is reduced because of the actions of the thermal loop, the DPPM loop or the $V_{IN(LOW)}$ loop.

The value of the fast-charge current is set by the resistor connected from the ISET pin to VSS, and is given by the equation:

$$I_{CHG} = \frac{K_{ISET}I_{SET}}{R_{ISET}}$$  \hspace{1cm} (2)

The charge current limit is adjustable up to 1.5 A. The valid resistor range is 590 $\Omega$ to 5.9 k$\Omega$. If $I_{CHG}$ is programmed as greater than the input current limit, the battery will not charge at the rate of $I_{CHG}$ but at the slower rate of $I_{IN(MAX)}$ (minus the load current on the OUT pin, if any). In this case, the charger timers will be proportionately slowed down.

### 9.3.5.1 Charge Current Translator

When the charger is enabled, internal circuits generate a current proportional to the charge current at the ISET input. The current out of ISET is $1/400$ ($\pm10\%$) of the charge current. This current, when applied to the external charge current programming resistor, $R_{ISET}$, generates an analog voltage that can be monitored by an external host to calculate the current sourced from BAT.

$$V_{ISET} = \frac{I_{CHARGE}}{400 \times R_{ISET}}$$  \hspace{1cm} (3)
Feature Description (continued)

![Battery Charging Flow Diagram](image)

**Figure 18. Battery Charging Flow Diagram**
Feature Description (continued)

9.3.5.2 Battery Detection and Recharge

The bq2407x automatically detects if a battery is connected or removed. Once a charge cycle is complete, the battery voltage is monitored. When the battery voltage falls below \( V_{RCH} \), the battery detection routine is run. During battery detection, current \( I_{BAT(DET)} \) is pulled from the battery for a duration \( t_{DET} \) to see if the voltage on BAT falls below \( V_{LOWV} \). If not, charging begins. If it does, then it indicates that the battery is missing or the protector is open. Next, the precharge current is applied for \( t_{DET} \) to close the protector if possible. If \( V_{BAT} < V_{RCH} \), then the protector closed and charging is initiated. If \( V_{BAT} > V_{RCH} \), then the battery is determined to be missing and the detection routine continues.

9.3.5.3 Battery Disconnect (SYSOFF Input, bq24076, bq24078)

The bq24076 and bq24078 feature a SYSOFF input that allows the user to turn the FET Q2 off and disconnect the battery from the OUT pin. This is useful for disconnecting the system load from the battery, factory programming where the battery is not installed or for host side impedance track fuel gauging, such as bq27500, where the battery open circuit voltage level must be detected before the battery charges or discharges. The \( /CHG \) output remains low when SYSOFF is high. Connect SYSOFF to VSS, to turn Q2 on for normal operation. SYSOFF is internally pulled to VBAT through \( \sim 5 \, M\Omega \) resistor.

9.3.5.4 Dynamic Charge Timers (TMR Input)

The bq2407x devices contain internal safety timers for the pre-charge and fast-charge phases to prevent potential damage to the battery and the system. The timers begin at the start of the respective charge cycles. The timer values are programmed by connecting a resistor from TMR to VSS. The resistor value is calculated using the following equation:

\[
\begin{align*}
  t_{PRECHG} &= K_{TMR} \times R_{TMR} \\
  t_{MAXCHG} &= 10 \times K_{TMR} \times R_{TMR}
\end{align*}
\]

Leave TMR unconnected to select the internal default timers. Disable the timers by connecting TMR to VSS. Reset the timers by toggling the CE pin, or by toggling EN1, EN2 pin to put the device in and out of USB suspend mode (EN1 = HI, EN2 = HI).

Note that timers are suspended when the device is in thermal shutdown, and the timers are slowed proportionally to the charge current when the device enters thermal regulation.

During the fast charge phase, several events increase the timer durations.

- The system load current activates the DPPM loop which reduces the available charging current
- The input current is reduced because the input voltage has fallen to \( V_{IN(LOW)} \)
- The device has entered thermal regulation because the IC junction temperature has exceeded \( T_{J(REG)} \)

During each of these events, the internal timers are slowed down proportionately to the reduction in charging current. For example, if the charging current is reduced by half for two minutes, the timer clock is reduced to half the frequency and the counter counts half as fast resulting in only one minute of “counting” time.

If the pre charge timer expires before the battery voltage reaches \( V_{LOWV} \), the bq2407x indicates a fault condition. Additionally, if the battery current does not fall to \( I_{TERM} \) before the fast charge timer expires, a fault is indicated. The CHG output flashes at approximately 2 Hz to indicate a fault condition. The fault condition is cleared by toggling CE or the input power, entering/ exiting USB suspend mode, or an OVP event.

9.3.5.5 Status Indicators (PGOOD, CHG)

The bq2407x contains two open-drain outputs that signal its status. The PGOOD output signals when a valid input source is connected. PGOOD is low when \( (V_{BAT} + V_{IN(DT)}) < V_{IN} < V_{OVP} \). When the input voltage is outside of this range, PGOOD is high impedance.

The charge cycle after power-up, CE going low, or exiting OVP is indicated with the CHG pin on (low - LED on), whereas all refresh (subsequent) charges will result in the CHG pin off (open - LED off). In addition, the CHG signals timer faults by flashing at approximately 2 Hz.
9.3.5.6 Thermal Regulation and Thermal Shutdown

The bq2407x contain a thermal regulation loop that monitors the die temperature. If the temperature exceeds $T_{J(REG)}$, the device automatically reduces the charging current to prevent the die temperature from increasing further. In some cases, the die temperature continues to rise despite the operation of the thermal loop, particularly under high $V_{IN}$ and heavy OUT system load conditions. Under these conditions, if the die temperature increases to $T_{J(OFF)}$, the input FET Q1 is turned OFF. FET Q2 is turned ON to ensure that the battery still powers the load on OUT. Once the device die temperature cools by $T_{J(OFF-HYS)}$, the input FET Q1 is turned on and the device returns to thermal regulation. Continuous overtemperature conditions result in a “hiccup” mode. During thermal regulation, the safety timers are slowed down proportionately to the reduction in current limit.

Note that this feature monitors the die temperature of the bq2407x. This is not synonymous with ambient temperature. Self heating exists due to the power dissipated in the IC because of the linear nature of the battery charging algorithm and the LDO associated with OUT. A modified charge cycle with the thermal loop active is shown in Figure 19. Battery termination is disabled during thermal regulation.

---

**Table 2. PGOOD Status Indicator**

<table>
<thead>
<tr>
<th>INPUT STATE</th>
<th>PGOOD OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN} &lt; V_{UVLO}$</td>
<td>High-impedance</td>
</tr>
<tr>
<td>$V_{UVLO} &lt; V_{IN} &lt; V_{BAT} + V_{IN(DT)}$</td>
<td>High-impedance</td>
</tr>
<tr>
<td>$V_{BAT} + V_{IN(DT)} &lt; V_{IN} &lt; V_{OVP}$</td>
<td>Low</td>
</tr>
<tr>
<td>$V_{IN} &gt; V_{OVP}$</td>
<td>High-impedance</td>
</tr>
</tbody>
</table>

**Table 3. CHG Status Indicator**

<table>
<thead>
<tr>
<th>CHARGE STATE</th>
<th>CHG OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging</td>
<td>Low (for first charge cycle)</td>
</tr>
<tr>
<td>Charging suspended by thermal loop</td>
<td>Low</td>
</tr>
<tr>
<td>Safety timers expired</td>
<td>Flashing at 2 Hz</td>
</tr>
<tr>
<td>Charging done</td>
<td></td>
</tr>
<tr>
<td>Recharging after termination</td>
<td>High-impedance</td>
</tr>
<tr>
<td>IC disabled or no valid input power</td>
<td></td>
</tr>
<tr>
<td>Battery absent</td>
<td></td>
</tr>
</tbody>
</table>
9.3.6 Battery Pack Temperature Monitoring

The bq2407x features an external battery pack temperature monitoring input. The TS input connects to the NTC thermistor in the battery pack to monitor battery temperature and prevent dangerous over-temperature conditions. During charging, $I_{NTC}$ is sourced to TS and the voltage at TS is continuously monitored. If, at any time, the voltage at TS is outside of the operating range ($V_{\text{COLD}}$ to $V_{\text{HOT}}$), charging is suspended. The timers maintain their values but suspend counting. When the voltage measured at TS returns to within the operation window, charging is resumed and the timers continue counting. When charging is suspended due to a battery pack temperature fault, the CHG pin remains low and continues to indicate charging.

For applications that do not require the TS monitoring function, connect a 10-kΩ resistor from TS to VSS to set the TS voltage at a valid level and maintain charging.

The allowed temperature range for 103AT-2 type thermistor is 0°C to 50°C. However, the user may increase the range by adding two external resistors. See Figure 20 for the circuit details. The values for $R_s$ and $R_p$ are calculated using the following equations:
\[
R_s = \frac{-(R_{TH} + R_{TC}) \pm \sqrt{(R_{TH} + R_{TC})^2 - 4\left[R_{TH} \times R_{TC} + \frac{V_H \times V_C}{(V_H - V_C) \times I_{TS} \times (R_{TC} - R_{TH})}\right]}}{2}
\]

\[
R_p = \frac{V_H \times (R_{TH} + R_s)}{I_{TS} \times (R_{TH} + R_s) - V_H}
\]

where
- \(R_{TH}\): Thermistor Hot Trip Value found in thermistor data sheet
- \(R_{TC}\): Thermistor Cold Trip Value found in thermistor data sheet
- \(V_H\): IC’s Hot Trip Threshold = 0.3 V nominal
- \(V_C\): IC’s Cold Trip Threshold = 2.1 V nominal
- \(I_{TS}\): IC’s Output Current Bias = 75 µA nominal
- NTC Thermistor Semitec 103AT-4

Rs and Rp 1% values were chosen closest to calculated values in Table 4.

### Table 4. Calculated Values

<table>
<thead>
<tr>
<th>COLD TEMP RESISTANCE AND TRIP THRESHOLD, Ω (°C)</th>
<th>HOT TEMP RESISTANCE AND TRIP THRESHOLD, Ω (°C)</th>
<th>EXTERNAL BIAS RESISTOR, Rs (Ω)</th>
<th>EXTERNAL BIAS RESISTOR, Rp (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28000 (–0.6)</td>
<td>4000 (51)</td>
<td>0</td>
<td>∞</td>
</tr>
<tr>
<td>28480 (–1)</td>
<td>3536 (55)</td>
<td>487</td>
<td>845000</td>
</tr>
<tr>
<td>28480 (–1)</td>
<td>3021 (60)</td>
<td>1000</td>
<td>549000</td>
</tr>
<tr>
<td>33890 (–5)</td>
<td>4026 (51)</td>
<td>76.8</td>
<td>158000</td>
</tr>
<tr>
<td>33890 (–5)</td>
<td>3536 (55)</td>
<td>576</td>
<td>150000</td>
</tr>
<tr>
<td>33890 (–5)</td>
<td>3021 (60)</td>
<td>1100</td>
<td>140000</td>
</tr>
</tbody>
</table>

RHOT and RCOLD are the thermistor resistance at the desired hot and cold temperatures, respectively. The temperature window cannot be tightened more than using only the thermistor connected to TS, it can only be extended.

![Figure 20. Extended TS Pin Thresholds](image-url)
9.4 Device Functional Modes

9.4.1 Sleep Mode
When the input is between UVLO and \(V_{\text{IN(DT)}}\), the device enters sleep mode. After entering sleep mode for >20 ms the internal FET connection between the IN and OUT pin is disabled and pulling the input to ground will not discharge the battery, other than the leakage on the BAT pin. If one has a full 1000-mAHr battery and the leakage is 10 \(\mu\)A, then it would take \(1000 \text{ mAHr} / 10 \mu\text{A} = 100000\) hours (11.4 years) to discharge the battery. The self-discharge of the battery is typically five times higher than this.

9.4.2 Explanation of Deglitch Times and Comparator Hysteresis

**NOTE**

Figure 21 to Figure 25 are not to scale.

---

**Figure 21. Power-Up, Power-Down, Power Good Indication**

**Figure 22. Precharge to Fast-Charge, Fast- to Pre-Charge Transition – \(t_{DGL(1)(LOWV)}\), \(t_{DGL(2)(LOWV)}\)**
Device Functional Modes (continued)

Figure 23. Recharge – $t_{DGL(RCH)}$

Figure 24. OUT Short-Circuit – Supplement Mode

Figure 25. Battery Pack Temperature Sensing – TS Pin. Battery Temperature Increasing
10 Application and Implementation

NOTE
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI’s customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

10.1 Application Information

The bq2407x devices power the system while simultaneously and independently charging the battery. The input power source for charging the battery and running the system can be an AC adapter or a USB port. The devices feature dynamic power-path management (DPPM), which shares the source current between the system and battery charging and automatically reduces the charging current if the system load increases. When charging from a USB port, the input dynamic power management (VIN-DPM) circuit reduces the input current limit if the input voltage falls below a threshold, preventing the USB port from crashing. The power-path architecture also permits the battery to supplement the system current requirements when the adapter cannot deliver the peak system currents.

The bq2407x is configurable to be host controlled for selecting different input current limits based on the input source connected, or a fully stand alone device for applications that do not support multiple types of input sources.

10.2 Typical Application

\[ V_{IN} = UVLO \text{ to } V_{OVP}, \quad I_{FASTCHG} = 800 \text{ mA}, \quad I_{IN(MAX)} = 1.3 \text{ A}, \quad \text{Battery Temperature Charge Range} = 0°C \text{ to } 50°C, \quad 6.25\text{-hour Fastcharge Safety Timer} \]

![Diagram](image-url)

Figure 26. Using bq24076/bq24078 in a Host-Controlled Charger Application
Typical Application (continued)

10.2.1 Design Requirements
- Supply voltage = 5 V
- Fast charge current of approximately 800 mA; ISET - pin 16
- Input current limit = 1.3 A; ILIM - pin 12
- Termination current threshold = 110 mA; ITERM – pin 15 (bq24074 only)
- Safety timer duration, Fast-Charge = 6.25 hours; TMR – pin 14
- TS – Battery Temperature Sense = 10 kΩ NTC (103AT-2)

10.2.2 Detailed Design Procedure

10.2.2.1 bq2407x Charger Design Example
See Figure 26 for a schematic of the design example.

10.2.2.1.1 System ON/OFF (SYSOFF) (bq24076 or bq24078 only)
Connect SYSOFF high to disconnect the battery from the system load. Connect SYSOFF low for normal operation

10.2.2.2 Calculations

10.2.2.2.1 Program the Fast Charge Current (ISET):
\[ R_{ISET} = \frac{K_{ISET}}{I_{CHG}} \]
\[ K_{ISET} = 890 \Omega \text{ from the electrical characteristics table.} \]
\[ R_{ISET} = \frac{890 \Omega}{0.8 \text{ A}} = 1.1125 \text{ kΩ} \]
Select the closest standard value, which for this case is 1.13 kΩ. Connect this resistor between ISET (pin 16) and V_{SS}.

10.2.2.2.2 Program the Input Current Limit (ILIM)
\[ R_{ILIM} = \frac{K_{ILIM}}{I_{ILIM}} \]
\[ K_{ILIM} = 1550 \Omega \text{ from the electrical characteristics table.} \]
\[ R_{ISET} = \frac{1550 \Omega}{1.3 \text{ A}} = 1.192 \text{ kΩ} \]
Select the closest standard value, which for this case is 1.18 kΩ. Connect this resistor between ILIM (pin 12) and V_{SS}.

10.2.2.2.3 Program 6.25-hour Fast-Charge Safety Timer (TMR)
\[ R_{TMR} = \frac{I_{MAXCHG}}{(10 \times K_{TMR})} \]
\[ K_{TMR} = 48 \text{ s/kΩ from the electrical characteristics table.} \]
\[ R_{TMR} = \frac{(6.25 \text{ hr} \times 3600 \text{ s/hr})}{(10 \times 48 \text{ s/kΩ})} = 46.8 \text{ kΩ} \]
Select the closest standard value, which for this case is 46.4 kΩ. Connect this resistor between TMR (pin 2) and V_{SS}.

10.2.2.3 TS Function
Use a 10-kΩ NTC thermistor in the battery pack (103AT-2). For applications that do not require the TS monitoring function, connect a 10-kΩ resistor from TS to VSS to set the TS voltage at a valid level and maintain charging.

10.2.2.4 CHG and PGOOD
LED Status: Connect a 1.5-kΩ resistor in series with a LED between OUT and CHG to indicate charging status. Connect a 1.5-kΩ resistor in series with a LED between OUT and PGOOD to indicate when a valid input source is connected.
Typical Application (continued)

Processor Monitoring Status: Connect a pullup resistor (on the order of 100 kΩ) between the power rail of the processor and CHG and PGOOD.

10.2.2.5 Selecting IN, OUT, and BAT Pin Capacitors

In most applications, all that is needed is a high-frequency decoupling capacitor (ceramic) on the power pin, input, output and battery pins. Using the values shown on the application diagram, is recommended. After evaluation of these voltage signals with real system operational conditions, one can determine if capacitance values can be adjusted toward the minimum recommended values (DC load application) or higher values for fast high amplitude pulsed load applications. Note if designed high input voltage sources (bad adaptors or wrong adaptors), the capacitor needs to be rated appropriately. Ceramic capacitors are tested to 2x their rated values so a 16-V capacitor may be adequate for a 30-V transient (verify tested rating with capacitor manufacturer).
Typical Application (continued)

10.2.3 Application Curves

Figure 27. Adapter Plug-In
Battery Connected

Figure 28. Battery Detection
Battery Inserted

Figure 29. Battery Detection
Battery Removed

Figure 30. Entering and Exiting DPPM Mode

Figure 31. Entering and Exiting Battery Supplement Mode

Figure 32. Entering and Exiting Battery Supplement Mode
Typical Application (continued)

**Figure 33. Charger ON/OFF Using CE**

**Figure 34. OVP Fault**

**Figure 35. System ON/OFF With Input Connected**

**Figure 36. System ON/OFF With Input Not Connected**
11 Power Supply Recommendations

Some adapters implement a half rectifier topology, which causes the adapter output voltage to fall below the battery voltage during part of the cycle. To enable operation with adapters under those conditions, the bq2407x family keeps the charger on for at least 20 msec (typical) after the input power puts the part in sleep mode. This feature enables use of external adapters using 50 Hz networks. The input must not drop below the UVLO voltage for the charger to work properly. Thus, the battery voltage should be above the UVLO to help prevent the input from dropping out. Additional input capacitance may be needed.

12 Layout

12.1 Layout Guidelines

- To obtain optimal performance, the decoupling capacitor from IN to GND (thermal pad) and the output filter capacitors from OUT to GND (thermal pad) should be placed as close as possible to the bq2407x, with short trace runs to both IN, OUT and GND (thermal pad).
- All low-current GND connections should be kept separate from the high-current charge or discharge paths from the battery. Use a single-point ground technique incorporating both the small signal ground path and the power ground path.
- The high current charge paths into IN pin and from the OUT pin must be sized appropriately for the maximum charge current in order to avoid voltage drops in these traces.
- The bq2407x family is packaged in a thermally enhanced MLP package. The package includes a thermal pad to provide an effective thermal contact between the IC and the printed circuit board (PCB); this thermal pad is also the main ground connection for the device. Connect the thermal pad to the PCB ground connection. Full PCB design guidelines for this package are provided in QFN/SON PCB Attachment Application Note (SLUA271).
12.2 Layout Example

Figure 37. Layout Schematic
12.3 Thermal Considerations

The bq24076/78 family is packaged in a thermally enhanced MLP package. The package includes a thermal pad to provide an effective thermal contact between the IC and the printed circuit board (PCB). The power pad should be directly connected to the VSS pin. Full PCB design guidelines for this package are provided in QFN/SON PCB Attachment Application Note (SLUA271). The most common measure of package thermal performance is thermal impedance ($\theta_{JA}$) measured (or modeled) from the chip junction to the air surrounding the package surface (ambient). The mathematical expression for $\theta_{JA}$ is:

$$\theta_{JA} = \frac{T_J - T}{P}$$

where

- $T_J$ = chip junction temperature
- $T$ = ambient temperature
- $P$ = device power dissipation

Factors that can influence the measurement and calculation of $\theta_{JA}$ include:

- Whether or not the device is board mounted
- Trace size, composition, thickness, and geometry
- Orientation of the device (horizontal or vertical)
- Volume of the ambient air surrounding the device under test and airflow
- Whether other surfaces are in close proximity to the device being tested

Due to the charge profile of Li-Ion batteries the maximum power dissipation is typically seen at the beginning of the charge cycle when the battery voltage is at its lowest. Typically after fast charge begins the pack voltage increases to $\approx 3.4$ V within the first 2 minutes. The thermal time constant of the assembly typically takes a few minutes to heat up so when doing maximum power dissipation calculations, $3.4$ V is a good minimum voltage to use. This is verified, with the system and a fully discharged battery, by plotting temperature on the bottom of the PCB under the IC (pad should have multiple vias), the charge current and the battery voltage as a function of time. The fast charge current will start to taper off if the part goes into thermal regulation.

The device power dissipation, $P$, is a function of the charge rate and the voltage drop across the internal PowerFET. It can be calculated from the following equation when a battery pack is being charged:

$$P = (V_{IN} - V_{OUT}) \times I_{OUT} + (V_{OUT} - V_{BAT}) \times I_{BAT}$$

The thermal loop feature reduces the charge current to limit excessive IC junction temperature. It is recommended that the design not run in thermal regulation for typical operating conditions (nominal input voltage and nominal ambient temperatures) and use the feature for non typical situations such as hot environments or higher than normal input source voltage. With that said, the IC will still perform as described, if the thermal loop is always active.
13  Device and Documentation Support

13.1  Device Support

13.1.1  Third-Party Products Disclaimer

TI’S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

13.2  Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

<table>
<thead>
<tr>
<th>PARTS</th>
<th>PRODUCT FOLDER</th>
<th>ORDER NOW</th>
<th>TECHNICAL DOCUMENTS</th>
<th>TOOLS &amp; SOFTWARE</th>
<th>SUPPORT &amp; COMMUNITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>bq24076</td>
<td>Click here</td>
<td>Click here</td>
<td>Click here</td>
<td>Click here</td>
<td>Click here</td>
</tr>
<tr>
<td>bq24078</td>
<td>Click here</td>
<td>Click here</td>
<td>Click here</td>
<td>Click here</td>
<td>Click here</td>
</tr>
</tbody>
</table>

13.3  Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on Alert me to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

13.4  Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

**TI E2E™ Online Community**  *TI's Engineer-to-Engineer (E2E) Community.* Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support**  *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

13.5  Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

13.6  Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

13.7  Glossary

**SLYZ022 — TI Glossary.**
This glossary lists and explains terms, acronyms, and definitions.

14  Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.
## PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan</th>
<th>Lead/Ball Finish</th>
<th>MSL Peak Temp</th>
<th>Op Temp (°C)</th>
<th>Device Marking</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ24076RGTR</td>
<td>ACTIVE</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>3000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-2-260C-1 YEAR</td>
<td>-40 to 85</td>
<td></td>
<td>B24076</td>
</tr>
<tr>
<td>BQ24076RGTT</td>
<td>ACTIVE</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>250</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-2-260C-1 YEAR</td>
<td>-40 to 85</td>
<td></td>
<td>B24076</td>
</tr>
<tr>
<td>BQ24078RGTR</td>
<td>ACTIVE</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>3000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-2-260C-1 YEAR</td>
<td>-40 to 85</td>
<td></td>
<td>B24078</td>
</tr>
<tr>
<td>BQ24078RGTT</td>
<td>ACTIVE</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>250</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU NIPDAU</td>
<td>Level-2-260C-1 YEAR</td>
<td>-40 to 85</td>
<td></td>
<td>B24078</td>
</tr>
</tbody>
</table>

(1) The marketing status values are defined as follows:
**ACTIVE:** Product device recommended for new designs.
**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.
**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) **MSL, Peak Temp.** - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) **Lead/Ball Finish** - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and
continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.
### TAPE AND REEL INFORMATION

#### REEL DIMENSIONS

![Reel Diameter Diagram]

#### TAPE DIMENSIONS

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>Dimension designed to accommodate the component width</td>
</tr>
<tr>
<td>B0</td>
<td>Dimension designed to accommodate the component length</td>
</tr>
<tr>
<td>K0</td>
<td>Dimension designed to accommodate the component thickness</td>
</tr>
<tr>
<td>W</td>
<td>Overall width of the carrier tape</td>
</tr>
<tr>
<td>P1</td>
<td>Pitch between successive cavity centers</td>
</tr>
</tbody>
</table>

#### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

![Quadrant Diagram]

*All dimensions are nominal.*

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0  (mm)</th>
<th>B0  (mm)</th>
<th>K0  (mm)</th>
<th>P1  (mm)</th>
<th>W  (mm)</th>
<th>Pin 1 Quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ24076RGTR</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>3000</td>
<td>330.0</td>
<td>12.4</td>
<td>3.3</td>
<td>3.3</td>
<td>1.1</td>
<td>8.0</td>
<td>12.0</td>
<td>Q2</td>
</tr>
<tr>
<td>BQ24076RGTT</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>250</td>
<td>180.0</td>
<td>12.5</td>
<td>3.3</td>
<td>3.3</td>
<td>1.1</td>
<td>8.0</td>
<td>12.0</td>
<td>Q2</td>
</tr>
<tr>
<td>BQ24078RGTR</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>3000</td>
<td>330.0</td>
<td>12.4</td>
<td>3.3</td>
<td>3.3</td>
<td>1.1</td>
<td>8.0</td>
<td>12.0</td>
<td>Q2</td>
</tr>
<tr>
<td>BQ24078RGTT</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>250</td>
<td>180.0</td>
<td>12.5</td>
<td>3.3</td>
<td>3.3</td>
<td>1.1</td>
<td>8.0</td>
<td>12.0</td>
<td>Q2</td>
</tr>
</tbody>
</table>
TAPE AND REEL BOX DIMENSIONS

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ24076RGTR</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>3000</td>
<td>338.0</td>
<td>355.0</td>
<td>50.0</td>
</tr>
<tr>
<td>BQ24076RGTT</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>250</td>
<td>205.0</td>
<td>200.0</td>
<td>33.0</td>
</tr>
<tr>
<td>BQ24078RGTR</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>3000</td>
<td>338.0</td>
<td>355.0</td>
<td>50.0</td>
</tr>
<tr>
<td>BQ24078RGTT</td>
<td>VQFN</td>
<td>RGT</td>
<td>16</td>
<td>250</td>
<td>205.0</td>
<td>200.0</td>
<td>33.0</td>
</tr>
</tbody>
</table>

*All dimensions are nominal*
Images above are just a representation of the package family, actual package may vary. Refer to the product data sheet for package details.
NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.
NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).

5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
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