PMI8994/PMI8996 Power Management IC

Device Specification

LM80-NT441-15 Rev. C

February 16, 2018
## Revision history

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description</th>
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<tr>
<td>A</td>
<td>December 2014</td>
<td>Initial release</td>
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</tbody>
</table>
| B        | February 2016 | - Removed references to QTI.  
- In Table 3-5, Battery charger specifications, updated footnote 34 on charger switching frequency.  
- In Table 3-28, UVLO Performance Specification: removed 75mV as Vlowbatt step.  
- Removed section 6.3 Daisy chain components  
- Removed Section 6.4 Board-level reliability |
| C        | February 2018 | Updated the document as per the new branding guidelines                     |
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1 Introduction

This document provides a description of chipset capabilities. Not all features are available, nor are all features supported in the software.

NOTE: Enabling some features may require additional licensing fees.

1.1 Documentation overview

This device specification defines the PMI8994/PMI8996 power management IC (PMIC). Technical information for the PMI8994/PMI8996 is primarily covered by the documents listed in Table 1-1; these documents should be studied for a thorough understanding of the IC and its applications. Released PMI8994/PMI8996 documents are posted at https://discuss.96boards.org/c/products/dragonboard820c and are available for download.

Table 1-1 Primary PMI8994/PMI8996 device documentation

<table>
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<th>Document number</th>
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<tr>
<td>LM80-NT411-15</td>
<td>This document provides all PMI8994/PMI8996 electrical and mechanical specifications. Additional material includes pad assignment definitions, shipping, storage, and handling instructions, PCB mounting guidelines, and part reliability. This document can be used by company purchasing departments to facilitate procurement.</td>
</tr>
<tr>
<td>LM80-NT411-17</td>
<td>This document provides a history of PMI8994 revisions. It explains how to identify the various IC revisions and discusses known issues (or bugs) for each revision and how to work around them.</td>
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This PMI8994/PMI8996 device specification is organized as follows:

Chapter 1 Provides an overview of PMI8994/PMI8996 documentation, shows a high-level PMI8994/PMI8996 functional block diagram, lists the device features, and lists terms and acronyms used throughout this document.

Chapter 2 Defines the IC pad assignments.

Chapter 3 Defines the IC electrical performance specifications, including absolute maximum ratings and operating conditions.

Chapter 4 Provides IC mechanical information, including dimensions, markings, ordering information, moisture sensitivity, and thermal characteristics.

Chapter 5 Discusses shipping, storage, and handling of PMI8994/PMI8996 devices.
Chapter 6 Presents procedures and specifications for mounting the PMI8994/PMI8996 onto printed circuit boards (PCBs).

Chapter 7 Presents PMI8994/PMI8996 reliability data, including definitions of the qualification samples and a summary of qualification test results.

1.2 PMI8994/PMI8996 introduction

The PMI8994/PMI8996 (Figure 1-1) supplements the PM8994/PM8996 device to integrate all wireless handset power management, general housekeeping, and user interface support functions into a two IC solution. This versatile solution is suitable for multimode, multiband phones, and other wireless products such as data cards and PDAs.

The PMI8994/PMI8996 mixed-signal BiCMOS device is available in the 210-pad wafer-level nanoscale package (210 WLNSP) that includes ground pads for improved electrical ground, mechanical stability, and thermal conductivity.

Since the PMI8994/PMI8996 includes so many diverse functions, its operation is more easily understood by considering major functional blocks individually. Therefore, the PMI8994/PMI8996 document set is organized by the following device functionality:

- Input power management
- Output power management
- General housekeeping
- User interfaces
- IC interfaces
- Configurable pads – either multipurpose pads (MPPs) or general-purpose input/output (GPIOs) – that can be configured to function within some of the other categories

Most information contained in this device specification is organized accordingly – including the circuit groupings within the block diagram (Figure 1-1), pad descriptions (Chapter 2), and detailed electrical specifications (Chapter 3).
Five major functional blocks:
1) Input power management
2) Output power management
3) General housekeeping
4) User interfaces
5) IC-level interfaces

**PMI8994/PMI8996**
- 4 MPPs
- 10 GPIOs

**Input power management**
- Current paths & controls
- Charger SMPS FETs
- Battery FET & controller
- Fuel Gauge
- WiPower interface

**IC-level interfaces**
- Infrastructure LDOs
- GPIOs
- Memory & controls
- Poweron circuits
- SPMI & interrupt mgr

**Output Power Management**
- Boost/bypass SMPS
- HF-SMPS S1
- FT-SMPS S2 & S3
- VREF
- 5 V Smartboost SMPS

**General housekeeping**
- on-chip clocks
- Clock circuits
- sampled data
- HKADC

**User Interfaces**
- Display bias
- White LED SMPS
- WLED sinks
- Flash/torch drivers
- Haptics
- RGB drivers

**Protection/CP/bypass**
- USB connector
- DC jack or WiPower
- LC network
- Battery Module
- WiPower controls
- Bypass caps

**Others**
- others
- to/from PM

**Other digital functions & analog support**
- AMOLED = active-matrix organic light-emitting diode (display)
- TFT = thin film transistor (display)
- WLED = white LED (high voltage)
- RGB = red/blue/green
- FT-SMPS = fast transient SMPS
- HF-SMPS = high frequency SMPS
- XO = crystal oscillator
- HK = housekeeping

Figure 1-1 High-level PMI8994/PMI8996 functional block diagram
1.3 PMI8994/PMI8996 features

NOTE: Some hardware features integrated within the PMI8994/PMI8996 device must be enabled through the IC software.

1.3.1 Summary of PMI8994/PMI8996 features

Table 1-2 lists the PMI8994/PMI8996 features.

Table 1-2 PMI8994/PMI8996 features

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<td><strong>Input power management</strong></td>
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<td>Battery charger</td>
<td>Switching charger (SCHG) – switched mode battery charger with reverse boost mode capability</td>
</tr>
<tr>
<td></td>
<td>■ Highly efficient (~93% peak efficiency) power conversion eliminates heat issues</td>
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<tr>
<td></td>
<td>■ Supports Qualcomm® Quick Charge™ Technology Charge 2.0 for fast charging</td>
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<tr>
<td></td>
<td>■ Supports parallel charging using SMB1357 companion IC for increased efficiency and lower power dissipation at higher charge currents</td>
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<tr>
<td></td>
<td>■ High charging current in constant current charging mode, up to 3.0 A</td>
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<td></td>
<td>■ Supports trickle charge, precharge, constant current charging, and constant voltage charging</td>
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<tr>
<td></td>
<td>■ Two input paths with automatic and programmable input current limit for universal USB/AC/DC adapter compatibility</td>
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<tr>
<td></td>
<td>■ A4WP Wireless Power (Qualcomm® WiPower™ wireless charging technology) v1.2 support</td>
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<tr>
<td></td>
<td>■ Automatic power source detection, prioritization, and programmable input current limiting per USB charging specification 1.2 (USB2.0/3.0 compliant)</td>
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<tr>
<td></td>
<td>■ Up to 750 mA charging output from a 500 mA USB port using TurboCharge™ Mode</td>
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<td></td>
<td>■ Input/output current path control allows system operation with deeply discharged/missing battery</td>
</tr>
<tr>
<td></td>
<td>■ JEITA and JISC 8714 support</td>
</tr>
<tr>
<td></td>
<td>■ Real-time charge and discharge current measurement</td>
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<tr>
<td></td>
<td>■ +4.0 V to +10 V operating input voltage range</td>
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<tr>
<td></td>
<td>■ +28 V (USB input), +20 V (DC/WiPower input) input voltage tolerance</td>
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<tr>
<td></td>
<td>■ (nonoperating) with overvoltage protection (OVP)</td>
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<tr>
<td></td>
<td>■ USB on-the-go (OTG) support up to 1A (USB OTG standard compliant and USB-IF ACA specification compliant)</td>
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<tr>
<td></td>
<td>■ Reverse boost support for flash LED current, up to 2.5 A</td>
</tr>
<tr>
<td></td>
<td>■ Supports concurrency cases for USB OTG and flash LED</td>
</tr>
<tr>
<td></td>
<td>■ Comprehensive protection features</td>
</tr>
<tr>
<td>WiPower support</td>
<td>■ Based upon the A4WP interface specification</td>
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<td>■ IC-level interfacing signals for WiPower ICs such as the Stark DIV2 charge pump IC</td>
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<td><strong>Fuel gauge</strong></td>
<td>- Optimized mixed algorithm with current and voltage monitoring</td>
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<td>- Highly accurate battery state-of-charge estimation</td>
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<td>- 16-bit dedicated current ADC (15 bits plus sign bit)</td>
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<tr>
<td></td>
<td>- 15-bit dedicated voltage ADC for measuring VBATT, BATT_THERM, BATT_ID, and USB_ID</td>
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<td>- Operates independently of software and reports state of charge without algorithms running on the APQ device:</td>
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<td>- No external non-volatile memory required</td>
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<td></td>
<td>- No external configuration required</td>
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<td></td>
<td>- Precise voltage, current temperature, and aging compensation</td>
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<td></td>
<td>- Complete battery cycling not required to maintain accuracy</td>
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<td></td>
<td>- Missing battery detection</td>
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<td>- Supports multiple battery profile loading via software</td>
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<td><strong>BIF support</strong></td>
<td>Battery Serial Interface (BSI) support for MIPI-BIF enabled battery packs via the BATT_ID pad</td>
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<td><strong>Output voltage regulation</strong></td>
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<td>System rail boost/bypass SMPS</td>
<td>- Integrated boost/bypass SMPS for operation down to battery voltages of 2.5 V</td>
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<td></td>
<td>- True bypass design supporting up to 2 A</td>
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<td><strong>Switched-mode power supplies</strong></td>
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<td>HF-SMPS</td>
<td>- One high frequency SMPS at 1.0 A for transceiver power</td>
</tr>
<tr>
<td></td>
<td>- ~85% peak efficiency</td>
</tr>
<tr>
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<td>- up to 6.4 MHz switching frequency</td>
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<tr>
<td>FT-SMPS</td>
<td>- Two fast transient SMPS at 4 A each, ganged as a dual-phase supply for graphics core power</td>
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<td>- 3.2 MHz switching frequency</td>
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<td>- Autonomous phase control features fast adding for fast changes in load</td>
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<td></td>
<td>- M-phase current balancing enhancements and light load current balancing</td>
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<td>+5 V SmartBoost SMPS</td>
<td>- One at 1.3 A (+5 V) for high-power audio</td>
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<td><strong>General housekeeping</strong></td>
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<td>On-chip ADC</td>
<td>Housekeeping (HK) ADC supports internal and external (via MPPs) monitoring</td>
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<td>Internal clocks</td>
<td>Derived from system 19.2 MHz XO via input from PM8994</td>
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<td>Programmable boot sequence</td>
<td>Programmable boot sequence (PBS) with one time programmable (OTP) memory and user programmable RAM for customizable power-on, power-off, and reset sequences</td>
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<tr>
<td>Display bias supplies</td>
<td>Dual synchronous SMPS topology: Boost and inverting buck-boost</td>
</tr>
<tr>
<td></td>
<td>- Supports thin film transistor LCD (TFT-LCD) and AMOLED</td>
</tr>
<tr>
<td></td>
<td>- 86% efficiency converters for both rails with compact BOM</td>
</tr>
<tr>
<td></td>
<td>- 2.5 V to 4.6 V input voltage range</td>
</tr>
<tr>
<td></td>
<td>- Independently programmable positive and negative output voltages</td>
</tr>
<tr>
<td></td>
<td>- S-Wire interface for programming negative rail</td>
</tr>
<tr>
<td></td>
<td>- Programmable output voltage:</td>
</tr>
<tr>
<td></td>
<td>□ LCD display: +5 V to +6.1 V and -1.4 V to -6.0 V</td>
</tr>
<tr>
<td></td>
<td>□ AMOLED display: +4.6 V to +5 V and -1.4 V to -5.4 V</td>
</tr>
<tr>
<td></td>
<td>- 100 mV resolution on both bias rails</td>
</tr>
<tr>
<td></td>
<td>- Output voltage accuracy of ±1.7% on negative rail and ±0.8% on positive rail</td>
</tr>
<tr>
<td></td>
<td>- 350 mA output current capability on both supply rails</td>
</tr>
<tr>
<td></td>
<td>- Auto output disconnect and active discharge on module shutdown</td>
</tr>
<tr>
<td></td>
<td>- Short circuit protection</td>
</tr>
<tr>
<td></td>
<td>- Auto power sequencing on module enable/disable</td>
</tr>
<tr>
<td></td>
<td>- Anti-ringing compensation on both rails</td>
</tr>
<tr>
<td></td>
<td>- Light load mode for high efficiency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>White LED (WLED) backlighting</th>
<th>Switched-mode boost supply to adaptively boost voltage for series WLEDs together with four regulated current sinks:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Four LED strings of up to 30 mA each, configurable in 2.5 mA steps</td>
</tr>
<tr>
<td></td>
<td>- 28 V maximum boost voltage</td>
</tr>
<tr>
<td></td>
<td>- Hybrid dimming mode (analog dimming at high LED currents, digital dimming at low LED currents)</td>
</tr>
<tr>
<td></td>
<td>- 12-bit analog dimming</td>
</tr>
<tr>
<td></td>
<td>- 9-bit digital dimming</td>
</tr>
<tr>
<td></td>
<td>- Each current sink can be independently controlled via a combination of the brightness control register, full scale current setting register, and an external CABC PWM input.</td>
</tr>
<tr>
<td></td>
<td>- 85% efficiency under typical conditions and 15 mA/string</td>
</tr>
<tr>
<td></td>
<td>- Light load efficiency mode</td>
</tr>
<tr>
<td></td>
<td>- High efficiency always on mode</td>
</tr>
<tr>
<td></td>
<td>- Short circuit detection/protection</td>
</tr>
<tr>
<td></td>
<td>- Isolation of output from input using an external FET</td>
</tr>
<tr>
<td></td>
<td>- Fixed voltage regulation mode for AMOLED panels, supports 7.75 V AMOLED reference</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Red/green/blue (RGB) LED drivers</th>
<th>Three high side current sources for driving LEDs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Independent brightness control of R, G, and B channels.</td>
</tr>
<tr>
<td></td>
<td>- Supports up to 3 LPG channels for PWM dimming (6 or 9 bits of resolution)</td>
</tr>
<tr>
<td></td>
<td>- Sources up to 8 mA per channel</td>
</tr>
<tr>
<td></td>
<td>- Supplied from system-rail boost/bypass for low battery operation</td>
</tr>
<tr>
<td></td>
<td>- ±7% absolute accuracy</td>
</tr>
<tr>
<td></td>
<td>- 300 mV headroom with headroom/dropout detection</td>
</tr>
<tr>
<td>Feature</td>
<td>PMI8994/PMI8996 capability</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------</td>
</tr>
</tbody>
</table>
| **Flash drivers** | Two independent high-side current sources for driving LEDs  
- Up to 1.0 A per channel  
- Flexible to support one LED or two LEDs with 2.0 A maximum current  
- Fully programmable LED currents (0–1.0 A per LED, with 12.5 mA/step)  
- ±8.5% absolute accuracy, ±7% matching accuracy  
- Current ramp up/down control (programmable ramp rate)  
- Current mask upon GSM/PA_ON input  
- Torch mode support at 200 mA per channel  
- Thermal current derating  
- Short/open circuit detection  
- Max-on safety timer, watchdog timer, and thermal shutdown safety |
| **Haptics driver** | One full H-bridge power stage for driving haptics  
- Bidirectional drive capability with support for active braking  
- Support for eccentric rotating machines (ERM)/linear resonant actuators (LRA)  
- Programmable PWM frequency from 25 kHz to 250 kHz, in 25 kHz steps  
- Programmable LRA frequency from 50 Hz to 300 Hz, with a 0.5 Hz tuning resolution  
- 6-bit control for output amplitude from 0 V - Vmax, where Vmax is configurable from 1.2 V to 3.6 V, in 100 mV steps for different LRAs  
- Support for internal 8-bit LUT to store haptics pattern, repeat, and loop  
- Dual PWM for double the effective switching frequency  
- Automatic resonance tracking  
- External input for audio/PWM mode support  
- Short circuit detection and current limit protection |
| **General-purpose current drivers** | Two MPPs can function as static current sinks as their alternate functions  
- Support for up to 40 mA current configurable, in 5 mA steps  
- ±20% accuracy |
| **Light pulse generators** | Four internally routable PWM generators for a variety of functions  
- Selectable PWM clock – 1 kHz, 32 kHz, or 19.2 MHz  
- 6, 7, or 9-bit PWM value from lookup table (LUT) or programmed with SPMI  
- 64-element programmable LUT containing the PWM values to be used for pattern generation  
- Programmable high and low LUT indexes  
- Programmable up or down index counting |
| **IC-level interfaces** | Two-line serial power management interface (MIPI SPMI) |
| **Primary status and control** | Supported by SPMI |
| **Interrupt managers** | Interfacing signals for WiPower ICs |
| **WiPower support** | Battery UICC alarm for graceful shutdown to prevent corruption of UICC on a battery disconnection event |
| **BUA** | |

---

Table 1-2  PMI8994/PMI8996 features (cont.)
### 1.4 Terms and acronyms

Table 1-3 defines terms and acronyms used throughout this document.

#### Table 1-3 Terms and acronyms

<table>
<thead>
<tr>
<th>Term or acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC</td>
<td>Analog-to-digital converter</td>
</tr>
<tr>
<td>API</td>
<td>Application programming interface</td>
</tr>
<tr>
<td>ATC</td>
<td>Auto-trickle charger</td>
</tr>
<tr>
<td>AVS</td>
<td>Adaptive voltage scaling</td>
</tr>
<tr>
<td>BIF</td>
<td>Battery interface</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>DVS</td>
<td>Dynamic voltage scaling</td>
</tr>
<tr>
<td>ERM</td>
<td>Eccentric rotating machine</td>
</tr>
<tr>
<td>FT-SMPS</td>
<td>Fast transient SMPS</td>
</tr>
<tr>
<td>GPIO</td>
<td>General-purpose input/output</td>
</tr>
<tr>
<td>GSM</td>
<td>Global system for mobile communications</td>
</tr>
<tr>
<td>HF-SMPS</td>
<td>High frequency SMPS</td>
</tr>
<tr>
<td>HK</td>
<td>Housekeeping</td>
</tr>
<tr>
<td>ID</td>
<td>Identification</td>
</tr>
<tr>
<td>LDO</td>
<td>Low dropout (linear regulator)</td>
</tr>
<tr>
<td>Li</td>
<td>Lithium</td>
</tr>
</tbody>
</table>
Table 1-3 Terms and acronyms (cont.)

<table>
<thead>
<tr>
<th>Term or acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>Light pulse generator</td>
</tr>
<tr>
<td>LRA</td>
<td>Linear resonance actuator</td>
</tr>
<tr>
<td>MHL</td>
<td>Mobile high-definition link</td>
</tr>
<tr>
<td>MPP</td>
<td>Multipurpose pad</td>
</tr>
<tr>
<td>Mux</td>
<td>Multiplexer</td>
</tr>
<tr>
<td>NSP</td>
<td>Nanoscale package</td>
</tr>
<tr>
<td>OTG</td>
<td>On-the-go</td>
</tr>
<tr>
<td>OTP</td>
<td>One-time programmable</td>
</tr>
<tr>
<td>PA</td>
<td>Power amplifier</td>
</tr>
<tr>
<td>PBM</td>
<td>Pulse burst modulation</td>
</tr>
<tr>
<td>PBS</td>
<td>Programmable boot sequence</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed circuit board</td>
</tr>
<tr>
<td>PDA</td>
<td>Personal digital assistant</td>
</tr>
<tr>
<td>PFM</td>
<td>Pulse frequency modulation</td>
</tr>
<tr>
<td>PLL</td>
<td>Phase locked loop</td>
</tr>
<tr>
<td>PM</td>
<td>Power management</td>
</tr>
<tr>
<td>PMI</td>
<td>Power management interface</td>
</tr>
<tr>
<td>PWM</td>
<td>Pulse width modulation</td>
</tr>
<tr>
<td>QTI</td>
<td>Qualcomm Technologies, Inc.</td>
</tr>
<tr>
<td>RCO</td>
<td>RC oscillator</td>
</tr>
<tr>
<td>SCHG</td>
<td>Switching charger (switch-mode buck for battery charging)</td>
</tr>
<tr>
<td>SMPL</td>
<td>Sudden momentary power loss</td>
</tr>
<tr>
<td>SMPS</td>
<td>Switched-mode power supply (DC-to-DC converter)</td>
</tr>
<tr>
<td>SPMI</td>
<td>System power management interface</td>
</tr>
<tr>
<td>SSC</td>
<td>SMPS step control</td>
</tr>
<tr>
<td>SVS</td>
<td>Static voltage scaling</td>
</tr>
<tr>
<td>TCXO</td>
<td>Temperature-compensated crystal oscillator</td>
</tr>
<tr>
<td>UART</td>
<td>Universal asynchronous receiver/transmitter</td>
</tr>
<tr>
<td>UICC</td>
<td>Universal integrated circuit card</td>
</tr>
<tr>
<td>UIM</td>
<td>User identity module</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal mobile telecommunications system</td>
</tr>
<tr>
<td>USB</td>
<td>Universal serial bus</td>
</tr>
<tr>
<td>UVLO</td>
<td>Under voltage lockout</td>
</tr>
<tr>
<td>VCO</td>
<td>Voltage-controlled oscillator</td>
</tr>
<tr>
<td>WLNSP</td>
<td>Wafer-level NSP</td>
</tr>
<tr>
<td>XO</td>
<td>Crystal oscillator</td>
</tr>
</tbody>
</table>
1.5 Special marks

Special marks used in this document are defined below:

Table 1-4 Special marks

<table>
<thead>
<tr>
<th>Mark</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ]</td>
<td>Brackets ([ ]) sometimes follow a pad, register, or bit name. These brackets enclose a range of numbers. For example, DATA [7:4] may indicate a range that is 4 bits in length, or DATA[7:0] may refer to eight DATA pads.</td>
</tr>
<tr>
<td>_N</td>
<td>A suffix of _N indicates an active low signal. For example, PON_RESET_N.</td>
</tr>
<tr>
<td>0x0000</td>
<td>Hexadecimal numbers are identified with an x in the number, (for example, 0x0000). All numbers are decimal (base 10) unless otherwise specified. Non-obvious binary numbers have the term binary enclosed in parentheses at the end of the number, [for example, 0011 (binary)].</td>
</tr>
<tr>
<td></td>
<td>A vertical bar in the outside margin of a page indicates that a change was made since the previous revision of this document.</td>
</tr>
</tbody>
</table>
2 Pad definitions

The PMI8994/PMI8996 is available in the 210 WLNSP – see Chapter 4 for package details. A high-level view of the pad assignments is shown in Figure 2-1.
Figure 2-1  PMI8994/PMI8996 pad assignments (top view)
2.1 I/O parameter definitions

Table 2-1 I/O description (pad type) parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pad attribute</td>
<td></td>
</tr>
<tr>
<td>AI</td>
<td>Analog input</td>
</tr>
<tr>
<td>AO</td>
<td>Analog output</td>
</tr>
<tr>
<td>DI</td>
<td>Digital input (CMOS)</td>
</tr>
<tr>
<td>DO</td>
<td>Digital output (CMOS)</td>
</tr>
<tr>
<td>PI</td>
<td>Power input; a pad that handles 10 mA or more of current flow into the device ¹</td>
</tr>
<tr>
<td>PO</td>
<td>Power output; a pad that handles 10 mA or more of current flow out of the device ¹</td>
</tr>
<tr>
<td>Z</td>
<td>High-impedance (Hi-Z or Hi-Z) output</td>
</tr>
<tr>
<td>GNDP</td>
<td>Power ground; a pad that handles 10 mA or more of current flow returning to ground. Layout considerations must be made for these pads.</td>
</tr>
<tr>
<td>GNDC</td>
<td>Common ground; a pad that does not handle a significant amount of current flow, typically used for grounding digital circuits and substrates.</td>
</tr>
</tbody>
</table>

GPIO pads, when configured as outputs, have configurable drive strengths that depend upon the GPIO pad’s supply voltage. See electrical specifications in Chapter 3 for details.

1. The maximum current levels expected on PI and PO type pads are listed in Chapter 3.

2.2 Pad descriptions

Descriptions of all pads are presented in the following tables, organized by functional group:

- Table 2-2 Input power management
- Table 2-3 Output power management
- Table 2-4 General housekeeping
- Table 2-5 User interfaces
- Table 2-6 IC-level interfaces
- Table 2-7 Configurable input/output – MPPs and GPIOs
- Table 2-8 Power supply pads
- Table 2-9 Ground pads
### Table 2-2 Pad descriptions – input power management functions

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Charger/OTG interface</strong></td>
</tr>
<tr>
<td>118, 119, 120</td>
<td>DC_IN</td>
<td>PI</td>
<td>One of two potential charger input power sources that can be connected to the DC jack or WiPower. This is a power entry node for the charger and connects to the OVP circuitry.</td>
</tr>
<tr>
<td>193, 194, 195, 208, 209, 210</td>
<td>USB_IN</td>
<td>PI, PO</td>
<td>One of two potential charger input power sources or output during USB-OTG operation. This is a power entry node for the charger and connects to the OVP circuitry.</td>
</tr>
<tr>
<td>186</td>
<td>USB_DM</td>
<td>AI</td>
<td>USB data minus for power source detection only; data transactions are handled by the APQ device.</td>
</tr>
<tr>
<td>171</td>
<td>USB_DP</td>
<td>AI/AO</td>
<td>USB data plus for power source detection only; data transactions are handled by the APQ device.</td>
</tr>
<tr>
<td>146</td>
<td>USB_ID</td>
<td>AI</td>
<td>OTG mode enable or OTG ID monitor. Input that can be used to either enable OTG mode (this function can also be controlled by the OTG enable bit) or to detect the OTG ID resistor value.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Switching charger (SCHG)</strong></td>
</tr>
<tr>
<td>162</td>
<td>BOOT_CAP</td>
<td>AO</td>
<td>Charger bootstrap node for bootstrapping the charger startup bias network with input power before starting the SCHG.</td>
</tr>
<tr>
<td>133, 134, 135</td>
<td>MID_DC_IN</td>
<td>AO</td>
<td>Mid-FET capacitor node for accurate current level sensing through OVP FETs of DC_IN; called mid-FET capacitor due to its placement between the OVP FET and the high-side switching FET.</td>
</tr>
<tr>
<td>178, 179, 180</td>
<td>MID_USB_IN</td>
<td>AO</td>
<td>Mid-FET capacitor node for accurate current level sensing through OVP FETs of USB_IN; called mid-FET capacitor due to its placement between the OVP FET and the high-side switching FET.</td>
</tr>
<tr>
<td>173, 188, 202, 203</td>
<td>VBATT</td>
<td>PI, PO</td>
<td>Battery voltage node, connects to BATFET. Output is for charging, and input is for all other operations.</td>
</tr>
<tr>
<td>187</td>
<td>VBATT_SNS</td>
<td>AI</td>
<td>Battery voltage sense input.</td>
</tr>
<tr>
<td>161</td>
<td>VDIR_CHG</td>
<td>AO, DI</td>
<td>Battery charge to discharge the status pad, indicating charge current and charge direction (analog output voltage is proportional to charge current). Can be configured as a digital input to indicate that PA activity is upcoming.</td>
</tr>
<tr>
<td>174, 189, 204, 205</td>
<td>VPH_PWR</td>
<td>PI, PO</td>
<td>Primary system supply node, SCHG regulated node.</td>
</tr>
<tr>
<td>148, 149, 150</td>
<td>DC_IN_OUT</td>
<td>PO</td>
<td>OVP-protected output directly from either DCIN or USBIN. This pad is also the regulated output for the SMBC operating in reverse boost mode to supply USB OTG host mode and/or camera flash.</td>
</tr>
<tr>
<td>163, 164, 165, 176, 177</td>
<td>VSW_CHG</td>
<td>PI, PO</td>
<td>Charger SMPS switching node.</td>
</tr>
<tr>
<td>147</td>
<td>SYSON</td>
<td>PO</td>
<td>Auxiliary supply that provides an OVP-protected 5 V output independent of charging state if the input voltage is valid from a connected charger or OTG voltage generation.</td>
</tr>
<tr>
<td>131</td>
<td>USBPHY_ON</td>
<td>DO</td>
<td>Indicates APSD is complete and the attached device is not an HVDCP; used as a power-on to enable a USB PHY.</td>
</tr>
</tbody>
</table>
Table 2-2 Pad descriptions – input power management functions (cont.)

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>191, 192, 207</td>
<td>GND_CHG</td>
<td>GNDP</td>
<td>Specific ground for the SCHG. Layout considerations must be made for this pad.</td>
</tr>
<tr>
<td>170</td>
<td>GND_REF_CHG</td>
<td>GNDP</td>
<td>Dedicated ground for the charger-specific master bandgap. Special considerations must be made to ensure this ground is properly connected on the PCB.</td>
</tr>
</tbody>
</table>

**SCHG digital signals**

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>159</td>
<td>EN_CHG</td>
<td>DI</td>
<td>Enable input (factory programmable option). Logic high or low (programmable) to enable and/or resume charging. Can be activated by register bit.</td>
</tr>
<tr>
<td>145</td>
<td>STAT_CHG</td>
<td>DO</td>
<td>Status/fault/interrupt indicator. Indicates charging or fault status. Multiplexed static (fault) or pulsed output (IRQ). Programmable polarity.</td>
</tr>
<tr>
<td>158</td>
<td>USB_CS</td>
<td>DI</td>
<td>This is for controlling the default current limit for USB when an SDP is connected and automatic power source detection detects the SDP and is in pad control mode</td>
</tr>
</tbody>
</table>

**Fuel gauge/battery interface**

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>BATT_MINUS</td>
<td>AI</td>
<td>Battery minus terminal sense input. Direct connection to the battery (-).</td>
</tr>
<tr>
<td>110</td>
<td>BATT_PLUS</td>
<td>AI</td>
<td>Battery plus terminal sense input. Direct connection to the battery (+).</td>
</tr>
<tr>
<td>124</td>
<td>CS_MINUS</td>
<td>AI</td>
<td>Current sense resistor minus sense input. It connects to the low side of the current sense element.</td>
</tr>
<tr>
<td>109</td>
<td>CS_PLUS</td>
<td>AI</td>
<td>Current sense resistor plus sense input. It connects to the high side of the current sense element.</td>
</tr>
<tr>
<td>140</td>
<td>VREG_FG1</td>
<td>AO</td>
<td>Bypass capacitor for the internal fuel gauge LDO. It is only used by the fuel gauge and must not be used as a general LDO output.</td>
</tr>
<tr>
<td>201</td>
<td>VREG_FG2</td>
<td>AO</td>
<td>Bypass capacitor for the internal fuel gauge LDO. It is only used by the fuel gauge and must not be used as a general LDO output.</td>
</tr>
<tr>
<td>169</td>
<td>GND_FG</td>
<td>GNDP</td>
<td>Analog ground for FG. LDO bypass capacitors connect here.</td>
</tr>
<tr>
<td>155</td>
<td>BATT_ID</td>
<td>AI</td>
<td>Battery ID input to ADC and MIPI BIF interface. It can be used for missing battery detection.</td>
</tr>
<tr>
<td>154</td>
<td>BATT_THERM</td>
<td>AI</td>
<td>Battery temperature input to ADC for measuring pack temperature. It is used for charger safe operation and BMS/FG.</td>
</tr>
<tr>
<td>139</td>
<td>R_BIAS</td>
<td>AO</td>
<td>Dedicated voltage source for BAT_THERM resistor network biasing.</td>
</tr>
</tbody>
</table>

**Wireless power (WiPower) interface**

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>206</td>
<td>WIPWR_CHG_OK</td>
<td>DO</td>
<td>Charger request hardware output signal to WiPower. Hi-Z indicates a WiPower charge request. It asserts low to indicate charge done or do not request WiPower charging.</td>
</tr>
</tbody>
</table>
Table 2-2  Pad descriptions – input power management functions (cont.)

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>143</td>
<td>WIPWR_RST_N</td>
<td>DO</td>
<td>Hardware signal that allows PMI to hold the APQ device in reset until power is ready for a dead battery case.</td>
</tr>
<tr>
<td>132</td>
<td>WIPWR_DIV2_EN</td>
<td>DI</td>
<td>Charge pump divide-by-2 indication from the WiPower front end; mode indication to PMI (pass through or divide-by-2) so the appropriate current limit can be selected.</td>
</tr>
</tbody>
</table>

1. See Table 2-1 for parameter and acronym definitions.

Table 2-3  Pad descriptions – output power management functions

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>System rail boost/bypass</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17, 31, 32</td>
<td>VSW_BST_BYP</td>
<td>PO</td>
<td>Boost/bypass SMPS switch node.</td>
</tr>
<tr>
<td>2, 3</td>
<td>VREG_BST_BYP</td>
<td>PO</td>
<td>Boost/bypass SMPS regulated output.</td>
</tr>
<tr>
<td>33</td>
<td>FB_BST_BYP</td>
<td>AI</td>
<td>Boost/bypass SMPS feedback node.</td>
</tr>
<tr>
<td>34</td>
<td>MODE_BST_BYP</td>
<td>DI</td>
<td>Boost/bypass SMPS enable input.</td>
</tr>
<tr>
<td>18</td>
<td>VDD_BST_BYP</td>
<td>PI</td>
<td>Boost/bypass SMPS supply power input.</td>
</tr>
<tr>
<td>1, 16</td>
<td>GND_BST_BYP</td>
<td>GNDP</td>
<td>Ground for boost/bypass SMPS circuits.</td>
</tr>
<tr>
<td></td>
<td><strong>5 V SmartBoost SMPS circuits</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>61, 62</td>
<td>VSW_5V_BST</td>
<td>PI</td>
<td>Boost SMPS switch node.</td>
</tr>
<tr>
<td>46, 47</td>
<td>VREG_5V_BST</td>
<td>PO</td>
<td>Boost SMPS regulated output.</td>
</tr>
<tr>
<td>64</td>
<td>FB_5V_BST</td>
<td>AI</td>
<td>Boost SMPS sense input.</td>
</tr>
<tr>
<td>65</td>
<td>REQ_5V_BST</td>
<td>DI</td>
<td>Hardware signal to request a 5 V boost for audio.</td>
</tr>
<tr>
<td>63</td>
<td>GND_5V_BST</td>
<td>GNDP</td>
<td>Boost SMPS power ground.</td>
</tr>
<tr>
<td></td>
<td><strong>High-frequency buck SMPS circuits</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>VSW_S1</td>
<td>PO</td>
<td>S1 SMPS switch node.</td>
</tr>
<tr>
<td>29</td>
<td>VREG_S1</td>
<td>AI</td>
<td>S1 SMPS sense input.</td>
</tr>
<tr>
<td>14, 15</td>
<td>VDD_S1</td>
<td>PI</td>
<td>S1 SMPS supply power input.</td>
</tr>
<tr>
<td>45</td>
<td>GND_S1</td>
<td>GNDP</td>
<td>S1 SMPS power ground.</td>
</tr>
<tr>
<td></td>
<td><strong>Fast transient buck SMPS circuits</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11, 26, 41</td>
<td>VSW_S2</td>
<td>PO</td>
<td>S2 SMPS switch node.</td>
</tr>
<tr>
<td>39</td>
<td>VREG_S2</td>
<td>AI</td>
<td>S2 SMPS sense input.</td>
</tr>
<tr>
<td>24</td>
<td>VREF_NEG_S2</td>
<td>AI</td>
<td>S2 SMPS ground sense, route as differential pair with VREG_S2.</td>
</tr>
<tr>
<td>12, 27, 42</td>
<td>VDD_S2</td>
<td>PI</td>
<td>S2 SMPS supply power input.</td>
</tr>
<tr>
<td>10, 25, 40</td>
<td>GND_S2</td>
<td>GNDP</td>
<td>S2 SMPS power ground.</td>
</tr>
<tr>
<td>5, 20, 35</td>
<td>VSW_S3</td>
<td>PO</td>
<td>S3 SMPS switch node.</td>
</tr>
<tr>
<td>37</td>
<td>VREG_S3</td>
<td>AI</td>
<td>S3 SMPS sense input.</td>
</tr>
<tr>
<td>22</td>
<td>VREF_NEG_S3</td>
<td>AI</td>
<td>S3 SMPS ground sense; route as a differential pair with VREG_S3.</td>
</tr>
</tbody>
</table>
Table 2-3  Pad descriptions – output power management functions (cont.)

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4, 19</td>
<td>VDD_S3</td>
<td>PI</td>
<td>S3 SMPS supply power input.</td>
</tr>
<tr>
<td>6, 21, 36</td>
<td>GND_S3</td>
<td>GNDP</td>
<td>S3 SMPS power ground.</td>
</tr>
</tbody>
</table>

Master bandgap

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td>REF_BYP</td>
<td>AO</td>
<td>Bypass capacitor for dedicated master bandgap regulator. This LDO must only be used for the master bandgap and must not be used as a general LDO output.</td>
</tr>
<tr>
<td>81</td>
<td>GND_REF</td>
<td>GNDP</td>
<td>Dedicated ground for the master bandgap. Special considerations must be made to ensure this ground is properly connected on the PCB.</td>
</tr>
</tbody>
</table>

1. See Table 2-1 for parameter and acronym definitions.

Table 2-4  Pad descriptions – general housekeeping functions

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name 1</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
</table>
| HK ADC circuits
| 53    | VREG_ADC_LDO | AO       | Bypass capacitor input for dedicated LDO for HK ADC circuits. This LDO must only be used for HK ADC circuits and must not be used as a general LDO output. |
| 84    | VDD_ADC_LDO | PI       | Input supply power for dedicated LDO for HK ADC circuits. |

Clock circuits

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>CLK_IN</td>
<td>AI</td>
<td>19.2 MHz clock input (from PM8994).</td>
</tr>
</tbody>
</table>

PMIC power infrastructure

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>AVDD_BYP</td>
<td>AO</td>
<td>Bypass capacitor for dedicated LDO analog infrastructure circuits. This LDO must only be used for analog infrastructure circuits and must not be used as a general LDO output.</td>
</tr>
<tr>
<td>69</td>
<td>DVDD_BYP</td>
<td>AO</td>
<td>Bypass capacitor for dedicated LDO digital infrastructure circuits. This LDO must only be used for digital infrastructure circuits and must not be used as a general LDO output.</td>
</tr>
</tbody>
</table>

GPIOs may be configured for general housekeeping functions not listed here.  
MPPs may be configured for general housekeeping functions not listed here.  

1. See Table 2-1 for parameter and acronym definitions.  
2. GPIOs may be configured for user interface functions. To assign a GPIO a particular function, identify all of your application’s requirements and map each GPIO to its function – carefully avoiding assignment conflicts. All GPIOs are listed in Table 2-7.  
3. Other user interface MPP functions are possible. To assign an MPP a particular function, identify all of your application’s requirements and map each MPP to its function – carefully avoiding assignment conflicts. All MPPs are listed in Table 2-7.
### Table 2-5 Pad descriptions – user interface functions

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>± Display bias for LCD/AMOLED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>137, 152</td>
<td>VSW_DIS_P</td>
<td>PO</td>
<td>Display positive bias: boost SMPS switch node.</td>
</tr>
<tr>
<td>136</td>
<td>VDIS_P_OUT</td>
<td>PO</td>
<td>Display positive bias: boost SMPS regulated output.</td>
</tr>
<tr>
<td>138</td>
<td>VDIS_P_FB</td>
<td>AI</td>
<td>Display positive bias: boost SMPS sense input.</td>
</tr>
<tr>
<td>181, 182</td>
<td>VSW_DIS_N</td>
<td>PO</td>
<td>Display negative bias: boost SMPS switch node.</td>
</tr>
<tr>
<td>196, 197</td>
<td>VDIS_N_OUT</td>
<td>PO</td>
<td>Display negative bias: boost SMPS regulated output.</td>
</tr>
<tr>
<td>168</td>
<td>VDIS_N_FB</td>
<td>AI</td>
<td>Display negative bias: boost SMPS sense input.</td>
</tr>
<tr>
<td>167</td>
<td>DIS_N_CAP_REF</td>
<td>AO</td>
<td>Input for external capacitor used for voltage reference. It is used to tune inverting buck boost slew rates.</td>
</tr>
<tr>
<td>183</td>
<td>GND_DIS_N_REF</td>
<td>GNDP</td>
<td>Ground for external capacitor used for voltage reference.</td>
</tr>
<tr>
<td>184</td>
<td>DIS_SCTRL</td>
<td>DI</td>
<td>Hardware SWIRE interface for LCD and AMOLED displays; can enable positive bias, negative bias, and set voltages with a series of positive pulses. Typically used for AMOLED displays.</td>
</tr>
<tr>
<td>198</td>
<td>VDD_1P8_DIS_N</td>
<td>PI</td>
<td>1.8 Vsupply power input for inverting buck boost controller circuits.</td>
</tr>
<tr>
<td>166</td>
<td>VDD_DIS_N</td>
<td>PI</td>
<td>Display positive bias: supply power input for boost circuits.</td>
</tr>
<tr>
<td>153</td>
<td>VDD_DIS_P</td>
<td>PI</td>
<td>Display negative bias: supply power input for inverting buck boost controller circuits.</td>
</tr>
<tr>
<td>151</td>
<td>GND_DIS_P</td>
<td>GNDP</td>
<td>Display positive bias: power ground.</td>
</tr>
<tr>
<td>Flash and torch LED drivers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75, 89</td>
<td>FLSH_LED1</td>
<td>AO</td>
<td>Flash/toch high-side current source for LED1. It connects to a node of flash LED.</td>
</tr>
<tr>
<td>104, 105</td>
<td>FLSH_LED2</td>
<td>AO</td>
<td>Flash/toch high-side current source for LED2. It connects to a node of flash LED.</td>
</tr>
<tr>
<td>58</td>
<td>VSNS_FLSH</td>
<td>AI</td>
<td>Sense point for VPH_PWR. It is used to detect VPH_PWR collapse during flash so the flash current can be reduced.</td>
</tr>
<tr>
<td>90</td>
<td>VDD_FLASH</td>
<td>PI</td>
<td>Flash current source 5 Vsupply power input.</td>
</tr>
<tr>
<td>74</td>
<td>VDD_TORCH</td>
<td>PI</td>
<td>Torch current source 5 Vsupply power input.</td>
</tr>
<tr>
<td>59</td>
<td>VDD_FLSH_C</td>
<td>PI</td>
<td>Flash/toch module controller circuits supply power input.</td>
</tr>
<tr>
<td>Haptics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>HAP_OUT_P</td>
<td>AO</td>
<td>Haptics H-bridge driver output positive.</td>
</tr>
<tr>
<td>51</td>
<td>HAP_OUT_N</td>
<td>AO</td>
<td>Haptics H-bridge driver output negative.</td>
</tr>
<tr>
<td>38</td>
<td>HAP_PWM_IN</td>
<td>DI</td>
<td>PWM input for haptic control.</td>
</tr>
<tr>
<td>49</td>
<td>VDD_HAP</td>
<td>PI</td>
<td>Haptics supply power input.</td>
</tr>
<tr>
<td>50</td>
<td>GND_HAP</td>
<td>GNDP</td>
<td>Haptics power ground.</td>
</tr>
</tbody>
</table>
Table 2-5  Pad descriptions – user interface functions (cont.)

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>RGB_RED</td>
<td>AO</td>
<td>RGB LED high-side current source for the red LED.</td>
</tr>
<tr>
<td>80</td>
<td>RGB_GRN</td>
<td>AO</td>
<td>RGB LED high-side current source for the green LED.</td>
</tr>
<tr>
<td>79</td>
<td>RGB_BLU</td>
<td>AO</td>
<td>RGB LED high-side current source for the blue LED.</td>
</tr>
<tr>
<td>94</td>
<td>VDD_RGB</td>
<td>PI</td>
<td>RGB LED supply power input. The controller ground is shared with WLED module.</td>
</tr>
</tbody>
</table>

**White LED SMPS**

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>VSW_WLED</td>
<td>PO</td>
<td>WLED boost SMPS switch node.</td>
</tr>
<tr>
<td>121</td>
<td>VREG_WLED</td>
<td>AI</td>
<td>WLED boost SMPS sense input.</td>
</tr>
<tr>
<td>106</td>
<td>VDD_WLED</td>
<td>PI</td>
<td>WLED boost SMPS supply power input.</td>
</tr>
<tr>
<td>91</td>
<td>GND_WLED</td>
<td>GNDP</td>
<td>WLED boost SMPS power ground.</td>
</tr>
<tr>
<td>123</td>
<td>WLED_CABC</td>
<td>DI</td>
<td>PWM input for content adaptive backlight control (CABC) dimming from display controller; typically used for dynamic dimming of LCD displays.</td>
</tr>
<tr>
<td>77</td>
<td>WLED_SINK1</td>
<td>AO</td>
<td>WLED low-side current sink input, string 1.</td>
</tr>
<tr>
<td>92</td>
<td>WLED_SINK2</td>
<td>AO</td>
<td>WLED low-side current sink input, string 2.</td>
</tr>
<tr>
<td>93</td>
<td>WLED_SINK3</td>
<td>AO</td>
<td>WLED low-side current sink input, string 3.</td>
</tr>
<tr>
<td>78</td>
<td>WLED_SINK4</td>
<td>AO</td>
<td>WLED low-side current sink input, string 4.</td>
</tr>
<tr>
<td>108</td>
<td>GND_WLED_I</td>
<td>GNDP</td>
<td>WLED low-side current sink power ground.</td>
</tr>
</tbody>
</table>

GPIOs may be configured for user interface functions.  

MPPs may be configured for user interface functions not listed here.

1. See Table 2-1 for parameter and acronym definitions.
2. GPIOs may be configured for user interface functions. To assign a GPIO a particular function, identify all of your application’s requirements and map each GPIO to its function – carefully avoiding assignment conflicts. All GPIOs are listed in Table 2-7.
3. Other user interface MPP functions are possible. To assign an MPP a particular function, identify all of your application’s requirements and map each MPP to its function – carefully avoiding assignment conflicts. All MPPs are listed in Table 2-7.
### Table 2-6 Pad descriptions – IC-level interface functions

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IC-level interfacing power supply</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>VDD_APQ_IO</td>
<td>PI</td>
<td>Input supply power for digital I/O signals to/from the APQ device.</td>
</tr>
<tr>
<td><strong>Power on/off/reset control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>SHDN_N</td>
<td>DI</td>
<td>Shutdown hardware signal input to initiate graceful shutdown to a low-power state</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>when pulled low. This signal comes from PM8994/PM8996 S4 regulator and has several</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PON/POFF/RESET scenarios described in the power on/off/reset section.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cmax = 10 pF</td>
</tr>
<tr>
<td>71</td>
<td>PS_HOLD</td>
<td>DI</td>
<td>Power supply hold control input. This signal's main purpose is to tell PM8994/PM8996</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>to keep its power supplies on and can initiate a reset or power down when asserted low.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>This signal comes from PM8994/PM8996 PON_RESET output and has several PON/POFF/RESET</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>scenarios described in the power on/off/reset section.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cmax = 10 pF</td>
</tr>
<tr>
<td>55</td>
<td>RESIN_N</td>
<td>DI</td>
<td>Reset hardware signal input to initiate various types of resets, clear faults, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>clear interrupts.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cmax = 10 pF</td>
</tr>
<tr>
<td>185</td>
<td>KYPD_PWR_N</td>
<td>DI</td>
<td>PON hardware signal input to initiate PON sequence when asserted low. This pad can be</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>used to exit ship mode.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cmax = 10 pF</td>
</tr>
<tr>
<td>160</td>
<td>PGOOD_SYSOK</td>
<td>DO</td>
<td>PON hardware signal output to initiate PON on PM8994/PM8996 when charger input is</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>inserted. It can also initiate a graceful shutdown of PM8994/PM8996 when the battery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>is removed. It connects to PM8994/PM8996 SHDN_N and PON_1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cmax = 10 pF</td>
</tr>
<tr>
<td><strong>System power management interface</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>SPMI_CLK</td>
<td>DI</td>
<td>SPMI communication bus clock signal.</td>
</tr>
<tr>
<td>87</td>
<td>SPMI_DATA</td>
<td>DI, DO</td>
<td>SPMI communication bus data signal.</td>
</tr>
<tr>
<td><strong>Battery UICC alarm (BUA)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>BUA</td>
<td>DO</td>
<td>Battery UICC alarm hardware signal for informing the APQ of a battery removal alarm and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>receiving UICC removal alarm.</td>
</tr>
<tr>
<td><strong>Miscellaneous IC-level interfaces</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>144</td>
<td>USB_ID_RVAL1</td>
<td>DO</td>
<td>Output indicating USB_ID resistor value to identify the type of attached device to the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>system. It is used in combination with USB_ID_RVAL2 (JIG) and can be used to identify</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>when MCPC audio or factory boot modes have been detected with USB_ID.</td>
</tr>
<tr>
<td>172</td>
<td>USB_ID_RVAL2</td>
<td>DO</td>
<td>Output indicating USB_ID resistor value to identify the type of attached device to the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>system. It is used in combination with USB_ID_RVAL1 (BOOT) and can be used to identify</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>when MCPC audio or factory boot modes have been detected with USB_ID.</td>
</tr>
</tbody>
</table>

GPIOs may be configured for IC-level interface functions not listed here.  
MPPs may be configured for IC-level interface functions.
1. See Table 2-1 for parameter and acronym definitions.
2. Other IC-level interface GPIO functions are possible. To assign a GPIO a particular function, identify all of your application’s requirements and map each GPIO to its function – carefully avoiding assignment conflicts. All GPIOs are listed in Table 2-7.
3. MPPs may be configured for IC-level interface functions. To assign an MPP a particular function, identify all of your application’s requirements and map each MPP to its function – carefully avoiding assignment conflicts. All MPPs are listed in Table 2-7.

Table 2-7  Pad descriptions – configurable input/output functions

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Configurable function</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPP functions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>MPP_1</td>
<td>WLED_BL_DIM</td>
<td>DO-Z</td>
<td>Configurable; default Hi-Z output. Light pulse generators (LPG) PWM used for external WLED backlight dimming.</td>
</tr>
<tr>
<td>43</td>
<td>MPP_2</td>
<td>FLSH_STROBE</td>
<td>DO-Z</td>
<td>Configurable; default Hi output. Digital input for flash strobe signal.</td>
</tr>
<tr>
<td>73</td>
<td>MPP_3</td>
<td>PMI_SPON</td>
<td>DO</td>
<td>Configurable; default Hi-Z output. Interface with PM8994 to continue secondary PON sequence.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TX_GTR_THRESH</td>
<td>DI</td>
<td>Digital input for transmit greater than threshold to mask flash current.</td>
</tr>
<tr>
<td>88</td>
<td>MPP_4</td>
<td>EXT_FET_CTL</td>
<td>DO-Z</td>
<td>Configurable; default Hi-Z output. Digital output to toggle external FET gate drive. Used for WLED boost short circuit protection.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LED_DRV</td>
<td>AO</td>
<td>Current sink with four programmable current settings. Can be used to drive a general-purpose LED.</td>
</tr>
<tr>
<td><strong>GPIO functions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>GPIO_1</td>
<td></td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down.</td>
</tr>
<tr>
<td>127</td>
<td>GPIO_2</td>
<td>HDMI_EN</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down. This pad is the digital output to toggle HDMI enable.</td>
</tr>
<tr>
<td>113</td>
<td>GPIO_3</td>
<td>EXT_FET_CTL</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down. Digital output to toggle external FET gate drive.</td>
</tr>
<tr>
<td>114</td>
<td>GPIO_4</td>
<td>USB2_HS_ID</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down. Digital output for high-speed USB2 ID.</td>
</tr>
<tr>
<td>83</td>
<td>GPIO_5</td>
<td>USB3_OTG_VBUS_EN</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down. Digital output to toggle USB3 OTG bus voltage enable.</td>
</tr>
<tr>
<td>68</td>
<td>GPIO_6</td>
<td>USB2_VBUS</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down. Digital input for USB2 bus voltage detection.</td>
</tr>
<tr>
<td>111</td>
<td>GPIO_7</td>
<td>MASK_2</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 μA pull-down. Digital input for optional additional flash mask. See User interfaces: Flash/torch for more details.</td>
</tr>
</tbody>
</table>
### Table 2-7 Pad descriptions – configurable input/output functions (cont.)

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Configurable function</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>126</td>
<td>GPIO_8</td>
<td>MASK_3</td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 µA pull-down. Digital input for optional additional flash mask. See the User interfaces: Flash/torch for more details.</td>
</tr>
<tr>
<td>157</td>
<td>GPIO_9</td>
<td></td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 µA pull-down.</td>
</tr>
<tr>
<td>142</td>
<td>GPIO_10</td>
<td></td>
<td>DI-Z</td>
<td>Configurable; default digital input with 10 µA pull-down.</td>
</tr>
</tbody>
</table>

1. See Table 2-1 for the parameter and acronym definitions.

**NOTE:** All GPIOs default to digital input with a 10 µA pull-down. All MPPs default to Hi-Z.

**NOTE:** Configure unused MPPs as 0 mA current sinks (Hi-Z) and GPIOs as digital inputs with their internal pull-downs enabled.

### Table 2-8 Pad descriptions – power supply pads

#### Power inputs

**Note:** Power inputs are grouped with their respective module. These can be found in the previous tables.

### Table 2-9 Pad descriptions – ground pads

#### Common grounds

**Note:** This table only includes common ground pads. Power ground pads are grouped with their respective modules, and can be found in the previous tables.

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>190</td>
<td>GNDC_SUB</td>
<td>GNDC</td>
<td>Substrate ground seal.</td>
</tr>
<tr>
<td>141</td>
<td>GNDC_FG</td>
<td>GNDC</td>
<td>Fuel gauge controller ground.</td>
</tr>
<tr>
<td>156</td>
<td>GNDC_SUB_FG</td>
<td>GNDC</td>
<td>Fuel gauge substrate ground.</td>
</tr>
<tr>
<td>48</td>
<td>GNDC_BST</td>
<td>GNDC</td>
<td>Boost SMPS controller ground.</td>
</tr>
<tr>
<td>13, 28</td>
<td>GNDC_S1</td>
<td>GNDC</td>
<td>S1 SMPS controller ground.</td>
</tr>
<tr>
<td>23</td>
<td>GNDC_SUB_S2S3</td>
<td>GNDC</td>
<td>Substrate ground for S2 and S3 power FETs.</td>
</tr>
<tr>
<td>7, 9</td>
<td>GNDC_S2S3</td>
<td>GNDC</td>
<td>S2, S3 SMPS controller ground.</td>
</tr>
<tr>
<td>8</td>
<td>GNDC_SUB</td>
<td>GNDC</td>
<td>Substrate ground seal.</td>
</tr>
<tr>
<td>67, 99, 100</td>
<td>GNDC</td>
<td>GNDC</td>
<td>Internal common ground.</td>
</tr>
<tr>
<td>57, 85, 86</td>
<td>GNDC_IDSS</td>
<td>GNDC</td>
<td>Ground for digital subsystem circuits.</td>
</tr>
<tr>
<td>97, 98</td>
<td>GNDC_MBG</td>
<td>GNDC</td>
<td>Ground for MBG regulator controller.</td>
</tr>
<tr>
<td>107</td>
<td>GNDC_DIS_P</td>
<td>GNDC</td>
<td>Display bias controller ground.</td>
</tr>
<tr>
<td>199</td>
<td>GNDC_DIS_N</td>
<td>GNDC</td>
<td>Display bias controller ground.</td>
</tr>
</tbody>
</table>
Table 2-9  Pad descriptions – ground pads (cont.)

<table>
<thead>
<tr>
<th>Pad #</th>
<th>Pad name</th>
<th>Pad type</th>
<th>Functional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>122</td>
<td>GND_SUB_DIS_P</td>
<td>GNDC</td>
<td>Substrate ground.</td>
</tr>
<tr>
<td>200</td>
<td>GND_SUB_DIS_N</td>
<td>GNDC</td>
<td>Substrate ground.</td>
</tr>
<tr>
<td>60</td>
<td>GNDC_FLSH</td>
<td>GNDC</td>
<td>Flash/torch controller ground.</td>
</tr>
<tr>
<td>103</td>
<td>GNDC_SUB</td>
<td>GNDC</td>
<td>Substrate ground.</td>
</tr>
<tr>
<td>66</td>
<td>GNDC_HAP</td>
<td>GNDC</td>
<td>Haptics controller ground.</td>
</tr>
</tbody>
</table>

1. See Table 2-1 for the parameter and acronym definitions.
3 Electrical specifications

3.1 Absolute maximum ratings

Operating the PMI8994/PMI8996 under conditions beyond its absolute maximum ratings (Table 3-1) may damage the device. Absolute maximum ratings are limiting values to be considered individually when all other parameters are within their specified operating ranges. Functional operation and specification compliance under any absolute maximum condition, or after exposure to any of these conditions, is not guaranteed or implied. Exposure may affect device reliability.

Table 3-1 Absolute maximum ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input power management functions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USB_IN</td>
<td>-0.3</td>
<td>+28</td>
<td>V</td>
</tr>
<tr>
<td>DC_IN</td>
<td>-0.3</td>
<td>+20</td>
<td>V</td>
</tr>
<tr>
<td>MID_USB_IN</td>
<td>-0.3</td>
<td>+28</td>
<td>V</td>
</tr>
<tr>
<td>MID_DC_IN</td>
<td>-0.3</td>
<td>+20</td>
<td>V</td>
</tr>
<tr>
<td>VBATT, VBATT_SNS</td>
<td>-0.5</td>
<td>+6.0</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>-0.5</td>
<td>+7.0</td>
<td>V</td>
</tr>
<tr>
<td>VPH_PWR</td>
<td>-0.5</td>
<td>+6.0</td>
<td>V</td>
</tr>
<tr>
<td><strong>Power supply pads</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDD_FLASH</td>
<td>-0.3</td>
<td>+12</td>
<td>V</td>
</tr>
<tr>
<td>VDD_XXX</td>
<td>-0.5</td>
<td>+6.0</td>
<td>V</td>
</tr>
<tr>
<td><strong>Signal pads</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_IN</td>
<td>-0.5</td>
<td>V_{XX} + 0.5</td>
<td>V</td>
</tr>
</tbody>
</table>

**ESD protection and thermal conditions** – see Section 7.1 and Section.

1. V_{XX} is the supply voltage associated with the input or output pad to which the test voltage is applied.
3.2 Operating conditions

Operating conditions include parameters that are under the control of the user: power supply voltage and ambient temperature (Table 3-2). The PMI8994/PMI8996 meets all performance specifications listed in Section 3.3 through Section 3.9.2 when used and/or stored within the operating conditions, unless otherwise noted in those sections (provided the absolute maximum ratings have never been exceeded).

Table 3-2 Operating conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input power management functions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USB_IN</td>
<td>+3.7</td>
<td>–</td>
<td>+10</td>
<td>V</td>
</tr>
<tr>
<td>DC_IN</td>
<td>+3.7</td>
<td>–</td>
<td>+10</td>
<td>V</td>
</tr>
<tr>
<td>VPH_PWR</td>
<td>+2.5</td>
<td>+3.6</td>
<td>+4.75</td>
<td>V</td>
</tr>
<tr>
<td>VBATT, VBATT_SNS</td>
<td>+2.5</td>
<td>+3.6</td>
<td>+4.75</td>
<td>V</td>
</tr>
<tr>
<td><strong>Power supply pads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDD_APQ_IO</td>
<td>+1.75</td>
<td>+1.80</td>
<td>+1.85</td>
<td>V</td>
</tr>
<tr>
<td>VDD_1P8_DIS_N</td>
<td>+1.75</td>
<td>+1.80</td>
<td>+1.85</td>
<td>V</td>
</tr>
<tr>
<td>VDD_FLASH</td>
<td>+2.5</td>
<td>–</td>
<td>+5.5</td>
<td>V</td>
</tr>
<tr>
<td>VDD_RGB, VDD_TORCH</td>
<td>+2.5</td>
<td>–</td>
<td>+5.5</td>
<td>V</td>
</tr>
<tr>
<td>VDD_XXX</td>
<td>All power supply pads not listed elsewhere (XXX defined in Table 2-8)</td>
<td>+2.5</td>
<td>+3.6</td>
<td>+4.75</td>
</tr>
<tr>
<td><strong>Signal pads</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_IN</td>
<td>Voltage on any non-power-supply pad 2</td>
<td>0</td>
<td>–</td>
<td>V_{XX} + 0.5</td>
</tr>
<tr>
<td><strong>Thermal conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T_C</td>
<td>Case operating temperature</td>
<td>-30</td>
<td>+25</td>
<td>+85</td>
</tr>
</tbody>
</table>

1. Applicable during flash mode of operation. VDD_FLASH is generally tied to DC_IN_OUT, and can have voltage as high as +10 V with charger connected when not in flash mode of operation.
2. V_{XX} is the supply voltage associated with the input or output pad to which the test voltage is applied.
3.3 DC power consumption

This section specifies DC power supply currents for the various IC operating modes (Table 3-3). Typical currents are based on IC operation at room temperature (+25°C) using default settings.

Table 3-3 DC power supply currents

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_ACTIVE</td>
<td>Supply current, active mode 1</td>
<td>–</td>
<td>670</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>I_SLEEP</td>
<td>Supply current, sleep mode 2</td>
<td>–</td>
<td>209</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>I_OFF</td>
<td>Supply current, off mode 3</td>
<td>–</td>
<td>29</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>Battery missing detection configuration:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>–</td>
<td>41</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID only (240 kΩ)</td>
<td>–</td>
<td>41</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID only (1.5 kΩ)</td>
<td>–</td>
<td>57</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>THERM only</td>
<td>–</td>
<td>34</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID (240 kΩ) and THERM</td>
<td>–</td>
<td>45</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID (1.5 kΩ) and THERM</td>
<td>–</td>
<td>62</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>I_SHIP</td>
<td>Supply current, ship mode 4</td>
<td>–</td>
<td>17</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>Battery missing detection configuration:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td>–</td>
<td>29</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID only (240 kΩ)</td>
<td>–</td>
<td>45</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID only (1.5 kΩ)</td>
<td>–</td>
<td>45</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>THERM only</td>
<td>–</td>
<td>34</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td></td>
<td>ID (240 kΩ) and THERM</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>I_USB</td>
<td>USB charger current in suspend mode 5</td>
<td>–</td>
<td>600</td>
<td>1000</td>
<td>µA</td>
</tr>
<tr>
<td>I_DC</td>
<td>DC charger current in suspend mode 6</td>
<td>–</td>
<td>800</td>
<td>1400</td>
<td>µA</td>
</tr>
</tbody>
</table>

1. I_ACTIVE is the total supply current from the battery with the PMIC on after its primary power-on sequence. In this state the boost-bypass is enabled in auto-boost mode driving no load, the charger module is enabled, and the fuel gauge module is enabled.

2. I_SLEEP is the average supply current from the battery with the PMIC on after executing its sleep sequence. In this state the boost-bypass is enabled in forced-bypass mode driving no load, the charger module is enabled, the fuel gauge module is enabled, and the internal PMIC infrastructure is in a low-power state. External component assumptions are BATT_THERM pull-up to R_BIAS: 68 kΩ, BATT_THERM resistance: infinite, BATT_ID resistance: 240 kΩ, fuel gauge ESR pulses disabled.

3. I_OFF is the total supply current from the battery with PMI8994/PMI8996 off. This only applies when the temperature is between -30°C and +60°C.

4. I_SHIP is the total supply current from the battery with PMI8994/PMI8996 in ship mode. This only applies when the temperature is between -30°C and +60°C.

5. I_USB is the total supply current from a USB charger when the phone has a good battery (VBATT > 3.2 V and not being charged). During USB suspend, current from a PC is limited to 2.5 mA. The specified I_USB value allows 0.85 mA for external components connected to VBUS during suspend.

6. I_DC is the total supply current from a DC charger when the phone has a good battery (VBATT > 3.2 V and not being charged).
3.4 Digital logic characteristics

The charger has unique digital signaling characteristics as listed within Section 3.4.2; all other PMI8994/PMI8996 digital I/O characteristics are specified in Table 3-4.

Table 3-4  Digital I/O characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IH}$ High-level input voltage</td>
<td>$0.65 \cdot V_{IO}$</td>
<td>–</td>
<td>$V_{IO} + 0.3$</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$V_{IL}$ Low-level input voltage</td>
<td>–0.3</td>
<td>–</td>
<td>$0.35 \cdot V_{IO}$</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>$V_{SHYS}$ Schmitt hysteresis voltage</td>
<td>15</td>
<td>–</td>
<td>–</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>$I_L$ Input leakage current 2</td>
<td>$V_{IO} = \text{max}, V_{IN} = 0 \text{ V to } V_{IO}$</td>
<td>-0.20</td>
<td>–</td>
<td>+0.20</td>
<td>μA</td>
</tr>
<tr>
<td>$V_{OH}$ High-level output voltage</td>
<td>$I_{out} = I_{OH}$</td>
<td>$V_{IO} - 0.45$</td>
<td>–</td>
<td>$V_{IO}$</td>
<td>V</td>
</tr>
<tr>
<td>$I_{OL}$ Low-level output current 3</td>
<td>$V_{out} = V_{OL}$</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>$C_{IN}$ Input capacitance 4</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>5</td>
<td>pF</td>
</tr>
</tbody>
</table>

1. $V_{IO}$ is the supply voltage for the PMIC interface (most PMIC digital I/Os).
2. MPP and GPIO pads comply with the input leakage specification only when configured as a digital input or set to the tri-state mode.
3. Output current specifications apply to all digital outputs unless specified otherwise, and are superseded by specifications for specific pads (such as MPP and GPIO pads).
4. Input capacitance is guaranteed by design, but is not 100% tested.
### 3.4.1 Battery charger

The PMI8994/PMI8996 features a fully programmable switch-mode Li-ion battery charger, input power and output power controller for portable devices. The device is designed to be used in conjunction with systems using single-cell Li-ion and Li-polymer battery packs. The PMI8994/PMI8996 provides three major functions to the end-system: input selection and arbitration, system output supply and control, and battery charging. The device is fully programmable via the SPMI interface.

#### Table 3-5 Battery charger specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input source control, protection, and CurrentPath power path management</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input voltage range</td>
<td>V_FLOAT = 4.2 V</td>
<td>3.70</td>
<td>–</td>
<td>10.0</td>
<td>V</td>
</tr>
<tr>
<td>USB_IN</td>
<td></td>
<td>3.70</td>
<td>–</td>
<td>10.0</td>
<td>V</td>
</tr>
<tr>
<td>DC_IN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input voltage lockout</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Undervoltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Threshold, falling V, option A</td>
<td></td>
<td>3.50</td>
<td>3.60</td>
<td>3.70</td>
<td>V</td>
</tr>
<tr>
<td>Threshold, falling V, option B</td>
<td></td>
<td>6.90</td>
<td>7.20</td>
<td>7.50</td>
<td>V</td>
</tr>
<tr>
<td>USB_FAIL low threshold</td>
<td></td>
<td>4.00</td>
<td>4.15</td>
<td>4.30</td>
<td>V</td>
</tr>
<tr>
<td>Over-voltage 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold, rising V, option A</td>
<td>50 mA prebias enabled</td>
<td>6.20</td>
<td>6.40</td>
<td>6.50</td>
<td>V</td>
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<tr>
<td>Threshold, rising V, option B</td>
<td></td>
<td>6.90</td>
<td>7.20</td>
<td>7.50</td>
<td>V</td>
</tr>
<tr>
<td>Threshold, rising V, option C</td>
<td></td>
<td>10.0</td>
<td>10.3</td>
<td>10.6</td>
<td>V</td>
</tr>
<tr>
<td>Hysteresis</td>
<td></td>
<td>–</td>
<td>0.20</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Absolute input current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USB_IN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USB 2.0 with USB_CS = USB_IN</td>
<td>USB_CS is in register-control mode by default</td>
<td>400</td>
<td>440</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td>USB 2.0 with USB_CS = GND</td>
<td></td>
<td>58</td>
<td>80</td>
<td>100</td>
<td>mA</td>
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<tr>
<td>USB 3.0 with USB_CS = USB_IN</td>
<td></td>
<td>775</td>
<td>838</td>
<td>900</td>
<td>mA</td>
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<tr>
<td>USB 3.0 with USB_CS = GND</td>
<td></td>
<td>102</td>
<td>125</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>USB_CS = float, set for 1000 mA</td>
<td>Programmable 300 to 3000 mA</td>
<td>-80 mA</td>
<td>–</td>
<td>+80 mA</td>
<td>mA</td>
</tr>
<tr>
<td>All other settings 3</td>
<td>Programmable 300 to 2000 mA</td>
<td>-6.0%</td>
<td>–</td>
<td>+6.0%</td>
<td>%</td>
</tr>
<tr>
<td>DC_IN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Set for 1000 mA</td>
<td></td>
<td>940</td>
<td>1000</td>
<td>1060</td>
<td>mA</td>
</tr>
<tr>
<td>All other settings 3</td>
<td>Programmable 300 to 2000 mA</td>
<td>-45 mA</td>
<td>–</td>
<td>+45 mA</td>
<td>mA</td>
</tr>
<tr>
<td>Thermal protection – see Table 3-6</td>
<td></td>
<td>-3.5%</td>
<td>–</td>
<td>+3.5%</td>
<td>%</td>
</tr>
<tr>
<td><strong>AICL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AICL threshold accuracy</td>
<td>HC mode, DC_IN / USB_IN falling, V_CL set to 4.25 V</td>
<td>-3.5</td>
<td>–</td>
<td>+3.5</td>
<td>%</td>
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<tr>
<td>AICL hysteresis</td>
<td></td>
<td>–</td>
<td>200</td>
<td>–</td>
<td>mV</td>
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<tr>
<td>AICL glitch filter (rising/falling)</td>
<td></td>
<td>–</td>
<td>20</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>AICL auto-timer; four valid settings</td>
<td>Re-initiates AICL algorithm</td>
<td>–</td>
<td>45–360</td>
<td>–</td>
<td>sec</td>
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Table 3-5 Battery charger specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
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<tr>
<td>APSD 4</td>
<td></td>
<td></td>
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<tr>
<td>D+ source voltage (Vdp_src)</td>
<td>Current = 125 µA</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>V</td>
</tr>
<tr>
<td>Data detect voltage (Vdata_ref)</td>
<td></td>
<td>0.250</td>
<td>0.325</td>
<td>0.400</td>
<td>V</td>
</tr>
<tr>
<td>D+ pull-up voltage (Vdp_up)</td>
<td></td>
<td>3.0</td>
<td>–</td>
<td>3.6</td>
<td>V</td>
</tr>
<tr>
<td>D- sink current (Idm_sink)</td>
<td></td>
<td>50</td>
<td>–</td>
<td>150</td>
<td>µA</td>
</tr>
<tr>
<td>Data contact detect current source (Idp_src)</td>
<td></td>
<td>7</td>
<td>–</td>
<td>13</td>
<td>µA</td>
</tr>
<tr>
<td>Timing characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D+ source on time (tdp_src_on)</td>
<td></td>
<td>100</td>
<td>–</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>D+ source off to high current (tspsrc_hicrnt)</td>
<td></td>
<td>40</td>
<td>–</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>D+ source off to connect (tdpsrc_on)</td>
<td></td>
<td>40</td>
<td>–</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>DCD timeout (tdcd_timeout), option 1</td>
<td></td>
<td>321</td>
<td>328</td>
<td>335</td>
<td>ms</td>
</tr>
<tr>
<td>DCD timeout (tdcd_timeout), option 2</td>
<td></td>
<td>642</td>
<td>656</td>
<td>670</td>
<td>ms</td>
</tr>
<tr>
<td>Charger detect debounce (chgr_det_dbnc)</td>
<td></td>
<td>10</td>
<td>–</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>D+/D- capacitance (Cdp_dm)</td>
<td>APSD completed; D+/D- are Hi-Z</td>
<td>–</td>
<td>4</td>
<td>–</td>
<td>pF</td>
</tr>
<tr>
<td>WiPower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input impedance limiter</td>
<td>±1 divided by input current limit accuracy</td>
<td>-3.85</td>
<td>–</td>
<td>4.17</td>
<td>%</td>
</tr>
<tr>
<td>Input power limiter</td>
<td>Maximum power drawn from PMI; smartphone setting</td>
<td>–</td>
<td>–</td>
<td>5</td>
<td>W</td>
</tr>
<tr>
<td>DC_IN voltage comparator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold</td>
<td>DIV2_EN = high</td>
<td>–</td>
<td>6.5</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Hysteresis</td>
<td></td>
<td>–</td>
<td>320</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>DIV2_EN falling-edge deglitch timer</td>
<td>Four programmable settings; DIV2_EN high-to-low; AICL disabled-to-enabled</td>
<td>0</td>
<td>–</td>
<td>500</td>
<td>µs</td>
</tr>
<tr>
<td>Battery charging with switching charger (SCHG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Float voltage (VFLT) range &amp; nominal</td>
<td>20 mV steps</td>
<td>3.60</td>
<td>4.20</td>
<td>4.50</td>
<td>V</td>
</tr>
<tr>
<td>Float voltage accuracy</td>
<td></td>
<td>T = 0°C to 70°C</td>
<td>–</td>
<td>–</td>
<td>±0.5</td>
</tr>
<tr>
<td>V FLT ≥ 4.2 V</td>
<td></td>
<td>–</td>
<td>–</td>
<td>±1.0</td>
<td>%</td>
</tr>
<tr>
<td>V FLT &lt; 4.2 V</td>
<td></td>
<td>890</td>
<td>1000</td>
<td>1110</td>
<td>mA</td>
</tr>
<tr>
<td>Fast charge current accuracy</td>
<td>1000 mA</td>
<td>T = 0°C to 70°C</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>All other settings 3</td>
<td>Programable 300–3000 mA in 32 steps</td>
<td>–</td>
<td>–</td>
<td>+0.110</td>
<td>+2.5%</td>
</tr>
<tr>
<td>Charge termination current accuracy 5</td>
<td>100 mA</td>
<td>T = 0°C to 70°C</td>
<td>–</td>
<td>–</td>
<td>±50</td>
</tr>
<tr>
<td>All other settings 3</td>
<td>Programable 50–600 mA in 8 steps</td>
<td>–</td>
<td>–</td>
<td>±20</td>
<td>%</td>
</tr>
<tr>
<td>Charge termination glitch filter</td>
<td></td>
<td>–</td>
<td>1</td>
<td>–</td>
<td>sec</td>
</tr>
</tbody>
</table>

1. See text for comments.
2. All data is relative to a smartphone setting.
3. 32 steps.
4. 8 steps.
### Table 3-5 Battery charger specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge threshold voltage ( (V_{FLT} - V_{BAT}) )</td>
<td>PMI8994</td>
<td>–</td>
<td>200</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td>PMI8996</td>
<td>–</td>
<td>100 or 150</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Precharge to fast charge threshold accuracy</td>
<td>PMI8994</td>
<td>–</td>
<td>–</td>
<td>±4</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>VBAT rising; 2.8 V setting</td>
<td>–</td>
<td>–</td>
<td>±4</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Programmable 2.4–3.0 V in 4 steps</td>
<td>–</td>
<td>–</td>
<td>±4</td>
<td>%</td>
</tr>
<tr>
<td>Precharge current accuracy</td>
<td>T = 0°C to 70°C</td>
<td>–</td>
<td>–</td>
<td>±20</td>
<td>mA</td>
</tr>
<tr>
<td>100 mA</td>
<td>Programmable 100–550 mA in 5 steps</td>
<td>–</td>
<td>–</td>
<td>±20</td>
<td>mA</td>
</tr>
<tr>
<td>All other settings 3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>±20</td>
<td>mA</td>
</tr>
<tr>
<td>Precharge current accuracy</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Trickle to precharge voltage threshold</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Trickle charge current</td>
<td>PMI8994</td>
<td>–</td>
<td>45</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>PMI8996</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Charger buck regulator</td>
<td>PMI8994</td>
<td>1.92</td>
<td>2</td>
<td>2.08</td>
<td>MHz</td>
</tr>
<tr>
<td></td>
<td>PMI8996</td>
<td>1.92</td>
<td>2</td>
<td>2.08</td>
<td>kHz</td>
</tr>
<tr>
<td>Switching frequency 7</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>±1.0</td>
<td>%</td>
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<tr>
<td>Duty cycle</td>
<td>Maximum</td>
<td>–</td>
<td>99.3</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>Minimum</td>
<td>–</td>
<td>0</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Regulated output voltage (VPH)</td>
<td>VPH = VPH_PWR</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Charging, VPH_MIN &lt; VPH &lt; VPH_MAX</td>
<td>USB_IN or DC_IN = 9.0 V</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>Not charging, VBAT &gt; VPH_MIN option A</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Not charging, VBAT &gt; VPH_MIN option B</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Maximum regulated output voltage</td>
<td>Charging disabled</td>
<td>–</td>
<td>4.6</td>
<td>–</td>
<td>V</td>
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<tr>
<td>Minimum regulated output voltage</td>
<td>Three programmable settings for PMI8994</td>
<td>–</td>
<td>3.15</td>
<td>–</td>
<td>V</td>
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<tr>
<td>Charging</td>
<td>Four programmable settings for PMI8996</td>
<td>–</td>
<td>3.45</td>
<td>–</td>
<td>V</td>
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<tr>
<td></td>
<td>–</td>
<td>3.6</td>
<td>–</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Regulated output voltage accuracy</td>
<td>VPH = 3.6 V, I_SYS = 0 A</td>
<td>–</td>
<td>±1.0</td>
<td>±2.5</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>VPH = 4.3 V, I_SYS = 0 A</td>
<td>–</td>
<td>±1.0</td>
<td>±2.5</td>
<td>%</td>
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<tr>
<td>Output voltage load regulation</td>
<td>Load steps from 0 to 1 A in 15 microseconds</td>
<td>–</td>
<td>VBAT - 0.2</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VBAT - 0.1</td>
<td>–</td>
<td>VBAT - 0.1</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Parameter</td>
<td>Comments ¹</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Units</td>
</tr>
<tr>
<td>-----------</td>
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<tr>
<td>BATFET regulation voltage when an ideal diode</td>
<td>Ideal diode; V_OUT falling, VBAT &gt; V_OUT, I_OUT = 300 mA</td>
<td>–</td>
<td>VBAT - 0.050</td>
<td>VBAT - 0.075</td>
<td>V</td>
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<tr>
<td>Efficiency</td>
<td>USB_IN charging efficiency of PMI8996.</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
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<tr>
<td>USB_IN</td>
<td>- Peak, 5 V input</td>
<td>–</td>
<td>92.3</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>Peak, 9 V input</td>
<td>–</td>
<td>89.1</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>3 A charge current, 9 V input</td>
<td>–</td>
<td>85.1</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>DC_IN</td>
<td>- Peak, 5 V input</td>
<td>–</td>
<td>91.4</td>
<td>–</td>
<td>%</td>
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<td></td>
<td>Peak, 7 V input</td>
<td>–</td>
<td>89.9</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>Peak, 9 V input</td>
<td>–</td>
<td>88.6</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>1.5 A charge current, 5 V input</td>
<td>–</td>
<td>87.3</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>1.5 A charge current, 7 V input</td>
<td>–</td>
<td>88.7</td>
<td>–</td>
<td>%</td>
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<tr>
<td></td>
<td>1.5 A charge current, 9 V input</td>
<td>–</td>
<td>88.2</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>USB_IN charging power dissipation of PMI8996.</td>
<td>–</td>
<td>2032</td>
<td>–</td>
<td>mW</td>
</tr>
<tr>
<td>USB_IN</td>
<td>3 A charge current, 9 V input</td>
<td>–</td>
<td>849</td>
<td>–</td>
<td>mW</td>
</tr>
<tr>
<td>DC_IN</td>
<td>1.5 A charge current, 5 V input</td>
<td>–</td>
<td>882</td>
<td>–</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>1.5 A charge current, 7 V input</td>
<td>–</td>
<td>887</td>
<td>–</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>1.5 A charge current, 9 V input</td>
<td>–</td>
<td>882</td>
<td>–</td>
<td>mW</td>
</tr>
<tr>
<td>SYSON analog output</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SYSON output voltage</td>
<td>For PMI8994, I_OUT = 50 mA; USB_IN or DC_IN &gt; 5.0 V</td>
<td>4.7</td>
<td>5.0</td>
<td>5.3</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>For PMI8996, I_OUT = 50 mA; USB_IN or DC_IN &gt; 5.5 V</td>
<td>5.17</td>
<td>5.5</td>
<td>5.83</td>
<td>V</td>
</tr>
<tr>
<td>Battery FET</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Battery FET on resistance</td>
<td>–</td>
<td>10</td>
<td>16</td>
<td>mΩ</td>
<td></td>
</tr>
<tr>
<td>Battery FET continuous current ³</td>
<td>Pad limited</td>
<td>–</td>
<td>–</td>
<td>6</td>
<td>A</td>
</tr>
<tr>
<td>Battery FET peak current ³</td>
<td>Pad limited, 10% duty cycle</td>
<td>–</td>
<td>–</td>
<td>8</td>
<td>A</td>
</tr>
<tr>
<td>USB-OTG, HDMI, MHL modes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>OTG output voltage</td>
<td>4.75</td>
<td>5.00</td>
<td>5.25</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>See Table 3-6 for typical OTG efficiency curve</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>OTG battery UVLO accuracy, VBAT falling</td>
<td>2.70 to 3.30 V settings</td>
<td>–</td>
<td>–</td>
<td>±4</td>
<td>%</td>
</tr>
<tr>
<td>OTG-specific UVLO hysteresis</td>
<td>T = 0°C to 70°C</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>OTG-specific standby current</td>
<td>See “Current consumption” in Table 3-5</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Protection</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VBAT overvoltage lockout</td>
<td>VBAT rising</td>
<td>–</td>
<td>V_FLT + 0.1</td>
<td>–</td>
<td>V</td>
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### Table 3-5  Battery charger specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments ¹</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic charger shutdown threshold (VASHDN)</td>
<td>DC_MODE - VBAT or USB_MODE - VBAT</td>
<td>120</td>
<td>180</td>
<td>240</td>
<td>mV</td>
</tr>
<tr>
<td>Voltage (falling)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hysteresis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charge inhibit threshold voltage (V_FLT - VBAT)</td>
<td>Four steps, after power applied</td>
<td>50</td>
<td>–</td>
<td>300</td>
<td>mV</td>
</tr>
<tr>
<td>Precharge timeout accuracy</td>
<td></td>
<td></td>
<td>–</td>
<td>±20</td>
<td>%</td>
</tr>
<tr>
<td>Complete charge timeout accuracy</td>
<td></td>
<td></td>
<td>–</td>
<td>±20</td>
<td>%</td>
</tr>
<tr>
<td>System start-up holdoff timer</td>
<td></td>
<td></td>
<td>200</td>
<td>–</td>
<td>msec</td>
</tr>
<tr>
<td>USB_MODE</td>
<td></td>
<td></td>
<td>5</td>
<td>–</td>
<td>msec</td>
</tr>
<tr>
<td>DC_MODE</td>
<td></td>
<td></td>
<td>10</td>
<td>15</td>
<td>msec</td>
</tr>
<tr>
<td>Charger start-up holdoff timer</td>
<td></td>
<td></td>
<td>250</td>
<td>–</td>
<td>msec</td>
</tr>
<tr>
<td>Enabled</td>
<td></td>
<td></td>
<td>–</td>
<td>–</td>
<td>msec</td>
</tr>
<tr>
<td>Disabled</td>
<td></td>
<td></td>
<td>1</td>
<td>–</td>
<td>msec</td>
</tr>
<tr>
<td>Battery voltage glitch filter</td>
<td></td>
<td></td>
<td>–</td>
<td>175</td>
<td>msec</td>
</tr>
<tr>
<td>Watchdog timer</td>
<td></td>
<td></td>
<td>–</td>
<td>36</td>
<td>sec</td>
</tr>
<tr>
<td>Option A</td>
<td></td>
<td></td>
<td>–</td>
<td>18</td>
<td>sec</td>
</tr>
<tr>
<td>Option B</td>
<td></td>
<td></td>
<td>–</td>
<td>64</td>
<td>sec</td>
</tr>
<tr>
<td>Charger thermal protection</td>
<td></td>
<td></td>
<td>–</td>
<td>100</td>
<td>°C</td>
</tr>
<tr>
<td>Charging current reduction, option A</td>
<td></td>
<td></td>
<td>–</td>
<td>–</td>
<td>°C</td>
</tr>
<tr>
<td>Charging current reduction, option B</td>
<td></td>
<td></td>
<td>–</td>
<td>110</td>
<td>°C</td>
</tr>
<tr>
<td>Charging current reduction, option C</td>
<td></td>
<td></td>
<td>–</td>
<td>120</td>
<td>°C</td>
</tr>
<tr>
<td>Charging current reduction, option D</td>
<td></td>
<td></td>
<td>–</td>
<td>130</td>
<td>°C</td>
</tr>
<tr>
<td>Shutdown</td>
<td></td>
<td></td>
<td>–</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Shutdown hysteresis</td>
<td></td>
<td></td>
<td>–</td>
<td>20</td>
<td>°C</td>
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See Table 3-6 for battery thermistor monitoring specifications.

### Low battery (SYSOK output pad)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments ¹</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low battery voltage/SYSOK detection</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td>steps</td>
</tr>
<tr>
<td>Threshold range (VBAT falling)</td>
<td>15 programmable steps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold accuracy</td>
<td></td>
<td></td>
<td>2.5</td>
<td>–</td>
<td>3.70</td>
</tr>
<tr>
<td>Threshold hysteresis (rising)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±2</td>
</tr>
</tbody>
</table>

### VDIR_CHG analog output

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments ¹</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>R = ratio of VDIR_CHG to I_CHG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For PMI8994, V = I_CHG × 0.8 Ω</td>
<td></td>
<td></td>
<td>0.8</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>For PMI8996, V = I_CHG × 0.5 Ω</td>
<td></td>
<td></td>
<td>0.5</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VDIR_CHG accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_CHG = 500 mA</td>
<td>T = 0°C to 70°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_CHG = 1000 mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±40</td>
</tr>
<tr>
<td>VDIR_CHG output drive strength ²</td>
<td>Maximum load capacitance</td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

1. The comments refer to the specific characteristics or constraints of the parameter values.
2. Maximum load capacitance refers to the maximum capacitance that the output can drive.
Table 3-5  Battery charger specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-level input voltage (V_{IH})</td>
<td>Charger digital interface pads:</td>
<td>1.4</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Low-level input voltage (V_{IL})</td>
<td>CHG_EN, WIPWR_DIV2_EN, WIPWR_CHG_OK, USB_CS</td>
<td>–</td>
<td>–</td>
<td>0.6</td>
<td>V</td>
</tr>
<tr>
<td>EN high-level input voltage (V_{IH})</td>
<td></td>
<td>1.2</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>EN low-level input voltage (V_{IL})</td>
<td></td>
<td>–</td>
<td>–</td>
<td>0.4</td>
<td>V</td>
</tr>
<tr>
<td>Output low-level (V_{OL}), 3 mA sink</td>
<td>STAT_CHG, PGOOD_SYSOK</td>
<td>–</td>
<td>–</td>
<td>0.3</td>
<td>V</td>
</tr>
<tr>
<td>R_{PULL} (push-pull configuration)</td>
<td>PGOOD_SYSOK</td>
<td>–</td>
<td>1.27</td>
<td>–</td>
<td>kΩ</td>
</tr>
<tr>
<td></td>
<td>USBPHY_ON</td>
<td>–</td>
<td>1.27</td>
<td>–</td>
<td>kΩ</td>
</tr>
<tr>
<td></td>
<td>VDD = 1.8 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VDD = 5.0 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Current consumption**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{LEAK}</td>
<td>EN_CHG, USB_CS</td>
<td>–</td>
<td>–</td>
<td>1.0</td>
<td>μA</td>
</tr>
<tr>
<td></td>
<td>STAT_CHG</td>
<td>–</td>
<td>–</td>
<td>1.0</td>
<td>μA</td>
</tr>
<tr>
<td>Ground current</td>
<td>Input present, SHDN = H, USB_IN/DC_IN = 0 V</td>
<td>45</td>
<td>70</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>Standby (battery)</td>
<td>No input, SHDN = L</td>
<td>12</td>
<td>20</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>Shutdown (battery)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspend (DC_IN) ^{9}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspend (USB_IN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>PFM mode, no load</td>
<td>–</td>
<td>2</td>
<td>5</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>PWM mode, no load</td>
<td>–</td>
<td>15</td>
<td>24</td>
<td>mA</td>
</tr>
<tr>
<td>OTG-specific standby current</td>
<td>No load, PFM mode</td>
<td>–</td>
<td>3</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>No load, PWM mode</td>
<td>–</td>
<td>27</td>
<td>–</td>
<td>mA</td>
</tr>
</tbody>
</table>

1. T = -30°C to +85°C, DC_IN or USB_IN = 5.0 V, V_{FLT} = 4.2 V, and VBAT = 3.7 V unless otherwise noted.
2. Overvoltage lockout depends on the allowed input adapter type selection.
3. Not 100% production tested. Guaranteed by design and/or characterization.
4. Refer to the USB battery charging specifications 1.1 and 1.2.
5. Charge termination current sensed by charger analog sensor. By using a fuel gauge ADC, PMI8996 can achieve a higher charge termination current accuracy.
6. Battery recharging can also be handled by fuel gauge, based on the battery SoC.
7. Although the PMI8994 oscillator frequency can be programmed to 3 MHz, only 2 MHz is supported. For PMI8996, the default switching frequency of 750 kHz is trimmed 10% lower to achieve better charger efficiency.
8. Drive strength/load capacitance is guaranteed by design, but is not 100% tested.
9. See Table 3-3 for USB_IN and DC_IN suspend current consumption.
3.4.2 Fuel gauge

The fuel gauge module offers a hardware-based algorithm that is able to accurately estimate the battery’s state of charge by using current monitoring and voltage-based techniques. This hybrid approach ensures both excellent short-term linearity and long-term accuracy. Furthermore, neither full battery charge cycling, nor zero-current-load conditions, are required to maintain the accuracy.

The fuel gauge measures the battery pack temperature by sensing the voltage across an external thermistor. Missing battery detection is also incorporated to accurately monitor battery insertion and removal scenarios, while properly updating the state of charge when a battery is reconnected.

Using precise measurements of battery voltage, current, and temperature, the fuel gauging algorithm compensates for the variation in battery characteristics across temperature changes and aging effects. This provides a dependable state of charge estimate throughout the entire life of the battery and across a broad range of operating conditions.

A low level of interaction with the system is required. A broad range of configuration registers are provided to fit the requirements various applications.

Performance specifications for PMI8994 and PMI8996 fuel gauge are presented in Table 3-6 and Table 3-7, respectively.

Table 3-6 PMI8994 fuel gauge performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>State of charge accuracy</td>
<td>See Figure 3-9 and Figure 3-10 for typical SoC accuracy curves.</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Voltage ADC – battery voltage conversion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC resolution</td>
<td>–</td>
<td>–</td>
<td>15</td>
<td>–</td>
<td>bits</td>
</tr>
<tr>
<td>LSB magnitude</td>
<td>–</td>
<td>152.6</td>
<td>–</td>
<td>µV</td>
<td></td>
</tr>
<tr>
<td>Conversion time</td>
<td>15 bits</td>
<td></td>
<td>163.84</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>Input voltage range</td>
<td>2.8</td>
<td>–</td>
<td>4.6</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Gain error</td>
<td></td>
<td></td>
<td>–</td>
<td>±0.2</td>
<td>%</td>
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<tr>
<td>T = 25°C</td>
<td></td>
<td></td>
<td>–</td>
<td>±0.3</td>
<td>%</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>3.4</td>
<td>to</td>
<td>4.4 V</td>
</tr>
<tr>
<td>Input referred offset error</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+2.5</td>
<td>mV</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>3.4</td>
<td>to</td>
<td>4.4 V</td>
</tr>
<tr>
<td>Voltage ADC – thermistor voltage conversion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC resolution</td>
<td>–</td>
<td>–</td>
<td>12</td>
<td>–</td>
<td>bits</td>
</tr>
<tr>
<td>LSB magnitude</td>
<td>–</td>
<td>659</td>
<td>–</td>
<td>µV</td>
<td></td>
</tr>
<tr>
<td>Conversion time</td>
<td>1.47</td>
<td>–</td>
<td>392</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Input voltage range</td>
<td>% of R_BIAS</td>
<td>0</td>
<td>90.5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Gain error</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+0.6</td>
<td>%</td>
</tr>
<tr>
<td>T = -20°C to +70°C</td>
<td></td>
<td></td>
<td>1</td>
<td>to</td>
<td>2.7 V</td>
</tr>
<tr>
<td>Input referred offset error</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+0.6</td>
<td>%</td>
</tr>
<tr>
<td>T = -20°C to +70°C</td>
<td></td>
<td></td>
<td>1</td>
<td>to</td>
<td>2.7 V</td>
</tr>
<tr>
<td>Gain error</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+0.6</td>
<td>%</td>
</tr>
<tr>
<td>T = -20°C to +70°C</td>
<td></td>
<td></td>
<td>1</td>
<td>to</td>
<td>2.7 V</td>
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Table 3-6  PMI8994 fuel gauge performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Supported resistance range 2</td>
<td></td>
<td>10</td>
<td></td>
<td>100</td>
<td>kΩ</td>
</tr>
<tr>
<td>Supported resistor accuracy</td>
<td></td>
<td></td>
<td>0.50</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Supported beta value range</td>
<td></td>
<td></td>
<td>3200</td>
<td></td>
<td>kΩ</td>
</tr>
<tr>
<td>Accuracy of converted temperature</td>
<td></td>
<td>-2</td>
<td></td>
<td>+2</td>
<td>°C</td>
</tr>
<tr>
<td>T = -20°C to +60°C</td>
<td></td>
<td>-3</td>
<td></td>
<td>+3</td>
<td>°C</td>
</tr>
<tr>
<td>Biasing voltage (R_BIAS)</td>
<td></td>
<td>2.7</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Biasing voltage accuracy</td>
<td></td>
<td>-10</td>
<td></td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td><strong>Voltage ADC – USB ID voltage conversion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC resolution</td>
<td></td>
<td></td>
<td>12</td>
<td></td>
<td>bits</td>
</tr>
<tr>
<td>LSB magnitude</td>
<td></td>
<td></td>
<td>659.2</td>
<td></td>
<td>µV</td>
</tr>
<tr>
<td>Conversion time</td>
<td></td>
<td></td>
<td>20.5</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>Input voltage range % of R_BIAS</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>87.4</td>
</tr>
<tr>
<td>Gain error</td>
<td></td>
<td>-0.6</td>
<td></td>
<td>+0.6</td>
<td>%</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>USB_ID &gt; 1 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input referred offset error</td>
<td></td>
<td>-6</td>
<td></td>
<td>+6</td>
<td>mV</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>USB_ID ≤ 1 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supported resistance range</td>
<td></td>
<td>0</td>
<td></td>
<td>850</td>
<td>kΩ</td>
</tr>
<tr>
<td>Biasing voltage (R_BIAS)</td>
<td></td>
<td>2.7</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Biasing voltage accuracy</td>
<td></td>
<td>-10</td>
<td></td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td><strong>Voltage ADC – battery ID voltage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC resolution</td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td>bits</td>
</tr>
<tr>
<td>LSB magnitude</td>
<td></td>
<td></td>
<td>9.8</td>
<td></td>
<td>µV</td>
</tr>
<tr>
<td>Conversion time</td>
<td></td>
<td></td>
<td>2.6</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>Input voltage range 0 – 2.5 V</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Battery current accuracy</td>
<td></td>
<td></td>
<td>-25</td>
<td></td>
<td>+25</td>
</tr>
<tr>
<td>3.0 V &lt; VBATT &lt; 4.4 V, T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>-1.25</td>
<td></td>
<td>+1.25</td>
</tr>
<tr>
<td></td>
<td>l_batt</td>
<td>≤ 2 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>l_batt</td>
<td>&gt; 2 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input referred offset error</td>
<td></td>
<td>-10</td>
<td></td>
<td>+10</td>
<td>mV</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>BAT_ID ≤ 1 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supported resistance range 3</td>
<td></td>
<td>1</td>
<td></td>
<td>450</td>
<td>kΩ</td>
</tr>
<tr>
<td>Bias current accuracy</td>
<td></td>
<td></td>
<td>-8</td>
<td></td>
<td>+8</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td>-6</td>
<td></td>
<td>+6</td>
</tr>
<tr>
<td>5 µA setting</td>
<td></td>
<td></td>
<td>-4</td>
<td></td>
<td>+4</td>
</tr>
<tr>
<td>15 µA setting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 µA setting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current ADC – external sensing battery current</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC resolution</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td>bits</td>
</tr>
</tbody>
</table>

Note: Table contains specifications for various electrical parameters, including supported resistance ranges, accuracy details, and conversion temperatures.
## PMI8994 fuel gauge performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSB magnitude</td>
<td></td>
<td>–</td>
<td>1.5</td>
<td>–</td>
<td>µV</td>
</tr>
<tr>
<td>Conversion time</td>
<td></td>
<td>–</td>
<td>163</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>Gain error</td>
<td>VBATT = 3.0 to 4.4 V</td>
<td>-1</td>
<td>–</td>
<td>+1</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>T = 25°C</td>
<td>-1.25</td>
<td>–</td>
<td>+1.25</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>T = 0°C to +70°C</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Supported resistance range</td>
<td></td>
<td>–</td>
<td>10</td>
<td>–</td>
<td>mΩ</td>
</tr>
<tr>
<td>Supported resistor accuracy</td>
<td></td>
<td>1</td>
<td>0.5</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Converted battery current LSB</td>
<td></td>
<td>–</td>
<td>152.6</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>Converted battery current range</td>
<td></td>
<td>-4.8</td>
<td>–</td>
<td>+4.8</td>
<td>A</td>
</tr>
<tr>
<td>Input referred offset error</td>
<td>T = 0°C to +70°C, VBATT = 3.0 to 4.4 V</td>
<td>-25</td>
<td>–</td>
<td>+25</td>
<td>mA</td>
</tr>
</tbody>
</table>

### Current ADC – internal sensing battery current

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Signed representation</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC resolution</td>
<td>–</td>
<td>15</td>
<td>–</td>
<td>–</td>
<td>bits</td>
</tr>
<tr>
<td>LSB magnitude</td>
<td>–</td>
<td>1.5</td>
<td>–</td>
<td>–</td>
<td>µV</td>
</tr>
<tr>
<td>Conversion time</td>
<td>–</td>
<td>163</td>
<td>–</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>Battery current accuracy</td>
<td>VBATT &gt; 3.6 V, T = 0°C to +70°C</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="pmi8994-fuel-gauge-performance-specifications-internal-sensing-battery-current.png" alt="Table" /></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Converted battery current LSB</td>
<td>–</td>
<td>152.6</td>
<td>–</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>Converted battery current range</td>
<td>–</td>
<td>-4</td>
<td>–</td>
<td>+4</td>
<td>A</td>
</tr>
</tbody>
</table>

### ADC shared parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC clock conversion frequency</td>
<td>193</td>
<td>200</td>
<td>205</td>
<td>kHz</td>
</tr>
<tr>
<td>T = 0°C to +70°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Current consumption

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>–</td>
<td>1000</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>Sleep</td>
<td>10</td>
<td>140</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>BCL in LPM state</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. T = -30°C to +85°C, +2.7 V < VBATT < +4.5 V unless otherwise noted. All voltages are relative to GND.
2. It is not recommended to place any capacitance on the BATT_THERM pad. Capacitance greater than 40 nF with a 10 kΩ nominal thermistor resistance may result in error in the converted temperature exceeding the specification limits.
3. It is not recommended to place any capacitance on the BATT_ID pad. Adding capacitance may result in error in the converted battery ID exceeding the specification if the following capacitances are exceeded:

- \( \text{BATT} \_\text{ID} = 1 \, \text{k}\Omega \) to \( 15 \, \text{k}\Omega \): 10 nF
- \( \text{BATT} \_\text{ID} = 19 \, \text{k}\Omega \) to \( 140 \, \text{k}\Omega \): 4.7 nF
- \( \text{BATT} \_\text{ID} = 240 \, \text{k}\Omega \) to \( 450 \, \text{k}\Omega \): 0.47 nF

**Figure 3-9** PMI8994 SoC accuracy plot for 1.15 A discharging (4.35 V 3 Ah battery), measured on PMI8994 v2.0
PMI8994/PMI8996 Power Management IC Device Specification

Electrical specifications

Figure 3-10 PMI8994 SoC accuracy plot for 1.15 A discharging 4.2 V 1.5 Ah battery, measured on PMI8994 v2.0
SoC accuracy: 1.5A charging with 5V DCP, 4.35V 3Ah battery at 25°C (external current sensing)

Figure 3-11 PMI8994 SoC accuracy plot for 1.5 A charging with 5 V DCP (4.35 V 3 Ah battery), measured on PMI8994 v2.0

Table 3-7 PMI8996 fuel gauge performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC clock frequency from standby oscillator</td>
<td>$T_J = 25^\circ$C</td>
<td>196</td>
<td>200</td>
<td>204</td>
<td>KHz</td>
</tr>
<tr>
<td></td>
<td>$T_J = 0^\circ$C to +70°C</td>
<td>193</td>
<td>200</td>
<td>207</td>
<td>KHz</td>
</tr>
<tr>
<td>Biasing voltage (R_BIAS)</td>
<td>–</td>
<td>2.7</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Minimum input supply voltage for memory volatile content retention</td>
<td>–</td>
<td>2.6</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td><strong>Voltage ADC – battery voltage conversion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC resolution</td>
<td>–</td>
<td>–</td>
<td>15</td>
<td></td>
<td>bits</td>
</tr>
<tr>
<td>LSB magnitude</td>
<td>–</td>
<td>152.6</td>
<td></td>
<td></td>
<td>µV</td>
</tr>
<tr>
<td>Conversion time</td>
<td>15 bits</td>
<td>–</td>
<td>163.84</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>Input voltage range</td>
<td>2.8</td>
<td>–</td>
<td>4.7</td>
<td></td>
<td>V</td>
</tr>
</tbody>
</table>
### Table 3-7  PMI8996 fuel gauge performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
</table>
| Battery voltage absolute accuracy, (PLUSBATT - MINUSBATT) | T = 25°C  
VBATT = 3.8 V  
No input connected | -0.15 | –    | +0.15 | %    |
|                                                | T = 0°C to +70°C  
VBATT = 3.8 V  
No input connected | -0.2  | –    | +0.2  | %    |
|                                                | T = 25°C  
VBATT = 3.8 V  
5 V USB Input | -0.25 | –    | +0.25 | %    |
|                                                | T = 0°C to +70°C  
VBATT = 3.8 V  
5 V USB Input | -0.3  | –    | +0.3  | %    |

**Voltage ADC – thermistor voltage conversion**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermistor voltage resolution</td>
<td>Programmable</td>
<td>9</td>
<td>–</td>
<td>12</td>
<td>bits</td>
</tr>
<tr>
<td>Thermistor voltage input range</td>
<td>% of R_BIAS</td>
<td>0</td>
<td>–</td>
<td>91.2</td>
<td>%</td>
</tr>
<tr>
<td>Thermistor voltage LSB</td>
<td>V_R_BIAS = 2.7 V</td>
<td>659</td>
<td>–</td>
<td>5273</td>
<td>µV</td>
</tr>
</tbody>
</table>
| Thermistor voltage absolute accuracy           | T = -20°C to +70°C  
V_R_BIAS = 2.7 V  
V_BAT_THERM > 1 V | -0.8 | –    | +0.8  | %    |
|                                                | T = -20°C to +70°C  
V_R_BIAS = 2.7 V  
V_BAT_THERM < 1 V | -8   | –    | 8     | mV   |
| Supported thermistor value range               | 10            | –      | 100  | kΩ     |
| Supported thermistor accuracy                  | –             | 0.50   | –    | %     |
| Supported thermistor beta value range          | 3200          | –      | 4400 |       |
| Supported thermistor capacitor value           | BAT_ThermRES = 10 k | –     | 5    | 150   | nF   |
| Battery temperature measurement accuracy       | T = -0°C to +50°C  
Thermistor accuracy = 0.5%  
IBATT < 50 mA  
Thermistor B = 3200  
Thermistor value = 68 K | -2 | –    | +2   | C    |
|                                                | T = -20°C to +60°C  
Thermistor accuracy = 0.5%  
IBATT < 50 mA  
Thermistor B = 3200  
Thermistor value = 68 K | -3 | –    | +3   | C    |
| Time between updates                           | 1.47          | –      | 392  | s     |
| Biasing voltage (R_BIAS)                       | T = 25°C  
During ADC conversion | –    | 2.7   | –    | V    |
### Table 3-7 PMI8996 fuel gauge performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biasing voltage accuracy</strong></td>
<td>T = 0°C to +70°C During ADC conversion</td>
<td>-10</td>
<td>10</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

**Voltage ADC – battery ID voltage**

| ADC reading resolution           | –           | 9   | –   | bits |
| LSB magnitude                    | –           | 9.8 | –   | mV   |
| Conversion time                  | –           | 2.6 | –   | ms   |
| Input voltage range              | 0           | 2.5 | V   |      |
| Gain error                       | T = 0°C to +70°C BATT_ID > 1 V | -1  | ±0.75 | +1 | %   |
| Input referred offset error      | T = 0°C to +70°C BATT_ID ≤ 1 V | -10 | –   | +10 | mV |

**Current ADC – external sensing battery current**

| Battery current accuracy         | T = 0°C to +70°C VBATT = 3.0 to 4.4 V IBATT < -1 A (charge) IBATT > 1 A (discharge) | -1.5 | –   | +1.5 | %   |

| Termination current accuracy     | T = 0°C to +70°C VBATT = 4.4 V IBATT = -0.3 A | -15 | –   | +15 | mA |

| Supported resistance range       | –           | 10  | –   | mΩ   |
| Supported resistor accuracy      | –           | 0.5 | 1   | %   |
| Converted battery current LSB   | 10 mΩ Rsense | –   | 152.6 | – | µA |
| Converted battery current range | 10 mΩ Rsense | -5.0 | –   | +5.0 | A   |

**Current ADC – internal sensing battery current**

| Battery current accuracy         | T = 0°C to +70°C VBATT = 3.4 to 4.4 V Vsys_MIN = 3.0 V | -7  | –   | +7  | %   |

| T = 0°C to +70°C VBATT = 3.4 to 4.4 V Vsys_MIN = 3.0 V | -70 | –   | +70 | mA |
Table 3-7  PMI8996 fuel gauge performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
</table>
| Termination current accuracy       | T = 0°C to +70°C  
VBATT = 4.4 V  
IBATT = -0.3 A | -40 | –   | +40 | mA   |
| Converted battery current LSB      | –            | 152.6 | –   | –   | µA   |
| Converted battery current range    | -5.0         | –   | +5.0 | –   | A    |
| Conversion time                    | 15 bits      | –   | 163 | –   | ms   |

**Current consumption**

<table>
<thead>
<tr>
<th>Ground current</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Fuel gauge is converting voltage/current</td>
<td>–</td>
<td>1000</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>Sleep</td>
<td>Estimated average sleep current</td>
<td>–</td>
<td>30</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>Sleep</td>
<td>Rock bottom sleep current</td>
<td>10</td>
<td>–</td>
<td>–</td>
<td>µA</td>
</tr>
</tbody>
</table>

1. T = -10°C to +70°C, +2.7 V < VBATT < +4.5 V, unless otherwise noted. All voltages are relative to GND.
3.4.2.1 Battery serial interface

Battery Serial Interface (BSI) implements the physical layer of MIPI battery interface (BIF) to connect either low cost or smart battery pack. When interfaced with a smart battery, BSI enables a single wire serial interface which allows digital communication between mobile device (host) and battery (slave) over battery communication line (BCL) or battery ID (BATT_ID) line. The purpose of BIF is to provide a method to communicate battery characteristics information to ensure safe and efficient charging control under all operating conditions. The software detects if a smart battery is connected and enables digital communication over BCL. BIF also provides battery authentication through digital unique ID (UID) so that host device can take appropriate action when an unauthorized battery is connected to the phone.

Table 3-8 BSI performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MIPI-BIF I/O electrical specifications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCL logic high or idle voltage</td>
<td></td>
<td>1.2</td>
<td>–</td>
<td>2.25</td>
<td>V</td>
</tr>
<tr>
<td>R_ID = 240 kΩ–450 kΩ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_PU = 5 µA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCL logic low voltage</td>
<td></td>
<td>–</td>
<td>–</td>
<td>0.1</td>
<td>V</td>
</tr>
<tr>
<td>R_ID = 450 Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal ID pull-up current source - See Table 3-6 for Battery ID specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal fast pull-up resistor</td>
<td></td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>kΩ</td>
</tr>
<tr>
<td>BCL idle DC voltage for low-cost battery</td>
<td></td>
<td>0.294</td>
<td>–</td>
<td>2.1</td>
<td>V</td>
</tr>
<tr>
<td>Programmable range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_ID = 19.6 kΩ–140 kΩ</td>
<td></td>
<td>-4</td>
<td>–</td>
<td>+4</td>
<td>%</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MIPI-BIF I/O timing specifications for smart battery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIF time base range</td>
<td>Based on software programming</td>
<td>2</td>
<td>–</td>
<td>150</td>
<td>µs</td>
</tr>
<tr>
<td>Rise time</td>
<td>0 to 1.1 V</td>
<td>–</td>
<td>–</td>
<td>500</td>
<td>ns</td>
</tr>
<tr>
<td>R_ID = 240 kΩ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_BCL = 50 pF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall time</td>
<td>VOH_BCL (max) to 0.1</td>
<td>–</td>
<td>–</td>
<td>50</td>
<td>ns</td>
</tr>
<tr>
<td>R_ID = 450 kΩ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_BCL = 50 pF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MIPI-BIF timing specifications for battery removal detection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery removal debounce filter time</td>
<td>Software programmable with step of 31 µs (32 kHz sleep clock)</td>
<td>0</td>
<td>–</td>
<td>1</td>
<td>ms</td>
</tr>
<tr>
<td>Programmable range</td>
<td></td>
<td>-16</td>
<td>–</td>
<td>+16</td>
<td>%</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. T = -30°C to +85°C, +2.7 V < VBATT < +4.5 V unless otherwise noted. All voltages are relative to GND.
3.5 Output power management

Output power management performance specifications are split into five functional categories as defined within its block diagram (Figure 3-12). Before providing performance specifications for these functions, the outputs and their expected uses are listed (Table 3-9).

Figure 3-12 Output power management functional block diagram

<table>
<thead>
<tr>
<th>Type/output</th>
<th>Rated current/1 expected peak</th>
<th>Default conditions/2 specified range 3</th>
<th>Expected usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF/S1</td>
<td>1000 mA/860 mA</td>
<td>Off at 1.025 V/0.375–1.400 V</td>
<td>PM8994 LDO 1 for subregulation</td>
</tr>
<tr>
<td>FT/S2</td>
<td>4000 mA/4000 mA</td>
<td>On at 1.000 V/0.350–1.355 V</td>
<td>Graphics core</td>
</tr>
<tr>
<td>FT/S3</td>
<td>4000 mA/4000 mA</td>
<td>On at 1.000 V/0.350–1.355 V</td>
<td>Graphics core</td>
</tr>
<tr>
<td>Boost/bypass</td>
<td>2000 mA/1000 mA</td>
<td>On at 3.300 V/3.000 to 5.200 V</td>
<td>Microphone bias, torch, and PM8994/PM8996 LDOs 9, 10, 13, 17, 18, 19, 20, 21, 22, 23, 24, and 29 for subregulation</td>
</tr>
<tr>
<td>+5 V boost</td>
<td>1300 mA/600 mA</td>
<td>Off at 5.000 V/4.5 to 5.5 V</td>
<td>Speaker driver, (host mode for concurrency case)</td>
</tr>
</tbody>
</table>

1. Rated current is the maximum for which specification compliance is guaranteed unless stated otherwise.
2. All regulators have default voltage settings, whether they default on or not; the voltage and state depends upon the programmable boot sequencer (PBS) configuration.
3. The specified voltage range is the programmed range for which performance is guaranteed to meet all specs. For usage outside this range, submit a case to QTI for approval.
3.5.1 Boost/bypass SMPS

At a very high level, the boost/bypass SMPS can be described as a boost converter with the option to bypass the boost function. When the input voltage (VPH_PWR) is lower than the target output voltage, the boost/bypass works in its boost mode to maintain a constant output voltage that is higher than the input voltage. When the input voltage is higher than the target output voltage, the boost function is bypassed, thereby passing the input voltage to the output terminal.

Pertinent performance specifications are given in Table 3-10.

Table 3-10 Boost/bypass SMPS performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1, 2</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage VPH_PWR</td>
<td></td>
<td>2.5</td>
<td>–</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage range, 50 mV steps</td>
<td>Specified performance range</td>
<td>3.0</td>
<td>3.15</td>
<td>5.2</td>
<td>V</td>
</tr>
<tr>
<td>Rated load current (I_rated)</td>
<td>Continuous current delivery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_{in} \geq 3.3 \text{ V} )</td>
<td></td>
<td>2000</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>( V_{in} \geq 3.0 \text{ V}, V_{out} &lt; 3.6 \text{ V} )</td>
<td></td>
<td>1500</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>( V_{in} \geq 2.5 \text{ V}, V_{out} &lt; 3.3 \text{ V} )</td>
<td></td>
<td>1000</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Inductor current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Programmable range</td>
<td>For 1 A and above</td>
<td>500</td>
<td>–</td>
<td>4000</td>
<td>mA</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td>–</td>
<td>–</td>
<td>±30</td>
<td>%</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Programmable; range &amp; default values</td>
<td>1.6</td>
<td>3.2</td>
<td>6.4</td>
<td>MHz</td>
</tr>
<tr>
<td>Output voltage error</td>
<td>Boost mode; over process, battery voltage, and temperature (PVT)</td>
<td>–</td>
<td>–</td>
<td>±1</td>
<td>%</td>
</tr>
<tr>
<td>At 3.3 V output (trim value)</td>
<td></td>
<td>–</td>
<td>–</td>
<td>±2</td>
<td>%</td>
</tr>
<tr>
<td>Over V_out range</td>
<td></td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>Average efficiency over stated range of current; ( V_{in} = 2.8 \text{ V}, V_{out} = 3.3 \text{ V}, F_{sw} = 3.2 \text{ MHz} )</td>
<td>–</td>
<td>85</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>( I_{load} = 1 \text{ to 10 mA} )</td>
<td></td>
<td>–</td>
<td>93</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>( I_{load} = 10 \text{ to 250 mA} )</td>
<td></td>
<td>–</td>
<td>95</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>( I_{load} = 250 \text{ to 500 mA} )</td>
<td>See Figure 3-13 for typical efficiency curve</td>
<td>–</td>
<td>94</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>( I_{load} = 500 \text{ to 1000 mA} )</td>
<td></td>
<td>–</td>
<td>89</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>( I_{load} = 1000 \text{ to 2000 mA} )</td>
<td></td>
<td>–</td>
<td>89</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Enable settling time</td>
<td>From enable to within 5% of final value</td>
<td>–</td>
<td>400</td>
<td>–</td>
<td>µs</td>
</tr>
<tr>
<td>Forced bypass to boost settling time</td>
<td>( V_{in} = 2.8 \text{ V}, V_{out} = 3.3 \text{ V}, I_{load} = 10 \text{ mA} )</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>µs</td>
</tr>
<tr>
<td>Load regulation, boosting</td>
<td>( V_{in} = 2.8 \text{ V}, V_{out} = 3.3 \text{ V}, I_{load} = 0.01 \times I_{rated} )</td>
<td>–</td>
<td>–</td>
<td>±0.3</td>
<td>%</td>
</tr>
<tr>
<td>Line regulation, boosting</td>
<td>( V_{in} = 2.8 \text{ V} ) to 3.3 V; ( I_{load} = 600 \text{ mA} )</td>
<td>–</td>
<td>–</td>
<td>1.0</td>
<td>%</td>
</tr>
<tr>
<td>Output voltage ripple</td>
<td>Entire load range; ( V_{out} = 3.3 \text{ V} )</td>
<td>–</td>
<td>–</td>
<td>80</td>
<td>mVpp</td>
</tr>
</tbody>
</table>
Table 3-10  Boost/bypass SMPS performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1, 2</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient under/overshoot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load step</td>
<td></td>
<td>-100</td>
<td>–</td>
<td>200</td>
<td>mVpp</td>
</tr>
<tr>
<td>While boosting</td>
<td>800 mA load step in 5 µsec</td>
<td>-100</td>
<td>–</td>
<td>200</td>
<td>mVpp</td>
</tr>
<tr>
<td>With bypass/boost transition</td>
<td>800 mA load step in 5 µsec</td>
<td>-100</td>
<td>–</td>
<td>200</td>
<td>mVpp</td>
</tr>
<tr>
<td>Line step (V_in dip)</td>
<td></td>
<td>-100</td>
<td>–</td>
<td>200</td>
<td>mVpp</td>
</tr>
<tr>
<td>While boosting</td>
<td>600 mA load; 500 mV dip over 10 µsec</td>
<td>-100</td>
<td>–</td>
<td>200</td>
<td>mVpp</td>
</tr>
<tr>
<td>With bypass/boost transition</td>
<td>600 mA load; 500 mV dip over 10 µsec</td>
<td>-100</td>
<td>–</td>
<td>200</td>
<td>mVpp</td>
</tr>
<tr>
<td>Combination load &amp; line steps</td>
<td>-150</td>
<td>–</td>
<td>300</td>
<td></td>
<td>mVpp</td>
</tr>
<tr>
<td>FET on resistance</td>
<td></td>
<td>–</td>
<td>60</td>
<td>110</td>
<td>mΩ</td>
</tr>
<tr>
<td>Boost NFET</td>
<td></td>
<td>–</td>
<td>55</td>
<td>90</td>
<td>mΩ</td>
</tr>
<tr>
<td>Boost PFET</td>
<td></td>
<td>–</td>
<td>55</td>
<td>90</td>
<td>mΩ</td>
</tr>
<tr>
<td>Bypass PFET</td>
<td></td>
<td>–</td>
<td>55</td>
<td>90</td>
<td>mΩ</td>
</tr>
<tr>
<td>Bypass resistance</td>
<td>Inductor to output</td>
<td>–</td>
<td>60</td>
<td>85</td>
<td>mΩ</td>
</tr>
<tr>
<td>Ground current</td>
<td></td>
<td>–</td>
<td>–</td>
<td>600</td>
<td>µA</td>
</tr>
<tr>
<td>Auto-boost mode, boosting</td>
<td></td>
<td>–</td>
<td>–</td>
<td>250</td>
<td>µA</td>
</tr>
<tr>
<td>Auto-boost mode, bypassing</td>
<td></td>
<td>–</td>
<td>0.3</td>
<td>5</td>
<td>µA</td>
</tr>
<tr>
<td>Forced-bypass mode</td>
<td></td>
<td>–</td>
<td>0.3</td>
<td>1</td>
<td>µA</td>
</tr>
</tbody>
</table>

1. All specifications apply over the device’s operating conditions, load current range, and capacitor ESR range unless noted otherwise. Derated capacitor values are: C_in = 1 µF (4.7 µF nominal), C_out = 15 µF (2x22 µF nominal) (derated over voltage, temperature, and aging). Using a capacitor with an effective capacitance less than the stated derated capacitor values can result in instability and is not supported.

2. Performance characteristics that may degrade if the rated output current is exceeded are voltage error, efficiency, and output ripple voltage.
3.5.2 HF-SMPS

The PMI8994/PMI8996 includes one HF-SMPS circuit. It supports pulse width modulation (PWM) and pulse frequency modulation (PFM) modes, and the automatic transition between modes, depending upon the load current. Pertinent performance specifications are given in Table 3-11.

Table 3-11 HF-SMPS performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage</td>
<td>VPH_PWR</td>
<td>2.5</td>
<td>–</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 mV steps</td>
<td>Programmable range</td>
<td>1.550</td>
<td>–</td>
<td>3.1250</td>
<td>V</td>
</tr>
<tr>
<td>12.5 mV steps</td>
<td></td>
<td>0.375</td>
<td>1.025</td>
<td>1.5625</td>
<td></td>
</tr>
<tr>
<td>Rated load current</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1000</td>
<td>mA</td>
</tr>
<tr>
<td>PWM mode</td>
<td>l_rated; continuous current delivery</td>
<td>200</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>PFM mode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-13  Boost/bypass efficiency plot, measured on PMI8994 v2.0
Table 3-11  HF-SMPS performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short circuit/peak current limit (through inductor)</td>
<td>VREG pad shorted; I_limit set via SPMI</td>
<td>0.7 x</td>
<td>I_limit</td>
<td>1.3 x</td>
<td>mA</td>
</tr>
<tr>
<td>Voltage error</td>
<td>PFM and PWM modes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOUT &gt; 1.0 V, I_rated/2</td>
<td>-2</td>
<td>-1</td>
<td>1</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>VOUT &lt; 1.0 V, I_rated/2</td>
<td>-20</td>
<td>-10</td>
<td>10</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Overall output error</td>
<td>Voltage error, load and line regulation, plus temperature and process variations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM mode</td>
<td>V_out &gt; 1.0 V, I_rated /2</td>
<td>-2</td>
<td>2</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>V_out &lt; 1.0 V, I_rated /2</td>
<td>-20</td>
<td>-20</td>
<td>40</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>PFM mode</td>
<td>V_out &gt; 1.0 V, I_rated /2</td>
<td>-2</td>
<td>2</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>V_out &lt; 1.0 V, I_rated /2</td>
<td>-20</td>
<td>-20</td>
<td>40</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Temperature coefficient</td>
<td></td>
<td></td>
<td></td>
<td>±100</td>
<td>ppm/C</td>
</tr>
<tr>
<td>Efficiency 3</td>
<td>VDD_Sx = 3.6 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM mode</td>
<td>V_out = 1.8 V, I_load = 300 mA</td>
<td>–</td>
<td>90</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>V_out = 1.8 V, I_load = 10 to 600 mA</td>
<td>–</td>
<td>85</td>
<td>–</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>V_out = 1.8 V, I_load = 800 mA</td>
<td>–</td>
<td>80</td>
<td>–</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>PFM mode</td>
<td>V_out = 1.2 V, I_load = 5 mA</td>
<td>–</td>
<td>80</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Enable settling time</td>
<td>From enable to within 1% of final value</td>
<td>5</td>
<td>20</td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>Enable overshoot</td>
<td>Slow start</td>
<td>–</td>
<td>–</td>
<td>3</td>
<td>%</td>
</tr>
<tr>
<td>V_out &gt; 1.0 V, no load</td>
<td>–</td>
<td>–</td>
<td>30</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Fast start</td>
<td>V_out &gt; 1.0 V, no load</td>
<td>–</td>
<td>–</td>
<td>6</td>
<td>%</td>
</tr>
<tr>
<td>V_out &gt; 1.0 V, no load</td>
<td>–</td>
<td>–</td>
<td>60</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Voltage step settling time per LSB</td>
<td>To within 1% of final value</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>µs</td>
</tr>
<tr>
<td>Response to load transitions 4</td>
<td>PWM mode and auto mode, ~300 ns transient step</td>
<td>–</td>
<td>–</td>
<td>40</td>
<td>mV</td>
</tr>
<tr>
<td>Dip due to low-to-high load</td>
<td>–</td>
<td>–</td>
<td>70</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Spike due to high-to-low load</td>
<td>–</td>
<td>–</td>
<td>70</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Response to PFM/PWM and PWM/PFM transitions 4</td>
<td>-40</td>
<td>–</td>
<td>40</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Load transient + ripple measured relative to the PWM mode</td>
<td>For 1 A load step, 47 µF load capacitor</td>
<td>-40</td>
<td>–</td>
<td>70</td>
<td>mV</td>
</tr>
<tr>
<td>Output ripple voltage</td>
<td>Tested at the switching frequency</td>
<td>–</td>
<td>20</td>
<td>40</td>
<td>mVpp</td>
</tr>
<tr>
<td>PWM pulse-skipping mode</td>
<td>40 mA load; 20 MHz BW</td>
<td>–</td>
<td>20</td>
<td>40</td>
<td>mVpp</td>
</tr>
<tr>
<td>PWM non-pulse-skipping mode</td>
<td>l_rated; 20 MHz BW</td>
<td>–</td>
<td>10</td>
<td>20</td>
<td>mVpp</td>
</tr>
<tr>
<td>PFM mode</td>
<td>50 or 100 mA load; 20 MHz BW</td>
<td>–</td>
<td>–</td>
<td>50</td>
<td>mVpp</td>
</tr>
<tr>
<td>HC-PFM mode</td>
<td>50 or 100 mA load; 20 MHz BW</td>
<td>–</td>
<td>–</td>
<td>70</td>
<td>mVpp</td>
</tr>
<tr>
<td>Load regulation</td>
<td>V_in ≥ V_out + 1 V;</td>
<td>–</td>
<td>–</td>
<td>0.25</td>
<td>%</td>
</tr>
<tr>
<td>l_load = 0.01 × l_rated to l_rated</td>
<td></td>
<td>–</td>
<td>0.25</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Line regulation</td>
<td>V_in = 3.2 V to 4.2 V; l_load = 100 mA</td>
<td>–</td>
<td>–</td>
<td>0.25</td>
<td>%/V</td>
</tr>
</tbody>
</table>
### Table 3-11  HF-SMPS performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power-supply ripple rejection</td>
<td>PSRR</td>
<td>40</td>
<td>–</td>
<td>–</td>
<td>dB</td>
</tr>
<tr>
<td>50 Hz to 1 kHz</td>
<td></td>
<td>20</td>
<td>–</td>
<td>–</td>
<td>dB</td>
</tr>
<tr>
<td>1 kHz to 100 kHz</td>
<td></td>
<td>30</td>
<td>–</td>
<td>–</td>
<td>dB</td>
</tr>
<tr>
<td>100 kHz to 1 MHz</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>dB</td>
</tr>
<tr>
<td>Output noise</td>
<td></td>
<td>–</td>
<td>-95</td>
<td>–</td>
<td>dBm/Hz</td>
</tr>
<tr>
<td>F &lt; 5 kHz</td>
<td></td>
<td>–</td>
<td>-100</td>
<td>–</td>
<td>dBm/Hz</td>
</tr>
<tr>
<td>F = 5 kHz to 10 kHz</td>
<td></td>
<td>–</td>
<td>-100</td>
<td>–</td>
<td>dBm/Hz</td>
</tr>
<tr>
<td>F = 10 kHz to 500 kHz</td>
<td></td>
<td>–</td>
<td>-110</td>
<td>–</td>
<td>dBm/Hz</td>
</tr>
<tr>
<td>F = 500 kHz to 1 MHz</td>
<td></td>
<td>–</td>
<td>-110</td>
<td>–</td>
<td>dBm/Hz</td>
</tr>
<tr>
<td>F &gt; 2 MHz</td>
<td></td>
<td>–</td>
<td>-110</td>
<td>–</td>
<td>dBm/Hz</td>
</tr>
<tr>
<td>Ground current</td>
<td>No load</td>
<td>–</td>
<td>550</td>
<td>750</td>
<td>µA</td>
</tr>
<tr>
<td>PWM mode</td>
<td></td>
<td>–</td>
<td>50</td>
<td>70</td>
<td>µA</td>
</tr>
<tr>
<td>PFM mode, auto</td>
<td></td>
<td>–</td>
<td>20</td>
<td>30</td>
<td>µA</td>
</tr>
<tr>
<td>PFM mode, manual</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>µA</td>
</tr>
</tbody>
</table>

1. All specifications apply over the device’s operating conditions, load current range, and capacitor ESR range unless noted otherwise.

2. Performance characteristics that may degrade if the rated output current is exceeded are voltage error, efficiency, and output ripple voltage.

3. Figure 3-14 shows efficiency of S1 in auto mode.

4. 400 mA load change within the range from I_rated/20 to I_rated. Note that larger load capacitors result in lower voltage dips.
3.5.3 FT-SMPS

The PMI8994/PMI8996 includes two FT-SMPS circuits; in the APQ8094/APQ8096SGE chipset, they are combined for dual-phase support of the GFX domain. Supported modes include PWM, PFM, and autonomous mode control (AMC) in which the buck hardware manages PWM/PFM transitions based on load current. Additionally, multi-phase domains support autonomous phase control (APC) in which the phase count is autonomously managed by hardware to select the appropriate number of phases for optimal efficiency.

Pertinent target performance specifications are given in Table 3-12.

Table 3-12 FT-SMPS performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage range</td>
<td>LV range</td>
<td>0.350</td>
<td>–</td>
<td>1.35</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>MV range</td>
<td>0.700</td>
<td>–</td>
<td>2.200</td>
<td>V</td>
</tr>
<tr>
<td><strong>CMC NPM or AMC NPM, any number of phases</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated load current</td>
<td>I_rated per phase</td>
<td>4.0</td>
<td>–</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>Parameter</td>
<td>Comments</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Unit</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>DC output voltage accuracy</td>
<td>Including MBG, make tolerance, line and load regulation, and temperature (-30°C to 125°C)</td>
<td>-2</td>
<td>-16</td>
<td>+2</td>
<td>+16</td>
</tr>
<tr>
<td>DC output voltage accuracy</td>
<td>VREG ≥ 0.8</td>
<td>-2</td>
<td>-</td>
<td>+2</td>
<td>+16</td>
</tr>
<tr>
<td>DC output voltage accuracy</td>
<td>VREG &lt; 0.8</td>
<td>-16</td>
<td>-</td>
<td>+16</td>
<td>%</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>Measured across Cout where sense lines are tapped</td>
<td>–</td>
<td>7</td>
<td>15</td>
<td>mVpp</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>Single-phase</td>
<td>–</td>
<td>7</td>
<td>15</td>
<td>mVpp</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>Multi-phase</td>
<td>–</td>
<td>15</td>
<td></td>
<td>mVpp</td>
</tr>
<tr>
<td>Line transient response</td>
<td>GSM burst induced line transient represented by: Rbat = 350 mΩ; Istep = 2 A with 10 µs slew; VPH_PWR capacitance = 100 µF</td>
<td>–</td>
<td>–</td>
<td>20</td>
<td>mVpp</td>
</tr>
<tr>
<td>CMC NPM or AMC NPM, multi-phase</td>
<td>Phase current mismatch Relative to ideal balanced current.</td>
<td>-25</td>
<td>–</td>
<td>+25</td>
<td>%</td>
</tr>
<tr>
<td>Ground current</td>
<td>Ground current (CMC NPM) No load, single-phase</td>
<td>–</td>
<td>0.55</td>
<td>0.80</td>
<td>mA</td>
</tr>
<tr>
<td>Ground current per phase</td>
<td>(CMC NPM or AMC NPM) No load, multi-phase</td>
<td>–</td>
<td>1.9</td>
<td>2.3</td>
<td>mA</td>
</tr>
<tr>
<td>Ground current (CMC LPM)</td>
<td>No load, single- or multi-phase</td>
<td>–</td>
<td>55</td>
<td>90</td>
<td>µA</td>
</tr>
<tr>
<td>Ground current per phase</td>
<td>(AMC LPM) No load, single- or multi-phase</td>
<td>–</td>
<td>80</td>
<td>110</td>
<td>µA</td>
</tr>
<tr>
<td>CMC NPM or AMC load transient, any number of phases</td>
<td>Response to load transient (undershoot/overshoot) 1.5 A load step per phase for S2A/S12A, and 2 A load step per phase for all other domains; transient step ~100 ns, 1 V output</td>
<td>-50</td>
<td>–</td>
<td>+80</td>
<td>mV</td>
</tr>
<tr>
<td>CMC LPM or AMC LPM, CPC or APC, any number of phases</td>
<td>DC output voltage accuracy Including MBG, make tolerance, line and load regulation, and temperature (-30°C to 125°C)</td>
<td>-2</td>
<td>-</td>
<td>+4</td>
<td>%</td>
</tr>
<tr>
<td>CMC LPM, any number of phases</td>
<td>VSET ≥ 0.8V</td>
<td>-2</td>
<td>-</td>
<td>+4</td>
<td>%</td>
</tr>
<tr>
<td>CMC LPM, any number of phases</td>
<td>VSET &lt; 0.8V</td>
<td>-16</td>
<td>-</td>
<td>+32</td>
<td>mV</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>Measured across Cout where sense lines are tapped</td>
<td>–</td>
<td>25</td>
<td>40</td>
<td>mVpp</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>Single-phase</td>
<td>–</td>
<td>25</td>
<td>40</td>
<td>mVpp</td>
</tr>
<tr>
<td>Ripple voltage</td>
<td>Multi-phase</td>
<td>–</td>
<td>40</td>
<td>35</td>
<td>mVpp</td>
</tr>
<tr>
<td>Rated load current</td>
<td>CL_PFM = 1.404A</td>
<td>–</td>
<td>0.8</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>Transition specifications</td>
<td>NPM CPC change in phase count</td>
<td>–</td>
<td>25</td>
<td>–</td>
<td>µs</td>
</tr>
</tbody>
</table>
Table 3-12 FT-SMPS performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase current settling time</td>
<td>Time to achieve phase current match</td>
<td>–</td>
<td>–</td>
<td>200</td>
<td>µs</td>
</tr>
<tr>
<td></td>
<td>Steady state loading; all active phases in CCM; change in phase count</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other general characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>See Figure 3-15 for typical efficiency plot</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Enable settling time</td>
<td>Vout slewing to within 1% of final value</td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>µs</td>
</tr>
<tr>
<td>Voltage stepper undershoot/overshoot</td>
<td>1 LSB step slewing</td>
<td>-5</td>
<td>–</td>
<td>+5</td>
<td>mV</td>
</tr>
<tr>
<td>Peak output impedance</td>
<td>1 kHz to 1 MHz</td>
<td>–</td>
<td>–</td>
<td>40</td>
<td>mΩ</td>
</tr>
<tr>
<td>Discharge impedance</td>
<td></td>
<td>–</td>
<td>32</td>
<td>–</td>
<td>Ω</td>
</tr>
</tbody>
</table>

1. General specifications for the FTS 2.5 apply overall operating conditions of supply, temperature, process, and component variances except where noted.
2. Default components are assumed (470 nH, 2x 22 µF per phase) along with deployed configurations for the APQ8094/APQ8096SGE lineup.
3. Where parametric performance is influenced by external components, baseline components are assumed. Values listed are the component specified values, not the derated values. Derating must be taken into account to ensure robustness. Initial assumption is 50% derating on capacitors pending further assessment of specific component selections (rough allowance for temperature, tolerance, and voltage derating).
4. Acronyms are: low-power mode (LPM), normal power mode (NPM), autonomous mode control (AMC), commended (forced) mode control (CMC), autonomous phase control (APC), and commended (forced) phase control (CPC).
The boost switched-mode power supply (SMPS) is rated for 1300 mA output current, and is intended for generating +5 V to power circuits such as USB-OTG, HDMI/MHL/SlimPort, speaker drivers, LED indicators, and lighting. Pertinent performance specifications are listed in Table 3-13.

Table 3-13  Boost regulator performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1, 2</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage</td>
<td>VPH_PWR</td>
<td>2.5</td>
<td>–</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage ranges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Programmable range</td>
<td></td>
<td>50 mV steps</td>
<td>4.0</td>
<td>5.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Specified performance range</td>
<td></td>
<td>4.5</td>
<td>5.0</td>
<td>5.2</td>
<td>V</td>
</tr>
<tr>
<td>Rated current (I_rated)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_in = 4.2 V to 4.5 V</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1300</td>
<td>mA</td>
</tr>
<tr>
<td>V_in = 3.6 V to 4.2 V</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1200</td>
<td>mA</td>
</tr>
<tr>
<td>V_in = 3.0 V to 3.6 V</td>
<td></td>
<td>–</td>
<td>–</td>
<td>900</td>
<td>mA</td>
</tr>
<tr>
<td>V_in = 2.5 V to 3.0 V</td>
<td></td>
<td>–</td>
<td>–</td>
<td>600</td>
<td>mA</td>
</tr>
<tr>
<td>Inductor current</td>
<td>Programmable</td>
<td>1.6</td>
<td>4.0</td>
<td>4.0</td>
<td>A</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Programmable; range &amp; default values</td>
<td>1.6</td>
<td>1.6</td>
<td>9.6</td>
<td>MHz</td>
</tr>
</tbody>
</table>
### Table 3-13  Boost regulator performance specifications (cont.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1, 2</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage error</td>
<td>I_out = 600 mA</td>
<td>-1.5</td>
<td>–</td>
<td>+1.5%</td>
<td>%</td>
</tr>
<tr>
<td>Efficiency</td>
<td>I_load = 600 mA</td>
<td>–</td>
<td>88</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Boost output settling time</td>
<td>From BST_REQ to within 90% of final value; VPH_PWR = 3 V, V_out = 5 V, I_out = 0.9 A</td>
<td>–</td>
<td>200</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>Load regulation</td>
<td>I_load = 100 to 1300 mA</td>
<td>–</td>
<td>0.1</td>
<td>0.5 %</td>
<td>%</td>
</tr>
<tr>
<td>Line regulation</td>
<td>VPH_PWR = 3.0 to 4.5 V, V_out = 5 V, I_load = 600 mA</td>
<td>–</td>
<td>0.2</td>
<td>0.7 %</td>
<td>%</td>
</tr>
<tr>
<td>Output ripple 3</td>
<td>1300 mA load</td>
<td>–</td>
<td>–</td>
<td>80</td>
<td>mVpp</td>
</tr>
<tr>
<td>PWM mode</td>
<td>–</td>
<td>–</td>
<td>160</td>
<td>mVpp</td>
<td></td>
</tr>
<tr>
<td>Pulse-skipping mode</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Transient response 4</td>
<td>Voltage dip due to load transient</td>
<td>–</td>
<td>–</td>
<td>140</td>
<td>mV</td>
</tr>
<tr>
<td>Voltage spike due to load transient</td>
<td>–</td>
<td>–</td>
<td>120</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Forced boost threshold</td>
<td>SmartBoost function enabled; BST_REQ = 0, I_load = 600 mA</td>
<td>3.0</td>
<td>3.1</td>
<td>3.2</td>
<td>V</td>
</tr>
<tr>
<td>Vdip</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Hysteresis</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Asynchronous threshold</td>
<td>SmartBoost function enabled; BST_REQ = 0, I_load = 600 mA</td>
<td>4.45</td>
<td>4.55</td>
<td>4.65</td>
<td>V</td>
</tr>
<tr>
<td>Vasync</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Hysteresis</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Ground current</td>
<td>VDD = +3.6 V, Vout = 5.1 V, F_sw = 1.6 MHz</td>
<td>–</td>
<td>–</td>
<td>1200</td>
<td>µA</td>
</tr>
<tr>
<td>Active, no load</td>
<td>–</td>
<td>–</td>
<td>5</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>Leakage into switch node</td>
<td>–</td>
<td>0.3</td>
<td>–</td>
<td>µA</td>
<td></td>
</tr>
</tbody>
</table>

1. All specifications apply at VPH_PWR = 3.6 V, T = -30ºC to +85ºC, VREG_5V = 5.0 V, L = 2.2 µH, and C = 10 µF (capacitance value derated from 22 µF nominal) unless noted otherwise.

2. Performance characteristics that may degrade if the rated output current is exceeded:
   - Voltage error
   - Output ripple
   - Efficiency

3. Ripple voltage is measured within a 20 MHz bandwidth, and does not include glitches.

4. The stated transient response performance is achieved regardless of the transitory mode – turning the regulator on and off, changing load conditions, changing input voltage, or reprogramming the output voltage setting.
3.5.5 Reference circuit

All PMIC regulator circuits, and some other internal circuits, are driven by a common, on-chip voltage reference circuit. An on-chip series resistor supplements an off-chip 0.1 µF bypass capacitor at the REF_BYP pad to create a low-pass function that filters the reference voltage distributed throughout the device.

**NOTE:** Do not load the REF_BYP pad. Use an MPP configured as an analog output if the reference voltage is needed off-chip.

Applicable voltage reference performance specifications are given in Table 3-14.

### Table 3-14 Voltage reference performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal internal VREF</td>
<td>At REF_BYP pad</td>
<td>–</td>
<td>1.250</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage deviations</td>
<td>Over temperature only, -20 to +120ºC</td>
<td>–</td>
<td>–</td>
<td>±0.32</td>
<td>%</td>
</tr>
<tr>
<td>Normal operation</td>
<td>All operating conditions</td>
<td>–</td>
<td>–</td>
<td>±0.50</td>
<td>%</td>
</tr>
<tr>
<td>Sleep mode</td>
<td>All operating conditions</td>
<td>–</td>
<td>–</td>
<td>±1.00</td>
<td>%</td>
</tr>
</tbody>
</table>

3.5.6 Internal voltage-regulator connections

Some regulator supply voltages and/or outputs are connected internally to power other PMIC circuits. These circuits will not operate properly unless their source voltage regulators are enabled and set to their proper voltages. These requirements are summarized in Table 3-15.

### Table 3-15 Internal voltage regulator connections

<table>
<thead>
<tr>
<th>Voltage supply or regulator output</th>
<th>Default</th>
<th>Supported circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD_APQ_IO</td>
<td>1.8 V</td>
<td>GPIOs and MPPs; SPMI</td>
</tr>
<tr>
<td>VPH_PWR</td>
<td>3.6 V</td>
<td>GPIOs and MPPs</td>
</tr>
<tr>
<td>VREG_ADC_LDO</td>
<td>1.8 V</td>
<td>AMUX/HKADC (dedicated; do not alter)</td>
</tr>
</tbody>
</table>
3.6 General housekeeping

General housekeeping performance specifications are split into four functional categories as defined within its block diagram (Figure 3-16).

Figure 3-16 General housekeeping functional block diagram
3.6.1 Analog multiplexer and scaling circuits

Analog switches, multiplexers, and voltage-scaling circuits select and condition a single analog signal for routing to the on-chip HKADC. Available multiplexer and scaling functions are summarized in Table 3-16.

### Table 3-16 Analog multiplexer and scaling functions

<table>
<thead>
<tr>
<th>Ch #</th>
<th>Description</th>
<th>Typical input range (V)</th>
<th>Scaling</th>
<th>Typical output range (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>USB_IN</td>
<td>3 to 10</td>
<td>1/20</td>
<td>0.15 to 0.50</td>
</tr>
<tr>
<td>1</td>
<td>DC_IN</td>
<td>3 to 10</td>
<td>1/20</td>
<td>0.15 to 0.50</td>
</tr>
<tr>
<td>9</td>
<td>0.625 V reference voltage</td>
<td>0.625</td>
<td>1</td>
<td>0.625</td>
</tr>
<tr>
<td>10</td>
<td>1.25 V reference voltage</td>
<td>1.25</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>12</td>
<td>0.625 V reference voltage buffer</td>
<td>0.625</td>
<td>1</td>
<td>0.625</td>
</tr>
<tr>
<td>13</td>
<td>Die-temperature monitor</td>
<td>0.4 to 0.9</td>
<td>1</td>
<td>0.4 to 0.9</td>
</tr>
<tr>
<td>14</td>
<td>GND_REF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>VDD_ADC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>MPP_1</td>
<td>0.05 to 1.5</td>
<td>1</td>
<td>0.05 to 1.5</td>
</tr>
<tr>
<td>32</td>
<td>MPP_1</td>
<td>0.3 to VPH_PWR</td>
<td>1/3</td>
<td>0.1 to 1.70</td>
</tr>
<tr>
<td>63</td>
<td>Module power off 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>67</td>
<td>USB_DP</td>
<td>0.3 to VPH_PWR</td>
<td>1/3</td>
<td>0.1 to 1.70</td>
</tr>
<tr>
<td>68</td>
<td>USB_DM</td>
<td>0.3 to VPH_PWR</td>
<td>1/3</td>
<td>0.1 to 1.70</td>
</tr>
</tbody>
</table>

1. Input voltage must not exceed the ADC reference voltage generated by VREG_ADC_LDO (1.8 V).
2. Channel 32 should be selected when the analog multiplexer is not being used; this prevents the scalers from loading the inputs.

**NOTE:** Gain and offset errors are different through each analog multiplexer channel. Each path should be calibrated individually over its valid gain and offset settings for best accuracy.

### Table 3-17 Analog multiplexer performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage (Vadc)</td>
<td>Connected internally to VREG_ADC</td>
<td>–</td>
<td>1.8</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage range</td>
<td></td>
<td>0.1</td>
<td>–</td>
<td>Vadc – 0.10</td>
<td>V</td>
</tr>
<tr>
<td>Full specification compliance</td>
<td></td>
<td>0.05</td>
<td>–</td>
<td>Vadc – 0.05</td>
<td>V</td>
</tr>
<tr>
<td>Degraded accuracy at edges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input referred offset errors</td>
<td></td>
<td></td>
<td></td>
<td>±2.0</td>
<td>mV</td>
</tr>
<tr>
<td>Channels with x1 scaling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channels with 1/3 scaling</td>
<td></td>
<td></td>
<td></td>
<td>±1.5</td>
<td>mV</td>
</tr>
<tr>
<td>Channels with 1/20 scaling</td>
<td></td>
<td></td>
<td></td>
<td>±2.0</td>
<td>mV</td>
</tr>
<tr>
<td>Parameter</td>
<td>Comments</td>
<td>Min</td>
<td>Typ</td>
<td>Max</td>
<td>Units</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-------</td>
</tr>
<tr>
<td>Gain errors, including scaling</td>
<td>Excludes VREG_ADC output error</td>
<td></td>
<td></td>
<td>±0.20</td>
<td>%</td>
</tr>
<tr>
<td>Channels with x1 scaling</td>
<td></td>
<td></td>
<td></td>
<td>±0.15</td>
<td>%</td>
</tr>
<tr>
<td>Channels with 1/3 scaling</td>
<td></td>
<td></td>
<td></td>
<td>±0.28</td>
<td>%</td>
</tr>
<tr>
<td>Integrated nonlinearity (INL)</td>
<td>Input referred to account for scaling</td>
<td>-3</td>
<td></td>
<td>+3</td>
<td>mV</td>
</tr>
<tr>
<td>Input resistance</td>
<td>Input referred to account for scaling</td>
<td>10</td>
<td></td>
<td>–</td>
<td>MΩ</td>
</tr>
<tr>
<td>Channels with x1 scaling</td>
<td></td>
<td></td>
<td></td>
<td>–</td>
<td>MΩ</td>
</tr>
<tr>
<td>Channels with 1/3 scaling</td>
<td></td>
<td>1</td>
<td></td>
<td>–</td>
<td>MΩ</td>
</tr>
<tr>
<td>Channels with 1/20 scaling</td>
<td></td>
<td>0.77</td>
<td></td>
<td>–</td>
<td>MΩ</td>
</tr>
<tr>
<td>Channel-to-channel isolation</td>
<td>1 V AC input at 1 kHz</td>
<td>50</td>
<td></td>
<td>–</td>
<td>dB</td>
</tr>
<tr>
<td>Output settling time</td>
<td>C&lt;sub&gt;load&lt;/sub&gt; = 28 pF</td>
<td>–</td>
<td>–</td>
<td>25</td>
<td>µs</td>
</tr>
<tr>
<td>Output noise level</td>
<td>f = 1 kHz</td>
<td>–</td>
<td>–</td>
<td>2</td>
<td>µV/Hz&lt;sup&gt;1/2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1. Multiplexer offset error, gain error, and INL are measured as shown in Figure 3-17. Supporting comments:
   • The non-linearity curve is exaggerated for illustrative purposes.
   • Input and output voltages must stay within the ranges stated in Table 3-16; voltages beyond these ranges result in nonlinearity, and are beyond specification.
   • Offset is determined by measuring the slope of the endpoint line (m) and calculating its Y-intercept value (b):
     \[
     \text{Offset} = b = y_1 - m \cdot x_1
     \]
   • Gain error is calculated from the ideal response and the endpoint line as the ratio of their two slopes (in percentage):
     \[
     \text{Gain_error} = \left\{ \frac{\text{slope of endpoint line}}{\text{slope of ideal response}} - 1 \right\} \times 100\%
     \]
   • INL is the worst-case deviation from the endpoint line. The endpoint line removes the gain and offset errors to isolate nonlinearity:
     \[
     \text{INL(min)} = \min[V_{\text{out(actual at V_x input)}} - V_{\text{out(endpoint line at V_x input)}}]
     \]
     \[
     \text{INL(max)} = \max[V_{\text{out(actual at V_x input)}} - V_{\text{out(endpoint line at V_x input)}}]
     \]

2. The AMUX output and a typical load are modeled in Figure 3-18. After S1 closes, the voltage across C2 settles within the specified settling time.
Figure 3-17  Multiplexer offset and gain errors

Figure 3-18  Analog multiplexer load condition for settling time specification
Table 3-18 AMUX input to ADC output end-to-end accuracy

<table>
<thead>
<tr>
<th>AMUX Ch #</th>
<th>Function</th>
<th>Typical input range</th>
<th>Typical output range</th>
<th>AMUX input to ADC output end-to-end accuracy, RSS</th>
<th>AMUX input to ADC output end-to-end accuracy, WCS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min (V)</td>
<td>Max (V)</td>
<td>Min (V)</td>
<td>Max (V)</td>
</tr>
<tr>
<td>0</td>
<td>USB_IN</td>
<td>3</td>
<td>10</td>
<td>1/20</td>
<td>0.15</td>
</tr>
<tr>
<td>1</td>
<td>DC_IN</td>
<td>3</td>
<td>10</td>
<td>1/20</td>
<td>0.15</td>
</tr>
<tr>
<td>9</td>
<td>0.625 V reference voltage</td>
<td>0.625</td>
<td>0.625</td>
<td>1</td>
<td>0.625</td>
</tr>
<tr>
<td>10</td>
<td>1.25 V reference voltage</td>
<td>1.25</td>
<td>1.25</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>12</td>
<td>0.625 V reference voltage</td>
<td>0.625</td>
<td>0.625</td>
<td>1</td>
<td>0.625</td>
</tr>
<tr>
<td>13</td>
<td>Die-temperature monitor</td>
<td>0.4</td>
<td>0.9</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>14–15</td>
<td>GND_REF, VDD_ADC</td>
<td>Direct connections to ADC for calibration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>MPP_1</td>
<td>0.1</td>
<td>1.7</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>32</td>
<td>MPP_1</td>
<td>0.3</td>
<td>5.1</td>
<td>1/3</td>
<td>0.1</td>
</tr>
<tr>
<td>63</td>
<td>Module power-off</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>67</td>
<td>USB_DP</td>
<td>0.3</td>
<td>5.1</td>
<td>1/3</td>
<td>0.1</td>
</tr>
<tr>
<td>68</td>
<td>USB_DM</td>
<td>0.3</td>
<td>5.1</td>
<td>1/3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

1. The minimum and maximum accuracy values correspond to the minimum and maximum input voltage to the AMUX channel.
2. Accuracy based on root sum square (RSS) of the individual errors.
3. Accuracy is based on worst-case straight sum (WCS) of all errors.
4. Absolute uses 0.625 V and 1.25 V MBG voltage reference as calibration points. Ratiometric uses the GNDC and VREG_ADC_LDO as the calibration points.
3.6.2 HKADC circuit

Any of the four multipurpose pads can be used as an ADC input. Their input voltages must not exceed the ADC’s reference voltage (1.8 V, generated by the on-chip ADC LDO). HKADC performance specifications are listed in Table 3-19.

Table 3-19 HK/XO ADC performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage</td>
<td>Connected to internal LDO</td>
<td>–</td>
<td>1.8</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td>–</td>
<td>–</td>
<td>15</td>
<td>bits</td>
</tr>
<tr>
<td>Analog-input bandwidth</td>
<td></td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>kHz</td>
</tr>
<tr>
<td>Sample rate</td>
<td>CLK_IN/8</td>
<td>–</td>
<td>2.4</td>
<td>–</td>
<td>MHz</td>
</tr>
<tr>
<td>Offset error</td>
<td>Relative to full-scale</td>
<td>–</td>
<td>–</td>
<td>±1</td>
<td>%</td>
</tr>
<tr>
<td>Gain error</td>
<td>Relative to full-scale</td>
<td>–</td>
<td>–</td>
<td>±1</td>
<td>%</td>
</tr>
<tr>
<td>INL</td>
<td>15-bit output</td>
<td>–</td>
<td>–</td>
<td>±8</td>
<td>LSB</td>
</tr>
<tr>
<td>DNL</td>
<td>15-bit output</td>
<td>–</td>
<td>–</td>
<td>±4</td>
<td>LSB</td>
</tr>
</tbody>
</table>

3.6.3 Clock input

The PMI8994/PMI8996 requires a reference clock that is generated by the PM8994/PM8996 and applied to the PMI’s CLK_IN pad; this pad’s input characteristics are listed in Table 3-20.

Table 3-20 XO input performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input frequency range</td>
<td>19.2 MHz signal is required</td>
<td>–</td>
<td>19.2</td>
<td>–</td>
<td>MHz</td>
</tr>
<tr>
<td>Input impedance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance</td>
<td>At 19.2 MHz</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>kΩ</td>
</tr>
<tr>
<td>Capacitance</td>
<td></td>
<td>–</td>
<td>–</td>
<td>2.0</td>
<td>pF</td>
</tr>
<tr>
<td>Input amplitude</td>
<td></td>
<td>1.0</td>
<td>1.8</td>
<td>2.0</td>
<td>V pp</td>
</tr>
</tbody>
</table>
3.6.4 Over-temperature protection (smart thermal control)

The PMIC includes over-temperature protection in stages, depending on the level of urgency as the die temperature rises:

- Stage 0 – normal operating conditions.
- Stage 1 – 90°C to 100°C (configurable threshold); an interrupt is sent to the MDM without shutting down any PMIC circuits.

Temperature hysteresis is incorporated, such that the die temperature must cool significantly before the device can be powered on again. If any start signals are present while at Stage 3, they are ignored until Stage 0 is reached. When the device cools enough to reach Stage 0 and a start signal is present, the PMIC will power up immediately.

3.7 User interfaces

User interfaces performance specifications are split into six functional categories as defined within its block diagram (Figure 3-19).
Figure 3-19  User interface functional block diagram
3.7.1 Haptics

Haptics uses vibration to communicate an event or action through human touch. In a mobile phone, haptics is used to simulate the feeling of a real mechanical key by providing tactile feedback to the user as confirmation of touchscreen contact, or dynamic feedback to enhance the user’s gaming experience. Pertinent performance specifications are listed in Table 3-21.

Table 3-21 Haptics performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments 1</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage</td>
<td>Connected at VDD_HAP (VH below)</td>
<td>2.50</td>
<td>3.6</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak, no load</td>
<td>At HAP_OUT_P and HAP_OUT_N</td>
<td>–</td>
<td>–</td>
<td>VH</td>
<td>V</td>
</tr>
<tr>
<td>Average (V_HA)</td>
<td>Differential, over one PWM cycle</td>
<td>0.25</td>
<td>3.6</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Maximum drive</td>
<td>Differential, over one PWM cycle</td>
<td>1.2</td>
<td>3.6</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Duty cycle &lt; 95%</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Output voltage2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak, no load</td>
<td>At HAP_OUT_P and HAP_OUT_N</td>
<td>–</td>
<td>–</td>
<td>VH</td>
<td>V</td>
</tr>
<tr>
<td>Average (V_HA)</td>
<td>Differential, over one PWM cycle</td>
<td>0</td>
<td>3.6</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Maximum drive</td>
<td>Differential, over one PWM cycle</td>
<td>1.2</td>
<td>3.6</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Duty cycle &lt; 95%</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Output current limit</td>
<td>Cycle-to-cycle limit</td>
<td>300</td>
<td>400</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td>R_ELM or R_load = 20 Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>R_ELM or R_load = 10 Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>On resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R_ON_P</td>
<td>High side switch</td>
<td>0.25</td>
<td>0.50</td>
<td>1.25</td>
<td>Ω</td>
</tr>
<tr>
<td>R_ON_N</td>
<td>Low side switch</td>
<td>0.25</td>
<td>0.50</td>
<td>1.25</td>
<td>Ω</td>
</tr>
<tr>
<td>Internal PWM frequency</td>
<td></td>
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<td>kHz</td>
</tr>
<tr>
<td>Programmable options</td>
<td></td>
<td>253</td>
<td>503</td>
<td>1076</td>
<td>kHz</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td>–</td>
<td>–</td>
<td>±16</td>
<td>%</td>
</tr>
<tr>
<td>LRA resonance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td>Programmable period</td>
<td></td>
<td>3.33</td>
<td>5</td>
<td>10</td>
<td>ms</td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td>–</td>
<td>20</td>
<td></td>
<td>µs</td>
</tr>
<tr>
<td>LRA self-resonance capture</td>
<td></td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>Hz</td>
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<td>HAP_PWM_IN voltage</td>
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<td>0</td>
<td>1.8</td>
<td></td>
<td>V</td>
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<tr>
<td>Start-up time</td>
<td>Enable to full output drive voltage</td>
<td>–</td>
<td>–</td>
<td>100</td>
<td>µs</td>
</tr>
<tr>
<td>Ground current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Active</td>
<td>–</td>
<td>3.0</td>
<td>–</td>
<td></td>
<td>mA</td>
</tr>
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<td>Shutdown</td>
<td>–</td>
<td>1.0</td>
<td>–</td>
<td></td>
<td>µA</td>
</tr>
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</table>

1. All specifications apply at VDD_HAP = 3.6 V, T = -30°C to +85°C, and F_pwm = 500 kHz unless noted otherwise.
2. Output voltage is programmable in steps of 116 mV. ‘VH’ = VDD_HAP (3.6 V typical).
3. VDD_HAP > V_HA + I_out x (R_ON_P + R_ON_N).
### 3.7.2 Display ± bias

The PMIC generates the plus and minus bias voltages for LCD and AMOLED displays; pertinent performance specifications are listed in Table 3-22 and Table 3-23, respectively.

#### Table 3-22 Display plus bias performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational input voltage</td>
<td>Connected at VDD_DIS_P</td>
<td>2.50</td>
<td>–</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage (VDIS_P_OUT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range, no load to 150 mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>Programmable</td>
<td>5.0</td>
<td>–</td>
<td>6.1</td>
<td>V</td>
</tr>
<tr>
<td>Total output voltage variation</td>
<td>V_out = 5.0 to 6.0 V, I_load = 50 mA</td>
<td>–</td>
<td>–</td>
<td>±75</td>
<td>mV</td>
</tr>
<tr>
<td>Output current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load regulation</td>
<td>I_load = 10 to 150 mA; V_out = 5.5 V</td>
<td>–</td>
<td>1</td>
<td>5</td>
<td>mV</td>
</tr>
<tr>
<td>Line regulation</td>
<td>VDD = 2.5 to 4.75 V at I_load = 50 mA</td>
<td>–</td>
<td>1</td>
<td>5</td>
<td>mV</td>
</tr>
<tr>
<td>Load transient</td>
<td>I_out = 3 to/from 30 mA in 150 µs</td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Line transient</td>
<td>VDD = 3.6 to/from 3.1 V in 10 µs; I_out = 50 mA</td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Output ripple</td>
<td>V_out = 5.5 V; F_sw = 1.6 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disabled pulse skipping</td>
<td>I_out = 50 mA</td>
<td>–</td>
<td>10</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Enabled pulse skipping</td>
<td>I_out = 5 mA</td>
<td>–</td>
<td>15</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Efficiency</td>
<td>I_out = 30 mA</td>
<td>–</td>
<td>92</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Programmable</td>
<td>–</td>
<td>1.6</td>
<td>3.2</td>
<td>MHz</td>
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<tr>
<td>Discharge resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast discharge</td>
<td></td>
<td>–</td>
<td>70</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>Slow discharge</td>
<td></td>
<td>–</td>
<td>140</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>NFET minimum on-time</td>
<td></td>
<td>–</td>
<td>40</td>
<td>–</td>
<td>ns</td>
</tr>
<tr>
<td>Soft start time (no load)</td>
<td>Programmable range and nominal, 200 µs step; VDD = 3.6 V, V_out = 0 to 6.1 V</td>
<td>200</td>
<td>400</td>
<td>800</td>
<td>µs</td>
</tr>
<tr>
<td>Output slew time, 100 mV step</td>
<td>V_out_new = 0.9 × V_out_old</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>µs</td>
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<tr>
<td>Short circuit protection</td>
<td>VDD - V_out</td>
<td>–</td>
<td>0.6</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Debounce</td>
<td>Programmable (2 µs default)</td>
<td>2</td>
<td>–</td>
<td>32</td>
<td>µs</td>
</tr>
<tr>
<td>Ground current</td>
<td>VDD = 2.5 to 4.75 V, Vout = 5.5 V, pulse skipping active</td>
<td>–</td>
<td>500</td>
<td>1000</td>
<td>µA</td>
</tr>
<tr>
<td>Active, no load</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1.0</td>
<td>µA</td>
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### Table 3-22 Display plus bias performance specifications (cont.)

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<thead>
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<th>Parameter</th>
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<th>Min</th>
<th>Typ</th>
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<th>Units</th>
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<td><strong>Specifications for AMOLED applications</strong> 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Operational input voltage</td>
<td>Connected at VDD_DIS_P</td>
<td>2.50</td>
<td></td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage (VDIS_P_OUT)</td>
<td>Programmable</td>
<td></td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Range, no load to 350 mA</td>
<td>VDD = 2.5 to 4.75 V</td>
<td>4.6</td>
<td></td>
<td>5.0</td>
<td>V</td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Total output voltage variation</td>
<td>VDD = 2.5 to 4.75 V, V_out = 4.6 V, I_load = 150 mA</td>
<td>–</td>
<td></td>
<td>±34</td>
<td>mV</td>
</tr>
<tr>
<td>Output current</td>
<td></td>
<td>–</td>
<td></td>
<td>350</td>
<td>mA</td>
</tr>
<tr>
<td>Load regulation</td>
<td></td>
<td>–</td>
<td>1</td>
<td>5</td>
<td>mV</td>
</tr>
<tr>
<td>Line regulation</td>
<td></td>
<td>–</td>
<td>1</td>
<td>5</td>
<td>mV</td>
</tr>
<tr>
<td>Load transient</td>
<td></td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Line transient</td>
<td></td>
<td>–</td>
<td>±30</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Output ripple</td>
<td></td>
<td></td>
<td>10</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Disabled pulse skipping</td>
<td></td>
<td></td>
<td>15</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Enabled pulse skipping</td>
<td></td>
<td></td>
<td>15</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Efficiency</td>
<td>I_out = 150 mA</td>
<td>–</td>
<td>94</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Programmable</td>
<td>–</td>
<td>1.6</td>
<td>3.2</td>
<td>MHz</td>
</tr>
<tr>
<td>Discharge resistance</td>
<td></td>
<td>–</td>
<td>70</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>Fast discharge</td>
<td></td>
<td>–</td>
<td>140</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>Slow discharge</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NFET minimum on-time</td>
<td></td>
<td>–</td>
<td>40</td>
<td>–</td>
<td>ns</td>
</tr>
<tr>
<td>Soft start time (no load)</td>
<td>Programmable range and nominal, 200 μs step; VDD = 3.6 V, V_out = 0 to 6.1 V</td>
<td>200</td>
<td>400</td>
<td>800</td>
<td>μs</td>
</tr>
<tr>
<td>Output slew time, 100 mV step</td>
<td></td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>μs</td>
</tr>
<tr>
<td>Short circuit protection</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Threshold</td>
<td>VDD - V_out</td>
<td>–</td>
<td>0.6</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Debounce</td>
<td>Programmable (2 μs default)</td>
<td>2</td>
<td>–</td>
<td>32</td>
<td>μs</td>
</tr>
<tr>
<td>Ground current</td>
<td></td>
<td>–</td>
<td>500</td>
<td>1000</td>
<td>μA</td>
</tr>
<tr>
<td>Active, no load</td>
<td>VDD = 2.5 to 4.75 V, Vout = 4.6 V, pulse skipping active</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shutdown</td>
<td></td>
<td>–</td>
<td>1.0</td>
<td>–</td>
<td>μA</td>
</tr>
</tbody>
</table>

1. All specifications apply at VDD_DIS_x = 3.6 V, F_sw = 1.6 MHz, T = -30°C to +85°C, VDIS_P_OUT = 5.5 V, L = 4.7 µH, and C = 10 µF (capacitance value derated from 22 µF nominal) unless noted otherwise.

2. All specifications apply at VDD_DIS_x = 3.6 V, F_sw = 1.6 MHz, T = -30°C to +85°C, VDIS_P_OUT = 4.6 V, L = 4.7 µH, and C = 10 µF (capacitance value derated from 22 µF nominal) unless noted otherwise.
Figure 3-20  Display plus bias efficiency plot for LCD mode measured on PMI8994 v2.0

Figure 3-21  Display plus bias efficiency plot for AMOLED mode measured on PMI8994 v2.0
### Table 3-23 Display minus bias performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
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<tr>
<td><strong>Specifications for LCD applications</strong> ^1</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Operational input voltage</td>
<td>Connected at VDD_DIS_N</td>
<td>2.50</td>
<td>3.6</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage (VDIS_N_OUT)</td>
<td>Programmable</td>
<td>-1.4</td>
<td>–</td>
<td>-6.0</td>
<td>V</td>
</tr>
<tr>
<td>Range, no load to 100 mA</td>
<td></td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Total output voltage variation</td>
<td>V_out = -5.0 to -6.0 V, I_load = 50 mA</td>
<td>–</td>
<td>–</td>
<td>±60</td>
<td>mV</td>
</tr>
<tr>
<td>Output current</td>
<td></td>
<td>–</td>
<td>–</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>Load regulation</td>
<td>I_load = 10 to 150 mA</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>Line regulation</td>
<td>VDD = 2.5 to 4.75 V at I_load = 50 mA</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>Load transient</td>
<td>I_out = 3 to/from 30 mA in 150 µs</td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Line transient</td>
<td>VDD = 3.6 to/from 3.1 V in 20 µs; I_out = 50 mA</td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Output ripple</td>
<td>V_out = -5.5 V; F_sw = 1.6 MHz</td>
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<td></td>
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<td>Disabled pulse skipping</td>
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<td>–</td>
<td>10</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Enabled pulse skipping</td>
<td></td>
<td>–</td>
<td>30</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
<td>–</td>
<td>84</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Programmable</td>
<td>–</td>
<td>1.48</td>
<td>3.2</td>
<td>MHz</td>
</tr>
<tr>
<td>Discharge resistance</td>
<td></td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>Fast discharge</td>
<td></td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>Ω</td>
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<tr>
<td>Slow discharge</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Power-up/power-down delay ^2</td>
<td>Programmable range, 8 ms default</td>
<td>1</td>
<td>–</td>
<td>8</td>
<td>ms</td>
</tr>
<tr>
<td>Soft start time (no load)</td>
<td>0–90% of VREG_DISN, C_ext = 47 nF</td>
<td>–</td>
<td>1.0</td>
<td>–</td>
<td>ms</td>
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<tr>
<td>Short circuit protection</td>
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</tr>
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<td>Threshold</td>
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<td>–</td>
<td>0.6</td>
<td>–</td>
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</tr>
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<td>Debounce</td>
<td>PROGRAMMABLE</td>
<td>2</td>
<td>4</td>
<td>32</td>
<td>µs</td>
</tr>
<tr>
<td>Ground current</td>
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<td>600</td>
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<td>µA</td>
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<td>Active, no load</td>
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<td>–</td>
<td>1.0</td>
<td>–</td>
<td>µA</td>
</tr>
<tr>
<td>Shutdown</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
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<td><strong>Specifications for AMOLED applications</strong> ^3</td>
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<td>Operational input voltage</td>
<td>Connected at VDD_DIS_N</td>
<td>2.50</td>
<td>3.6</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage (VDIS_N_OUT)</td>
<td>Programmable</td>
<td>-1.4</td>
<td>–</td>
<td>-5.4</td>
<td>V</td>
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<tr>
<td>Range, VDD = 2.5 to 4.75 V</td>
<td></td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>mV</td>
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<tr>
<td>Resolution</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Total output voltage variation</td>
<td>VDD = 2.5 to 4.75 V, V_out = -1.4 to -4.4 V, I_load = 150 mA</td>
<td>–</td>
<td>–</td>
<td>±60</td>
<td>mV</td>
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### Table 3-23 Display minus bias performance specifications (cont.)

<table>
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<tr>
<th>Parameter</th>
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<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
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<tr>
<td>Output current</td>
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<td>V_out = -4.0 V</td>
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<td></td>
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<td>VPH_PWR = 2.85 to 4.75 V</td>
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<td>–</td>
<td>–</td>
<td>350</td>
<td>mA</td>
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<td>VPH_PWR = 2.65 to 4.75 V</td>
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<td>–</td>
<td>300</td>
<td>mA</td>
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<td>VPH_PWR = 2.50 to 4.75 V</td>
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<td>–</td>
<td>250</td>
<td>mA</td>
</tr>
<tr>
<td>Load regulation</td>
<td>I_load = 10 to 350 mA</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>Line regulation</td>
<td>VDD = 2.5 to 4.75 V at I_load = 150 mA</td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>Load transient</td>
<td>Transition in 150 µs</td>
<td>–</td>
<td>±25</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>I_out = 10 to/from 100 mA</td>
<td></td>
<td>–</td>
<td>±40</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>I_out = 30 to/from 300 mA</td>
<td></td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Line transient</td>
<td>VDD = 3.6 to/from 3.1 V in 20 µs; I_out = 150 mA</td>
<td>–</td>
<td>±20</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Output ripple</td>
<td>Disabled pulse skipping</td>
<td>I_out = 50 mA</td>
<td>–</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>Enabled pulse skipping</td>
<td>I_out = 5 mA</td>
<td>–</td>
<td>30</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>I_out = 50 mA</td>
<td>–</td>
<td>84</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Programmable</td>
<td>–</td>
<td>1.48</td>
<td>3.2</td>
<td>MHz</td>
</tr>
<tr>
<td>Discharge resistance</td>
<td>Fast discharge</td>
<td>–</td>
<td>50</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>Slow discharge</td>
<td></td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>Ω</td>
</tr>
<tr>
<td>Power-up/power-down delay</td>
<td>Programmable range, 8 ms default</td>
<td>1</td>
<td>–</td>
<td>8</td>
<td>ms</td>
</tr>
<tr>
<td>Soft start time (no load)</td>
<td>0-90% of VREG_DISN, C_ext = 1.5 nF</td>
<td>–</td>
<td>1.0</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>Short circuit protection</td>
<td>Threshold</td>
<td>GND - V_out</td>
<td>–</td>
<td>0.6</td>
<td>V</td>
</tr>
<tr>
<td>Debounce</td>
<td>Programmable (4 µs default)</td>
<td>2</td>
<td>4</td>
<td>32</td>
<td>µs</td>
</tr>
<tr>
<td>Output slew time, 100 mV step</td>
<td>V_out_new = 0.9 × V_out_old; C_ref = 1.5 nF; t_slew = 3 × (300 kΩ × C_ref)</td>
<td>–</td>
<td>1.35</td>
<td>–</td>
<td>ms</td>
</tr>
<tr>
<td>Ground current</td>
<td>Active, no load</td>
<td>VDD = 2.5 to 4.75 V, Vout = -4.4 V, pulse skipping active</td>
<td>–</td>
<td>600</td>
<td>1200</td>
</tr>
<tr>
<td>Shutdown</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1.0</td>
<td>µA</td>
</tr>
</tbody>
</table>

1. All specifications apply at VDD_DIS_x = 3.6 V, T = -30°C to +85°C, VDIS_N_OUT = -5.5 V, L = 4.7 µH, C = 10 µF (capacitance value derated from 22 µF nominal), and F_sw = 1.48 MHz unless noted otherwise.
2. Power-up delay is defined as the time from when VREG_DISP has reached steady state (~90% of final value) to when VREG_DISN is enabled during power-up. Power-down delay is defined as the time from when VREG_DISN has discharged (to < ~| 500 mV |) to when VREG_DISP is disabled during power-down.
3. All specifications apply at VDD_DIS_x = 3.6 V, T = -30°C to +85°C, VDIS_N_OUT = -2.4 V, L = 4.7 µH, C = 10 µF (capacitance value derated from 22 µF nominal), and F_sw = 1.48 MHz unless noted otherwise.
Figure 3-22  Display minus bias efficiency plot for LCD mode measured on PMI8994 v2.0

Figure 3-23  Display minus bias efficiency plot for AMOLED mode (-1.4 V) measured on PMI8994 v2.0
Figure 3-24  Display minus bias efficiency plot for AMOLED mode (-2.4 V) measured on PMI8994 v2.0

Figure 3-25  Display minus bias efficiency plot for AMOLED mode (-4.0 V) measured on PMI8994 v2.0
3.7.3 Flash drivers (including torch mode)

This high current (2.0 A) driver supports different input sources for flash and torch modes, works in various concurrency scenarios, and allows different LED configurations. Pertinent performance specifications are listed in Table 3-24.

Table 3-24 Flash and torch LED driver performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDD_FLASH</td>
<td>Expected source is PMI's DC_IN_OUT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash disabled</td>
<td></td>
<td>2.5</td>
<td>–</td>
<td>10</td>
<td>V</td>
</tr>
<tr>
<td>Flash enabled</td>
<td></td>
<td>–</td>
<td>–</td>
<td>5.8</td>
<td>V</td>
</tr>
<tr>
<td>VDD_TORCH</td>
<td>Expected source is PMI's VREG_BST_BYP</td>
<td>–</td>
<td>3.6</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Output current per LED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1000</td>
<td>mA</td>
</tr>
<tr>
<td>Torch</td>
<td></td>
<td>–</td>
<td>–</td>
<td>200</td>
<td>mA</td>
</tr>
<tr>
<td>Output current steps</td>
<td>Both flash and torch modes</td>
<td>–</td>
<td>12.5</td>
<td>–</td>
<td>mA</td>
</tr>
</tbody>
</table>
### 3.7.4 White LEDs

White LEDs (WLED) generate backlighting for the handset’s LCD. The PMIC supports WLEDs with a boost converter that generates the high voltage needed for powering a string of WLEDs, plus four output drivers for sinking the current from WLED strings. Brightness can be controlled via SPMI or externally via content adaptive backlight control (CABC). Other useful features include overvoltage protection, overcurrent protection, soft-start, and adaptive output voltage (as the WLED forward-voltage drop changes with temperature, the boost output voltage changes appropriately). Pertinent performance specifications are listed in Table 3-25.

**Table 3-24 Flash and torch LED driver performance specifications (cont.)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute current accuracy</td>
<td>VPH_PWR = 3.0 V to 4.75 V</td>
<td>-8.5</td>
<td>–</td>
<td>+8.5</td>
<td>%</td>
</tr>
<tr>
<td>Each LED ≥ 100 to 1000 mA</td>
<td>VDD_FLASH = V_LED + (0.5 to 1.5 V)</td>
<td>-7</td>
<td>–</td>
<td>+7</td>
<td>%</td>
</tr>
<tr>
<td>Each LED ≥ 12.5 to 200 mA (torch only)</td>
<td>VDD TORCH = V_LED + (0.5 to 1.5 V)</td>
<td>–</td>
<td>–</td>
<td>+7</td>
<td>%</td>
</tr>
<tr>
<td>LED current matching accuracy</td>
<td>VDD_FLASH = V_LED + (0.5 to 1.5 V); VDD TORCH = V_LED + (0.5 to 1.5 V)</td>
<td>–</td>
<td>–</td>
<td>+7</td>
<td>%</td>
</tr>
<tr>
<td>Each LED = 0.1 - 1.0 A</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+7</td>
<td>%</td>
</tr>
<tr>
<td>Current regulator dropout voltage</td>
<td>VDD – V_LED; range &amp; default</td>
<td>500</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection thresholds</td>
<td>Current output enabled</td>
<td>–</td>
<td>1.0</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Short circuit</td>
<td>Current output enabled</td>
<td>–</td>
<td>100</td>
<td>–</td>
<td>mV</td>
</tr>
<tr>
<td>Open circuit (VDD – V_LED)</td>
<td>Programmable range and default; 0.1 V step</td>
<td>2.5</td>
<td>3.1</td>
<td>3.2</td>
<td>V</td>
</tr>
<tr>
<td>VDD droop</td>
<td>Programmable range (10 ms steps)</td>
<td>10</td>
<td>–</td>
<td>1280</td>
<td>ms</td>
</tr>
<tr>
<td>Timers</td>
<td>Programmable range (1 sec steps)</td>
<td>2</td>
<td>–</td>
<td>33</td>
<td>sec</td>
</tr>
<tr>
<td>Flash max-on safety</td>
<td>For flash strobe, mask 1/2/3, VDD, and fault</td>
<td>0</td>
<td>–</td>
<td>128</td>
<td>µs</td>
</tr>
<tr>
<td>Video watchdog</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deglitch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current ramp</td>
<td>Step, LED current 0 to 1000 mA</td>
<td>–</td>
<td>12.5</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Step duration</td>
<td>0.2</td>
<td>6.7</td>
<td>27</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>Current derating</td>
<td>Programmable range, default</td>
<td>95</td>
<td>105</td>
<td>125</td>
<td>°C</td>
</tr>
<tr>
<td>Threshold (junction temperature)</td>
<td>Programmable range, 2.0 default</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>%/°C</td>
</tr>
<tr>
<td>Slope</td>
<td>Ground current</td>
<td>–</td>
<td>0.25</td>
<td>2</td>
<td>µA</td>
</tr>
<tr>
<td>Off state</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. All specifications apply at VPH_PWR = 3.6 V, T = -30°C to +85°C unless noted otherwise.
2. I_LED matching accuracy is determined by the following formula: abs(max(I1 - I2)) / (1/2 sum(I1:I2))
### Table 3-25 WLED boost converter and driver performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments ¹</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common to boost converter and current drivers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational input voltage</td>
<td>VPH_PWR</td>
<td>2.5</td>
<td>–</td>
<td>4.75</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage for full brightness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 strings (~16 WLEDs)</td>
<td>V_out = 28 V across panel, I_led = 20 mA per string</td>
<td>2.8</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>4 strings (~28 WLEDs)</td>
<td></td>
<td>3.6</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td><strong>Boost converter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage</td>
<td></td>
<td>6.0</td>
<td>–</td>
<td>28.5</td>
<td>V</td>
</tr>
<tr>
<td>Overvoltage protection</td>
<td>Programmable, 4 settings</td>
<td>29.3</td>
<td>31</td>
<td>31.7</td>
<td>V</td>
</tr>
<tr>
<td>30.0 V setting</td>
<td></td>
<td>28.8</td>
<td>29.5</td>
<td>30.3</td>
<td>V</td>
</tr>
<tr>
<td>29.5 V setting</td>
<td></td>
<td>18.7</td>
<td>19.4</td>
<td>20.1</td>
<td>V</td>
</tr>
<tr>
<td>19.5 V setting</td>
<td></td>
<td>17.1</td>
<td>17.8</td>
<td>18.5</td>
<td>V</td>
</tr>
<tr>
<td>18.0 V setting</td>
<td>Hysteresis</td>
<td>29.5 V setting</td>
<td>–</td>
<td>1.1</td>
<td>–</td>
</tr>
<tr>
<td>Overcurrent protection</td>
<td>Programmable, set to 980 mA</td>
<td>830</td>
<td>980</td>
<td>1200</td>
<td>mA</td>
</tr>
<tr>
<td>Switching frequency</td>
<td></td>
<td>–</td>
<td>0.8</td>
<td>–</td>
<td>MHz</td>
</tr>
<tr>
<td>Efficiency</td>
<td>VDD = 3.6 V, 25°C, F_sw = 0.8 MHz</td>
<td>–</td>
<td>86</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Peak</td>
<td>I_out = 15 mA/string (x4), 13.5 V out</td>
<td>–</td>
<td>80</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Average</td>
<td>I_out = 5 to 25 mA/string (x4)</td>
<td>–</td>
<td>75</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td>Light load</td>
<td>I_out = 1 to 5 mA/string (x4); PSM enabled</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
</tr>
<tr>
<td><strong>Current sinks ²</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-scale current range</td>
<td>Programmable range, 2.5 mA step</td>
<td>0</td>
<td>–</td>
<td>30</td>
<td>mA</td>
</tr>
<tr>
<td>Absolute accuracy, hybrid dimming</td>
<td>Combined CABC duty cycle and internal dimming control; I_led = 30 mA/string full scale; headroom = 0.4 V; VPH_PWR = 2.50 to 4.75 V</td>
<td>-2.1</td>
<td>–</td>
<td>+5.2</td>
<td>%</td>
</tr>
<tr>
<td>100% setting</td>
<td>–3.5</td>
<td>–</td>
<td>+3.0</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>50% setting</td>
<td>-3.5</td>
<td>–</td>
<td>+2.5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>25% setting</td>
<td>-6.5</td>
<td>–</td>
<td>+4.5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>10% setting</td>
<td>-12.0</td>
<td>–</td>
<td>+8.0</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>5% setting</td>
<td>-12.5</td>
<td>–</td>
<td>+8.0</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>2% setting</td>
<td>-15.5</td>
<td>–</td>
<td>+12.0</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>1% setting</td>
<td>-18.0</td>
<td>–</td>
<td>+14.5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>0.4% setting</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Matching accuracy, hybrid dimming</td>
<td>Any 2 strings; combined CABC duty cycle and internal dimming control; I_led = 30 mA/string full scale; headroom = 0.4 V; VPH_PWR = 2.50 to 4.75 V</td>
<td>–</td>
<td>–</td>
<td>3.0</td>
<td>%</td>
</tr>
<tr>
<td>100% setting</td>
<td>–</td>
<td>–</td>
<td>3.2</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>50% setting</td>
<td>–</td>
<td>–</td>
<td>3.6</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>25% setting</td>
<td>–</td>
<td>–</td>
<td>6.0</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>10% setting</td>
<td>–</td>
<td>–</td>
<td>10.0</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>5% setting</td>
<td>–</td>
<td>–</td>
<td>12.5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>2% setting</td>
<td>–</td>
<td>–</td>
<td>12.5</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>1% setting</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>0.4% setting</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>
### Electrical specifications

**Table 3-25  WLED boost converter and driver performance specifications (cont.)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute accuracy, analog dimming</td>
<td>Combined CABC duty cycle and internal dimming control; I_led = 30 mA/string full scale; headroom = 0.4 V; VPH_PWR = 2.50 to 4.75 V</td>
<td>-2.1</td>
<td>-3.5</td>
<td>+5.2</td>
<td>%</td>
</tr>
<tr>
<td>100% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>+3.0</td>
<td>%</td>
</tr>
<tr>
<td>50% setting</td>
<td></td>
<td>-6.5</td>
<td>-6.5</td>
<td>+2.5</td>
<td>%</td>
</tr>
<tr>
<td>25% setting</td>
<td></td>
<td>-11.0</td>
<td>-6.5</td>
<td>+4.5</td>
<td>%</td>
</tr>
<tr>
<td>10% setting</td>
<td></td>
<td>-30.0</td>
<td>-11.0</td>
<td>+13.5</td>
<td>%</td>
</tr>
<tr>
<td>5% setting</td>
<td></td>
<td>-65.0</td>
<td>-30.0</td>
<td>+40.0</td>
<td>%</td>
</tr>
<tr>
<td>2% setting</td>
<td></td>
<td>-65.0</td>
<td>-65.0</td>
<td>+75.0</td>
<td>%</td>
</tr>
<tr>
<td>1% setting</td>
<td></td>
<td>-65.0</td>
<td>-65.0</td>
<td>+75.0</td>
<td>%</td>
</tr>
<tr>
<td>Matching accuracy, analog dimming</td>
<td></td>
<td>-65.0</td>
<td>-65.0</td>
<td>+75.0</td>
<td>%</td>
</tr>
<tr>
<td>100% setting</td>
<td>Any 2 strings; CABC duty cycle control only; I_led = 30 mA/string full scale; headroom = 0.4 V; VPH_PWR = 2.50 to 4.75 V</td>
<td>-2.1</td>
<td>-2.5</td>
<td>2.5</td>
<td>%</td>
</tr>
<tr>
<td>50% setting</td>
<td></td>
<td>-2.5</td>
<td>-2.5</td>
<td>2.5</td>
<td>%</td>
</tr>
<tr>
<td>25% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>5.5</td>
<td>%</td>
</tr>
<tr>
<td>10% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>12.0</td>
<td>%</td>
</tr>
<tr>
<td>5% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>30.0</td>
<td>%</td>
</tr>
<tr>
<td>2% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>70.0</td>
<td>%</td>
</tr>
<tr>
<td>1% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>70.0</td>
<td>%</td>
</tr>
<tr>
<td>0.4% setting</td>
<td></td>
<td>-3.5</td>
<td>-3.5</td>
<td>70.0</td>
<td>%</td>
</tr>
<tr>
<td>Absolute accuracy, digital dimming</td>
<td>Combined CABC duty cycle and internal dimming control; I_led = 30 mA/string full scale; headroom = 0.4 V; VPH_PWR = 2.50 to 4.75 V; F_PWM = 2.34 kHz</td>
<td>-1.2</td>
<td>-1.2</td>
<td>+4.3</td>
<td>%</td>
</tr>
<tr>
<td>100% setting</td>
<td></td>
<td>-1.2</td>
<td>-1.2</td>
<td>+4.3</td>
<td>%</td>
</tr>
<tr>
<td>50% setting</td>
<td></td>
<td>-1.2</td>
<td>-1.2</td>
<td>+4.3</td>
<td>%</td>
</tr>
<tr>
<td>25% setting</td>
<td></td>
<td>-1.6</td>
<td>-1.6</td>
<td>+4.3</td>
<td>%</td>
</tr>
<tr>
<td>10% setting</td>
<td></td>
<td>-4.0</td>
<td>-4.0</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>2% setting</td>
<td></td>
<td>-6.0</td>
<td>-6.0</td>
<td>+0.0</td>
<td>%</td>
</tr>
<tr>
<td>1% setting</td>
<td></td>
<td>-6.0</td>
<td>-6.0</td>
<td>+0.0</td>
<td>%</td>
</tr>
<tr>
<td>0.4% setting</td>
<td></td>
<td>-6.0</td>
<td>-6.0</td>
<td>+0.0</td>
<td>%</td>
</tr>
<tr>
<td>Matching accuracy, digital dimming</td>
<td>Any 2 strings; combined CABC duty cycle and internal dimming control; I_led = 30 mA/string full scale; headroom = 0.4 V; VPH_PWR = 2.50 to 4.75 V; F_PWM = 2.34 kHz</td>
<td>-1.2</td>
<td>-1.2</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>100% setting</td>
<td></td>
<td>-1.2</td>
<td>-1.2</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>50% setting</td>
<td></td>
<td>-1.2</td>
<td>-1.2</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>25% setting</td>
<td></td>
<td>-1.6</td>
<td>-1.6</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>10% setting</td>
<td></td>
<td>-4.0</td>
<td>-4.0</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>2% setting</td>
<td></td>
<td>-6.0</td>
<td>-6.0</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>1% setting</td>
<td></td>
<td>-6.0</td>
<td>-6.0</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>0.4% setting</td>
<td></td>
<td>-6.0</td>
<td>-6.0</td>
<td>+2.0</td>
<td>%</td>
</tr>
<tr>
<td>CABC frequency</td>
<td>WLED is regulating, no flicker, no visual artifacts, no segment switching, hybrid dimming is enabled</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>kHz</td>
</tr>
<tr>
<td>CABC duty cycle</td>
<td></td>
<td>0.4</td>
<td>100</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Ground current</td>
<td>All current sinks are disabled</td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Pulse skipping enabled, no load</td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Force PFM, no load</td>
<td></td>
<td>0.5</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Leakage into switch node</td>
<td>VSW_WLED = 30 V, device is disabled</td>
<td>0.2</td>
<td></td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>Leakage into current sink input</td>
<td>WLED_x = 10 V, device is disabled</td>
<td>0.01</td>
<td></td>
<td></td>
<td>µA</td>
</tr>
</tbody>
</table>
3.7.5 Other current sinks and current drivers

Several types of low-voltage LED current drivers are available:

- Red, green, and blue (RGB) drivers that operate off a dedicated supply voltage.
- MPPs can be configured as current sinks that operate off VPH_PWR.
### 3.7.6 Light pulse generators

The LPG function is entirely embedded within the PMIC, so performance specifications are not appropriate. The LPG channel assignments and external availability are repeated below for the reader’s convenience.

#### Table 3-27 LPG channel assignments and external availability

<table>
<thead>
<tr>
<th>LPG channel</th>
<th>Internal connection</th>
<th>External availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG_OUT_3</td>
<td>WLED</td>
<td>MPP_1, MPP_2, MPP_3, or MPP_4</td>
</tr>
<tr>
<td>LPG_OUT_2</td>
<td>RGB red</td>
<td>MPP_1, MPP_2, MPP_3, or MPP_4</td>
</tr>
<tr>
<td>LPG_OUT_1</td>
<td>RGB green</td>
<td>MPP_1, MPP_2, MPP_3, or MPP_4</td>
</tr>
<tr>
<td>LPG_OUT_0</td>
<td>RGB blue</td>
<td>MPP_1, MPP_2, MPP_3, or MPP_4</td>
</tr>
</tbody>
</table>
3.8 IC-level interfaces

General housekeeping performance specifications are split into three functional categories as defined within its block diagram (Figure 3-16).

Figure 3-27  IC-level interfaces functional block diagram

3.8.1 Power-on circuits and power sequences

The PMI8994/PMI8996 complements the PM8994/PM8996 to meet the system’s power management needs. Power sequencing details are shared between the two ICs.

Concise summary: Dedicated circuits continuously monitor several events that might trigger a power-on sequence. If any of these events occur, the PMIC circuits are powered on, the handset's available power sources are determined, the correct source is enabled.

3.8.1.1 UVLO and low battery detection

The PMI monitors VBATT_SNS and VPH_PWR continuously to detect low and severely low supply voltage conditions. VBATT_SNS is compared with the Vlowbatt threshold to determine low battery status and permit system operation. Vlowbatt is the primary threshold setting for system operation. VPH_PWR is compared with the UVLO threshold and will prevent operation of PMI during a UVLO condition. Related voltage specifications are listed in Table 3-28.
### 3.8.2 SPMI and the interrupt managers

The SPMI is a bidirectional, two-line digital interface that meets the voltage and current level requirements stated in Section 3.4.

### 3.9 Configurable I/Os

#### 3.9.1 GPIO specifications

The 10 GPIO ports are digital I/Os that can be programmed for a variety of configurations (Table 3-29). General digital I/O performance specifications for the different configurations are included in Section 3.4.

**NOTE:** Unused GPIO pads should be configured as inputs with 10 µA pull-down (their default state).

<table>
<thead>
<tr>
<th>Table 3-28 UVLO performance specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Low battery rising threshold</td>
</tr>
<tr>
<td>Low battery falling threshold</td>
</tr>
<tr>
<td>Low battery accuracy</td>
</tr>
<tr>
<td>UVLO rising threshold</td>
</tr>
<tr>
<td>UVLO falling threshold</td>
</tr>
</tbody>
</table>

#### Table 3-29 Programmable GPIO configurations

<table>
<thead>
<tr>
<th>Configuration type</th>
<th>Configuration description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>■ No pull-up&lt;br&gt; ■ Pull-up (1.5, 30, or 31.5 µA)&lt;br&gt; ■ Pull-down (10 µA)&lt;br&gt; ■ Keeper</td>
</tr>
<tr>
<td>Output</td>
<td>Open-drain or CMOS&lt;br&gt; Inverted or non-inverted&lt;br&gt; Programmable drive current</td>
</tr>
</tbody>
</table>

1. Available pad voltages are:<br> – V_G0 = VPH_PWR<br> – V_G1 = dVdd (1.8 V)<br> – V_G2 = VDD_APQ_IO (1.8 V)<br> – V_G3 = VDD_APQ_IO (1.8 V)

GPIOs default to digital input with 10 µA pull-down at power-on; they must be configured properly for their intended purposes after power-on.
GPIOs are designed to run at a 4 MHz rate to support high-speed applications. The supported rate depends on the load capacitance and IR drop requirements. If the application specifies load capacitance, then the maximum rate is determined by the IR drop. If the application does not require a specific IR drop, then the maximum rate can be increased by increasing the supply voltage, and adjusting the drive strength according to the actual load capacitance.

3.9.2 MPP specifications

The PMI8994/PMI8996 includes four MPPs, and they can be configured for any of the functions specified within Table 3-30 with the following exceptions:

- Odd MPPs cannot be used as current sinks
- Even MPPs cannot be used as analog outputs

All MPPs default to Hi-Z at power-on and when disabled.

**NOTE:** Unused MPP pads should be configured to the Hi-Z state (their default state).
Table 3-30  Multipurpose pad performance specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPP configured as digital input</strong> 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic high-input voltage</td>
<td></td>
<td>0.65·V_M</td>
<td>–</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Logic low-input voltage</td>
<td></td>
<td>–</td>
<td>–</td>
<td>0.35·V_M</td>
<td>V</td>
</tr>
<tr>
<td><strong>MPP configured as digital output</strong> 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic high-output voltage</td>
<td>$I_{\text{out}} = I_{\text{OH}}$</td>
<td>V_M - 0.45</td>
<td>–</td>
<td>V_M</td>
<td>V</td>
</tr>
<tr>
<td>Logic low-output voltage</td>
<td>$I_{\text{out}} = I_{\text{OL}}$</td>
<td>0</td>
<td>–</td>
<td>0.45</td>
<td>V</td>
</tr>
<tr>
<td>Drive strength</td>
<td></td>
<td>5.1</td>
<td>7.3</td>
<td>15.2</td>
<td>mA</td>
</tr>
<tr>
<td>Logic high (V_M &gt; 2.5 V)</td>
<td></td>
<td>3.3</td>
<td>4.9</td>
<td>9.9</td>
<td>mA</td>
</tr>
<tr>
<td>Logic low (V_M &lt; 2.5 V)</td>
<td></td>
<td>5.9</td>
<td>11.3</td>
<td>36.0</td>
<td>mA</td>
</tr>
<tr>
<td><strong>MPP configured as analog input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(analog multiplexer input)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input current</td>
<td></td>
<td>–</td>
<td>–</td>
<td>100</td>
<td>nA</td>
</tr>
<tr>
<td>Input capacitance</td>
<td></td>
<td>–</td>
<td>–</td>
<td>10</td>
<td>pF</td>
</tr>
<tr>
<td><strong>MPP configured as analog output</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(buffered VREF output)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage error</td>
<td>-50 µA to +50 µA</td>
<td>–</td>
<td>–</td>
<td>30</td>
<td>mV</td>
</tr>
<tr>
<td>Temperature variation</td>
<td>Due to buffer only; does not include VREF variation (see Table 3-14.)</td>
<td>–</td>
<td>–</td>
<td>± 0.03</td>
<td>%</td>
</tr>
<tr>
<td>Load capacitance</td>
<td></td>
<td>–</td>
<td>–</td>
<td>25</td>
<td>pF</td>
</tr>
<tr>
<td>Ground current</td>
<td></td>
<td>–</td>
<td>0.17</td>
<td>0.20</td>
<td>mA</td>
</tr>
<tr>
<td><strong>MPPs configured as current sinks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power supply voltage</td>
<td></td>
<td>–</td>
<td>VDD</td>
<td>–</td>
<td>V</td>
</tr>
<tr>
<td>Output current</td>
<td>Programmable in 5 mA increments</td>
<td>0</td>
<td>–</td>
<td>40</td>
<td>mA</td>
</tr>
<tr>
<td>Output current accuracy</td>
<td>Any nonzero programmed current value; $V_{\text{out}} = 0.5$ to ($V_{\text{DD}} - 1$ V)</td>
<td>–</td>
<td>–</td>
<td>± 20</td>
<td>%</td>
</tr>
<tr>
<td>Dropout voltage</td>
<td>$V_{\text{IN}} - V_{\text{OUT}}$ while $I_{\text{OUT}}$ stays within its accuracy limits</td>
<td>–</td>
<td>–</td>
<td>500</td>
<td>mV</td>
</tr>
<tr>
<td>Ground current</td>
<td>Driver disabled</td>
<td>–</td>
<td>105</td>
<td>115</td>
<td>µA</td>
</tr>
</tbody>
</table>

1. Available pad voltages are:
   – $V_{\text{M0}} = $ VPH_PWR
   – $V_{\text{M1}} = dVdd$ (1.8 V)
   – $V_{\text{M2}} = $ VDD_APQ_IO (1.8 V)
   – $V_{\text{M3}} = $ VDD_APQ_IO (1.8 V)

Other digital I/O specifications are included in Table 3-4.
4 Mechanical information

4.1 Device physical dimensions

The PMI8994/PMI8996 is available in the 210 WLNSP that includes ground pads for improved grounding, mechanical strength, and thermal continuity. The 210 WLNSP has a 5.69 mm × 6.24 mm body with a maximum height of 0.55 mm. Pad 1 is located by an indicator mark on the top of the package. A simplified version of the 210 WLNSP outline drawing is shown in Figure 4-1.

Figure 4-1 210 WLNSP (5.69 × 6.24 × 0.55 mm) package outline drawing

NOTE: This is a simplified outline drawing.
4.2 Part marking

4.2.1 Specification-compliant devices

Table 4-1  PMI8994/PMI8996 device marking line definitions

<table>
<thead>
<tr>
<th>Line</th>
<th>Marking</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QUALCOMM</td>
<td>QTI company name or logo</td>
</tr>
<tr>
<td>2</td>
<td>PMI899x</td>
<td>QTI product name</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x = 4 for PMI8994</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x = 6 for PMI8996</td>
</tr>
<tr>
<td>3</td>
<td>PPI</td>
<td>P = Product configuration code – see Table 4-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PI = Program ID code – see Table 4-2</td>
</tr>
<tr>
<td>E</td>
<td>Blank or random</td>
<td>Additional content as necessary</td>
</tr>
<tr>
<td>4</td>
<td>XXXXXXXX</td>
<td>X XXXXXXXX = traceability information</td>
</tr>
<tr>
<td>5</td>
<td>FAYWWRR</td>
<td>F = wafer fab source of supply code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F = H for GLOBALFOUNDRIES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = assembly (ball drop) code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = U for Amkor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = K for SPIL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = M for JCET StatsChipPac</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y = single-digit year code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WW = workweek (based upon calendar year)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RR = product revision – see Table 4-2</td>
</tr>
<tr>
<td>6</td>
<td>• TTT ##</td>
<td>TTT = engineering trace code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>## = 2-digit wafer number</td>
</tr>
</tbody>
</table>
4.3 Device ordering information

4.3.1 Specification-compliant devices

This device can be ordered using the identification code shown in Figure 4-3 and explained below.

<table>
<thead>
<tr>
<th>Device ID code</th>
<th>AAA-AAAA</th>
<th>— P</th>
<th>— CCC</th>
<th>DDDDD</th>
<th>— EE</th>
<th>— RR</th>
<th>— S</th>
<th>— PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol definition</td>
<td>Product name</td>
<td>Config code</td>
<td>Number of pads</td>
<td>Package type</td>
<td>Shipping package</td>
<td>Product version</td>
<td>Source code</td>
<td>Program ID</td>
</tr>
<tr>
<td>Example</td>
<td>PMI-8994</td>
<td>— 0</td>
<td>— 210</td>
<td>WLNSP</td>
<td>— TR</td>
<td>— 00</td>
<td>— 0</td>
<td>— 00</td>
</tr>
</tbody>
</table>

Figure 4-3 Device identification code

Device ordering information details for all samples available to date are summarized in Table 4-2.

Table 4-2 Device identification code/ordering information details

<table>
<thead>
<tr>
<th>PMIC variant</th>
<th>P value</th>
<th>RR value</th>
<th>Hardware ID #</th>
<th>S value</th>
<th>PI value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS sample type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMI8994 CS (WiPower)</td>
<td>0</td>
<td>05</td>
<td>v2.0</td>
<td>0</td>
<td>03</td>
</tr>
<tr>
<td>PMI8996 CS (WiPower)</td>
<td>0</td>
<td>01</td>
<td>v1.1</td>
<td>0</td>
<td>01</td>
</tr>
</tbody>
</table>

1. ‘S’ is the source configuration code that identifies all the qualified die fabrication source combinations available at the time a particular sample type were shipped. S values are defined in Table 4-3.
2. ‘PI’ is the Program ID code that identifies an IC’s specific OTP programming that distinguishes it from other versions or variants. Defined feature sets available at the time of this document’s release are:
   – 00 = DC_IN charging path defaults to WiPower charging. This requires WiPower interfacing signals.
   – 01 = DC_IN charging path defaults to 5 V/9 V generic charging input. Interfacing signals not required.

Table 4-3 Source configuration code

<table>
<thead>
<tr>
<th>S value</th>
<th>Die</th>
<th>F value = H</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BiCMOS</td>
<td>Global Foundries</td>
</tr>
</tbody>
</table>

4.4 Device moisture-sensitivity level

Surface mount packages are susceptible to damage induced by absorbed moisture and high temperature. A package’s moisture-sensitivity level (MSL) indicates its ability to withstand exposure after it is removed from its shipment bag, while it’s on the factory floor awaiting PCB installation. A low MSL rating is better than a high rating; a low MSL device can be exposed on the factory floor longer than a high MSL device. All pertinent MSL ratings are summarized in Table 4-4.
QTI follows the latest IPC/JEDEC J-STD-020 standard revision for moisture-sensitivity qualification. The PMI8994/PMI8996 devices are classified as MSL1; the qualification temperature was 260°C +0°/-5°C. This qualification temperature (260°C +0°/-5°C) should not be confused with the peak temperature within the recommended solder reflow profile.

<table>
<thead>
<tr>
<th>MSL</th>
<th>Out-of-bag floor life</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unlimited</td>
<td>≤ 30°C/85% RH; PMI8994/PMI8996 rating</td>
</tr>
<tr>
<td>2</td>
<td>1 year</td>
<td>≤ 30°C/60% RH</td>
</tr>
<tr>
<td>2a</td>
<td>4 weeks</td>
<td>≤ 30°C/60% RH</td>
</tr>
<tr>
<td>3</td>
<td>168 hr</td>
<td>≤ 30°C/60% RH</td>
</tr>
<tr>
<td>4</td>
<td>72 hr</td>
<td>≤ 30°C/60% RH</td>
</tr>
<tr>
<td>5</td>
<td>48 hr</td>
<td>≤ 30°C/60% RH</td>
</tr>
<tr>
<td>5a</td>
<td>24 hr</td>
<td>≤ 30°C/60% RH</td>
</tr>
<tr>
<td>6</td>
<td>Mandatory bake before use. After bake, must be reflowed within the time limit specified on the label.</td>
<td>≤ 30°C/60% RH</td>
</tr>
</tbody>
</table>
5 Carrier, storage, and handling information

5.1 Carrier

5.1.1 Tape and reel information

All QTI carrier tape systems conform to EIA-481 standards.

A simplified sketch of the PMI8994/PMI8996 tape carrier is shown in Figure 5-1, including the proper part orientation, maximum number of devices per reel, and key dimensions.

Figure 5-1 Carrier tape drawing with part orientation

<table>
<thead>
<tr>
<th>Taping direction</th>
<th>Tape feed: Single</th>
<th>Reel diameter: 330 mm</th>
<th>Tape width: 16 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Units per reel: 4000</td>
<td>Hub diameter: 178 mm</td>
<td>Pocket pitch: 8 mm</td>
</tr>
</tbody>
</table>

Tape-handling recommendations are shown in Figure 5-2.
5.2 Storage

5.2.1 Bagged storage conditions

PMI8994/PMI8996 devices delivered in tape and reel carriers must be stored in sealed, moisture barrier, antistatic bags.

5.2.2 Out-of-bag duration

The out-of-bag duration is the time a device can be on the factory floor before being installed onto a PCB. It is defined by the device MSL rating as discussed in Section 4.4.

5.3 Handling

Tape handling was discussed in Section 5.1.1. Other (IC-specific) handling guidelines are presented below.

Unlike traditional IC devices, the die within a wafer-level package is not protected by an overmold and there is no substrate; hence, these devices are relatively fragile.

**NOTE:** To avoid damage to the die due to improper handling, these recommendations should be followed:

- Do not use tweezers; a vacuum tip is recommended for handling the devices.
- Carefully select a pickup tool for use during the SMT process.
- Do not make contact with the device when reworking or tuning components located near the device.

5.3.1 Baking

Wafer-level packages such as the 210 WLNSP should not be baked.
5.3.2 Electrostatic discharge

Electrostatic discharge (ESD) occurs naturally in laboratory and factory environments. An established high-voltage potential is always at risk of discharging to a lower potential. If this discharge path is through a semiconductor device, destructive damage may result.

ESD countermeasures and handling methods must be developed and used to control the factory environment at each manufacturing site.

QTI products must be handled according to the ESD Association standard: ANSI/ESD S20.20-1999, Protection of Electrical and Electronic Parts, Assemblies, and Equipment.

See Section 7.1 for the PMI8994/PMI8996 ESD ratings.
6 PCB mounting guidelines

6.1 RoHS compliance

The device is lead-free and RoHS-compliant. Its Sn/Ag/Cu solder balls use SAC405 composition. QTI defines its lead-free (or Pb-free) semiconductor products as having a maximum lead concentration of 1000 ppm (0.1% by weight) in raw (homogeneous) materials and end products.

6.2 SMT parameters

This section describes QTI board-level characterization process parameters. It is included to assist customers with their SMT process development; it is not intended to be a specification for their SMT processes.

6.2.1 Land pad and stencil design

The land-pattern and stencil recommendations presented in this section are based on QTI internal characterizations for lead-free solder pastes on an eight-layer PCB, built primarily to the specifications described in JEDEC JESD22-B111.

QTI recommends characterizing the land patterns according to each customer's processes, materials, equipment, stencil design, and reflow profile prior to PCB production. Optimizing the solder stencil pattern design and print process is critical to ensure print uniformity, decrease voiding, and increase board-level reliability.

General land-pattern guidelines:

- Non-solder-mask-defined (NSMD) pads provide the best reliability.
- Keep the solder-able area consistent for each pad, especially when mixing via-in-pad and non-via-in-pad in the same array.
- Avoid large solder mask openings over ground planes.
- Traces for external routing are recommended to be less than or equal to half the pad diameter, to ensure consistent solder-joint shapes.
One key parameter that should be evaluated is the ratio of aperture area to sidewall area, known as the area ratio (AR). QTI recommends square apertures for optimal solder-paste release. In this case, a simple equation can be used relating the side length of the aperture to the stencil thickness (as shown and explained in Figure 6-1). Larger area ratios enable better transfer of solder paste to the PCB, minimize defects, and ensure a more stable printing process. Inter-aperture spacing should be at least as thick as the stencil; otherwise, paste deposits may bridge.

![Figure 6-1 Stencil printing aperture area ratio (AR)](image)

Guidelines for an acceptable relationship between L and T are listed below, and are shown in Figure 6-2:

- $R = \frac{L}{4T} > 0.65$ – best
- $0.60 \leq R \leq 0.65$ – acceptable
- $R < 0.60$ – not acceptable

![Figure 6-2 Acceptable solder-paste geometries](image)
6.2.2 Reflow profile

Reflow profile conditions typically used by QTI for lead-free systems are listed in Table 6-1.

Table 6-1 QTI typical SMT reflow profile conditions (for reference only)

<table>
<thead>
<tr>
<th>Profile stage</th>
<th>Description</th>
<th>Temp range</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheat</td>
<td>Initial ramp</td>
<td>&lt; 150°C</td>
<td>3°C/s maximum</td>
</tr>
<tr>
<td>Soak</td>
<td>Flux activation</td>
<td>150–190°C</td>
<td>60–75 s</td>
</tr>
<tr>
<td>Ramp</td>
<td>Transition to liquidus (solder-paste melting point)</td>
<td>190–220°C</td>
<td>&lt; 30 s</td>
</tr>
<tr>
<td>Reflow</td>
<td>Time above liquidus</td>
<td>220–245°C</td>
<td>50–70 s</td>
</tr>
<tr>
<td>Cool down</td>
<td>Cool rate – ramp to ambient</td>
<td>&lt; 220°C</td>
<td>6°C/s maximum</td>
</tr>
</tbody>
</table>

1. During the reflow process, the recommended peak temperature is 245°C (minimum). This temperature should not be confused with the peak temperature reached during MSL testing, as described in Section 6.2.4.

6.2.3 SMT peak package-body temperature

This document states a peak package-body temperature in three other places within this document, and without explanation, they may appear to conflict. The three places are listed below, along with an explanation of the stated value and its meaning within that section’s context.

1. Section 4.4 – Device moisture-sensitivity level

PM8994/PM8996 devices are classified as MSL1 at 250°C. The temperature (250°C) included in this designation is the lower limit of the range stated for moisture resistance testing during the device qualification process, as explained in #2 below.

2. Section 7.1 – Reliability qualifications summary

One of the tests conducted for device qualification is the moisture resistance test. QTI follows J-STD-020-C, and hits a peak reflow temperature that falls within the range of 260°C +0/-5 °C (255°C to 260 °C).

3. Section 6.2.2 – Reflow profile

During a production board’s reflow process, the temperature seen by the package must be controlled. Obviously, the temperature must be high enough to melt the solder and provide reliable connections. However, it must not go so high that the device might be damaged. The recommended peak temperature during production assembly is 245°C. This is comfortably above the solder melting point (220°C), yet well below the proven temperature reached during qualification (250°C or more).
6.2.4  **SMT process verification**

QTI recommends verification of the SMT process prior to high-volume board assembly, including:

- Inline solder-paste deposition monitoring
- Reflow-profile measurement and verification
- Visual and x-ray inspection after soldering to confirm adequate alignment, solder voids, solder-ball shape, and solder bridging
- Cross-section inspection of solder joints for wetting, solder-ball shape, and voiding
# Part reliability

## Reliability qualifications summary

### Table 7-1  PMI8994 IC reliability evaluation

<table>
<thead>
<tr>
<th>Tests, standards, and conditions</th>
<th>Sample size</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average failure rate (AFR) in FIT ($\lambda$) failure in billion device-hours</strong></td>
<td>640</td>
<td>FIT = 179 at T500</td>
</tr>
<tr>
<td>HTOL: JESD22-A108-A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean time to failure (MTTF) $t = \frac{1}{\lambda}$ in million hours</strong></td>
<td>640</td>
<td>5.59 Mhrs</td>
</tr>
<tr>
<td>ESD – human-body model (HBM) rating</td>
<td>3</td>
<td>± 2000 V ²</td>
</tr>
<tr>
<td>JESD22-A114-F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESD – charge-device model (CDM) rating</td>
<td>3</td>
<td>±500 V</td>
</tr>
<tr>
<td>JESD22-C101-D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latch-up (I-test): EIA/JESD78C</td>
<td>3</td>
<td>±100 mA</td>
</tr>
<tr>
<td>Trigger current: ±100 mA; temperature: 85°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latch-up (Vsupply overvoltage): EIA/JESD78C</td>
<td>3</td>
<td>6.6 V</td>
</tr>
<tr>
<td>Trigger voltage: stress at 1.5 × Vdd max per device specification; temperature: 85°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture resistance test (MRT): J-STD-020C</td>
<td>400</td>
<td>MSL1 pass</td>
</tr>
<tr>
<td>Reflow at 260 +0/-5°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature cycle</strong>: JESD22-A104-B</td>
<td>400</td>
<td>Pass</td>
</tr>
<tr>
<td>Temperature: -55°C to 125°C; number of cycles: 1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle rate: 2 cycles per hour (cph)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preconditioning</strong>: JESD22-A113-F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSL1, reflow at 260 +0/-5°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Packaging tests do not appear here because the WLNSP has already been qualified prior to its use for the PMI8994 device.
2. HBM ESD rating is 2000 V with the following minor exceptions:
   a) VSW_WLED to GND → 1 kV HBM rating  
   All other pads meet 2000 V HBM ESD rating.
### Table 7-2 PMI8996 IC reliability evaluation

<table>
<thead>
<tr>
<th>Tests, standards, and conditions</th>
<th>Sample size</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average failure rate (AFR) in FIT (λ) failure in billion device-hours</td>
<td>717</td>
<td>FIT = 110</td>
</tr>
<tr>
<td>HTOL: JESD22-A108-A</td>
<td>717</td>
<td>Mean time to failure (MTTF) t = 1/λ in million hours</td>
</tr>
<tr>
<td>ESD – Human-body model (HBM) rating</td>
<td>3</td>
<td>±2000 V</td>
</tr>
<tr>
<td>JESD22-A114-F</td>
<td>3</td>
<td>500 V</td>
</tr>
<tr>
<td>ESD – Charged-device model (CDM) rating</td>
<td>3</td>
<td>100 mA</td>
</tr>
<tr>
<td>JESD22-C101-D</td>
<td>3</td>
<td>6.6 V</td>
</tr>
<tr>
<td>Latch-up (I-test): EIA/JESD78A</td>
<td>400</td>
<td>Pass</td>
</tr>
<tr>
<td>Trigger current: ±100 mA; temperature: 85°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latch-up (Vsupply overvoltage): EIA/JESD78A</td>
<td>400</td>
<td>Pass</td>
</tr>
<tr>
<td>Trigger voltage: Each VDD pad, stress at 1.5 × Vdd max per device specification; temperature: 85°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture resistance test (MRT): J-STD-020C</td>
<td>400</td>
<td>Pass</td>
</tr>
<tr>
<td>Reflow at 260 +0/-5°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature cycle: JESD22-A104-B</td>
<td>400</td>
<td>Pass</td>
</tr>
<tr>
<td>Temperature: -55°C to 125°C; number of cycles: 1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle rate: 2 cycles per hour (cph)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preconditioning: JESD22-A113-F</td>
<td>400</td>
<td>Pass</td>
</tr>
<tr>
<td>MSL1, reflow at 260 +0/-5°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Packaging tests do not appear here because the WLNSP has already been qualified prior to its use for the PMI8994 device.
2. HBM ESD rating is 2000 V with the following minor exception:
   a. VSW_WLED to GND → 1 kV HBM rating
   All other pads meet the 2000 V HBM ESD rating.
7.2 Qualification sample description

Device characteristics

Device name: PMI8994/PMI8996
Package type: 210 WLNSP
Package body size: 5.69 mm × 6.24 mm × 0.55 mm
Solder ball composition: SAC405
Process: Mixed-signal BiCMOS
Fab sites: GLOBALFOUNDRIES
Assembly sites: Amkor
               SPIL
               JCET StatsChipPac
Solder ball pitch: 0.40 mm
EXHIBIT 1

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