EOL PRODUCT
NO RECOMMENDED REPLACEMENT
contact our Technical Support Center at
https://www.renesas.com/support/contact.html

# ISL9238A

Buck-Boost Narrow VDC Batter... ...face and USB OTG

FN8978
Rev.1.00
Nov 30, 2017

The ISL9238A is a buck-boost Narrow Output Voltage DC (NVDC) charger. The ISL9238A provides the NVDC charging function, system bus regulation, and protection features for tablet, ultrabook, notebook, power bank, and any USB-C interface platform. Intersil's advanced R3™ Technology is used to provide high light-load efficiency and fast transient response.

In Charging mode the ISL9238A takes input power from a wide range of DC power sources (conventional AC/DC charger adapters, USB PD ports, travel adapters, etc.) and safely charges battery packs with up to 4-series cell Li-ion batteries.

As a NVDC topology charger, it also regulates the system output to a narrow DC range for stable system bus voltage. The system power can be provided from the adapter, battery, or a combination of both. The ISL9238A can operate with only a battery, only an adapter, or both connected. For Intel IMVP8 compliant systems the ISL9238A includes PSYS (System power monitor) functionality, which provides an analog signal representing total platform power. The PSYS output connects to a wide range of Intersil IMVP8 core regulators to provide an IMVP8 compliant power domain function.

The ISL9238A supports reverse buck, boost, or buck-boost operation to the input port from 2- to 4-cell batteries.

The ISL9238A has serial communication using SMBus/$I^2C$ that allows programming of many critical parameters to deliver a customized solution.

## Features

- Buck-boost NVDC charger for 1-, 2-, 3-, or 4-cell Li-ion batteries
- Input voltage range 3.2V to 23.4V (no dead zone)
- System output voltage 2.4V to 18.304V
- Autonomous charging option (automatic end of charging)
- System power monitor PSYS output, IMVP compliant
- Up to 1MHz switching frequency
- Adapter current and battery current monitor (AMON/BMON)
- PROCHOT# open-drain output, IMVP compliant
- Allows trickle charging of depleted battery
- Ideal diode control in Turbo mode
- Reverse buck, boost, and buck-boost operation from battery
- Two-level adapter current limit available
- Battery Ship mode option
- SMBus and auto-increment $I^2C$ compatible
- 4x4 32 Ld TQFN package

## Applications

- 1 to 4-cell tablet, ultrabook, notebook, power bank, and any USB-C interface portable device requiring batteries

## Related Literature

- For a full list of related documents, visit our website
  - ISL9238A product page

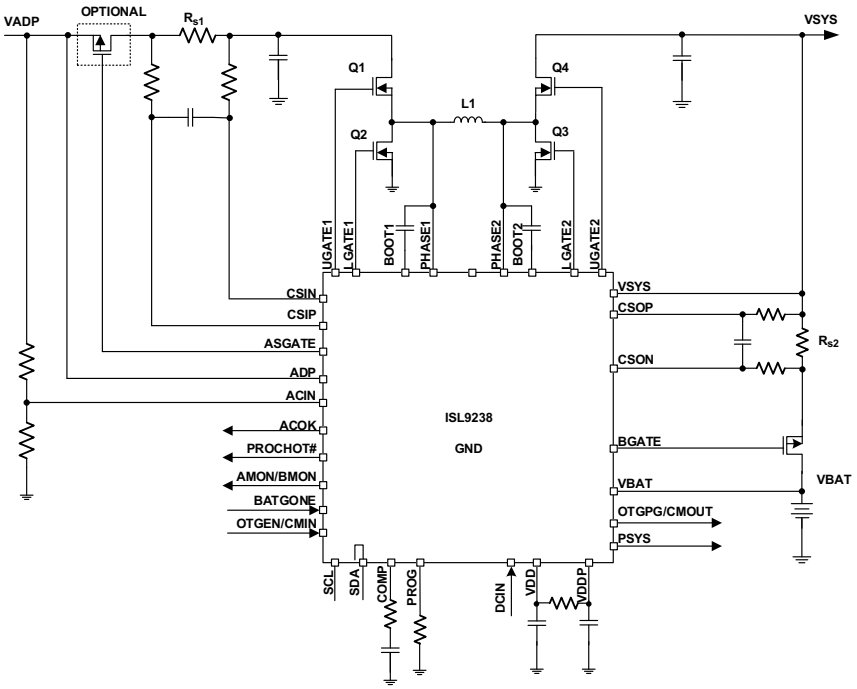



FIGURE 1. TYPICAL APPLICATION CIRCUIT

# Table of Contents


**Ordering Information** . . . . . 3
**Pin Configuration** . . . . . 4
**Pin Descriptions** . . . . . 4
**Block Diagram** . . . . . 6
**Simplified Application Circuit** . . . . . 7
**Absolute Maximum Ratings** . . . . . 8
**Thermal Information** . . . . . 8
**Recommended Operating Conditions** . . . . . 8
**Electrical Specifications** . . . . . 8
**SMBUS Timing Specification** . . . . . 14
**Gate Driver Timing Diagram** . . . . . 14
**Typical Performance** . . . . . 15
**General SMBus Architecture** . . . . . 18
Data Validity . . . . . 18
START and STOP Conditions . . . . . 18
Acknowledge . . . . . 18
SMBus Transactions . . . . . 19
Byte Format . . . . . 19
SMBus and I2C Compatibility . . . . . 19
**ISL9238A SMBus Commands** . . . . . 19
**Setting Charging Current Limit** . . . . . 21
**Setting Adapter Current Limit** . . . . . 21
Setting Two-Level Adapter Current Limit Duration . . . . . 22
Setting Maximum Charging Voltage or System Regulating Voltage . . . . . 23
Setting Minimum System Voltage . . . . . 23
Setting PROCHOT# Threshold for Adapter Overcurrent Condition . . . . . 23
Setting PROCHOT# Threshold for Battery Over Discharging Current Condition . . . . . 24
Setting PROCHOT# Debounce Time and Duration Time . . . . . 24
Control Registers . . . . . 24
OTG Voltage Register . . . . . 30
OTG Current Register . . . . . 30
Input Voltage Register . . . . . 30
Information Register . . . . . 31
**Application Information** . . . . . 32
R3 Modulator . . . . . 32
ISL9238A Buck-Boost Charger with USB OTG . . . . . 33
Soft-Start . . . . . 34
Programming Charger Option . . . . . 34
Autonomous Charging Mode . . . . . 35
Battery Ship Mode . . . . . 35
DE Operation . . . . . 35
Power Source Selection . . . . . 35
Battery Learn Mode . . . . . 36
Turbo Mode Support . . . . . 36
Two-Level Adapter Current Limit . . . . . 36
Current Monitor . . . . . 37
PSYS Monitor . . . . . 37
Trickle Charging . . . . . 37
System Voltage Regulation . . . . . 37
Charger Timeout . . . . . 37
USB OTG (On the Go) . . . . . 38
Stand-Alone Comparator . . . . . 38
Adapter Overvoltage Protection . . . . . 39
Battery Overvoltage Protection . . . . . 39
System Overvoltage Protection . . . . . 39
Way Overcurrent Protection (WOCP) . . . . . 39
Over-Temperature Protection . . . . . 39
Switching Power MOSFET Gate Capacitance . . . . . 39
Adapter Input Filter . . . . . 39
General Application Information . . . . . 40
Select the LC Output Filter . . . . . 40
Select the Input Capacitor . . . . . 40
Select the Switching Power MOSFET . . . . . 41
Select the Bootstrap Capacitor . . . . . 41
**Layout** . . . . . 42
**Revision History** . . . . . 44
**About Intersil** . . . . . 44
**Package Outline Drawing** . . . . . 45

# Ordering Information

| PART NUMBER (Notes 3, 4) | PART MARKING | TEMP. RANGE (°C) | PACKAGE (RoHS COMPLIANT) | PKG. DWG. # |
|---|---|---|---|---|
| ISL9238AHRTZ (Note 1) | 9238AH | -10 to +100 | 32 Ld 4x4 TQFN | L32.4x4D |
| ISL9238AIRTZ (Note 2) | 9238AI | -40 to +100 | 32 Ld 4x4 TQFN | L32.4x4D |
| ISL9238EVAL1Z | Evaluation Board | | | |

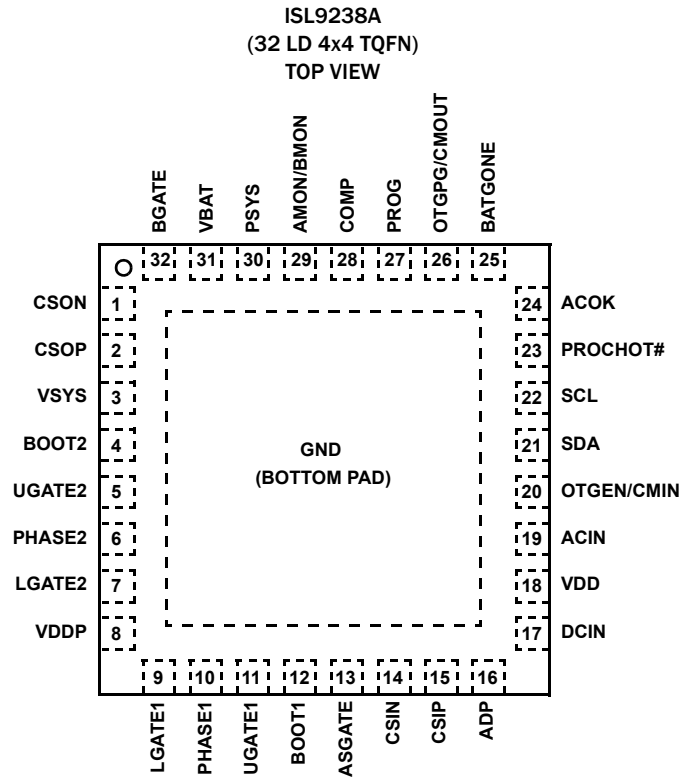
NOTES:

1. Add “-T” suffix for 6k unit, “-TK” suffix for 1k unit tape and reel options. Refer to TB347 for details on reel specifications.
2. Add “-T” suffix for 6k unit tape and reel option. Refer to TB347 for details on reel specifications.
3. These Pb-free plastic packaged products employ special Pb-free material sets, molding compounds/die attach materials, and 100% matte tin plate plus anneal (e3 termination finish, which is RoHS compliant and compatible with both SnPb and Pb-free soldering operations). Pb-free products are MSL classified at Pb-free peak reflow temperatures that meet or exceed the Pb-free requirements of IPC/JEDEC J STD-020.
4. For Moisture Sensitivity Level (MSL), see product information page for ISL9238A. For more information on MSL, see TB363.

**TABLE 1. KEY DIFFERENCES BETWEEN FAMILY OF PARTS**

| PART NUMBER | $I^2C$ READ ADDRESS | $I^2C$ WRITE ADDRESS |
|---|---|---|
| ISL9238 | 0b00010011 (0x13H) | 0b00010010 (0x12H) |
| ISL9238A | 0b00011011 (0x1BH) | 0b00011010 (0x1AH) |

# Pin Configuration




# Pin Descriptions

| PIN NUMBER | PIN NAME | DESCRIPTION |
|---|---|---|
| BOTTOM PAD | GND | Signal common of the IC. Unless otherwise stated, signals are referenced to the GND pin. It should also be used as the thermal pad for heat dissipation. |
| 1 | CSON | Battery current sense “–” input. Connect to battery current resistor negative input. Place a 0.1µF ceramic capacitor between CSOP to CSON to provide Differential mode filtering. |
| 2 | CSOP | Battery current sense “+” input. Connect to battery current resistor positive input. Place a 0.1µF ceramic capacitor between CSOP to CSON to provide Differential mode filtering. |
| 3 | VSYS | Provides feedback voltage for MaxSystemVoltage regulation. |
| 4 | BOOT2 | High-side MOSFET Q4 gate driver supply. Connect an MLCC capacitor across the BOOT2 and PHASE2 pins. The boot capacitor is charged through an internal boot diode connected from the VDDP to BOOT2 pins when the PHASE2 pin drops below VDDP minus the voltage drop across the internal boot diode. |
| 5 | UGATE2 | High-side MOSFET Q4 gate drive. |
| 6 | PHASE2 | Current return path for the high-side MOSFET Q4 gate drive. Connect this pin to the node consisting of the high-side MOSFET Q4 source, the low-side MOSFET Q3 drain and the one terminal of the inductor. |
| 7 | LGATE2 | Low-side MOSFET Q3 gate drive. |
| 8 | VDDP | Power supply for the gate drivers. Connect to VDD pin through a 4.7Ω resistor and connect a 1µF ceramic capacitor to GND. |
| 9 | LGATE1 | Low-side MOSFET Q2 gate drive. |
| 10 | PHASE1 | Current return path for the high-side MOSFET Q1 gate drive. Connect this pin to the node consisting of the high-side MOSFET Q1 source, the low-side MOSFET Q2 drain and the input terminal of the inductor. |
| 11 | UGATE1 | High-side MOSFET Q1 gate drive. |
| 12 | BOOT1 | High-side MOSFET Q1 gate driver supply. Connect an MLCC capacitor across the BOOT1 and PHASE1 pins. The boot capacitor is charged through an internal boot diode connected from the VDDP to BOOT1 pins when the PHASE1 pin drops below VDDP minus the voltage drop across the internal boot diode. |

# Pin Descriptions

| PIN NUMBER | PIN NAME | DESCRIPTION |
|---|---|---|
| 13 | ASGATE | Gate drive output to the P-channel adapter FET. The use of ASGATE FETs is optional, if it is not used, leave ASGATE pin floating.<br>When ASGATE turns on, it is clamped 10V below ADP pin voltage. |
| 14 | CSIN | Adapter current sense “-” input. |
| 15 | CSIP | Adapter current sense “+” input. The modulator also uses this for sensing input voltage in forward mode and output voltage in reverse mode. |
| 16 | ADP | Adapter input. Used to sense adapter voltage. When adapter voltage is higher than 3.2V, AGATE is turned on.<br>ADP pin is also one of the two internal low power LDO inputs. |
| 17 | DCIN | Input of an internal LDO providing power to the IC. Connect a diode OR from adapter and system outputs. Bypass this pin with an MLCC capacitor. |
| 18 | VDD | Output of the internal LDO; provide the bias power for the internal analog and digital circuit. Connect a 1µF ceramic capacitor to GND.<br>If VDD is pulled below 2V more than 1ms, ISL9238A will reset all the SMBus register values to the default. |
| 19 | ACIN | Adapter voltage sense. Use a resistor divider externally to detect adapter voltage. The adapter voltage is valid if the ACIN pin voltage is greater than 0.8V. |
| 20 | OTGEN/ CMIN | OTG function enable pin or stand-alone comparator input pin.<br>Pull high to enable OTG function. The OTG function is enabled when the control register is written to select OTG mode and when the battery voltage is above 5.2V.<br>When OTG function is not selected, this pin is the general purpose stand-alone comparator input. |
| 21 | SDA | SMBus data I/O. Connect to the data line from the host controller or smart battery. Connect a 10k pull-up resistor according to SMBus specification. |
| 22 | SCL | SMBus clock I/O. Connect to the clock line from the host controller or smart battery. Connect a 10k pull-up resistor according to SMBus specification. |
| 23 | PROCHOT# | Open-drain output. Pulled low when ACHOT, DCHOT or Low_VSYS is detected. IMVP-8 compliant. SMBus command to pull low with OTGCURRENT, BAGONE, ACOK, and general purpose comparator (refer to Table 15 on page 28). |
| 24 | ACOK | Adapter presence indicator output to indicate the adapter is ready. |
| 25 | BATGONE | Input pin to the IC. Logic high on this pin indicates the battery has been removed. Logic low on this pin indicates the battery is present.<br>BATGONE pin logic high will force BGATE FET to turn off under any circumstances. |
| 26 | OTGPG/ CMOUT | Open-drain output. OTG function output power-good indicator or the stand-alone comparator output.<br>When OTG function is enabled, low if OTG output voltage is not within regulation window.<br>When OTG function is not used, it is the general purpose comparator output. |
| 27 | PROG | A resistor from PROG pin to GND sets the following configurations:<br>1. Default number of the battery cells in series, 1-, 2-, 3-, or 4-cell.<br>2. Default switching frequency 733kHz or 1MHz.<br>3. Default adapter current limit value 0.476A or 1.5A.<br>4. Autonomous Charging mode enable or disable.<br>Refer to Table 23 for programming options. |
| 28 | COMP | Error amplifier output. Connect a compensation network externally from COMP to GND. |
| 29 | AMON/ BMON | Adapter current, OTG output current, battery charging current, or battery discharging current monitor output.<br>$V_{AMON} = 18x(V_{CSIP}-V_{CSIN})$ for adapter current monitor.<br>$V_{OTGCMON} = 18x(V_{CSIN}-V_{CSIP})$ for OTG output current monitor.<br>$V_{BMON_DISCHARGING} = 18x(V_{CSON}-V_{CSOP})$ for battery discharging current monitor.<br>$V_{BMON_CHARGING} = 36x(V_{CSOP}-V_{CSON})$ for battery charging current monitor. |
| 30 | PSYS | Current source output that indicates the whole platform power consumption.<br>PSYS gain = 1.44µA/W (default) or 0.723µA/W. |
| 31 | VBAT | Battery voltage sensing. Used for trickle charging detection and Ideal Diode mode control. Connect to >1µF ceramic capacitor from VBAT pin to GND.<br>VBAT pin is also one of the two internal low power LDO inputs. |
| 32 | BGATE | Gate drive output to the P-channel FET connecting the system and the battery. This pin can go high to disconnect the battery, low to connect the battery or operate in a Linear mode to regulate trickle charge current during trickle charge.<br>When BGATE turns on, it is clamped 10V below VSYS pin voltage. |

# Block Diagram

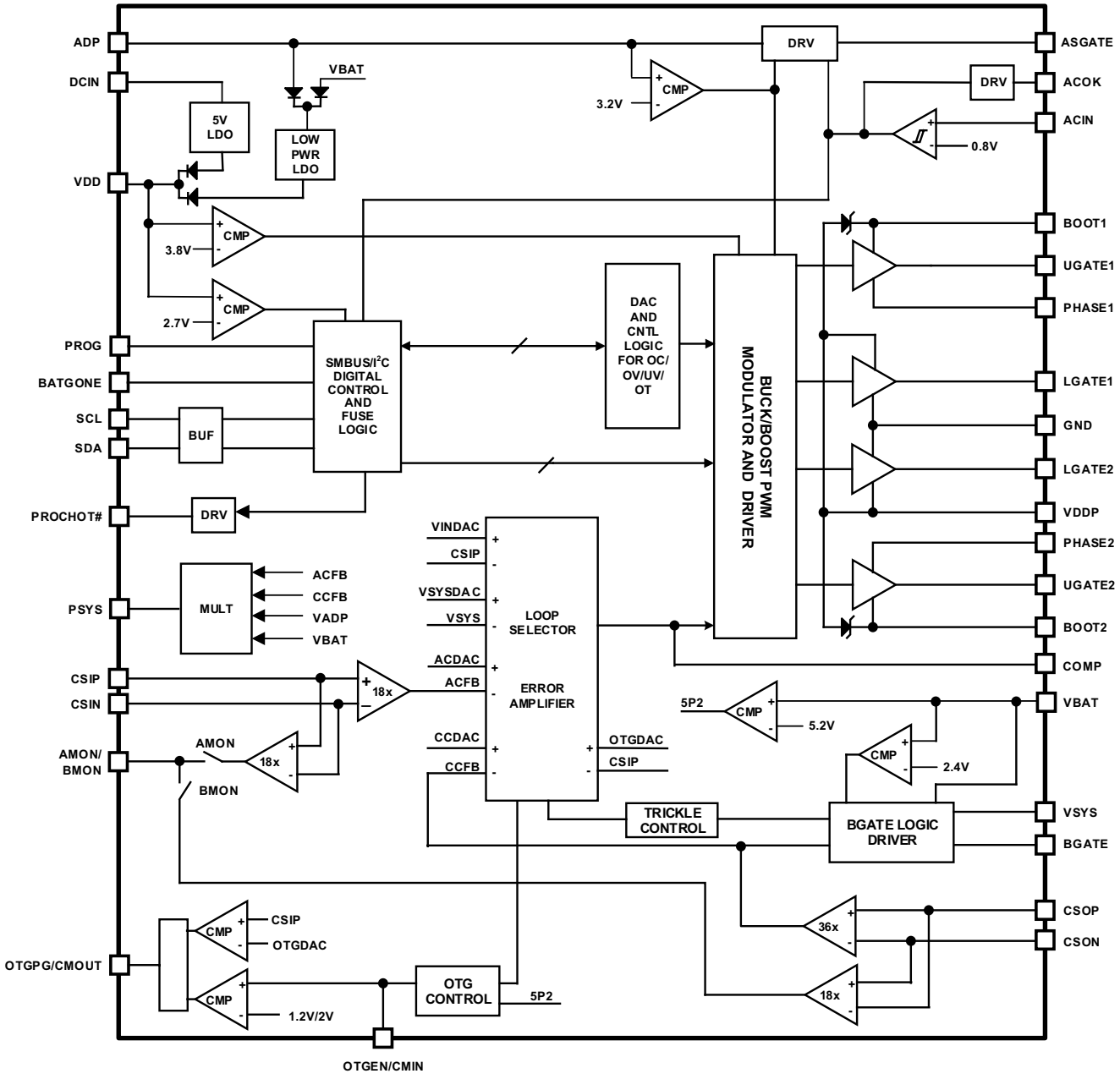



**FIGURE 2. BLOCK DIAGRAM**

# Simplified Application Circuit

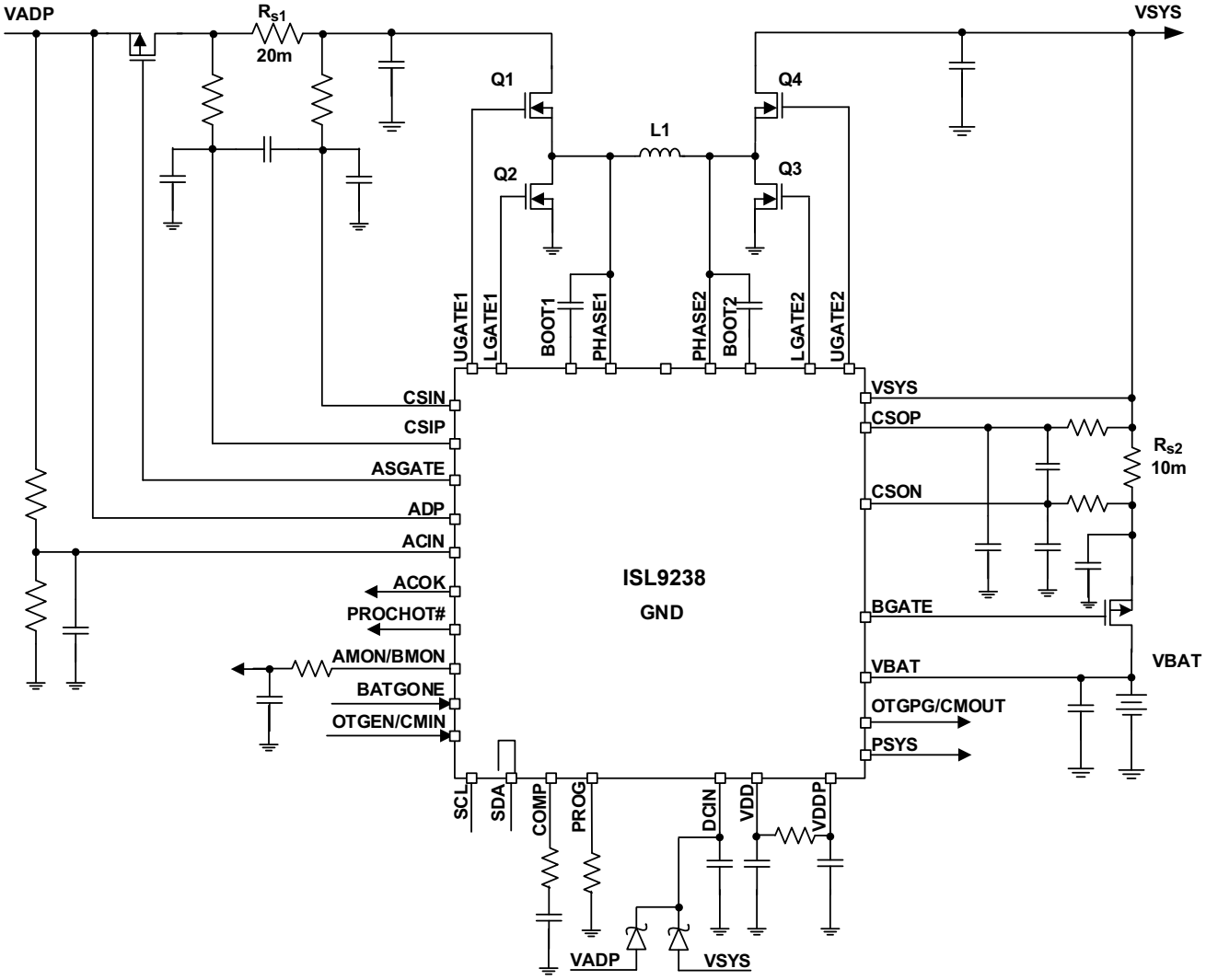



FIGURE 3. SIMPLIFIED APPLICATION DIAGRAM

## Absolute Maximum Ratings

CSIP, CSIN, DCIN, ADP, ASGATE . . . . . -0.3V to +28V
PHASE1 . . . . . (GND - 0.3V) to +28V
PHASE1 . . . . . GND-2V(<20ns) to +28V
BOOT1, UGATE1 . . . . . (GND - 0.3V) to +33V
PHASE2 . . . . . (GND - 0.3V) to +24V
PHASE2 . . . . . GND - 2V(<20ns) to +24V
BOOT2, UGATE2 . . . . . (GND - 0.3V) to +29V
LGATE1, LGATE2 . . . . . (GND - 0.3V) to +6.5V
LGATE1, LGATE2 . . . . . GND - 2V(<20ns) to +6.5V
VBAT, VSYS, CSOP, CSON, BGATE . . . . . -0.3V to +24V
VDD, VDDP. . . . . -0.3V to +6.5V
COMP . . . . . -0.3V to +6.5V
AMON/BMON, PSYS. . . . . -0.3V to +6.5V
OTGEN, BATGONE . . . . . -0.3V to +6.5V
ACIN, ACOK, PROCHOT#, OTGPG . . . . . -0.3V to +6.5V
CLK, DAT . . . . . -0.3V to +6.5V
BOOT1-PHASE1, BOOT2-PHASE2. . . . . -0.3V to +6.5V
CSIP-CSIN, CSOP-CSON . . . . . -0.5V to +0.5V
VDD. . . . . 70mA
ACIN, SDA, SCL, DCIN, ACOK. . . . . 2mA
ESD Rating
  Human Body Model (Tested per JESD22-A114E). . . . . 2kV
  Machine Model (Tested per JESD22-A115-A). . . . . 200V
  Charged Device Model (Tested per JESD22-C101A) . . . . . 1kV
Latch-Up (Tested per JESD-78B; Class 2, Level A) . . . . . 100mA

## Thermal Information

| Thermal Resistance (Typical) | $\theta_{JA}$ (°C/W) | $\theta_{JC}$ (°C/W) |
|---|---|---|
| 32 Ld TQFN Package (Notes 5, 6) . . . . . | 37 | 2 |

Ambient Temperature Range ($T_A$) . . . . . -10°C to +100°C
Junction Temperature Range ($T_J$) . . . . . -10°C to +125°C
Storage Temperature Range ($T_S$) . . . . . -65°C to +175°C
Pb-Free Reflow Profile . . . . . see TB493

## Recommended Operating Conditions

Ambient Temperature
  HRTZ . . . . . -10°C to +100°C
  IRTZ . . . . . -40°C to +100°C
Junction Temperature . . . . . -10°C to +125°C
Adapter voltage. . . . . +4V to +23V

*CAUTION: Do not operate at or near the maximum ratings listed for extended periods of time. Exposure to such conditions may adversely impact product reliability and result in failures not covered by warranty.*

NOTES:

5. $\theta_{JA}$ is measured in free air with the component mounted on a high-effective thermal conductivity test board with "direct attach" features. See TB379.
6. For $\theta_{JC}$, the "case temp" location is the center of the exposed metal pad on the package underside.

## Electrical Specifications

Operating conditions: ADP = CSIP = CSIN = 5V and 20V, $V_{SYS}$ = $V_{BAT}$ = CSOP = CSON = 8V, unless otherwise noted. **Boldface limits apply across the junction temperature range, -10°C to +125°C unless otherwise specified.**

| PARAMETER | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| **UVLO/ACOK** | | | | | | |
| VADP UVLO Rising | VADP_UVLO_r | | **3.1** | 3.3 | **3.5** | V |
| VADP UVLO Hysteresis | VADP_UVLO_h | | | 600 | | mV |
| $V_{BAT}$ UVLO Rising | VBAT_UVLO_r | | **2.30** | 2.45 | **2.65** | V |
| $V_{BAT}$ UVLO Hysteresis | VBAT_UVLO_h | | | 400 | | mV |
| $V_{BAT}$ 5P2V Rising | VBAT_5P2_r | | **5.05** | 5.20 | **5.65** | V |
| $V_{BAT}$ 5P2V Hysteresis | VBAT_5P2_h | | | 490 | | mV |
| VDD 2P7 POR Falling, SMBus and BGATE/BMON Active Threshold | VDD_2P7_f | | **2.50** | 2.70 | **2.9** | V |
| VDD 2P7 POR Hysteresis | VDD_2P7_h | | | 150 | | mV |
| VDD 3P8 POR Rising, Modulator and Gate Driver Active | VDD_3P8_r | | **3.6** | 3.8 | **3.9** | V |
| VDD 3P8 POR Hysteresis | VDD_3P8_h | | | 150 | | mV |
| ACIN Rising | ACIN_r | | **0.775** | 0.800 | **0.825** | V |
| ACIN Hysteresis | ACIN_h | | | 50 | | mV |

## Electrical Specifications

Operating conditions: ADP = CSIP = CSIN = 5V and 20V, $V_{SYS}$ = $V_{BAT}$ = CSOP = CSON = 8V, unless otherwise noted. **Boldface limits apply across the junction temperature range, -10°C to +125°C unless otherwise specified. (Continued)**

| PARAMETER | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| **LINEAR REGULATOR** | | | | | | |
| VDD Output Voltage | VDD | 6V < $V_{DCIN}$ < 23V, no load | **4.5** | 5.0 | **5.5** | V |
| VDD Dropout Voltage | VDD_dp | 30mA, $V_{DCIN}$ = 4V | | 85 | | mV |
| VDD Overcurrent Threshold | VDD_OC | HRTZ | **80** | 115 | **150** | mA |
| VDD Overcurrent Threshold | | IRTZ | **75** | 115 | **150** | mA |
| Battery Current | $I_{BAT1}$ | Battery only, BGATE on, PSYS OFF, BMON OFF, $V_{BAT}$ = 16.8V, DCIN current comes from battery, $I_{BAT}$ = $I_{VBAT}$ + $I_{CSOP}$ + $I_{CSON}$ + $I_{DCIN}$ + $I_{VSYS}$ | | 24 | **50** | µA |
| | $I_{BAT2}$ | Battery only, BGATE on, PSYS OFF, BMON ON, $V_{BAT}$ = 16.8V, DCIN current comes from battery, $I_{BAT}$ = $I_{VBAT}$ + $I_{CSOP}$ + $I_{CSON}$ + $I_{DCIN}$ + $I_{VSYS}$ | | 74 | | µA |
| | $I_{BAT3}$ | Battery only, BGATE on, PSYS ON, BMON OFF, $V_{BAT}$ = 16.8V, DCIN current comes from battery, $I_{BAT}$ = $I_{VBAT}$ + $I_{CSOP}$ + $I_{CSON}$ + $I_{DCIN}$ + $I_{VSYS}$ | | 905 | **1055** | µA |
| **ADAPTER CURRENT REGULATION, $R_{S1}$ = 20mΩ** | | | | | | |
| Adapter Current Accuracy | | CSIP-CSIN = 80mV | | 4 | | A |
| | | | **-2** | | **2** | % |
| | | CSIP-CSIN = 40mV | | 2 | | A |
| | | | **-2.5** | | **2.5** | % |
| | | CSIP-CSIN = 10mV | | 0.5 | | A |
| | | | **-10** | | **10** | % |
| Adapter Current PROCHOT# Threshold $R_{S1}$ = 20mΩ | $I_{ADP_HOT_TH10}$ | ACProchot = 0x1580H (5504mA) | | 5504 | | mA |
| | | | **-1.5** | | **1.5** | % |
| | | ACProchot = 0x0A80H (2688mA) | | 2688 | | mA |
| | | | **-3.0** | | **3.0** | % |
| | | ACProchot = 0x0400H (1024mA) | | 1024 | | mA |
| | | | **-6.0** | | **6.0** | % |
| **SYSTEM VOLTAGE REGULATION** | | | | | | |
| Maximum System Voltage Accuracy | HRTZ | MaxSystemVoltage for 1-cell (4.2V) | **-0.75** | | **0.75** | % |
| | | MaxSystemVoltage for 1-cell (8.4V) | **-0.6** | | **0.6** | % |
| | | MaxSystemVoltage for 3-cell and 4-cell (12.6V and 16.8V) | **-0.5** | | **0.5** | % |
| | IRTZ | MaxSystemVoltage for 1-cell (4.2V) | **-0.85** | | **0.85** | % |
| | | MaxSystemVoltage for 1-cell (8.4V) | **-0.7** | | **0.7** | % |
| | | MaxSystemVoltage for 3-cell and 4-cell (12.6V and 16.8V) | **0.55** | | **0.50** | % |
| Minimum System Voltage Accuracy | | | **-3** | | **3** | % |
| Input Voltage Regulation Accuracy | | 4.096V | **3.98** | | **4.22** | % |

## Electrical Specifications

Operating conditions: ADP = CSIP = CSIN = 5V and 20V, $V_{SYS}$ = $V_{BAT}$ = CSOP = CSON = 8V, unless otherwise noted. **Boldface limits apply across the junction temperature range, -10°C to +125°C unless otherwise specified. (Continued)**

| PARAMETER | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| **CHARGE CURRENT REGULATION, $R_{S2}$ = 10mΩ (LIMITS APPLY ACROSS TEMPERATURE RANGE OF 0°C TO +85°C)** | | | | | | |
| Charge Current Accuracy | | CSOP-CSON = 60mV | | 6.03 | | A |
| | | | **-2** | | **2** | % |
| | | CSOP-CSON = 20mV | | 2.01 | | A |
| | | | **-4** | | **4** | % |
| | | CSOP-CSON = 10mV | | 1.005 | | A |
| | | | **-5** | | **6** | % |
| | | CSOP-CSON = 5mV | | 0.501 | | A |
| | | | **-10** | | **12** | % |
| **BGATE CLAMP** | | | | | | |
| VSYS-VBGATE ON | | Charging enabled | **6.80** | 8.30 | **9.16** | V |
| VSYS-VBGATE OFF | | Charging disabled | | 0 | | V |
| **ASGATE CLAMP** | | | | | | |
| VADP-VASGATE ON | | | | 12 | | V |
| VSYS-VBGATE OFF | | | | 0 | | V |
| **TRICKLE CHARGING CURRENT REGULATION, $R_{S2}$ = 10mΩ (LIMITS APPLY ACROSS TEMPERATURE RANGE OF 0°C TO +85°C)** | | | | | | |
| Trickle Charge Current Accuracy | | Trickle, options 512mA | **410** | 512 | **614** | mA |
| | | Trickle, options 256mA | **205** | 256 | **334** | mA |
| | | Trickle, 128mA | **77** | 128 | **192** | mA |
| | | Trickle, 64mA | **16** | 64 | **128** | mA |
| Fast Charge to Trickle Charge Threshold | | $V_{SYS}$ - $V_{BGATE}$ | **4.23** | 5.18 | **5.97** | V |
| Trickle Charge to Fast Charge Threshold Hysteresis | | $V_{SYS}$ - $V_{BGATE}$ | **55** | 130 | **210** | mV |
| Fast Charge to Trickle Charge BGATE Threshold | | $V_{SYS}$ > 7V, $V_{FB}$ >> $V_{REF}$ | | 1.15 | | V |
| Trickle Charge to Fast Charge BGATE Threshold Hysteresis | | $V_{SYS}$ > 7V, $V_{FB}$ >> $V_{REF}$ | | 50 | | mV |
| **IDEAL DIODE MODE** | | | | | | |
| Entering Ideal Diode Mode VSYS Voltage Threshold | | BGATE off, VSYS falling $V_{VBAT}$ - $V_{VSYS}$ | **100** | 150 | **200** | mV |
| Exiting Ideal Diode Mode Battery Discharging Current Threshold | | $R_{S2}$ = 10mΩ | **110** | 200 | **290** | mA |
| Exiting Ideal Diode Mode Battery Charging Current Threshold | | $R_{S2}$ = 10mΩ | **50** | 130 | **200** | mA |
| BGATE Source | | VSYS - BGATE = 2V, charging disabled | **4** | 6 | **10** | mA |
| BGATE Sink | | BGATE - GND = 2V, charging enabled | **20** | 30 | **40** | µA |
| BGATE Sink | | BGATE - GND = 2V, in Ideal Diode mode | | 6 | | µA |
| **AMON/BMON** | | | | | | |
| **INPUT CURRENT SENSE AMPLIFIER, $R_{S1}$ = 20mΩ** | | | | | | |
| CSIP/CSIN Input Voltage Range | $V_{CSIP/N}$ | | **4** | | **23** | V/V |
| AMON Gain | | | | 17.97 | | V/V |
| AMON Accuracy $V_{AMON}$ = 17.9 * (CSIP - CSIN) | | $V_{CSIP}$ - $V_{CSIN}$ = 100mV (5A), CSIP = 5V - 20V | **-2** | | **2** | % |
| | | $V_{CSIP}$ - $V_{CSIN}$ = 20mV (1A), CSIP = 5V - 20V | **-5** | | **5** | % |
| | | $V_{CSIP}$ - $V_{CSIN}$ = 10mV (0.5A), CSIP = 5V - 20V | **-10** | | **10** | % |
| | | $V_{CSIP}$ - $V_{CSIN}$ = 2mV (0.1A), CSIP = 5V - 20V | **-40** | | **40** | % |

**Electrical Specifications** Operating conditions: ADP = CSIP = CSIN = 5V and 20V, $V_{SYS}$ = $V_{BAT}$ = CSOP = CSON = 8V, unless otherwise noted. **Boldface limits apply across the junction temperature range, -10°C to +125°C unless otherwise specified. (Continued)**

| PARAMETER | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| Reverse AMON Gain | | | | 17.9 | | V/V |
| AMON Accuracy $V_{AMON}$ = 17.9 * (CSIN - CSIP) | | $V_{CSIN}$ - $V_{CSIP}$ = 80mV (4A), CSIP = 4V - 22V | **-2.5** | | **2.5** | % |
| | | $V_{CSIN}$ - $V_{CSIP}$ = 20mV (1A), CSIP = 4V - 22V | **-6.5** | | **4.5** | % |
| | | $V_{CSIN}$ - $V_{CSIP}$ = 10mV (0.5A), CSIP = 4V - 22V | **-12** | | **9** | % |
| | | $V_{CSIN}$ - $V_{CSIP}$ = 5.12mV (0.256A), CSIP = 4V - 22V | **-25** | | **25** | % |
| AMON Minimum Output Voltage | | $V_{CSIP}$ - $V_{CSIN}$ = 0V | | | **30** | mV |
| **DISCHARGE CURRENT SENSE AMPLIFIER, $R_{S2}$ = 10mΩ** | | | | | | |
| BMON Gain (Battery Discharging) | | | | 17.78 | | V/V |
| BMON Accuracy $V_{BMON}$ = 17.9 * ($V_{CSON}$ - $V_{CSOP}$) | | $V_{CSON}$ - $V_{CSOP}$ = 100mV (10A), $V_{CSON}$ = 8V | **-2** | | **2** | % |
| | | $V_{CSON}$ - $V_{CSOP}$ = 20mV (2A), $V_{CSON}$ = 8V | **-7.0** | -1.5 | **3.0** | % |
| | | $V_{CSON}$ - $V_{CSOP}$ = 10mV (1A), $V_{CSON}$ = 8V | **-10.5** | -2.5 | **5.5** | % |
| | | $V_{CSON}$ - $V_{CSOP}$ = 6mV (0.6A), $V_{CSON}$ = 8V | **-17** | -4 | **12** | % |
| BMON Gain (Battery Charging) | | Limits apply across temperature range of 0°C to +85°C | | 35.7 | | V/V |
| BMON Accuracy $V_{BMON}$ = 35.7* ($V_{CSON}$ - $V_{CSOP}$) | | $V_{CSOP}$ - $V_{CSON}$ = 60mV (6A), $V_{CSON}$ = 8V | **-3** | | **3** | % |
| | | $V_{CSOP}$ - $V_{CSON}$ = 40mV (4A), $V_{CSON}$ = 8V | **-4** | | **4** | % |
| | | $V_{CSOP}$ - $V_{CSON}$ = 10mV (1A), $V_{CSON}$ = 8V | **-10** | | **10** | % |
| | | $V_{CSOP}$ - $V_{CSON}$ = 5mV (0.5A), $V_{CSON}$ = 8V | **-25** | | **25** | % |
| BMON Minimum Output Voltage | | $V_{CSOP}$ - $V_{CSON}$ = 0V | | | **30** | mV |
| Discharging Current PROCHOT# Threshold, $R_{S2}$ = 10mΩ | $I_{DIS_HOT_TH}$ | DCProchot = 2.048A | **1.77** | 2.08 | **2.39** | A |
| Discharging Current PROCHOT# Threshold, Battery Only, $R_{S2}$ = 10mΩ | $I_{DIS_HOT_TH}$ | DCProchot = 12A | **10.8** | 13.5 | **17** | A |
| | | DCProchot = 6A | **5.35** | 6.5 | **8** | A |
| AMON/BMON Source Resistance | | (Note 8) | | | **5** | Ω |
| AMON/BMON Sink Resistance | | (Note 8) | | | **5** | Ω |
| **BATGONE AND OTGEN** | | | | | | |
| High-Level Input Voltage | | | **0.9** | | | V |
| Low-Level Input Voltage | | | | | **0.4** | V |
| Input Leakage Current | | $V_{BATGONE}$ = 3.3V, 5V; $V_{OTGEN}$ = 3.3V, 5V | | | **1** | µA |
| **PROCHOT#** | | | | | | |
| PROCHOT# Debounce Time | | Prochot# Debounce register Bit<1:0> = 11 | **0.85** | 1 | **1.15** | ms |
| | | Prochot# Debounce register Bit<1:0> = 10 | **425** | 500 | **575** | µs |
| PROCHOT# Duration Time | | Prochot# Duration register Bit<2:0> = 011 | **8.5** | 10 | **11.5** | ms |
| | | Prochot# Duration register Bit<2:0> = 001 | **17** | 20 | **23** | ms |
| Low VSYS PROCHOT# Trip Threshold | $V_{LOW_VSYS_HOT}$ | Control1 register Bit<1:0> = 00 | **5.8** | 6.0 | **6.2** | V |
| | | Control1 register Bit<1:0> = 01 | **6.1** | 6.3 | **6.5** | V |
| | | Control1 register Bit<1:0> = 10 | **6.4** | 6.6 | **6.8** | V |
| | | Control1 register Bit<1:0> = 11 | **6.7** | 6.9 | **7.1** | V |

**Electrical Specifications** Operating conditions: ADP = CSIP = CSIN = 5V and 20V, $V_{SYS}$ = $V_{BAT}$ = CSOP = CSON = 8V, unless otherwise noted. **Boldface limits apply across the junction temperature range, -10°C to +125°C unless otherwise specified. (Continued)**

| PARAMETER | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| **PSYS** | | | | | | |
| PSYS Output Current<br>$R_{S1}$ = 20mΩ<br>$R_{S2}$ = 10mΩ<br>$I_{PSYS}$= 1.493 x Power + 1.43µA | $I_{PSYS}$<br>Control3 Bit<9> = 1 | $V_{CSIP}$ = 19V, $V_{CSIP-CSIN}$ = 80mV,<br>$V_{BAT}$ = 12V, $V_{CSOP-CSON}$ = 10mV | **-5** | | **5** | % |
| | | $V_{CSIP}$ = 19V, $V_{CSIP-CSIN}$ = 80mV,<br>$V_{BAT}$ = 12V, $V_{CSOP-CSON}$ = -10mV | **-5.3** | | **5.3** | % |
| | $I_{PSYS}$<br>Control3 Bit<9> = 0 | $V_{CSIP}$ = 19V, $V_{CSIP-CSIN}$ = 0mV,<br>$V_{BAT}$ = 8.4V, $V_{CSOP-CSON}$ = 20mV | **-7** | | **7** | % |
| | | $V_{CSIP}$ = 19V, $V_{CSIP-CSIN}$ = 0mV,<br>$V_{BAT}$ = 4.2V, $V_{CSOP-CSON}$ = 10mV | **-15** | | **15** | % |
| Maximum PSYS Output Voltage | $V_{PSYS_MAX}$ | | **4** | | | V |
| **OTG** | | | | | | |
| OTG Voltage | | OTGVoltage register = 5.12V | **4.95** | 5.03 | **5.12** | V |
| OTG Current (5V to 12V) | | OTGCurrent register = 512mA | **435** | 512 | **589** | mA |
| | | OTGCurrent register = 1024mA | **922** | 1024 | **1126** | mA |
| | | OTGCurrent register = 4096mA | **3975** | 4096 | **4240** | mA |
| **GENERAL PURPOSE COMPARATOR** | | | | | | |
| General Purpose Comparator Rising Threshold | | Reference = 1.2V | **1.15** | 1.2 | **1.25** | V |
| | | Reference = 2V | **1.95** | 2 | **2.05** | V |
| General Purpose Comparator Hysteresis | | Reference = 1.2V | **30** | 60 | **90** | mV |
| | | Reference = 2V | **30** | 60 | **90** | mV |
| **PROTECTION** | | | | | | |
| VSYS Overvoltage Rising Threshold | | MaxSystemVoltage register value = 8.4V | **8.95** | 9.15 | **9.35** | V |
| VSYS Overvoltage Hysteresis | | | **250** | 400 | **550** | mV |
| Adapter Way Overcurrent Rising Threshold (Note 8) | | $R_{S1}$ = 20mΩ | **7.5** | 12 | **18** | A |
| Adapter Way Overcurrent Hysteresis | | | **5** | 6.6 | **8** | A |
| Battery Discharge Way Overcurrent Rising Threshold (Note 8) | | $R_{S2}$ = 10mΩ | **10** | 20 | **32** | A |
| Battery Discharge Way Overcurrent Hysteresis (Note 8) | | | **7.5** | 9 | **10.5** | A |
| Over-Temperature Threshold (Note 8) | | | **140** | 150 | **160** | °C |
| Adapter Overvoltage Rising Threshold | | | **22.5** | 23.4 | **24** | V |
| Adapter Overvoltage Hysteresis | | | **150** | 350 | **500** | mV |
| OTG Undervoltage Falling Threshold | | OTG voltage = 5.004V | **3.45** | 3.80 | **4.25** | V |
| OTG Overvoltage Rising Threshold | | OTG voltage = 5.004V | **5.8** | 6.2 | **6.6** | V |

**Electrical Specifications** Operating conditions: ADP = CSIP = CSIN = 5V and 20V, $V_{SYS}$ = $V_{BAT}$ = CSOP = CSON = 8V, unless otherwise noted. **Boldface limits apply across the junction temperature range, -10°C to +125°C unless otherwise specified. (Continued)**

| PARAMETER | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| **OSCILLATOR** | | | | | | |
| Oscillator Frequency. Digital Core Only | | | **0.85** | 1 | **1.15** | MHz |
| Digital Debounce Time Accuracy (Note 8) | | | **-15** | | **15** | % |
| **MISCELLANEOUS** | | | | | | |
| Switching Frequency Accuracy | | COMP>1.7V and not in period stretching | **-15** | | **15** | % |
| Battery Learn Mode Auto-Exit Threshold | | MinSystemVoltage = 5.376V<br>Control1 register Bit<13> = 1 | **5.05** | 5.35 | **5.7** | V |
| Battery Learn Mode Auto-Exit Hysteresis (Note 8) | | | **180** | 330 | **480** | mV |
| **SMBus** | | | | | | |
| SDA/SCL Input Low Voltage | | 3.3V | | | **0.8** | V |
| SDA/SCL Input High Voltage | | 3.3V | **2** | | | V |
| SDA/SCL Input Bias Current | | 3.3V | | | **1** | µA |
| SDA, Output Sink Current | | SDA = 0.4V, on | **4** | | | mA |
| SMBus Frequency | $f_{SMB}$ | | **10** | | **400** | kHz |
| **GATE DRIVER** | | | | | | |
| UGATE1 Pull-Up Resistance | $UG1_{RPU}$ | 100mA source current | | 800 | **1200** | mΩ |
| UGATE1 Source Current | $UG1_{SRC}$ | UGATE1 - PHASE1 = 2.5V | **1.3** | 2 | | A |
| UGATE1 Pull-Down Resistance | $UG1_{RPD}$ | 100mA sink current | | 350 | **475** | mΩ |
| UGATE1 Sink Current | $UG1_{SNK}$ | UGATE1 - PHASE1 = 2.5V | **1.9** | 2.8 | | A |
| LGATE1 Pull-Up Resistance | $LG1_{RPU}$ | 100mA source current | | 800 | **1200** | mΩ |
| LGATE1 Source Current | $LG1_{SRC}$ | LGATE1 - GND = 2.5V | **1.3** | 2 | | A |
| LGATE1 Pull-Down Resistance | $LG1_{RPD}$ | 100mA sink current | | 300 | **450** | mΩ |
| LGATE1 Sink Current | $LG1_{SNK}$ | LGATE1 - GND = 2.5V | **2.3** | 3.5 | | A |
| LGATE2 Pull-Up Resistance | $LG2_{RPU}$ | 100mA source current | | 800 | **1200** | mΩ |
| LGATE2 Source Current | $LG2_{SRC}$ | LGATE2 - GND = 2.5V | **1.3** | 2 | | A |
| LGATE2 Pull-Down Resistance | $LG2_{RPD}$ | 100mA sink current | | 300 | **450** | mΩ |
| LGATE2 Sink Current | $LG2_{SNK}$ | LGATE2 - GND = 2.5V | **2.3** | 3.5 | | A |
| UGATE2 Pull-Up Resistance | $UG2_{RPU}$ | 100mA source current | | 800 | **1200** | mΩ |
| UGATE2 Source Current | $UG2_{SRC}$ | UGATE2 - PHASE2 = 2.5V | **1.3** | 2 | | A |
| UGATE2 Pull-Down Resistance | $UG2_{RPD}$ | 100mA sink current | | 300 | **450** | mΩ |
| UGATE2 Sink Current | $UG2_{SNK}$ | UGATE2 - PHASE2 = 2.5V | **2.3** | 3.5 | | A |
| UGATE1 to LGATE1 Dead Time | $t_{UG1LG1DEAD}$ | | **10** | 20 | **40** | ns |
| LGATE1 to UGATE1 Dead Time | $t_{LG1UG1DEAD}$ | | **10** | 20 | **40** | ns |
| LGATE2 to UGATE2 Dead Time | $t_{LG2UG2DEAD}$ | | **10** | 20 | **40** | ns |
| UGATE2 to LGATE2 Dead Time | $t_{UG2LG2DEAD}$ | | **10** | 20 | **40** | ns |

## SMBUS Timing Specification (Note 8)

| PARAMETERS | SYMBOL | TEST CONDITIONS | MIN (Note 7) | TYP | MAX (Note 7) | UNIT |
|---|---|---|---|---|---|---|
| SMBus Frequency | $F_{SMB}$ | | 10 | | 400 | kHz |
| Bus Free Time | $t_{BUF}$ | | 4.7 | | | µs |
| Start Condition Hold Time from SCL | $t_{HD:STA}$ | | 4 | | | µs |
| Start Condition Set-Up Time from SCL | $t_{SU:STA}$ | | 4.7 | | | µs |
| Stop Condition Set-Up Time from SCL | $t_{SU:STO}$ | | 4 | | | µs |
| SDA Hold Time from SCL | $t_{HD:DAT}$ | | 300 | | | ns |
| SDA Set-Up Time from SCL | $t_{SU:DAT}$ | | 250 | | | ns |
| SCL Low Period | $t_{LOW}$ | | 4.7 | | | µs |
| SCL High Period | $t_{HIGH}$ | | 4 | | | µs |
| SMBus Inactivity Timeout | | Maximum charging period without a SMBus Write to MaxSystemVoltage or ChargeCurrent register | | 175 | | s |

NOTES:

7. Parameters with MIN and/or MAX limits are 100% tested at +25°C, unless otherwise specified. Temperature limits established by characterization and are not production tested.
8. Limits established by characterization and are not production tested.

# Gate Driver Timing Diagram

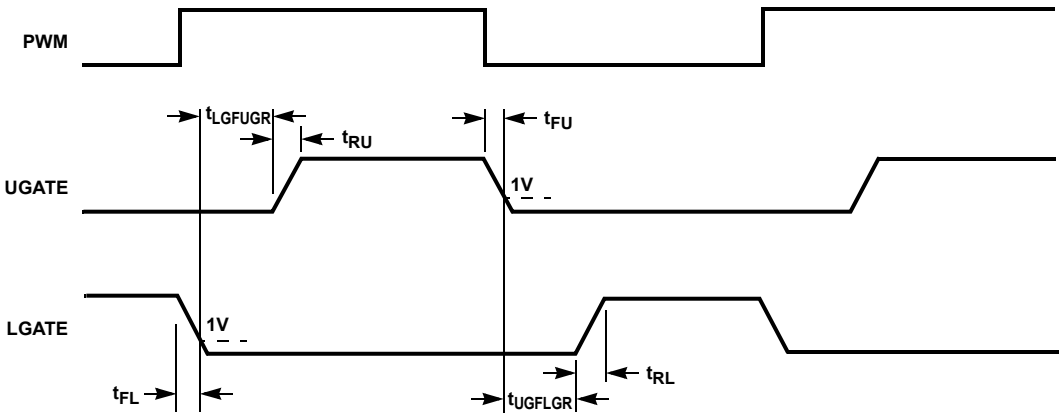



FIGURE 4. GATE DRIVER TIMING DIAGRAM

# Typical Performance

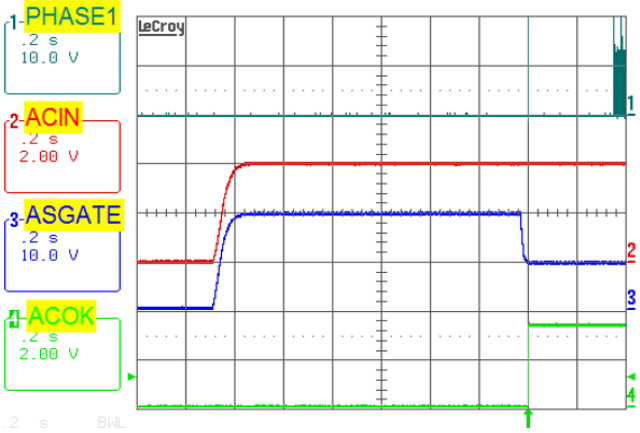



FIGURE 5. ADAPTER INSERTION, $V_{ADP}$ = 20V, $V_{BAT}$ = 11V, CHARGECURRENT = 0A

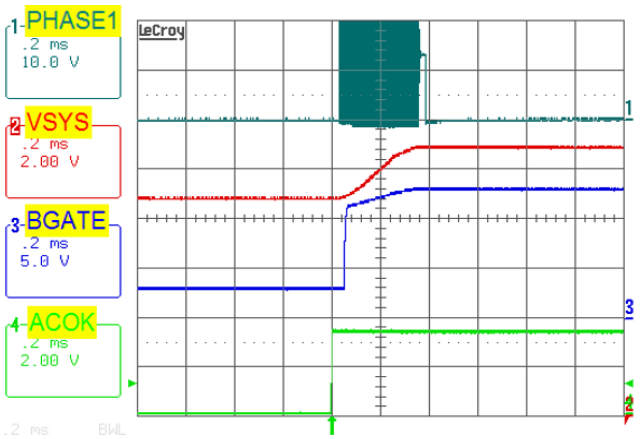



FIGURE 6. ADAPTER INSERTION, $V_{ADP}$ = 20V, $V_{BAT}$ = 11V, CHARGECURRENT = 0A (Figure 5 ZOOM IN)

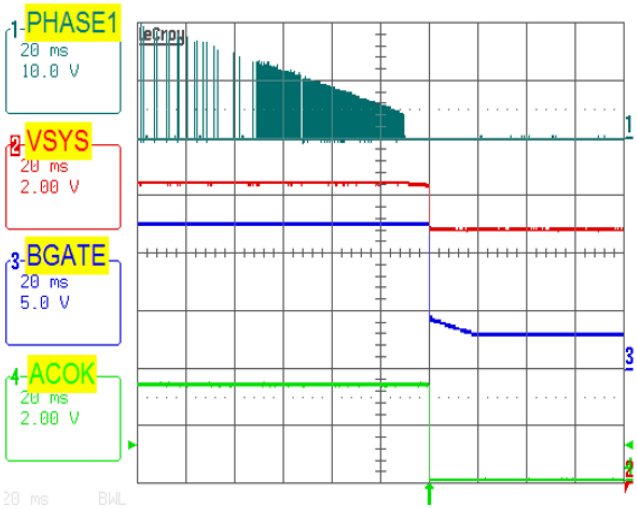



FIGURE 7. ADAPTER REMOVAL, $V_{ADP}$ = 20V, $V_{BAT}$ = 11V, CHARGECURRENT = 0A

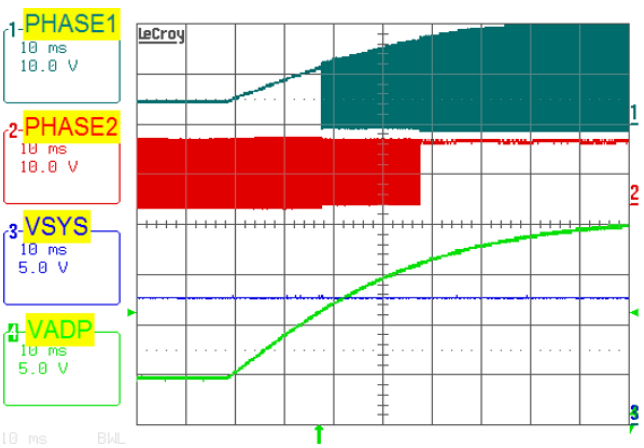



FIGURE 8. ADAPTER VOLTAGE RAMPS UP, BOOST -> BUCK-BOOST -> BUCK OPERATION MODE TRANSITION

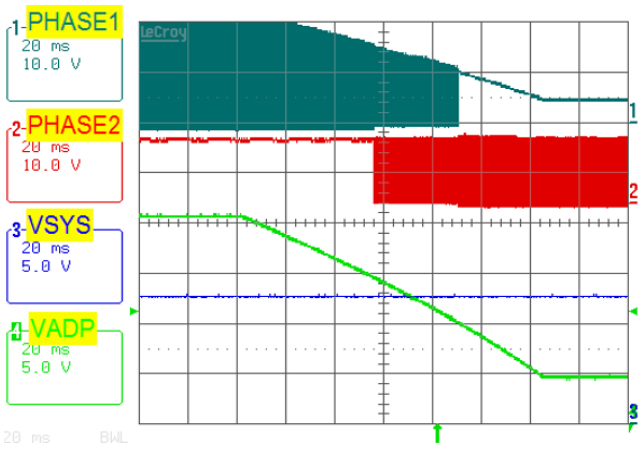



FIGURE 9. ADAPTER VOLTAGE RAMPS DOWN, BUCK -> BUCK-BOOST -> BOOST OPERATION MODE TRANSITION

## Typical Performance (Continued)

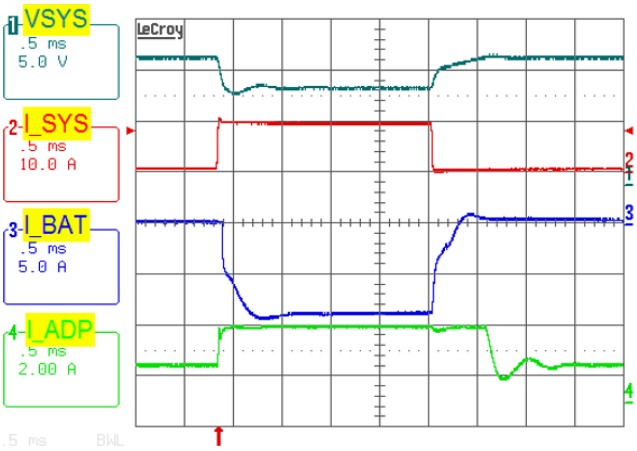



FIGURE 10. BOOST MODE, OUTPUT VOLTAGE LOOP TO ADAPTER CURRENT LOOP TRANSITION. $V_{ADP}$ = 5V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, SYSTEM LOAD 0.5A TO 10A STEP, ADAPTERCURRENTLIMIT = 3A, CHARGECURRENT = 0A

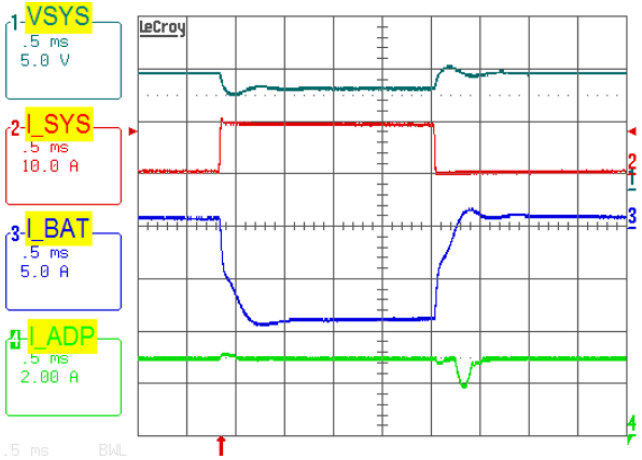



FIGURE 11. BOOST MODE, CHARGING CURRENT LOOP TO ADAPTER CURRENT LOOP TRANSITION. $V_{ADP}$ = 5V, MAXSYSTEMVOLTAGE = 12.5766V, $V_{BAT}$ = 11V, SYSTEM LOAD 0.5A TO 10A STEP, ADAPTERCURRENTLIMIT = 3A, CHARGECURRENT = 1A

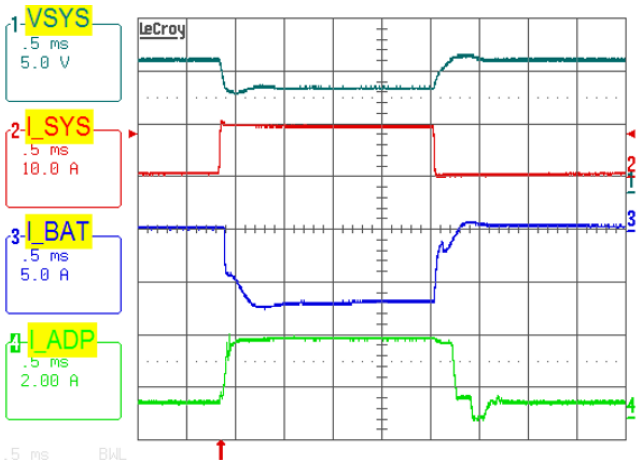



FIGURE 12. BUCK-BOOST MODE, OUTPUT VOLTAGE LOOP TO ADAPTER CURRENT LOOP TRANSITION. $V_{ADP}$ = 12V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, SYSTEM LOAD 1A TO 10A STEP, ADAPTERCURRENTLIMIT = 3A, CHARGECURRENT = 0A

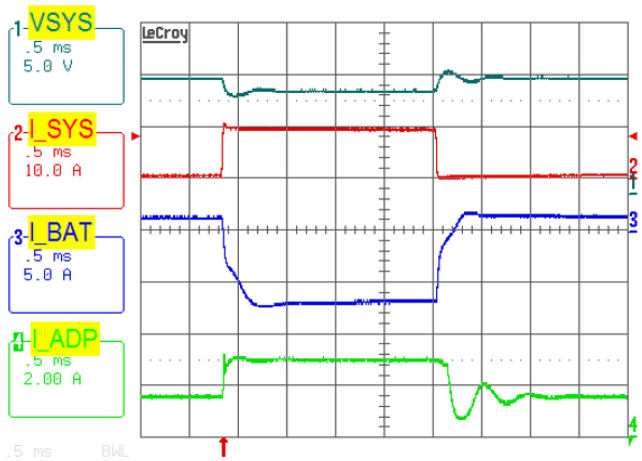



FIGURE 13. BUCK-BOOST MODE, CHARGING CURRENT LOOP TO ADAPTER CURRENT LOOP TRANSITION. $V_{ADP}$ = 12V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, SYSTEM LOAD 1A TO 10A STEP, ADAPTERCURRENTLIMIT = 3A, CHARGECURRENT = 1A

## Typical Performance (Continued)

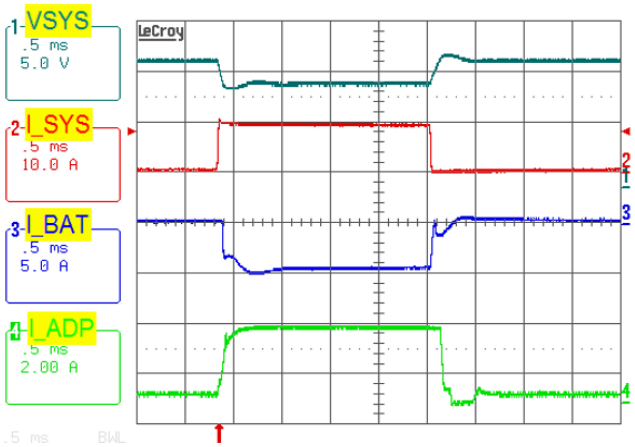



FIGURE 14. BUCK MODE, OUTPUT VOLTAGE LOOP TO ADAPTER CURRENT LOOP TRANSITION. $V_{ADP}$ = 20V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, SYSTEM LOAD 2A TO 10A STEP, ADAPTERCURRENTLIMIT = 3A, CHARGECURRENT = 0A

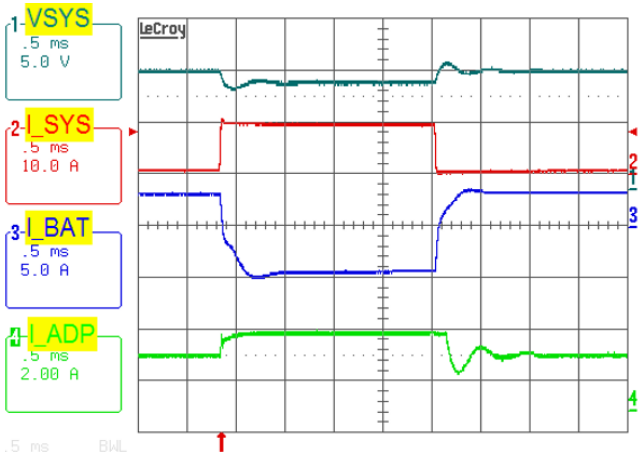



FIGURE 15. BUCK MODE, CHARGING CURRENT LOOP TO ADAPTER CURRENT LOOP TRANSITION. $V_{ADP}$ = 20V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, SYSTEM LOAD 2A TO 10A STEP, ADAPTERCURRENTLIMIT = 3A, CHARGECURRENT = 3A

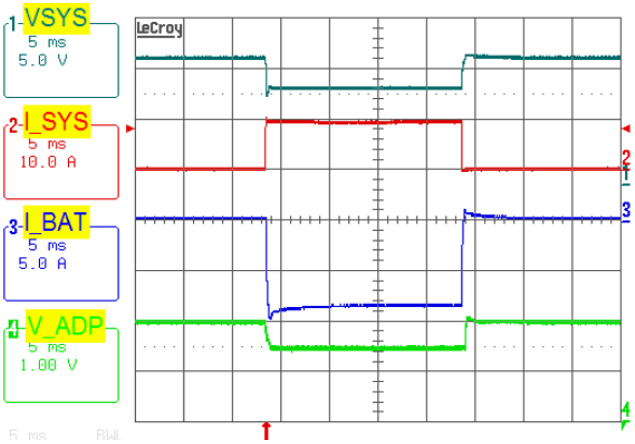



FIGURE 16. BOOST MODE, OUTPUT VOLTAGE LOOP TO INPUT VOLTAGE LOOP TRANSITION. $V_{ADP}$ = 5.004V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, VINDAC = 4.437V, SYSTEM LOAD 0A TO 10A STEP, CHARGECURRENT = 0A

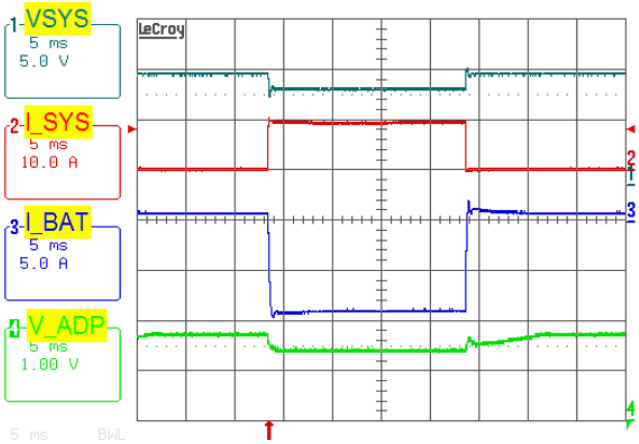



FIGURE 17. BOOST MODE, CHARGING CURRENT LOOP TO INPUT VOLTAGE LOOP TRANSITION. $V_{ADP}$ = 5.004V, MAXSYSTEMVOLTAGE = 12.576V, $V_{BAT}$ = 11V, VINDAC = 4.437V, SYSTEM LOAD 0A TO 10A STEP, CHARGECURRENT = 0.5A

## Typical Performance (Continued)

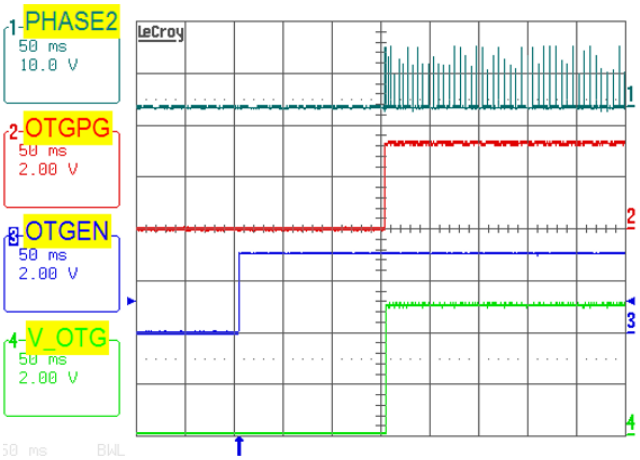



FIGURE 18. OTG MODE ENABLE, OTG ENABLE 150ms DEBOUNCE TIME

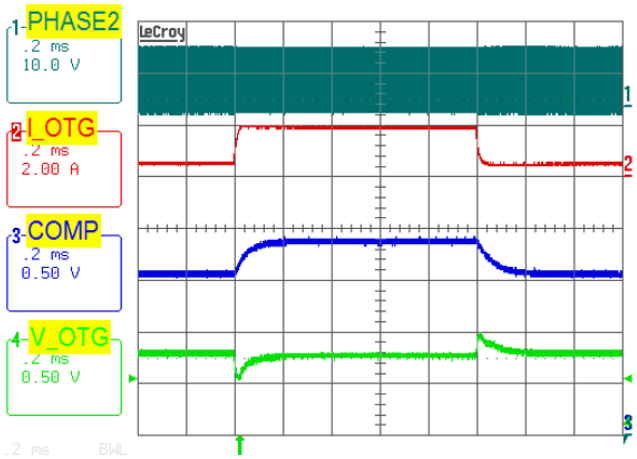



FIGURE 19. OTG MODE 0.5A TO 2A TRANSIENT LOAD, OTG VOLTAGE = 5.12V

## General SMBus Architecture

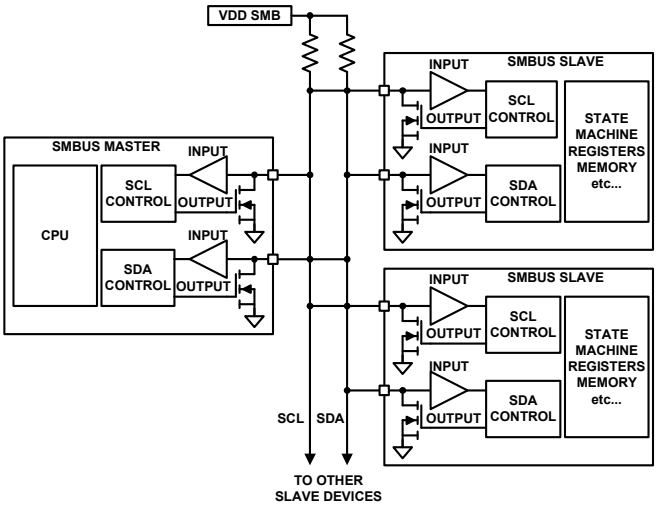



FIGURE 20. GENERAL SMBus ARCHITECTURE

### Data Validity

The data on the SDA line must be stable during the HIGH period of the SCL, unless generating a START or STOP condition. The HIGH or LOW state of the data line can only change when the clock signal on the SCL line is LOW. Refer to Figure 21.

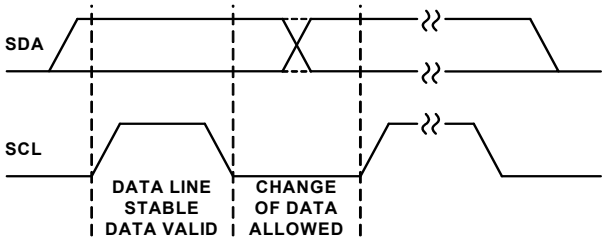



FIGURE 21. DATA VALIDITY

### START and STOP Conditions

Figure 22 START condition is a HIGH to LOW transition of the SDA line while SCL is HIGH.

The STOP condition is a LOW to HIGH transition on the SDA line while SCL is HIGH. A STOP condition must be sent before each START condition.

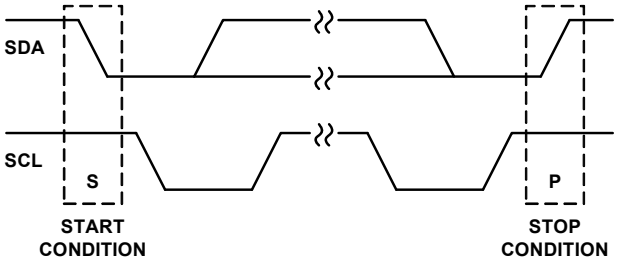



FIGURE 22. START AND STOP WAVEFORMS

### Acknowledge

Each address and data transmission uses 9 clock pulses. The ninth pulse is the Acknowledge bit (ACK). After the start condition, the master sends 7 slave address bits and a R/$\overline{W}$ bit during the next 8 clock pulses. During the 9th clock pulse, the device that recognizes its own address holds the data line low to acknowledge (Refer to Figure 23). The acknowledge bit is also used by both the master and the slave to acknowledge receipt of register addresses and data.

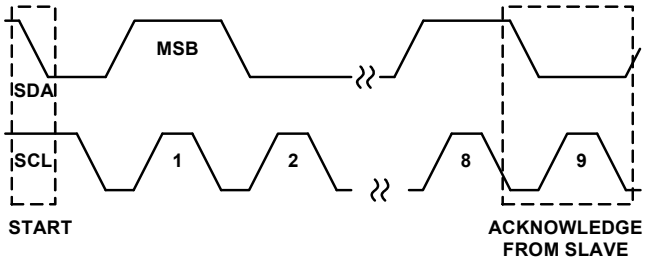



FIGURE 23. ACKNOWLEDGE ON THE SMBus

## SMBus Transactions

All transactions start with a control byte sent from the SMBus master device. The control byte begins with a Start condition, followed by 7 bits of slave address (0001101) and the R/$\overline{W}$ bit. The R/$\overline{W}$ bit is 0 for a WRITE or 1 for a READ. If any slave device on the SMBus bus recognizes its address, it will acknowledge by pulling the Serial Data (SDA) line low for the last clock cycle in the control byte. If no slave exists at that address or it is not ready to communicate, the data line will be one, indicating a not acknowledge condition.

After the control byte is sent and the ISL9238A acknowledges it, the second byte sent by the master must be a register address byte such as 0x14 for the ChargeCurrent register. The register address byte tells the ISL9238A which register the master will write or read. See Table 2 on page 20 for details of the registers. When the ISL9238A receives a register address byte, it will respond with an acknowledge.

## Byte Format

Every byte put on the SDA line must be 8 bits long and must be followed by an acknowledge bit. Data is transferred with the Most Significant Bit first (MSB) and the least significant bit last (LSB). The LO BYTE data is transferred before the HI BYTE data. For example, when writing 0x41A0, 0xA0 is written first and 0x41 is written second.

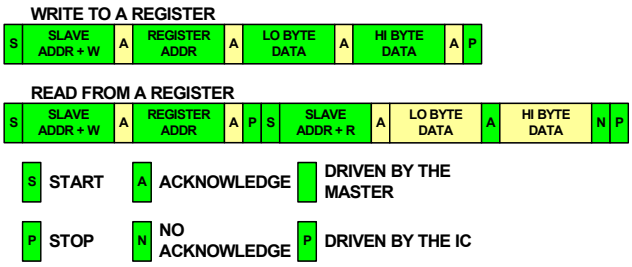



FIGURE 24. SMBus READ AND WRITE PROTOCOL

## SMBus and I²C Compatibility

The ISL9238A SMBus minimum input logic high voltage is 2V, so it is compatible with I²C with higher than 2V pull-up power supply.

The ISL9238A SMBus registers are 16 bits, so it is compatible with 16 bits I²C or 8 bits I²C with auto-increment capability.

# ISL9238A SMBus Commands

The ISL9238A receives control inputs from the SMBus interface after Power-On Reset (POR). The serial interface complies with the System Management Bus Specification, which can be downloaded from www.smbus.org. The ISL9238A uses the SMBus Read-word and Write-word protocols (see Figure 24) to communicate with the host system and a smart battery. The ISL9238A is an SMBus slave device and does not initiate communication on the bus. It responds to the 7-bit address 0b0001101_ as follows:

Read and Write address for ISL9238A is:

Read address = 0b00011011 (0X1BH)

Write address = 0b00011010 (0X1AH)

The data (SDA) and clock (SCL) pins have Schmitt-trigger inputs that can accommodate slow edges. Choose pull-up resistors for SDA and SCL to achieve rise times according to the SMBus specifications.

The illustration in this datasheet is based on current sensing resistors $R_{S1}$ = 20mΩ and $R_{S2}$ = 10mΩ unless otherwise specified.

**TABLE 2. REGISTER SUMMARY**

| REGISTER NAMES | REGISTER ADDRESS | READ/ WRITE | NUMBER OF BITS | DESCRIPTION | DEFAULT |
|---|---|---|---|---|---|
| ChargeCurrentLimit | 0x14 | R/W | 11 | [12:2]11-bit, LSB size 4mA, total range 6080mA with 10mΩ $R_{S2}$ | 0A |
| MaxSystemVoltage | 0x15 | R/W | 12 | [14:3]12-bit, LSB size 8mV, total range 18.304V | 4.192V for 1-cell |
| | | | | | 8.384V for 2-cell |
| | | | | | 12.576V for 3-cell |
| | | | | | 16.768V for 4-cell |
| T1 and T2 | 0x38 | R/W | 6 | Configure two-level adapter current limit duration | 0x000h |
| Control0 | 0x39 | R/W | 16 | Configure various charger options | 0x0000h |
| Information1 | 0x3A | R | 16 | Indicate various charger status | 0x0000h |
| AdapterCurrentLimit2 | 0x3B | R/W | 11 | [12:2]11-bit, LSB size 4mA, total range 6080mA with 20mΩ $R_{S1}$ | 1500mA |
| Control1 | 0x3C | R/W | 16 | Configure various charger options | 0x0000h |
| Control2 | 0x3D | R/W | 16 | Configure various charger options | 0x0000h |
| MinSystemVoltage | 0x3E | R/W | 6 | [13:8]6-bit, LSB size 256mV, total range 13.824V | 2.56V for 1-cell |
| | | | | | 5.12V for 2-cell |
| | | | | | 7.68V for 3-cell |
| | | | | | 10.24V for 4-cell |
| AdapterCurrentLimit1 | 0x3F | R/W | 11 | [12:2]11-bit, LSB size 4mA, total range 6080mA with 20mΩ $R_{S1}$ | Set by PROG pin |
| Revision ID | 0x44 | R | 8 | Revision ID register - Read only<br>0x01 - Rev1<br>0x02 - Rev2 | N/A |
| ACProchot# | 0x47 | R/W | 6 | [12:7] adapter current Prochot# threshold<br>Default 3.072A, 128mA resolution for 20mΩ $R_{S1}$ | 3.072A |
| DCProchot# | 0x48 | R/W | 6 | [13:8] Battery discharging current Prochot# threshold<br>Default 4.096A, 256mA resolution for 10mΩ $R_{S2}$ | 4.096A |
| OTG Voltage | 0x49 | R/W | 12 | [14:3] 12-bit, LSB size 12mV, total range 27.456V<br>OTG mode voltage reference | 5.004V |
| OTG Current | 0x4A | R/W | 6 | [12:7] 6-bit, LSB size 128mAV, total range 4.096A<br>OTG mode maximum current limit | 0.512A |
| $V_{IN}$ Voltage | 0x4B | R/W | 6 | [13:8] 6-bit, LSB size 341.3mV, total range 18.432mV<br>$V_{IN}$ loop voltage reference | 4.096V |
| Control3 | 0x4C | R/W | 16 | Configure various charger options | 0x0000h |
| Information2 | 0x4D | R | 16 | Indicate various charger status | 0x0000h |
| Control4 | 0x4E | R/W | 8 | [7:0] 8-bit, Configure various charger options | 0x0000h |
| Manufacturer ID | 0xFE | R | 8 | Manufacturers ID register – 0x49 - Read only | 0x0049h |
| Device ID | 0xFF | R | 8 | Device ID register - 0x0C- Read only | 0x000Ch |

# Setting Charging Current Limit

To set the charging current limit, write a 16-bit ChargeCurrentLimit command (0x14H or 0b00010100) using the Write-word protocol shown in Figure 24 on page 19 and the data format shown in Table 3 for a 10mΩ $R_{S2}$ or Table 4 for a 5mΩ $R_{S2}$.

The ISL9238A limits the charging current by limiting the CSOP-CSON voltage. By using the recommended current sense resistor values $R_{S1}$ = 20mΩ and $R_{S2}$ = 10mΩ, the register's LSB always translates to 4mA of charging current. The ChargeCurrentLimit register accepts any charging current command but only the valid register bits will be written to the register and the maximum values is clamped at 6080mA for $R_{S2}$ = 10mΩ.

After POR, the ChargeCurrentLimit register is reset to 0x0000H. To set the battery charging current value, write a non-zero number to the ChargeCurrentLimit register. The ChargeCurrentLimit register can be read back to verify its content.

Table 24 shows the conditions to enable fast charging according to the ChargeCurrentLimit register setting.

**TABLE 3. ChargeCurrentLimit REGISTER 0x14H (11-BIT, 4mA STEP, 10mΩ SENSE RESISTOR, x36)**

| BIT | DESCRIPTION |
|---|---|
| <1:0> | Not used |
| <2> | 0 = Add 0mA of charge current limit.<br>1 = Add 4mA of charge current limit. |
| <3> | 0 = Add 0mA of charge current limit.<br>1 = Add 8mA of charge current limit. |
| <4> | 0 = Add 0mA of charge current limit.<br>1 = Add 16mA of charge current limit. |
| <5> | 0 = Add 0mA of charge current limit.<br>1 = Add 32mA of charge current limit. |
| <6> | 0 = Add 0mA of charge current limit.<br>1 = Add 64mA of charge current limit. |
| <7> | 0 = Add 0mA of charge current limit.<br>1 = Add 128mA of charge current limit. |
| <8> | 0 = Add 0mA of charge current limit.<br>1 = Add 256mA of charge current limit. |
| <9> | 0 = Add 0mA of charge current limit.<br>1 = Add 512mA of charge current limit. |
| <10> | 0 = Add 0mA of charge current limit.<br>1 = Add 1024mA of charge current limit. |
| <11> | 0 = Add 0mA of charge current limit.<br>1 = Add 2048mA of charge current limit. |
| <12> | 0 = Add 0mA of charge current limit.<br>1 = Add 4096mA of charge current limit. |
| <13:15> | Not used |
| Maximum | <12:2> = 10111110000 6080mA |

**TABLE 4. ChargeCurrentLimit REGISTER 0x14H (11-BIT, 8mA STEP, 5mΩ SENSE RESISTOR, x36)**

| BIT | DESCRIPTION |
|---|---|
| <1:0> | Not used |
| <2> | 0 = Add 0mA of charge current limit.<br>1 = Add 8mA of charge current limit. |
| <3> | 0 = Add 0mA of charge current limit.<br>1 = Add 16mA of charge current limit. |
| <4> | 0 = Add 0mA of charge current limit.<br>1 = Add 32mA of charge current limit. |
| <5> | 0 = Add 0mA of charge current limit.<br>1 = Add 64mA of charge current limit. |
| <6> | 0 = Add 0mA of charge current limit.<br>1 = Add 128mA of charge current limit. |
| <7> | 0 = Add 0mA of charge current limit.<br>1 = Add 256mA of charge current limit. |
| <8> | 0 = Add 0mA of charge current limit.<br>1 = Add 512mA of charge current limit. |
| <9> | 0 = Add 0mA of charge current limit.<br>1 = Add 1024mA of charge current limit. |
| <10> | 0 = Add 0mA of charge current limit.<br>1 = Add 2048mA of charge current limit. |
| <11> | 0 = Add 0mA of charge current limit.<br>1 = Add 4096mA of charge current limit. |
| <12> | 0 = Add 0mA of charge current limit.<br>1 = Add 8192mA of charge current limit. |
| <13:15> | Not used |
| Maximum | <12:2> = 10111110000 12160mA |

# Setting Adapter Current Limit

To set the adapter current limit, write a 16-bit AdapterCurrentLimit1 command (0x3FH or 0b00111111) and/or AdapterCurrentLimit2 command (0x3BH or 0b00111011) using the Write-word protocol shown in Figure 24 on page 19 and the data format shown in Table 5 on page 22 for a 20mΩ $R_{S1}$ or Table 6 on page 22 for a 10mΩ $R_{S1}$.

The ISL9238A limits the adapter current by limiting the CSIP-CSIN voltage. By using the recommended current sense resistor values, the register's LSB always translates to 4mA of adapter current. Any adapter current limit command will be accepted but only the valid register bits will be written to the AdapterCurrentLimit1 and AdapterCurrentLimit2 registers and the maximum values is clamped at 6080mA for $R_{S1}$ = 20mΩ.

After adapter POR, the AdapterCurrentLimit1 register is reset to the value programmed through the PROG pin resistor. The AdapterCurrentLimit2 register is set to its default value of 1.5A or keep the value that is written to it previously if battery is present first. The AdapterCurrentLimit1 and AdapterCurrentLimit2 registers can be read back to verify their content.

To set a second level adapter current limit, write a 16-bit AdapterCurrentLimit2 (0x3BH or 0b00111011) command using the Write-word protocol shown in Figure 24 and the data format as shown in Table 5 for a 20mΩ $R_{S1}$ or Table 6 for a 10mΩ $R_{S1}$.

The AdapterCurrentLimit2 register has the same specification as the AdapterCurrentLimit1 register. Refer to "Two-Level Adapter Current Limit" on page 36 for detailed operation.

**TABLE 5. AdapterCurrentLimit1 REGISTER 0x3FH AND AdapterCurrentLimit2 REGISTER 0x3BH (11-BIT, 4mA STEP, 20mΩ SENSE RESISTOR, x18)**

| BIT | DESCRIPTION |
|---|---|
| <1:0> | Not used |
| <2> | 0 = Add 0mA of adapter current limit.<br>1 = Add 4mA of adapter current limit. |
| <3> | 0 = Add 0mA of adapter current limit.<br>1 = Add 8mA of adapter current limit. |
| <4> | 0 = Add 0mA of adapter current limit.<br>1 = Add 16mA of adapter current limit. |
| <5> | 0 = Add 0mA of adapter current limit.<br>1 = Add 32mA of adapter current limit. |
| <6> | 0 = Add 0mA of adapter current limit.<br>1 = Add 64mA of adapter current limit. |
| <7> | 0 = Add 0mA of adapter current limit.<br>1 = Add 128mA of adapter current limit. |
| <8> | 0 = Add 0mA of adapter current limit.<br>1 = Add 256mA of adapter current limit. |
| <9> | 0 = Add 0mA of adapter current limit.<br>1 = Add 512mA of adapter current limit. |
| <10> | 0 = Add 0mA of adapter current limit.<br>1 = Add 1024mA of adapter current limit. |
| <11> | 0 = Add 0mA of adapter current limit.<br>1 = Add 2048mA of adapter current limit. |
| <12> | 0 = Add 0mA of adapter current limit.<br>1 = Add 4096mA of adapter current limit. |
| <13:15> | Not used |
| Maximum | <12:4> = 10111110000 6080mA |

**TABLE 6. AdapterCurrentLimit1 REGISTER 0x3FH AND AdapterCurrentLimit2 REGISTER 0x3BH (11-BIT, 8mA STEP, 10mΩ SENSE RESISTOR, x18)**

| BIT | DESCRIPTION |
|---|---|
| <1:0> | Not used. |
| <2> | 0 = Add 0mA of adapter current limit.<br>1 = Add 8mA of adapter current limit. |
| <3> | 0 = Add 0mA of adapter current limit.<br>1 = Add 16mA of adapter current limit. |
| <4> | 0 = Add 0mA of adapter current limit.<br>1 = Add 32mA of adapter current limit. |
| <5> | 0 = Add 0mA of adapter current limit.<br>1 = Add 64mA of adapter current limit. |
| <6> | 0 = Add 0mA of adapter current limit.<br>1 = Add 128mA of adapter current limit. |
| <7> | 0 = Add 0mA of adapter current limit.<br>1 = Add 256mA of adapter current limit. |
| <8> | 0 = Add 0mA of adapter current limit.<br>1 = Add 512mA of adapter current limit. |

**TABLE 6. AdapterCurrentLimit1 REGISTER 0x3FH AND AdapterCurrentLimit2 REGISTER 0x3BH (11-BIT, 8mA STEP, 10mΩ SENSE RESISTOR, x18) (Continued)**

| BIT | DESCRIPTION |
|---|---|
| <9> | 0 = Add 0mA of adapter current limit.<br>1 = Add 1024mA of adapter current limit. |
| <10> | 0 = Add 0mA of adapter current limit.<br>1 = Add 2048mA of adapter current limit. |
| <11> | 0 = Add 0mA of adapter current limit.<br>1 = Add 4096mA of adapter current limit. |
| <12> | 0 = Add 0mA of adapter current limit.<br>1 = Add 8192mA of adapter current limit. |
| <13:15> | Not used |
| Maximum | <12:4> = 10111110000 12160mA |

## Setting Two-Level Adapter Current Limit Duration

For a two-level adapter current limit, write a 16-bit T1 and T2 command (0x38H or 0b00111000) using the Write-word protocol shown in Figure 24 and the data format shown in Table 5 or Table 6 to set the AdapterCurrentLimit1 duration t1. Write a 16-bit T2 command (0x38H or 0b00111000) to set AdapterCurrentLimit2 duration t2. T1 and T2 register accepts any command but only the valid register bits will be written. Refer to "Two-Level Adapter Current Limit" on page 36 for detailed operation.

**TABLE 7. T1 AND T2 REGISTER 0x38H**

| BIT | DESCRIPTION |
|---|---|
| <2:0><br>T1 | 000 = 10ms (default)<br>001 = 20ms<br>010 = 15ms<br>011 = 5ms<br>100 = 1ms<br>101 = 0.5ms<br>110 = 0.1ms<br>111 = 0ms |
| <7:3> | Not used |
| <10:8><br>T2 | 000 = 10µs (default)<br>001 = 100µs<br>010 = 500µs<br>011 = 1ms<br>100 = 300µs<br>101 = 750µs<br>110 = 2ms<br>111 = 10ms |
| <15:11> | Not used |

## Setting Maximum Charging Voltage or System Regulating Voltage

To set the maximum charging voltage or the system regulating voltage, write a 16-bit MaxSystemVoltage command (0x15H or 0b00010101) using the Write-word protocol shown in Figure 24 on page 19 and the data format as shown in Table 8.

The maximum system voltage range is 8mV to 18.304V. The MaxSystemVoltage register accepts any voltage command but only the valid register bits will be written to the register and the maximum values is clamped at 18.304V. ISL9238A accepts a 0V command, but register value does not change.

The MaxSystemVoltage register sets the battery full charging voltage limit. The MaxSystemVoltage register setting also is the system bus voltage regulation point when battery is absent or battery is present but is not in Charging mode. See "System Voltage Regulation" on page 37 for details.

The VSYS pin is used to sense the battery voltage for maximum charging voltage regulation. The VSYS pin is also the system bus voltage regulation sense point.

**TABLE 8. MaxSystemVoltage REGISTER 0x15H (8mV STEP)**

| BIT | DESCRIPTION |
|---|---|
| <2:0> | Not used |
| <3> | 0 = Add 0mV of charge voltage.<br>1 = Add 8mV of charge voltage. |
| <4> | 0 = Add 0mV of charge voltage.<br>1 = Add 16mV of charge voltage. |
| <5> | 0 = Add 0mV of charge voltage.<br>1 = Add 32mV of charge voltage. |
| <6> | 0 = Add 0mV of charge voltage.<br>1 = Add 64mV of charge voltage. |
| <7> | 0 = Add 0mV of charge voltage.<br>1 = Add 128mV of charge voltage. |
| <8> | 0 = Add 0mV of charge voltage.<br>1 = Add 256mV of charge voltage. |
| <9> | 0 = Add 0mV of charge voltage.<br>1 = Add 512mV of charge voltage. |
| <10> | 0 = Add 0mV of charge voltage.<br>1 = Add 1024mV of charge voltage. |
| <11> | 0 = Add 0mV of charge voltage.<br>1 = Add 2046mV of charge voltage. |
| <12> | 0 = Add 0mV of charge voltage.<br>1 = Add 4096mV of charge voltage. |
| <13> | 0 = Add 0mV of charge voltage.<br>1 = Add 8192mV of charge voltage. |
| <14> | 0 = Add 0mV of charge voltage.<br>1 = Add 16384mV of charge voltage. |
| <15> | Not used |
| Maximum | 18304mV |

## Setting Minimum System Voltage

To set the minimum system voltage, write a 16-bit MinSystemVoltage command (0x3EH or 0b00111110) using the Write-word protocol shown in Figure 24 on page 19 and the data format as shown in Table 9.

The minimum system voltage range is 256mV to 13.824V. The MinSystemVoltage register accepts any voltage command but only the valid register bits will be written to the register. The MinSystemVoltage register value should be set lower than the MaxSystemVoltage register value and the maximum value is clamped at 13.824V.

The MinSystemVoltage register sets the battery voltage threshold for entry and exit of the Trickle Charging mode and for entry and exit of the Learn mode. The VBAT pin is used to sense the battery voltage to compare with the MinSystemVoltage register setting. Refer to "Trickle Charging" on page 37 and "Battery Learn Mode" on page 36 for details.

The MinSystemVoltage register setting also is the system voltage regulation point when it is in Trickle Charging mode. The CSON pin is the system voltage regulation sense point in Trickle Charging mode. Refer to "System Voltage Regulation" on page 37" for details.

**TABLE 9. MinSystemVoltage REGISTER 0x3EH**

| BIT | DESCRIPTION |
|---|---|
| <7:0> | Not used |
| <8> | 0 = Add 0mV of charge voltage.<br>1 = Add 256mV of charge voltage. |
| <9> | 0 = Add 0mV of charge voltage.<br>1 = Add 512mV of charge voltage. |
| <10> | 0 = Add 0mV of charge voltage.<br>1 = Add 1024mV of charge voltage. |
| <11> | 0 = Add 0mV of charge voltage.<br>1 = Add 2046mV of charge voltage. |
| <12> | 0 = Add 0mV of charge voltage.<br>1 = Add 4096mV of charge voltage. |
| <13> | 0 = Add 0mV of charge voltage.<br>1 = Add 8192mV of charge voltage. |
| <15:14> | Not used |
| Maximum | 13824mV |

## Setting PROCHOT# Threshold for Adapter Overcurrent Condition

To set the PROCHOT# assertion threshold for adapter overcurrent condition, write a 16-bit ACProchot# command (0x47H or 0b01000111) using the Write-word protocol shown in Table 24 on page 19 and the data format shown in Table 10 on page 24. By using the recommended current sense resistor values, the register's LSB always translates to 128mA of adapter current. The ACProchot# register accepts any current command but only the valid register bits will be written to the register and the maximum value is clamped at 6400mA for $R_{S1}$ = 20mΩ.

After POR, the ACProchot# register is reset to 0x0C00H. The ACProchot# register can be read back to verify its content.

If the adapter current exceeds the ACProchot# register setting, PROCHOT# signal will assert after the debounce time programmed by the Control2 register Bit<10:9> and latch on for a minimum time programmed by Control2 register Bit<8:6>.

**TABLE 10. ACProchot# REGISTER 0x47H (20mΩ SENSING RESISTOR, 128mA STEP, x18 GAIN)**

| BIT | DESCRIPTION |
|---|---|
| <6:0> | Not used |
| <7> | 0 = Add 0mA of ACProchot# threshold.<br>1 = Add 128mA of ACProchot# threshold. |
| <8> | 0 = Add 0mA of ACProchot# threshold.<br>1 = Add 256mA of ACProchot# threshold. |
| <9> | 0 = Add 0mA of ACProchot# threshold.<br>1 = Add 512mA of ACProchot# threshold. |
| <10> | 0 = Add 0mA of ACProchot# threshold.<br>1 = Add 1024mA of ACProchot# threshold. |
| <11> | 0 = Add 0mA of ACProchot# threshold.<br>1 = Add 2048mA of ACProchot# threshold. |
| <12> | 0 = Add 0mA of ACProchot# threshold.<br>1 = Add 4096mA of ACProchot# threshold. |
| <15:13> | Not used |
| Maximum | <12:7> = 110010, 6400mA |

## Setting PROCHOT# Threshold for Battery Over Discharging Current Condition

To set the PROCHOT# signal assertion threshold for battery over discharging current condition, write a 16-bit DCProchot# command (0x48H or 0b01001000) using the Write-word protocol shown in Figure 24 on page 19 and the data format shown in Table 11. By using the recommended current sense resistor values, the register's LSB always translates to 256mA of adapter current. The DCProchot# register accepts any current command but only the valid register bits will be written to the register and the maximum values is clamped at 12.8A for $R_{S2}$ = 10mΩ.

After POR, the DCProchot# register is reset to 0x1000H. The DCProchot# register can be read back to verify its content.

If the battery discharging current exceeds the DCProchot# register setting, the PROCHOT# signal will assert after the debounce time programmed by the Control2 register Bit<10:9> and latch on for a minimum time programmed by Control2 register Bit<8:6>.

In battery only and Low Power mode, the DCProchot# threshold is set by Control0 register Bit<4:3>.

In battery only mode, DCProchot# function works only when PSYS is enabled, because enabling PSYS will activate the internal comparator reference. The Information register Bit<15> indicates if the internal comparator reference is active or not. When the adapter is present, the internal comparator reference is always active.

**TABLE 11. DCPROCHOT# REGISTER 0x48H (10mΩ SENSING RESISTOR, 256mA STEP, x18 GAIN)**

| BIT | DESCRIPTION |
|---|---|
| <7:0> | Not used |
| <8> | 0 = Add 0mA of DCProchot# threshold.<br>1 = Add 256mA of DCProchot# threshold. |
| <9> | 0 = Add 0mA of DCProchot# threshold.<br>1 = Add 512mA of DCProchot# threshold. |
| <10> | 0 = Add 0mA of DCProchot# threshold.<br>1 = Add 1024mA of DCProchot# threshold. |
| <11> | 0 = Add 0mA of DCProchot# threshold.<br>1 = Add 2048mA of DCProchot# threshold. |
| <12> | 0 = Add 0mA of DCProchot# threshold.<br>1 = Add 4096mA of DCProchot# threshold. |
| <13> | 0 = Add 0mA of DCProchot# threshold.<br>1 = Add 8192mA of DCProchot# threshold. |
| <15:14> | Not used. |
| Maximum | <13:8> = 110010, 12800mA |

## Setting PROCHOT# Debounce Time and Duration Time

The Control2 register Bit<10:9> configures the PROCHOT# signal debounce time before its assertion for ACProchot# and DCProchot#. The low system voltage Prochot# has a fixed debounce time of 10µs.

The Control2 register Bit<8:6> configures the minimum duration of Prochot# signal when asserted.

## Control Registers

The Control0, Control1, Control2, Control3, and Control4 registers configure the operation of the ISL9238A. To change certain functions or options after POR, write an 8-bit control command to Control0 register (0x39H or 0b00111001) or a 16-bit control command to Control1 register (0x3CH or 0b00111100) or Control2 register (0x3DH or 0b00111101) or Control3 register (0x4CH or 0b00111100) or Control4 register (0x4EH or 0b00111101) using the Write-word protocol shown in Figure 24 on page 19 and the data format shown in Tables 12, 13, 14, and 15 on page 16, respectively.

**TABLE 12. CONTROL0 REGISTER 0x39H**

<table>
<tr><th>BIT</th><th>BIT NAME</th><th>DESCRIPTION</th></tr>
<tr><td><15:13></td><td>Forward Buck and Buck-Boost Phase Comparator Threshold Offset</td><td>Bit<15:13> adjusts phase comparator threshold offset for forward buck and buck-boost<br>000 = 0mV<br>001 = 0.5mV<br>010 = 1mV<br>011 = 1.5mV<br>100 = -2mV<br>101 = -1.5mV<br>110 = -1mV<br>111 = -0.5mV</td></tr>
<tr><td><12:10></td><td>Forward and Reverse Boost Phase Comparator Threshold Offset</td><td>Bit<12:10> adjusts phase comparator threshold offset for forward and reverse boost<br>000 = 0mV<br>001 = 0.5mV<br>010 = 1mV<br>011 = 1.5mV<br>100 = -2mV<br>101 = -1.5mV<br>110 = -1mV<br>111 = -0.5mV</td></tr>
<tr><td><9:8></td><td>Reverse Buck and Buck-Boost Phase Comparator Threshold Offset</td><td>Bit<9:8> adjusts phase comparator threshold offset for forward and reverse boost<br>00 = 0mV<br>01 = 1mV<br>10 = -2mV<br>11 = -1mV</td></tr>
<tr><td><7></td><td>SMBus Timeout</td><td>The ISL9238A includes a timer to insure the SMBus master is active and to prevent overcharging the battery. If the adapter is present and if the ISL9238A does not receive a write to the MaxChargeVoltage or ChargeCurrentLimit register within 175s, ISL9238A will terminate charging. If a timeout occurs, writing the MaxChargeVoltage or ChargeCurrentLimit register will re-enable charging.<br>0 = Enable the SMBus timeout function<br>1 = Disable the SMBus timeout function</td></tr>
<tr><td><6:5></td><td>High-Side FET Short Detection Threshold</td><td>Bit<6:5> configures the high-side FET short detection PHASE node voltage threshold during low-side FET turning on.<br>00 = 400mV (default)<br>01 = 500mV<br>10 = 600mV<br>11 = 800mV</td></tr>
<tr><td><4:3></td><td>DCProchot# Threshold in Battery Only Low Power Mode</td><td>Bit<4:3> only configures the battery discharging current DCProchot# threshold in battery only Low Power mode indicated by the Information1 register 0x3A Bit<15>. If PSYS is enabled, battery discharge current DCProchot# threshold is set by the DCProchot# register 0x48 setting.
<table>
<tr><th>Bit<4:3></th><th>$R_{S2}$ = 10mΩ (A)</th><th>$R_{S2}$ = 20mΩ (A)</th><th>$R_{S2}$ = 5mΩ (A)</th></tr>
<tr><td>00</td><td>12 (Default)</td><td>6</td><td>24</td></tr>
<tr><td>01</td><td>10</td><td>5</td><td>20</td></tr>
<tr><td>10</td><td>8</td><td>4</td><td>16</td></tr>
<tr><td>11</td><td>6</td><td>3</td><td>12</td></tr>
</table></td></tr>
<tr><td><2></td><td>Input Voltage Regulation Loop</td><td>Bit<2> disables or enables the input voltage regulation loop.<br>0 = Enable (default)<br>1 = Disable</td></tr>
<tr><td><1:0></td><td></td><td>Not used</td></tr>
</table>

**TABLE 13. CONTROL1 REGISTER 0x3CH**

| BIT | BIT NAME | DESCRIPTION |
|---|---|---|
| <15:14> | General Purpose Comparator Assertion Debounce Time | Bit<15:14> configures the general purpose comparator assertion debounce time.<br>00 = 2µs (default)<br>01 = 12µs<br>10 = 2ms<br>11 = 5s |
| 13 | Exit Learn Mode Option | Bit<13> provides the option to Exit Learn mode when battery voltage is lower than MinSystemVoltage register setting.<br>0 = Stay in Learn mode even if $V_{BAT}$ < MinSystemVoltage register setting (default)<br>1 = Exit Learn mode if $V_{BAT}$ < MinSystemVoltage register setting |
| 12 | Learn Mode | Bit<12> enables or disables the Battery Learn mode.<br>0 = Disable (default)<br>1 = Enable<br>To enter Learn mode, BATGONE pin needs to be low, i.e., battery must be present. |
| 11 | OTG Function | Bit<11> enables or disables OTG function.<br>0 = Disable (default)<br>1 = Enable |
| 10 | Audio Filter | Bit<10> enables or disables the audio filter function.<br>0 = Disable (default)<br>1 = Enable |
| <9:8> | Switching Frequency | Bit<9:8> configures the switching frequency and overrides the switching frequency set by PROG pin.<br>00 = Switching frequency set by PROG pin (default)<br>01 = 839kHz<br>10 = 723kHz<br>11 = 635kHz<br>To keep the switching frequency set by PROG pin resistor, leave Bit<9:8> as it is or write code 00, which sets the same frequency as the PROG pin resistor does. |
| 7 | | Not used, When writing, write 0 |
| 6 | Turbo | Bit<6> enables or disables Turbo mode. When the turbo function is enabled, BGATE FET turns on in Turbo mode. Refer to Table 24 on page 36 for BGATE ON/OFF truth table.<br>0 = Enable (default)<br>1 = Disable |
| 5 | AMON/BMON Function | Bit<5> enables or disables the current monitor function AMON and BMON.<br>0 = Enable AMON/BMON (default)<br>1 = Disable AMON/BMON<br>Bit<5> is only valid in battery only mode. When adapter is present, AMON/BMON is automatically enabled and Bit<5> becomes invalid. |
| 4 | AMON or BMON | Bit<4> selects AMON or BMON as the output of AMON/BMON pin.<br>0 = AMON (default)<br>1 = BMON |
| 3 | PSYS | Bit<3> enables or disable system power monitor PSYS function.<br>0 = Disable (default)<br>1 = Enable |
| 2 | VSYS | Bit<2> enables or disables the buck-boost charger switching VSYS output. When disabled, ISL9238A stops switching and forces BGATE FET on.<br>0 = Enable (default)<br>1 = Disable |
| <1:0> | Low_VSYS_Prochot# Reference | Bit<1:0> configures the Low_VSYS_Prochot# assertion threshold.<br>00 = 6.0V (default)<br>01 = 6.3V<br>10 = 6.6V<br>11 = 6.9V<br>For 1-cell configuration, the Low_VSYS_Prochot# assertion threshold is fixed 2.4V. |

**TABLE 14. CONTROL2 REGISTER 0x3DH**

| BIT | BIT NAME | DESCRIPTION |
|---|---|---|
| <15:14> | Trickle Charging Current | Bit<15:14> configures the charging current in Trickle Charging mode.<br>00 = 256mA (default)<br>01 = 128mA<br>10 = 64mA<br>11 = 512mA |
| 13 | OTG Function Enable Debounce Time | Bit<13> configures the OTG function debounce time from when the ISL9238A receives the OTG enable command.<br>0 = 1.3s (default)<br>1 = 150ms |
| 12 | Two-Level Adapter Current Limit Function | Bit<12> enables or disables the two-level adapter current limit function.<br>0 = Disable (default)<br>1 = Enable |
| 11 | Adapter Insertion to Switching Debounce | Bit<11> configures the debounce time from adapter insertion to ACOK asserted high.<br>0 = 1.3s (default)<br>1 = 150ms<br><br>After VDD POR, for the first time adapter plugged in, the ASGATE turn-on delay is always 150ms, regardless of the Bit<11> setting. This bit only sets the ASGATE turn-on delay after ASGATE turns off at least one-time when VDD is above it POR value and Bit<11> default is 0 for 1.3s. |
| <10:9> | Prochot# Debounce | Bit<10:9> configures the Prochot# debounce time before its assertion for ACProchot# and DCProchot#.<br>00: 7µs (default)<br>01: 100µs<br>10: 500µs<br>11: 1ms<br>The Low_VSYS_Prochot# has fixed 10µs debounce time. |
| <8:6> | Prochot# Duration | Bit<8:6> configures the minimum duration of Prochot# signal when asserted.<br>000 = 10ms (default)<br>001 = 20ms<br>010 = 15ms<br>011 = 5ms<br>100 = 1ms<br>101 = 500µs<br>110 = 100µs<br>111 = 0s |
| 5 | ASGATE in OTG Mode | Bit<5> turns on or off the ASGATE FET in OTG mode.<br>0 = Turn ON ASGATE in OTG mode (default)<br>1 = Turn OFF ASGATE in OTG mode |
| 4 | CMIN Reference | Bit<4> configures the general purpose comparator reference voltage.<br>0 = 1.2V (default)<br>1 = 2V |
| 3 | General Purpose Comparator | Bit<3> enables or disabled the general purpose comparator.<br>0 = Enable (default)<br>1 = Disable |
| 2 | CMOUT Polarity | Bit<2> configures the general purpose comparator output polarity when asserted. The comparator reference voltage is connected at the inverting input node.<br>0 = CMOUT is High when CMIN is higher than reference (default)<br>1 = CMOUT is Low when CMIN is higher than reference |
| 1 | WOCP Function | Bit<1> enables or disables the WOC (Way Overcurrent) fault protection function.<br>0 = Enable WOCP (default)<br>1 = Disable WOCP |
| 0 | Battery OVP Function | Bit<0> enables or disables the Battery OV (Overvoltage) fault protection function.<br>0 = Disable Battery OVP (default)<br>1 = Enable Battery OVP |

TABLE 15. CONTROL3 REGISTER 0x4CH

| BIT | BIT NAME | DESCRIPTION |
|---|---|---|
| 15 | Reread PROG Pin Resistor | Bit<15> reread PROG pin resistor or not.<br>0 = Reread PROG pin resistor<br>1 = Do not reread PROG pin resistor |
| 14 | Reload ACLIM When Adapter Is Plugged In | Bit<14> reload AdapterCurrentLimit1 register set by PROG pin resistor.<br>0 = Reload AdapterCurrentLimit1 register<br>1 = Do not reload |
| 13 | Autonomous Charging Termination Time | Bit<13> configures autonomous charging termination time.<br>0 = 20ms<br>1 = 200ms |
| <12:11> | Charger Timeout | Bit<12:11> configures SMBus charger timeout time.<br>00 = 175s (default)<br>01 = 87.5s<br>10 = 43.75s<br>11 = 5s |
| 10 | BGATE OFF | Bit<10> enables or disables Battery Ship mode.<br>0 = Idle<br>1 = Force BGATE MOSFET OFF (enable Battery Ship mode) |
| 9 | PSYS Gain | Bit<9> configures the system power monitor PSYS output gain.<br>0 = 1.44µA/W (default)<br>1 = 0.723µA/W |
| 8 | Exit IDM Timer | Bit<8> configures Ideal Diode mode exit timer when battery discharge current is less than 300mA.<br>0 = 40ms (default)<br>1 = 80ms |
| 7 | Autonomous Charging Mode | Bit<7> enables Autonomous Charging mode.<br>0 = Enable Autonomous Charging mode<br>1 = Battery charging current control through SMBus |
| 6 | AC and CC Feedback Gain | Bit<6> configures AC and CC feedback gain for high current.<br>0 = Idle<br>1 = x0.5 |
| 5 | Input Current Limit Loop | Bit<5> disables input current limit loop.<br>0 = Enable input current limit loop<br>1 = Disable input current limit loop |
| 4 | Input Current Limit Loop when BATGONE = 1 | Bit<4> disables input current limit loop when BATGONE = 1.<br>0 = Enable ACLIM when BATGONE = 1<br>1 = Disable ACLIM when BATGONE = 1 |
| 3 | AMON/BMON Direction | Bit<3> configures AMON/BMON direction.<br>0 = Adapter current monitor/battery charging current monitor<br>1 = OTG output current monitor/battery discharging current monitor |
| 2 | Digital Reset | Bit<2> reset all SMBus register value to POR default value.<br>0 = Idle<br>1 = Reset |
| 1 | Buck-Boost Switching Period | Bit<1> configures switching period in Buck-Boost mode<br>0 = x1<br>1 = x2 (half switching frequency) |
| 0 | OTG Start-Up Delay | Bit<0> shorts OTG start-up time<br>0 = Idle<br>1 = Short OTG start-up time from 150ms to 1ms when Control2 register Bit<13> = 1 for 150ms |

TABLE 16. CONTROL4 REGISTER 0x4EH

| BIT | BIT NAME | DESCRIPTION |
|---|---|---|
| <15:8> | | Not used |
| 7 | OTGCURRENT PROCHOT# | Bit<6> enables or disables trigger PROCHOT# with OTGCURRENT.<br>0 = Disable<br>1 = Enable |
| 6 | BATGONE PROCHOT# | Bit<6> enables or disables trigger PROCHOT# with BATGONE.<br>0 = Disable<br>1 = Enable |
| 5 | ACOK PROCHOT# | Bit<6> enables or disables trigger PROCHOT# with ACOK.<br>0 = Disable<br>1 = Enable |
| 4 | Comparator PROCHOT# | Bit<6> enables or disables trigger PROCHOT# with General Purpose Comparator rising.<br>0 = Disable<br>1 = Enable |
| <3:2> | ACOK falling or BATGONE Rising Debounce | Bit<3:2> configures debounce time from ACOK falling or BATGONE rising to PROCHOT# trip.<br>00 = 2µs<br>01 = 25µs<br>10 = 125µs<br>11 = 250µs |
| 1 | PROCHOT# Clear | Bit<1> clear PROCHOT#.<br>0 = Idle<br>1 = Clear PROCHOT# |
| 0 | PROCHOT# Latch | Bit<0> manually reset PROCHOT#.<br>0 = PROCHOT# signal auto-clear<br>1 = Hold PROCHOT# low when tripped |

## OTG Voltage Register

The OTG voltage register contains SMBus readable and writable OTG mode output regulation voltage reference. The default is 5.004V. This register accepts any voltage command but only the valid register bits will be written to the register and the maximum value is clamped at 27.456V.

TABLE 17. OTGVOLTAGE REGISTER 0x49H

| BIT | DESCRIPTION |
|---|---|
| <2:0> | Not used |
| <3> | 0 = Add 0mV of OTG voltage<br>1 = Add 12mV of OTG voltage |
| <4> | 0 = Add 0mV of OTG voltage<br>1 = Add 24mV of OTG voltage |
| <5> | 0 = Add 0mV of OTG voltage<br>1 = Add 48mV of OTG voltage |
| <6> | 0 = Add 0mV of OTG voltage<br>1 = Add 96mV of OTG voltage |
| <7> | 0 = Add 0mV of OTG voltage<br>1 = Add 192mV of OTG voltage |
| <8> | 0 = Add 0mV of OTG voltage<br>1 = Add 384mV of OTG voltage |
| <9> | 0 = Add 0mV of OTG voltage<br>1 = Add 768mV of OTG voltage |
| <10> | 0 = Add 0mV of OTG voltage<br>1 = Add 1536mV of OTG voltage |
| <11> | 0 = Add 0mV of OTG voltage<br>1 = Add 3072mV of OTG voltage |
| <12> | 0 = Add 0mV of OTG voltage<br>1 = Add 6144mV of OTG voltage |
| <13> | 0 = Add 0mV of OTG voltage<br>1 = Add 12288mV of OTG voltage |
| <14> | 0 = Add 0mV of OTG voltage<br>1 = Add 24576mV of OTG voltage |
| <15> | Not used |
| Maximum | 27456mV |

## OTG Current Register

The OTG current register contains SMBus readable and writable OTG current limit. The default is 512mA. This register accepts any current command but only the valid register bits will be written to the register and the maximum values is clamped at 4096mA for $R_{S1}$ = 20mΩ.

TABLE 18. OTGCURRENT 0x4AH

| BIT | DESCRIPTION |
|---|---|
| <6:0> | Not used |
| <7> | 0 = Add 0mA of OTG current<br>1 = Add 128mA of OTG current |
| <8> | 0 = Add 0mA of OTG current<br>1 = Add 256mA of OTG current |
| <9> | 0 = Add 0mV of OTG current<br>1 = Add 512mA of OTG current |
| <10> | 0 = Add 0mV of OTG current<br>1 = Add 1024mA of OTG current |
| <11> | 0 = Add 0mV of OTG current<br>1 = Add 2048mA of OTG current |
| <12> | 0 = Add 0mV of OTG current<br>1 = Add 4096mA of OTG current |
| <15:13> | Not used |
| Maximum | 4096mA |

## Input Voltage Register

The input voltage register contains SMBus readable and writable input voltage limit. The default is 4.096V. This register accepts any current command but only the valid register bits will be written to the register and the maximum values is clamped at 18.432V.

TABLE 19. INPUT VOLTAGE REGISTER 0x4BH

| BIT | DESCRIPTION |
|---|---|
| <7:0> | Not used |
| <8> | 0 = Add 0mV of Input voltage<br>1 = Add 341.3mV of Input voltage |
| <9> | 0 = Add 0mA of Input voltage<br>1 = Add 682.6mV of Input voltage |
| <10> | 0 = Add 0mV of Input voltage<br>1 = Add 1365.3mV of Input voltage |
| <11> | 0 = Add 0mV of Input voltage<br>1 = Add 2730.6mV of Input voltage |
| <12> | 0 = Add 0mV of Input voltage<br>1 = Add 5461.3mV of Input voltage |
| <13> | 0 = Add 0mV of Input voltage<br>1 = Add 10922.6mV of Input voltage |
| <15:14> | Not used |
| Maximum | 18432mV |

## Information Register

The information register contains SMBus readable information about manufacturing and Operating modes. Table 21 identifies the bit locations of the information available.

TABLE 20. INFORMATION1 REGISTER 0x3AH

| BIT | DESCRIPTION |
|---|---|
| <3:0> | Not used |
| <4> | Bit<4> indicates if the Trickle Charging mode is active or not.<br>0 = Trickle Charging mode is not active<br>1 = Trickle Charging mode is active |
| <9:5> | Not used |
| <10> | Bit<10> indicates if the Low_VSYS_Prochot# is tripped or not.<br>0 = Low_VSYS Prochot# is not tripped<br>1 = Low_VSYS Prochot# is tripped |
| <11> | Bit<11> indicates if DCProchot# is tripped or not.<br>0 = DCProchot# is not tripped<br>1 = DCProchot# is tripped |
| <12> | Bit<12> indicates if ACProchot#/OTGCURRENTProchot# is tripped or not.<br>0 = ACProchot#/OTGCURRENTProchot# is not tripped<br>1 = ACProchot#/OTGCURRENTProchot# is tripped |
| <14:13> | Bit<14:13> indicates the active control loop.<br>00 = MaxSystemVoltage control loop is active<br>01 = Charging current loop is active<br>10 = Adapter current limit loop is active<br>11 = Input voltage loop is active |
| <15> | Bit<15> indicates if the internal reference circuit is active or not. Bit<15> = 0 indicates that ISL9238A is in Low Power mode.<br>0 = Reference is not active<br>1 = Reference is active |

TABLE 21. INFORMATION2 REGISTER 0x4DH

| BIT | DESCRIPTION |
|---|---|
| <4:0> | Program Resister read out.<br># of battery cell<br>Switching Frequency<br>Adapter current Limit |
| <7:5> | Bit<7:5> indicates the ISL9238A is in operation mode.<br>001 = Boost Mode<br>010 = Buck Mode<br>011 = Buck-Boost Mode<br>101 = OTG Boost Mode<br>110 = OTG Buck Mode<br>111 = OTG Buck-Boost Mode |
| <11:8> | Bit<11:8> indicates the ISL9238A state machine status<br>0000 = OFF<br>0001 = BATTERY<br>0010 = ADAPTER<br>0011 = ACOK<br>0100 = VSYS<br>0101 = CHARGE<br>0110 = ENOTG<br>0111 = OTG<br>1000 = ENLDO5<br>1001 = Not Applicable<br>1010 = TRIM/ENCHREF<br>1011 = ACHRG<br>1100 = CAL<br>1101 = AGON/AGONTG<br>1110 = WAIT/PSYS<br>1111 = ADPPSYS |
| <12> | Bit<10> indicates BATGONE pin status<br>0 = Battery is present<br>1 = No battery |
| <13> | Bit<11> indicates if the general purpose comparator output after debounce time<br>0 = Comparator output is low<br>1 = Comparator output is high |
| <14> | Bit<12> indicates the ACOK pin status<br>0 = No adapter<br>1 = Adapter is present |
| <15> | Not used |

# Application Information

## R3 Modulator

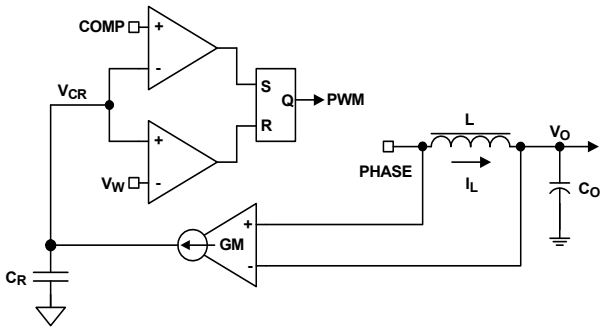



FIGURE 25. R3 MODULATOR

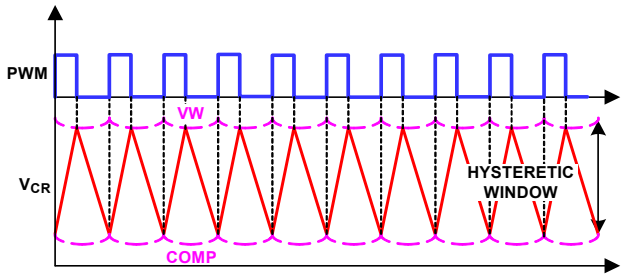



FIGURE 26. R3 MODULATOR OPERATION PRINCIPLES IN STEADY STATE

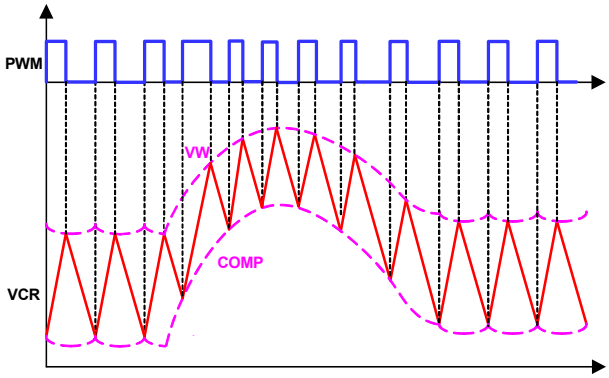



FIGURE 27. R3 MODULATOR OPERATION PRINCIPLES IN DYNAMIC RESPONSE

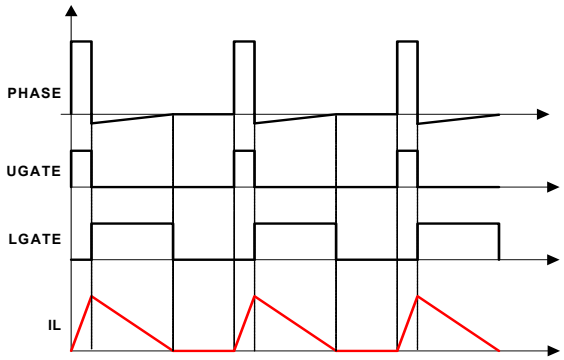



FIGURE 28. DIODE EMULATION

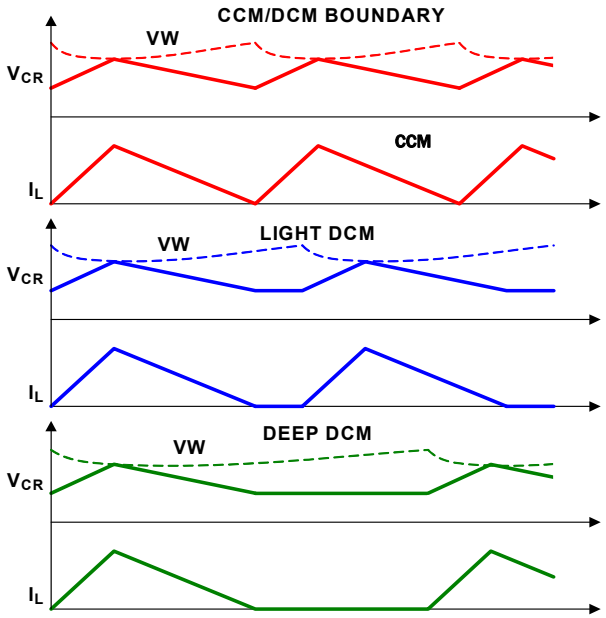



FIGURE 29. PERIOD STRETCHING

The ISL9238A uses the Intersil patented R3 (Robust Ripple Regulator) modulation scheme. The R3 modulator combines the best features of fixed frequency PWM and hysteretic PWM while eliminating many of their shortcomings. Figure 25 conceptually shows the R3 modulator circuit and Figure 26 shows the operation principles in steady state.

There is a fixed voltage window between VW and COMP. This voltage window is called the VW window in the following discussion. The modulator charges the ripple capacitor $C_R$ with a current source equal to $g_m(V_{IN}-V_O)$ during PWM on-time and discharges the ripple capacitor $C_R$ with a current source equal to $g_mV_O$, during PWM off-time, where $g_m$ is a gain factor. The $C_r$ voltage $V_{CR}$ therefore emulates the inductor current waveform. The modulator turns off the PWM pulse when $V_{CR}$ reaches VW and turns on the PWM pulse when it reaches COMP.

Because the modulator works with $V_{cr}$, which is large amplitude and noise free synthesized signal, it achieves lower phase jitter than conventional hysteretic mode modulator.

Figure 27 shows the operation principles during dynamic response. The COMP voltage rises during dynamic response, turning on PWM pulses earlier and more frequently temporarily, which allows for higher control loop bandwidth than conventional fixed frequency PWM modulator at the same steady state switching frequency.

The R3 modulator can operate in Diode Emulation (DE) mode to increase light-load efficiency. In DE mode the low-side MOSFET conducts when the current is flowing from source-to-drain and does not allow reverse current, emulating a diode. As shown in Figure 28, when LGATE is on, the low-side MOSFET carries current, creating negative voltage on the phase node due to the voltage drop across the ON-resistance. The IC monitors the current by monitoring the phase node voltage. It turns off LGATE when the phase node voltage reaches zero to prevent the inductor current from reversing the direction and creating unnecessary power loss.

If the load current is light enough, as Figure 28 on page 32 shows, the inductor current will reach and stay at zero before the next phase node pulse and the regulator is in Discontinuous Conduction Mode (DCM). If the load current is heavy enough, the inductor current will never reach 0A and the regulator is in CCM although the controller is in DE mode.

Figure 29 on page 32 shows the operation principle in Diode Emulation mode at light load. The load gets incrementally lighter in the three cases from top to bottom. The PWM on-time is determined by the VW window size, therefore is the same, making the inductor current triangle the same in the three cases. The R3 modulator clamps the ripple capacitor voltage $V_{CR}$ in DE mode to make it mimic the inductor current. It takes the COMP voltage longer to hit $V_{CR}$, naturally stretching the switching period. The inductor current triangles move further apart from each other, such that the inductor current average value is equal to the load current. The reduced switching frequency helps increase light-load efficiency.

## ISL9238A Buck-Boost Charger with USB OTG

The ISL9238A buck-boost charger drives an external N-channel MOSFET bridge comprised of two transistor pairs as shown in Figure 30. The first pair, Q1 and Q2, is a buck arrangement with the transistor center tap connected to an inductor “input” as is the case with a buck converter. The second transistor pair, Q3 and Q4, is a boost arrangement with the transistor center tap connected to the same inductor’s “output” as is the case with a boost converter. This arrangement supports bucking from a voltage input higher than the battery and also boosting from a voltage input lower than the battery.

In Buck mode, Q1 and Q2 turn on and off alternatively, while Q3 remains off and Q4 remains on.

In Boost mode, Q3 and Q4 turn on and off alternatively, while Q1 remains on and Q2 remains off.

In Buck-Boost mode, Q1 and Q3 turn on at the same time, Q3 turns off and Q4 turns on, Q1 turns off and Q2 turns on and after Q2 and Q4 turn off at the same time and Q1 and Q3 turn on again.

In OTG Buck mode, Q3 and Q4 turn on and off alternatively, while Q2 remains off and Q1 remains on.

In OTG Boost mode, Q1 and Q2 turn on and off alternatively, while Q4 remains on and Q3 remains off.

In OTG Buck-Boost mode, Q4 and Q2 turn on at the same time, Q2 turns off and Q1 turns on, Q4 turns off and Q3 turns on and after Q3 and Q1 turn off at the same time and Q4 and Q2 turn on again.

In OTG mode the output sensing point is the CSIP pin.

**TABLE 22. OPERATION MODE**

| MODE | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| Buck | Control FET | Sync. FET | OFF | ON |
| Boost | ON | OFF | Control FET | Sync. FET |
| Buck-Boost | Control FET | Sync. FET | Control FET | Sync. FET |
| OTG Buck | ON | OFF | Sync. FET | Control FET |
| OTG Boost | Sync. FET | Control FET | OFF | ON |
| OTG Buck-Boost | Sync. FET | Control FET | Sync. FET | Control FET |

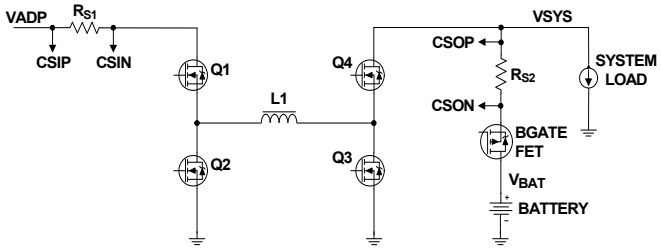



**FIGURE 30. BUCK-BOOST CHARGER TOPOLOGY**

The ISL9238A optimizes the Operation mode transition algorithm by considering the input and output voltage ratio and the load condition. When adapter voltage $V_{ADP}$ is rising and is higher than 94% of the system bus voltage VSYS, the ISL9238A will transit from Boost mode to Buck-Boost mode; if $V_{ADP}$ is higher than 120% of VSYS, the ISL9238A will forcedly transit from Buck-Boost mode to Buck mode at any circumstance. At heavier load, the mode transition point changes accordingly to accommodate the duty cycle change due to the power loss on the charger circuit.

When the adapter voltage $V_{ADP}$ is falling and is lower than 106% the system bus voltage VSYS, ISL9238A will transit from Buck mode to Buck-Boost mode; if $V_{ADP}$ is lower than 80% of VSYS, ISL9238A will transit from Buck-Boost mode to Boost mode.

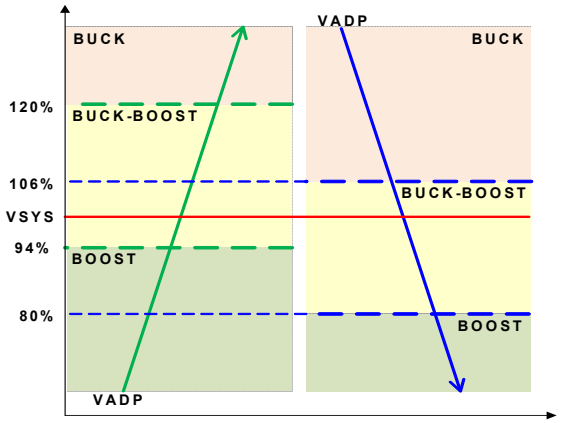



**FIGURE 31. OPERATION MODE**

When the OTG function is enabled with the SMBus command and OTGEN pin, and if battery voltage $V_{BAT}$ is higher than 5.2V, ISL9238A operates in the OTG mode, there is one digital bit to control ASGATE. OTG mode is not available for 1-cell battery systems.

The ISL9238A connects the system voltage rail to either the output of the buck-boost switcher or the battery. In Turbo event, the ISL9238A will turn on the BGATE FET to discharge the battery so the battery works with the adapter together to supply the system power.

## Soft-Start

The ISL9238A includes a low power LDO with nominal 5V output, which input is OR-ed from VBAT and ADP pins. The ISL9238A also includes a high power LDO with nominal 5V output, which input is from DCIN pin connected to the adapter and the system bus through an external OR-ing diode circuit. Both LDO outputs are tied to the VDD pin to provide the bias power and gate drive power for the ISL9238A. VDDP pin is the ISL9238A gate drive power supply input. Use an R-C filter to generate the VDDP pin voltage from the VDD pin voltage.

When $V_{DD}$ >2.7V, the ISL9238A digital block is activated and the SMBus register is ready to communicate with the master controller.

When VADP >3.2V, after 1.3s or 150ms debounce time set by Control2 register Bit<11> (after VDD POR, for the first time adapter plugged in, the ASGATE turn on delay is always 150ms), ASGATE starts turning on with 10µA sink current. During the 1.3s or 150ms debounce time, ISL9238A uses Intersil's patented technique to check if the input bus is short or not; if CSIP <2V or ACIN <0.8V, ASGATE will not turn on. The soft-start scheme will carefully bias up the input capacitors and protect the back-to-back ASGATE FETs against potential damage caused by the inrush current.

Use a voltage divider from the adapter voltage to set the ACIN pin voltage. The ISL9238A monitors the ACIN pin voltage to determine the presence of the adapter. When $V_{DD}$ >3.8V, the ACIN pin voltage exceeds 0.8V and ASGATE is fully turned on, the ISL9238A will allow the external circuit to pull up the ACOK pin. When ACOK is asserted, the ISL9238A will start switching.

The ACOK is an open-drain output pin indicating the presence of the adapter and readiness of the adapter to supply power to the system bus. The ISL9238A actively pulls ACOK low in the absence of the adapter.

Before ASGATE turns ON, the ISL9238A will source 10µA of current out of the PROG pin and read the pin voltage to determine the PROG resistor value. The PROG resistor programs the configurations of the ISL9238A.

In Battery Only mode, the ISL9238A enters Low Power mode if only battery is present. VDD is 5V from the low power LDO to minimize the power consumption. $V_{DD}$ becomes 5V when it exits the Low Power mode, such as when PSYS is enabled.

## Programming Charger Option

The resistor from the PROG pin to GND programs the configuration of the ISL9238A for the default number of battery cells in series, the default switching frequency, the default AdapterCurrentLimit1 register value and autonomous charging function. AdapterCurrentLimit2 register default value is 1.5A. Table 23 shows the programming options.

**TABLE 23. PROG PIN PROGRAMMING OPTIONS**

| PROG-GND RESISTANCE (kΩ) | | | CELL # | DEFAULT SWITCHING FREQUENCY | AUTONOMOUS CHARGING | DEFAULT ACLimit1 Reg(A) |
|---|---|---|---|---|---|---|
| MIN | TYP 1% | MAX | | | | |
| | 0 | | 1 | 733kHz | No | 0.476 |
| 8.3 | 8.45 | 8.6 | | 733kHz | No | 1.5 |
| 14.5 | 14.7 | 14.9 | | 1MHz | No | 1.5 |
| 20.7 | 21.0 | 21.3 | | 1MHz | No | 0.476 |
| 27.7 | 28.0 | 28.3 | | 733kHz | Yes | 0.476 |
| 35.3 | 35.7 | 36.1 | | 733kHz | Yes | 1.5 |
| 42.7 | 43.2 | 43.7 | 2 | 733kHz | Yes | 1.5 |
| 51.7 | 52.3 | 52.9 | | 733kHz | Yes | 0.476 |
| 61.2 | 61.9 | 62.6 | | 1MHz | No | 0.476 |
| 70.6 | 71.5 | 72.4 | | 1MHz | No | 1.5 |
| 81.5 | 82.5 | 83.5 | | 733kHz | No | 1.5 |
| 92.0 | 93.1 | 94.2 | | 733kHz | No | 0.476 |
| 104 | 105 | 106 | 3 | 733kHz | No | 0.476 |
| 116 | 118 | 120 | | 733kHz | No | 1.5 |
| 131 | 133 | 135 | | 1MHz | No | 1.5 |
| 145 | 147 | 149 | | 1MHz | No | 0.476 |
| 160 | 162 | 164 | | 733kHz | Yes | 0.476 |
| 176 | 178 | 180 | | 733kHz | Yes | 1.5 |
| 194 | 196 | 198 | 4 | 733kHz | Yes | 1.5 |
| 212 | 215 | 218 | | 733kHz | Yes | 0.476 |
| 234 | 237 | 240 | | 1MHz | No | 0.476 |
| 258 | 261 | 264 | | 1MHz | No | 1.5 |
| 284 | 287 | 290 | | 733kHz | No | 1.5 |
| 312 | 316 | 320 | | 733kHz | No | 0.476 |
| 344 | 348 | 352 | 1 | 733kHz | No | 0.476 |

The ISL9238A will use the default number of cells in series as Table 23 shows and set the default MaxSystemVoltage register value and default MinSystemVoltage register value accordingly.

The switching frequency can be changed through SMBus Control1 register Bit<9:8> after POR. Refer to SMBus Control1 register programming table on page 26 for detailed description.

Before ASGATE turns on, ISL9238A will source 10µA current out of the PROG pin and read the PROG pin voltage to determine the resistor value. However, application environmental noise may pollute the PROG pin voltage and cause incorrect reading. If noise is a concern, it is recommended to connect a capacitor from the PROG pin to GND to provide filtering. The resistor and the capacitor

RC time constant should be less than 40µs so the PROG pin voltage can rise to steady state before the ISL9238A reads it.

If ISL9238A is powered up from the battery, it will not read PROG resistor unless PSYS is enabled through SMBus Control1 register Bit<3>. In Battery Only mode, whenever PSYS is enabled, the ISL9238A will read PROG pin resistor and reset the configuration to the default.

Whenever the adapter is plugged in, ISL9238A will reset the AdapterCurrentLimit1 register to the default by reading the PROG pin resistor if it is not read before or by loading the previous reading result.

If PSYS is not enabled, ISL9238A will reset MaxSystemVoltage register and MinSystemVoltage register to their default values according to the PROG pin cell number setting. If PSYS is enabled, ISL9238A will keep the values in these two registers.

By default, the adapter current sensing resistor $R_{S1}$ is 20mΩ and battery current sensing resistor $R_{S2}$ is 10mΩ. Using this $R_{S1}$ = 20mΩ and $R_{S2}$ = 10mΩ option would result in 4mA/LSB correlation in the SMBus current commands.

If $R_{S1}$ and $R_{S2}$ values are different from this $R_{S1}$ = 20mΩ and $R_{S2}$ = 10mΩ option, the SMBus command needs to be scaled accordingly to obtain the correct current. Smaller current sense resistor values reduce the power loss while larger current sense resistor values give better accuracy.

If different current sensing resistors are used, the $R_{S1}$:$R_{S2}$ ratio should be kept as 2:1, then PSYS output can be scaled accordingly to reflect the total system power correctly.

The illustration in this datasheet is based on current sensing resistors $R_{S1}$ = 20mΩ and $R_{S2}$ = 10mΩ unless specified otherwise.

## Autonomous Charging Mode

The ISL9238A supports Autonomous Charging mode. This mode can be enabled/disabled through programming charging option resistor or SMBus Control3 register Bit<7>. When the Autonomous Charging mode is enabled, this mode can be also disabled by writing SMBus ChargingCurrentLimit or MaxSystemVoltage command.

The ISL9238A enters to the Autonomous Charging mode when the battery voltage is lower than MaxSystemVoltage -200mV per cell for 1ms debounce time and BGATE MOSFET is on.

In the Autonomous Charging mode, the ISL9238A starts to charge the battery with 2A (with $R_{S2}$ = 10mΩ), PROCHOT# pin (Autonomous Charging mode indication pin) is pulled down to GND and 175s charging timeout timer is disabled. The ISL9238A exits from Autonomous Charging mode when the battery charging current is less than 200mA (with $R_{S2}$ = 10mΩ) for 20ms or 200ms in CV loop. This autonomous charging termination time can be set by Control3 register Bit<13>. The ISL9238A re-enters Autonomous Charging mode when the battery voltage is discharged below MaxSystemVoltage - 200mV per cell. When ISL9238A stays in Autonomous Charging mode for 12hrs, which means the battery charging current is higher than 200mA and the battery can not be charged to MaxSystemVoltage for 12hrs, ISL9238A stops charging the battery and exits Autonomous Charging mode.

## Battery Ship Mode

ISL9238A supports Battery Ship mode. When Control3 register Bit <10> is 1, BGATE MOSFET stays off for Battery Ship mode.

## DE Operation

In DE mode of operation, the ISL9238A employs a phase comparator to monitor the PHASE node voltage during the low-side switching FET on-time in order to detect the inductor current zero crossing. The phase comparator needs a minimum on-time of the low-side switching FET for it to recognize inductor current zero crossing. If the low-side switching FET on-time is too short for the phase comparator to successfully recognize the inductor zero crossing, the ISL9238A may lose diode emulation ability. To prevent such a scenario, the ISL9238A employs a minimum low-side switching FET on-time. When the intended low-side switching FET on-time is shorter than the minimum value, the ISL9238A stretches the switching period in order to keep the low-side switching FET on-time at the minimum value, which causes the CCM switching frequency to drop below the set point.

## Power Source Selection

The ISL9238A automatically selects the adapter and/or the battery as the source for system power.

The BGATE pin drives a P-channel MOSFET gate that connects/disconnects the battery from the system and the switcher.

The ASGATE pin drives a pair of back-to-back common source PFETs to connect/disconnect the adapter from the system and the battery.

Use of the ASGATE pin is optional.

When battery voltage $V_{BAT}$ is higher than 2.4V and the adapter voltage $V_{ADP}$ is less than 3.2V, ISL9238A operates in Battery Only mode. During Battery Only mode, the ISL9238A turns on the BGATE FET to connect the battery to the system. In Battery Only mode, the ISL9238A consumes very low power, less than 20µA during this mode. The battery discharging current monitor BMON can be turned on during this mode to monitor the battery discharging current. If the battery voltage $V_{BAT}$ is higher than 5.2V, the system power monitor PSYS function also can be turned on during this mode to monitor system power.

In Battery Only mode, the USB OTG function can be enabled when the battery voltage $V_{BAT}$ is higher than 5.2V, see "USB OTG (On the Go)" on page 38 for details.

When the adapter voltage $V_{ADP}$ is more than 3.2V, ISL9238A turns on ASGATE. If VDD is higher than 3.8V, ISL9238A enters in the Forward Buck, Forward Boost, or Forward Buck-Boost mode depending upon the adapter and system voltage VSYS duty cycle ratio. The system bus voltage is regulated at the voltage set on the MaxSystemVoltage register. If the charge current register is programmed (non-zero), ISL9238A charges the battery either in Trickle Charging mode or Fast Charging mode, as long as BATGONE is low.

## Battery Learn Mode

The ISL9238A supports Battery Learn mode. The ISL9238A enters Battery Learn mode when it receives the SMBus Control command.

This mode of operation is used when it is desired to supply the system power from the battery even when the adapter is plugged in, such as calibration of the battery fuel gauge, hence the name “Battery Learn mode”.

Upon entering Battery Learn mode the ISL9238A will turn on the BGATE FET.

In Battery Learn mode, the ISL9238A turns on BGATE, keeps ASGATE on but turns off the buck-boost switcher regardless of whether the adapter is present or not.

There are three ways of exiting Battery Learn mode:

1. Receive Battery Learn mode exit command through SMBus.
2. Battery voltage is less than MinSystemVoltage register setting (according to Control1 register Bit<12> setting).
3. BATGONE pin voltage goes from logic LOW to HIGH.

In all these cases, the ISL9238A resumes switching immediately to supply power to the system bus from the adapter in order to prevent system voltage collapse.

## Turbo Mode Support

Turbo mode refers to the scenario when the system draws more power than the adapter’s power rating.

If the adapter current reaches the AdapterCurrentLimit1 register set value (or AdapterCurrentLimit2 register set value, if two-level adapter current limit function is enabled), or the adapter input voltage drops to the Input Voltage Regulation Reference set by Control0 register 0x39H Bit<2>, the ISL9238A will limit the input power by regulating the adapter current at AdapterCurrentLimit1/2 register set value, or by regulating the adapter voltage at the Input Voltage Regulation Reference point.

In Turbo mode, the system bus voltage VSYS will drop automatically or the charging current will drop automatically to limit the adapter input power. If the VSYS pin voltage is 150mV lower than the VBAT pin voltage, BGATE FET will turn on, such that the battery supplies the rest of the power required by the system.

If the ISL9238A detects 150mA charging current or if the battery discharging current is less than 200mA for longer than 40ms or 80ms, it will turn off BGATE to exit Turbo mode. Turbo mode exit timer can be configured through Control3 register 0x4C Bit<8>. Refer to Table 24 for BGATE control logic.

TABLE 24. BGATE ON/OFF TRUTH TABLE

| TURBO (CONTROL BIT) | CHARGECURRENT REGISTER | BGATE ON/OFF | |
|---|---|---|---|
| 0 = ENABLE 1 = DISABLE | 0 = ZERO 1 = NONZERO | SYSTEM LOAD NOT IN TURBO MODE RANGE | SYSTEM LOAD IN TURBO MODE RANGE |
| 0 | 0 | OFF | ON |
| 0 | 1 | ON for fast charge; Trickle charge is enabled | ON |
| 1 | 0 | OFF | OFF |
| 1 | 1 | ON for fast charge; Trickle charge is enabled | ON |

## Two-Level Adapter Current Limit

In a real system, Turbo event usually does not last very long. It is often no longer than milliseconds, a time length during which the adapter can supply current higher than its DC rating. The ISL9238A employs a two-level adapter current limit in order to fully take advantage of adapter’s surge capability and minimize the power drawn from the battery.

Figure 32 shows the two SMBus programmable adapter current limit levels, AdapterCurrentLimit1 and AdapterCurrentLimit2, as well as the durations t1 and t2. The two-level adapter current limit function is initiated when the adapter current is less than 100mA lower than the AdapterCurrentLimit1 register setting and it starts at AdapterCurrentLimit2 for t2 duration and then changes to AdapterCurrentLimit1 for t1 duration before repeating the pattern. These parameters can set adapter current limit with an envelope that allows the adapter to temporarily output surge current without requiring the charger to enter Turbo mode. Such operation maximizes battery life.

AdapterCurrentLimit1 register value can be higher or lower than AdapterCurrentLimit2 value.

The two-level adapter current limit function can be enabled and disabled through SMBus Control2 register Bit<12>. When the two-level adapter current limit function is disabled, only AdapterCurrentLimit1 value is used as the adapter current limit and AdapterCurrentLimit2 value is ignored.

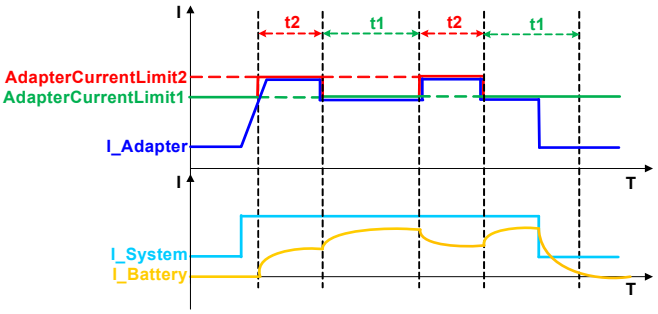



FIGURE 32. TWO-LEVEL ADAPTER CURRENT LIMIT

## Current Monitor

The ISL9238A provides an adapter current monitor/OTG current monitor or a battery charging current monitor/battery discharging current monitor through the AMON/BMON pin. The AMON output voltage is 18x (CSIP-CSIN) and 18x (CSIN-CSIP) voltage and the BMON output voltage is 18x (CSON-CSOP) and 36x (CSOP-CSON) voltage.

AMON and BMON function can be enabled or disabled through SMBus Control1 register Bit<5>, AMON or BMON can be selected through SMBus Control1 register Bit<4> and AMON/BMON direction can be configured through SMBus Control3 register Bit<3> as Table 13 on page 26 shows.

## PSYS Monitor

The ISL9238A PSYS pin provides a measure of the instantaneous power consumption of the entire platform. The PSYS pin outputs a current source described by Equation 1.

$$I_{PSYS} = K_{PSYS} \times (V_{ADP} \times I_{ADP} + V_{BAT} \times I_{BAT}) \quad \text{(EQ. 1)}$$

$K_{PSYS}$ is based on current sensing resistor $R_{S1}$ = 20mΩ and $R_{S2}$ = 10mΩ. $V_{ADP}$ is the adapter voltage in Volts, $I_{ADP}$ is the adapter current in Amperes, $V_{BAT}$ is the battery voltage and $I_{BAT}$ is the battery discharging current. When the battery is discharging, $I_{BAT}$ is a positive value; when the battery is being charged, $I_{BAT}$ is a negative value. The battery voltage $V_{BAT}$ is detected through CSON pin to maximize the power monitor accuracy in NVDC configuration Trickle Charge mode.

The $R_{S1}$ to $R_{S2}$ ratio must be 2:1 for a valid power calculation to occur. If the resistance values are higher (or lower) than the suggested values mentioned previously, $K_{PSYS}$ will be proportionally higher (or lower). As an example, if $R_{S1}$ = 10mΩ and $R_{S2}$ = 5mΩ, then the output current will be half that above for the same power. If the PSYS information is not needed then any $R_{S1}$:$R_{S2}$ ratio is acceptable.

The PSYS gain can be configured through SMBus Control3 register Bit<9>. The default PSYS gain is set to 1.44µA/W and 0.723µA/W PSYS gain option is available.

The PSYS information includes the power loss of the charger circuit and the actual power delivered to the system. Resistor $R_{PSYS}$ connected between the PSYS pin and GND converts the PSYS information from current to voltage.

PSYS accuracy limits and a typical accuracy scan are shown in Figure 33.

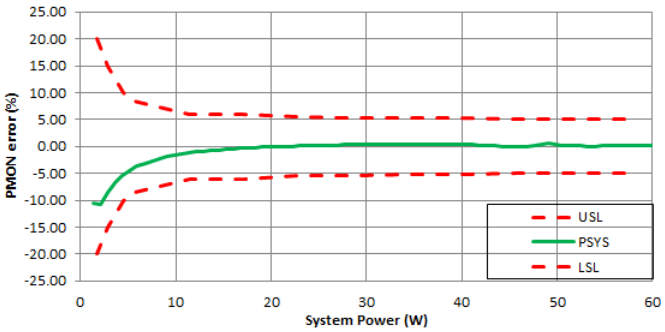



**FIGURE 33. PSYS ACCURACY AND LIMITS**

The PSYS function can be enabled or disabled through SMBus Control1 register Bit<3> as shown in Table 13 on page 26.

In Battery Only mode, the PSYS function cannot work if the battery voltage is less than 5.2V.

## Trickle Charging

The ISL9238A supports trickle charging to an overly discharged battery. It can activate the trickle charging function when the battery voltage is lower than MinSystemVoltage setting. The VBAT pin is the battery voltage sense point for Trickle Charge mode.

To enable Trickle Charging, set ChargeCurrent register to a non-zero value. To disable trickle charging, set ChargeCurrent register to 0. Refer to Table 24 on page 36 for trickle charging control logic.

The trickle charging current can be programmed to be 512mA, 256mA, 128mA or 64mA through SMBus Control2 register Bit<15:14> in Table 14 on page 27.

In Trickle Charging mode, the ISL9238A regulates the trickle charging current through the buck-boost switcher. Another independent control loop controls the BGATE FET such that the system voltage is maintained at the voltage set in the MinSystemVoltage register. The VSYS pin is the system voltage sensing point in Trickle Charging mode.

When the battery voltage is charged the MinSystemVoltage register value, the ISL9238A enters Fast Charging mode by limiting the charging current at the ChargeCurrentLimit register setting.

## System Voltage Regulation

If the battery is absent, or if a battery is present but BGATE is turned off, the ISL9238A will regulate the system bus voltage at the MaxSystemVoltage register setting. The VSYS pin is used to sense the system bus voltage.

## Charger Timeout

The ISL9238A includes a timer to insure the SMBus master is active and to prevent overcharging the battery. The ISL9238A will terminate charging by turning off BGATE FET if the charger has not received a write command to the MaxSystemVoltage or ChargeCurrent register within 175s (SMBus Control3 register Bit<12:11> = 00). Charger timeout time can be configured through SMBus Control3 register Bit<12:11>. When the charging is terminated by the timeout, the ChargeCurrent register will retain its value instead of resetting to zero. If a timeout occurs, MaxSystemVoltage or ChargeCurrent register must be written to re-enable charging.

The ISL9238A allows users to disable the charger timeout function through SMBus Control0 register Bit<7> as Table 12 on page 25 shows.

## USB OTG (On the Go)

When the OTG function is enabled with SMBus command and OTGEN pin and if battery voltage $V_{BAT}$ is higher than 5.2V, ISL9238A operates in the Reverse Buck, Reverse Boost, or Reverse Buck-Boost mode.

When the ISL9238A receives the command to enable the OTG function, it will start switching after the 1.3s or 150ms debounce time set by Control2 register Bit<13>. When the OTG output voltage reaches to the OTG output voltage set by register 0x49 Bit<14:3>, OTG power-good OTGPG will assert to High. Moreover, Control2 register Bit<5> can be used to turn ASGATE FET off to cut off the OTG output.

Before OTG mode starts switching, the CSIP pin voltage needs to drop below the OTG output overvoltage protection threshold (OTGVDAV + 100mV) first.

The default OTG output voltage is programmable up to 20V. The OTG Voltage register 0x49H can be used to configure the OTG output voltage.

The default OTG output current is limited at 512mA through $R_{S1}$. The OTGCurrent register 0x4AH can be used to adjust the OTG output current limit.

The ISL9238A includes the OTG output undervoltage and overvoltage protection functions. The UVP threshold is OTG output voltage -1.2V and the OVP threshold is OTG output voltage +1.2V.

When UV is detected, the ISL9238A will stop switching and turn off ASGATE and deassert OTGPG after 32ms and after 1.3s or 150ms debounce time set by Control2 register Bit<13>, it will resume switching.

When OV is detected, the ISL9238A will stop switching and deassert OTGPG. It will resume switching after 100µs when the OTG voltage drops below the OTG OV threshold.

BATGONE needs to be low to enable OTG mode. OTG mode is not available for 1-cell battery systems.

## Stand-Alone Comparator

The ISL9238A includes a general purpose stand-alone comparator. OTGEN/CMIN pin is the comparator input. The internal comparator reference is connected to the inverting input of the comparator and can be configured as 1.2V or 2V through SMBus Control2 register Bit<4>. The comparator output is the OTGPG/CMOUT pin and the output polarity when the comparator is tripped can be configured through SMBus register bit.

When Control2 register Bit<2> = 0 for normal comparator output polarity, if CMIN>Reference, CMOUT = High; if CMIN < Reference, CMOUT = Low.

When Control2 register Bit<2> = 1 for inversed comparator output polarity, if CMIN > Reference, CMOUT = Low; if CMIN < Reference, CMOUT = High.

In Battery Only mode, the stand-alone comparator is disabled unless PSYS is enabled through SMBus Control1 register Bit<3> to enable the internal reference, which is indicated through Information1 register Bit<15>.

Table 25 shows the OTG mode and the stand-alone comparator truth table.

**TABLE 25. OTG AND COMPARATOR TRUTH TABLE**

| | | | | DESCRIPTION |
|---|---|---|---|---|
| Control1 Register 0x3C | Control2 Register 0x3D | PIN-20 | PIN-26 | |
| Bit<11> OTG Function Enable/Disable | Bit<3> Comparator Enable/Disable | OTGEN/CMIN | OTGPG/CMOUT | |
| 0 | 0 | Comparator Input Pin CMIN | Comparator Output Pin CMOUT | OTG function is disabled.<br>Comparator is enabled. |
| 0 | 1 | X | X | Both OTG function and comparator are disabled. |
| 1 | 0 | Comparator Input Pin CMIN | Comparator Output Pin CMOUT | Both OTG function and comparator are enabled.<br>OTG function is enabled when $V_{BAT}$ > 5.2V and Control1 register Bit<11> = 1 without OTG power-good pin indication. While the Information1 register 0x3A Bit<6:5> = 11 indicates it is in OTG mode. |
| 1 | 1 | OTG Enable Input Pin OTGEN | OTG Power-Good Indication Pin OTGPG | Comparator is disabled.<br>OTG function is enabled when $V_{BAT}$ > 5.2V and ENOTG pin = High and Control1 register Bit<11> = 1 |

## Adapter Overvoltage Protection

If the ADP pin voltage exceeds 23.4V for more than 10µs, the ISL9238A will consider an adapter overvoltage condition has occurred. It will turn off the ASGATE MOSFETs to isolate the adapter from the system, deassert the ACOK signal by pulling it low and stop switching. BGATE will turn on for the battery to support the system load. When the ADP voltage drops below 23.04V from more than 100µs, it will start to turn on ASGATE and start switching.

## Battery Overvoltage Protection

If the VBAT pin voltage is higher than battery overvoltage threshold (Vbov) + MaxSystemVoltage for 1ms, it will declare the battery overvoltage and stop switching. Battery overvoltage threshold are 4% of MaxSystemVoltage for 1-cell battery setting and 2% of MaxSystemVoltage in 2-, 3- and 4-cells setting. It will resume switching with 1ms debounce time when VBAT pin voltage drops 0.5xVbov + MaxSystemVoltage. The ISL9238A allows users to disable the battery overvoltage protection function through SMBus Control2 register Bit<0>.

## System Overvoltage Protection

The ISL9238A provides system rail overvoltage protection. If the system voltage VSYS is 800mV higher than MaxSystemVoltage register set value, it will declare the system overvoltage and stop switching. It will resume switching without the 1.3s or 150ms debounce when VSYS drops 300mV below the system overvoltage threshold.

## Way Overcurrent Protection (WOCP)

In the case that the system bus is shorted, either a MOSFET short or an inductor short, the input current could be high. The ISL9238A includes input overcurrent protection to turn off the ASGATE and stop switching.

The ISL9238A provides adapter current and battery discharging current WOCP (Way Overcurrent Protection) function against the MOSFET short, system bus short and inductor short scenarios. The ISL9238A monitors the CSIP-CSIN voltage and CSON-CSOP voltage, compares them with the WOCP threshold 12A for adapter current and 20A for battery discharge current.

When the WOC comparator is tripped, ISL9238A counts one time within each 10µs. Whenever ISL9238A counts WOC to 7 times in 50ms, it turns off ASGATE, deasserts ACOK and stops switching immediately. After the 1.3s or 150ms debounce time set by Control2 register Bit<11>, it goes through the start-up sequence to retry.

The WOCP function can be disabled through Control2 register Bit<1>.

## Over-Temperature Protection

The ISL9238A will stop switching for self protection when the junction temperature exceeds +140°C.

When the temperature falls below +120°C and after a 100µs delay, the ISL9238A will start to switching.

## Switching Power MOSFET Gate Capacitance

The ISL9238A includes an internal 5V LDO output at VDD pin, which can be used to provide the switching MOSFET gate driver power through VDDP pin with an R-C filter. The 5V LDO output overcurrent protection threshold is 100mA nominal. When selecting the switching power MOSFET, the MOSFET gate capacitance should be considered carefully to avoid overloading the 5V LDO, especially in Buck-Boost mode when four MOSFETs are switching at the same time. For one MOSFET, the gate drive current can be estimated by Equation 2:

$$I_{driver} = Q_g \bullet f_{SW} \quad \text{(EQ. 2)}$$

where:

- $Q_g$ is the total gate charge, which can be found in the MOSFET datasheet
- $f_{SW}$ is switching frequency

## Adapter Input Filter

The adapter cable parasitic inductance and capacitance could cause some voltage ringing or an overshoot spike at the adapter connector node when the adapter is hot plugged in. This voltage spike could damage the ASGATE MOSFET or the ISL9238A pins connecting to the adapter connector node. One low cost solution is to add an RC snubber circuit at the adapter connector node to clamp the voltage spike as shown in Figure 34. A practical value of the RC snubber is 2.2Ω to 2.2µF while the appropriate values and power rating should be carefully characterized based on the actual design. Meanwhile it is not recommended to add a pure capacitor at the adapter connector node, which can cause an even bigger voltage spike due to the adapter cable or the adapter current path parasitic inductance.

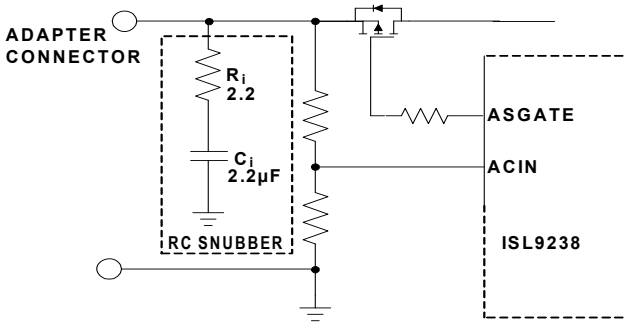



FIGURE 34. ADAPTER INPUT RC SNUBBER CIRCUIT

## General Application Information

This design guide is intended to provide a high-level explanation of the steps necessary to design a single-phase power converter. It is assumed that the reader is familiar with many of the basic skills and techniques referenced in the following section. In addition to this guide, Intersil provides complete reference designs that include schematics, bill of materials and example board layouts.

## Select the LC Output Filter

The duty cycle of an ideal buck converter in CCM is a function of the input and the output voltage. This relationship is written by Equation 3:

$$D = \frac{V_{OUT}}{V_{IN}} \quad \text{(EQ. 3)}$$

The output inductor peak-to-peak ripple current is written by Equation 4:

$$I_{P\text{-}P} = \frac{V_{OUT} \cdot (1 - D)}{f_{SW} \cdot L} \quad \text{(EQ. 4)}$$

A typical step-down DC/DC converter will have an $I_{P\text{-}P}$ of 20% to 40% of the maximum DC output load current for a practical design. The value of $I_{P\text{-}P}$ is selected based upon several criteria such as MOSFET switching loss, inductor core loss and the resistive loss of the inductor winding.

The DC copper loss of the inductor can be estimated by Equation 5:

$$P_{COPPER} = I_{LOAD}^{2} \cdot DCR \quad \text{(EQ. 5)}$$

where $I_{LOAD}$ is the converter output DC current.

The copper loss can be significant so attention has to be given to the DCR selection. Another factor to consider when choosing the inductor is its saturation characteristics at elevated temperatures. A saturated inductor could cause destruction of circuit components.

A DC/DC buck regulator must have output capacitance $C_O$ into which ripple current $I_{P\text{-}P}$ can flow. Current $I_{P\text{-}P}$ develops a corresponding ripple voltage $V_{P\text{-}P}$ across $C_O$, which is the sum of the voltage drop across the capacitor ESR and of the voltage change stemming from charge moved in and out of the capacitor. These two voltages are written by Equations 6 and 7:

$$\Delta V_{ESR} = I_{P\text{-}P} \cdot ESR \quad \text{(EQ. 6)}$$

$$V_C = \frac{I_{P\text{-}P}}{8 \cdot C_O \cdot f_{SW}} \quad \text{(EQ. 7)}$$

If the output of the converter has to support a load with high pulsating current, several capacitors will need to be paralleled to reduce the total ESR until the required $V_{P\text{-}P}$ is achieved. The inductance of the capacitor can cause a brief voltage dip if the load transient has an extremely high slew rate. Low inductance capacitors should be considered in this scenario. A capacitor dissipates heat as a function of RMS current and frequency. Be sure that $I_{P\text{-}P}$ is shared by a sufficient quantity of paralleled capacitors so that they operate below the maximum rated RMS current at $f_{SW}$. Take into account that the rated value of a capacitor can fade as much as 50% as the DC voltage across it increases.

## Select the Input Capacitor

The important parameters for the input capacitance are the voltage rating and the RMS current rating. For reliable operation, select capacitors with voltage and current ratings above the maximum input voltage and capable of supplying the RMS current required by the switching circuit. Their voltage rating should be at least 1.25x greater than the maximum input voltage, while a voltage rating of 1.5x is a preferred rating. Figure 35 is a graph of the input capacitor RMS ripple current, normalized relative to output load current, as a function of duty cycle and is adjusted for converter efficiency. The normalized RMS ripple current calculation is written as Equation 8:

$$I_{C_{IN}(RMS,NORMALIZED)} = \frac{I_{MAX} \cdot \sqrt{D \cdot (1 - D) + \frac{D \cdot k^2}{12}}}{I_{MAX}} \quad \text{(EQ. 8)}$$

where:

- $I_{MAX}$ is the maximum continuous $I_{LOAD}$ of the converter
- k is a multiplier (0 to 1) corresponding to the inductor peak-to peak ripple amplitude expressed as a ratio of $I_{MAX}$ (0 to 1)
- D is the duty cycle that is adjusted to take into account the efficiency of the converter, which is written as Equation 9:

$$D = \frac{V_{OUT}}{V_{IN} \cdot EFF} \quad \text{(EQ. 9)}$$

In addition to the capacitance, some low ESL ceramic capacitance is recommended to decouple between the drain of the high-side MOSFET and the source of the low-side MOSFET.

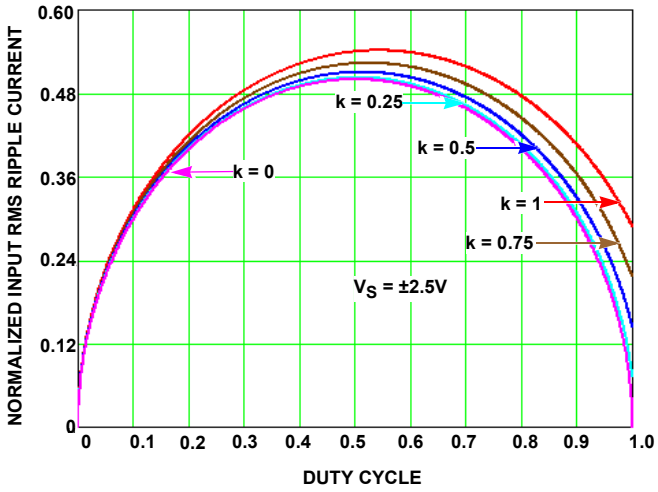



FIGURE 35. NORMALIZED RMS INPUT CURRENT AT EFF = 1

## Select the Switching Power MOSFET

Typically, a MOSFET cannot tolerate even brief excursions beyond their maximum drain-to-source voltage rating. The MOSFETs used in the power stage of the converter should have a maximum VDS rating that exceeds the sum of the upper voltage tolerance of the input power source and the voltage spike that occurs when the MOSFET switches off.

There are several power MOSFETs readily available that are optimized for DC/DC converter applications. The preferred high-side MOSFET emphasizes low gate charge so that the device spends the least amount of time dissipating power in the linear region. Unlike the low-side MOSFET, which has the drain-to-source voltage clamped by its body diode during turn off, the high-side MOSFET turns off with a VDS of approximately VIN - VOUT, plus the spike across it. The preferred low-side MOSFET emphasizes low $r_{DS(ON)}$ when fully saturated to minimize conduction loss. It should be noted that this is an optimal configuration of MOSFET selection for low duty cycle applications (D < 50%). For higher output, low input voltage solutions, a more balanced MOSFET selection for high- and low-side devices may be warranted.

For the Low-Side (LS) MOSFET, the power loss can be assumed to be conductive only and is written as Equation 10:

$$P_{CON_LS} \approx I_{LOAD}^{2} \cdot r_{DS(ON)_LS} \cdot (1 - D) \quad \text{(EQ. 10)}$$

For the High-Side (HS) MOSFET, the conduction loss is written by Equation 11:

$$P_{CON_HS} = I_{LOAD}^{2} \cdot r_{DS(ON)_HS} \cdot D \quad \text{(EQ. 11)}$$

For the High-Side MOSFET, the switching loss is written as Equation 12:

$$P_{SW_HS} = \frac{V_{IN} \cdot I_{VALLEY} \cdot t_{SWON} \cdot f_{SW}}{2} + \frac{V_{IN} \cdot I_{PEAK} \cdot t_{SWOFF} \cdot f_{SW}}{2} \quad \text{(EQ. 12)}$$

where:

- $I_{VALLEY}$ is the difference of the DC component of the inductor current minus 1/2 of the inductor ripple current
- $I_{PEAK}$ is the sum of the DC component of the inductor current plus 1/2 of the inductor ripple current
- $t_{SW(ON)}$ is the time required to drive the device into saturation
- $t_{SW(OFF)}$ is the time required to drive the device into cut-off

## Select the Bootstrap Capacitor

The selection of the bootstrap capacitor is written by Equation 13:

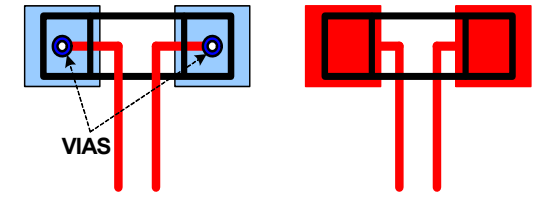
$$C_{BOOT} = \frac{Q_g}{\Delta V_{BOOT}} \quad \text{(EQ. 13)}$$

where:

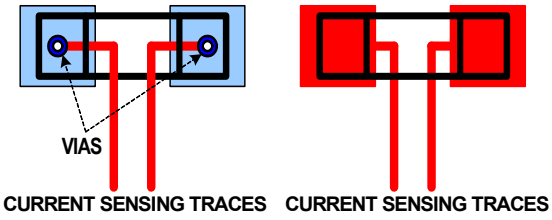
- $Q_g$ is the total gate charge required to turn on the high-side MOSFET
- $\Delta V_{BOOT}$, is the maximum allowed voltage decay across the boot capacitor each time the high-side MOSFET is switched on.

As an example, suppose the high-side MOSFET has a total gate charge $Q_g$, of 25nC at $V_{GS}$ = 5V and a $\Delta V_{BOOT}$ of 200mV. The calculated bootstrap capacitance is 0.125µF; for a comfortable margin, select a capacitor that is double the calculated capacitance. In this example, 0.22µF will suffice. Use an X7R or X5R ceramic capacitor.

# Layout

| PIN NUMBER | PIN NAME | LAYOUT GUIDELINES |
|---|---|---|
| BOTTOM PAD 33 | GND | Connect this ground pad to the ground plane through low impedance path. Recommend use of at least 5 vias to connect to ground planes in PCB to ensure there is sufficient thermal dissipation directly under the IC. |
| 1 | CSON | Run two dedicated trace with decent width in parallel (close to each other to minimize the loop area) from the two terminals of the battery current sensing resistor to the IC. Place the differential mode and common-mode RC filter components in general proximity of the controller.<br><br>Route the current sensing traces through vias to connect the center of the pads; or route the traces into the pads from the inside of the current sensing resistor. The following drawings show the two preferred ways of routing current sensing traces.<br><br>  <br> |
| 2 | CSOP | |
| 3 | VSYS | Signal pin. Provides feedback for the system bus voltage. Place the optional RC filter in general proximity of the controller. Run a dedicated trace from system bus to the pin and do not route near the switching traces. Do not share the same trace with the signal routing to the DCIN pin OR diodes. |
| 4 | BOOT2 | Switching pin. Place the bootstrap capacitor in general proximity of the controller. Use decent wide trace. Avoid any sensitive analog signal trace from crossing over or getting close. |
| 5 | UGATE2 | Run these two traces in parallel fashion with decent width. Avoid any sensitive analog signal trace from crossing over or getting close. Recommend routing PHASE2 trace to high-side MOSFET source pin instead of general copper.<br><br>The IC should be placed close to the switching MOSFETs gate terminals and keep the gate drive signal traces short for a clean MOSFET drive. The IC can be placed on the opposite side of the switching MOSFETs.<br><br>Place the output capacitors as close as possible to the switching high-side MOSFET drain and the low-side MOSFET source; and use shortest PCB trace connection. Place these capacitors on the same PCB layer with the MOSFETs instead of on different layers and using vias to make the connection.<br><br>Place the inductor terminal to the switching high-side MOSFET drain and low-side MOSFET source terminal as close as possible. Minimize this phase node area to lower the electrical and magnetic field radiation but make this phase node area big enough to carry the current. Place the inductor and the switching MOSFETs on the same layer of the PCB. |
| 6 | PHASE2 | |
| 7 | LGATE2 | Switching pin. Run LGATE2 trace in parallel with UGATE2 and PHASE2 traces on the same PCB layer. Use decent width. Avoid any sensitive analog signal trace from crossing over or getting close. |
| 8 | VDDP | Place the decoupling capacitor in general proximity of the controller. Run the trace connecting to VDD pin with decent width. |
| 9 | LGATE1 | Switching pin. Run LGATE1 trace in parallel with UGATE1 and PHASE1 traces on the same PCB layer. Use decent width. Avoid any sensitive analog signal trace from crossing over or getting close. |
| 10 | PHASE1 | Run these two traces in parallel fashion with decent width. Avoid any sensitive analog signal trace from crossing over or getting close. Recommend routing PHASE1 trace to high-side MOSFET source pin instead of general copper.<br><br>The IC should be placed close to the switching MOSFETs gate terminals and keep the gate drive signal traces short for a clean MOSFET drive. The IC can be placed on the opposite side of the switching MOSFETs.<br><br>Place the input capacitors as close as possible to the switching high-side MOSFET drain and the low-side MOSFET source; and use shortest PCB trace connection. Place these capacitors on the same PCB layer with the MOSFETs instead of on different layers and using vias to make the connection.<br><br>Place the inductor terminal to the switching high-side MOSFET drain and low-side MOSFET source terminal as close as possible. Minimize this phase node area to lower the electrical and magnetic field radiation but make this phase node area big enough to carry the current. Place the inductor and the switching MOSFETs on the same layer of the PCB. |
| 11 | UGATE1 | |

## Layout (Continued)

| PIN NUMBER | PIN NAME | LAYOUT GUIDELINES |
|---|---|---|
| 12 | BOOT1 | Switching pin. Place the bootstrap capacitor in general proximity of the controller. Use decent wide trace. Avoid any sensitive analog signal trace from crossing over or getting close. |
| 13 | ASGATE | Run this trace with decent width in parallel fashion with the ADP pin trace. |
| 14 | CSIN | Run two dedicated trace with decent width in parallel (close to each other to minimize the loop area) from the two terminals of the adapter current sensing resistor to the IC. Place the Differential mode and common-mode RC filter components in general proximity of the controller.<br><br>Route the current sensing traces through vias to connect the center of the pads; or route the traces into the pads from the inside of the current sensing resistor. The following drawings show the two preferred ways of routing current sensing traces.<br><br>  <br> |
| 15 | CSIP | |
| 16 | ADP | Run this trace with decent width in parallel fashion with the ASGATE pin trace. |
| 17 | DCIN | Place the OR diodes and the RC filter in general proximity of the controller. Run the VADP trace and VSYS trace to the OR diodes with decent width. |
| 18 | VDD | Place the RC filter connecting with VDDP pin in general proximity of the controller. Run the trace connecting to VDDP pin with decent width. |
| 19 | ACIN | Place the voltage divider resistors and the optional decoupling capacitor in general proximity of the controller. |
| 20 | OTGEN/CMIN | No special consideration. |
| 21 | SDA | Digital pins. No special consideration. Run SDA and SCL traces in parallel. |
| 22 | SCL | |
| 23 | PROCHOT# | Digital pin, open-drain output. No special consideration. |
| 24 | ACOK | Digital pin, open-drain output. No special consideration. |
| 25 | BATGONE | Digital pin. Place the 100kΩ resistor series in the BATGONE signal trace and the optional decoupling capacitor in general proximity of the controller. |
| 26 | OTGPG/CMOUT | Digital pin, open-drain output. No special consideration. |
| 27 | PROG | Signal pin. Place the PROG programming resistor in general proximity of the controller. |
| 28 | COMP | Place the compensation components in general proximity of the controller. Avoid any switching signal from crossing over or getting close. |
| 29 | AMON/BMON | No special consideration. Place the optional RC filter in general proximity of the controller. |
| 30 | PSYS | Signal pin, current source output. No special consideration. |
| 31 | VBAT | Place the optional RC filter in general proximity of the controller. Run a dedicated trace from the battery positive connection point to the IC. |
| 32 | BGATE | Use decent width trace from the IC to the BGATE MOSFET gate. Place the capacitor from BGATE to ground close to the MOSFET. |

## Revision History

The revision history provided is for informational purposes only and is believed to be accurate, however, not warranted. Please visit our website to make sure that you have the latest revision.

| DATE | REVISION | CHANGE |
|---|---|---|
| Nov 30, 2017 | FN8978.1 | Added Way Overcurrent Protection (WOCP) function to datasheet. |
| Oct 5, 2017 | FN8978.0 | Initial release. Previously on ISL9238 datasheet (FN8877).<br>Removed the WOCP feature. |

## About Intersil

Intersil Corporation is a leading provider of innovative power management and precision analog solutions. The company's products address some of the largest markets within the industrial and infrastructure, mobile computing, and high-end consumer markets.

For the most updated datasheet, application notes, related documentation, and related parts, see the respective product information page found at www.intersil.com.

For a listing of definitions and abbreviations of common terms used in our documents, visit www.intersil.com/glossary.

You can report errors or suggestions for improving this datasheet by visiting www.intersil.com/ask.

Reliability reports are also available from our website at www.intersil.com/support.

© Copyright Intersil Americas LLC 2017. All Rights Reserved.
All trademarks and registered trademarks are the property of their respective owners.

For additional products, see www.intersil.com/en/products.html

Intersil products are manufactured, assembled and tested utilizing ISO9001 quality systems as noted in the quality certifications found at www.intersil.com/en/support/qualandreliability.html

*Intersil products are sold by description only. Intersil may modify the circuit design and/or specifications of products at any time without notice, provided that such modification does not, in Intersil's sole judgment, affect the form, fit or function of the product. Accordingly, the reader is cautioned to verify that datasheets are current before placing orders. Information furnished by Intersil is believed to be accurate and reliable. However, no responsibility is assumed by Intersil or its subsidiaries for its use; nor for any infringements of patents or other rights of third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of Intersil or its subsidiaries.*

For information regarding Intersil Corporation and its products, see www.intersil.com

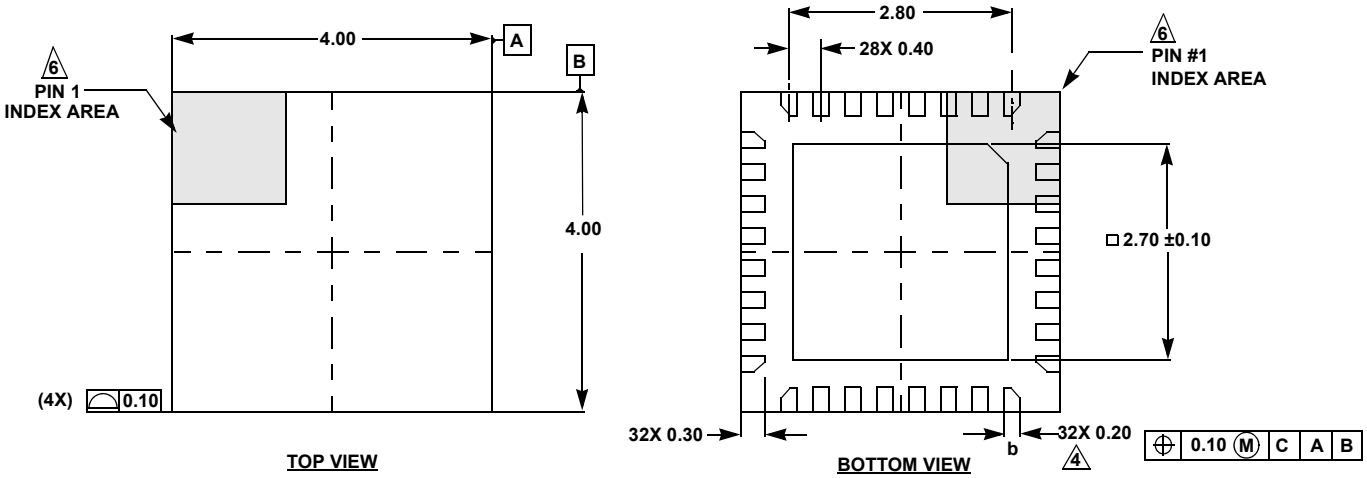
# Package Outline Drawing

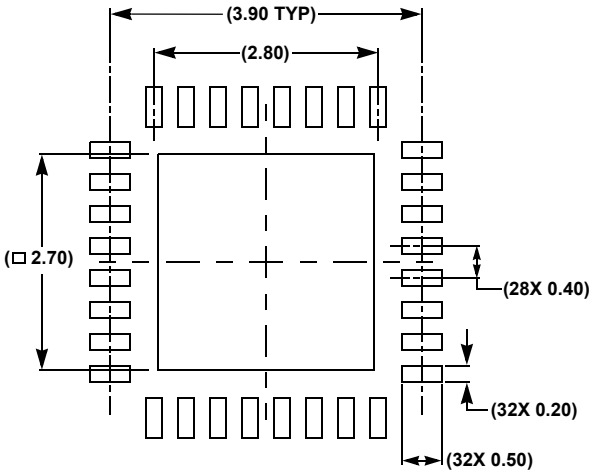
For the most recent package outline drawing, see L32.4x4D.

## L32.4x4D

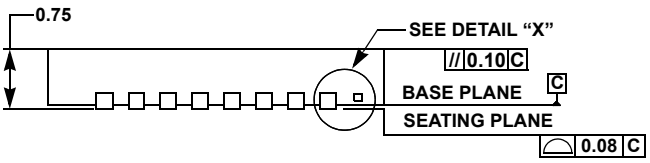
**32 LEAD THIN QUAD FLAT NO-LEAD PLASTIC PACKAGE**

**Rev 2, 10/16**

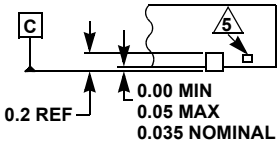



TYPICAL RECOMMENDED LAND PATTERN




SIDE VIEW




DETAIL "X"

**NOTES:**

1. Dimensions are in millimeters.
   Dimensions in ( ) for Reference Only.
2. Dimensioning and tolerancing conform to ASME Y14.5m-1994.
3. Unless otherwise specified, tolerance: Decimal ±0.05.
4. Dimension b applies to the metallized terminal and is measured between 0.15mm and 0.25mm from the terminal tip.
5. Tiebar shown (if present) is a non-functional feature.
6. The configuration of the pin #1 identifier is optional, but must be located within the zone indicated. The pin #1 identifier may be either a mold or mark feature.

Общество с ограниченной ответственностью «МосЧип» ИНН 7719860671 / КПП 771901001
Адрес: 105318, г.Москва, ул.Щербаковская д.3, офис 1107

**Данный компонент на территории Российской Федерации**

**Вы можете приобрести в компании MosChip.**

Для оперативного оформления запроса Вам необходимо перейти по данной ссылке:

http://moschip.ru/get-element

Вы можете разместить у нас заказ для любого Вашего проекта, будь то серийное производство или разработка единичного прибора.

В нашем ассортименте представлены ведущие мировые производители активных и пассивных электронных компонентов.

Нашей специализацией является поставка электронной компонентной базы двойного назначения, продукции таких производителей как XILINX, Intel (ex.ALTERA), Vicor, Microchip, Texas Instruments, Analog Devices, Mini-Circuits, Amphenol, Glenair.

Сотрудничество с глобальными дистрибьюторами электронных компонентов, предоставляет возможность заказывать и получать с международных складов практически любой перечень компонентов в оптимальные для Вас сроки.

На всех этапах разработки и производства наши партнеры могут получить квалифицированную поддержку опытных инженеров.

Система менеджмента качества компании отвечает требованиям в соответствии с ГОСТ Р ИСО 9001, ГОСТ РВ 0015-002 и ЭС РД 009

**Офис по работе с юридическими лицами:**

105318, г.Москва, ул.Щербаковская д.3, офис 1107, 1118, ДЦ «Щербаковский»

Телефон: +7 495 668-12-70 (многоканальный)

Факс: +7 495 668-12-70 (доб.304)

E-mail: info@moschip.ru

Skype отдела продаж:
moschip.ru
moschip.ru_4
moschip.ru_6
moschip.ru_9