

ISL95521A

Hybrid Power Boost (HPB) and Narrow VDC (NVDC) Combo Battery Charger with SMBus Interface

FN8841
Rev 2.00
Jul.19.19

The [ISL95521A](#) is a highly versatile combo battery charger configurable for operating as either a Hybrid Power Boost (HPB) charger or a Narrow VDC (NVDC) charger, supporting 2-, 3-, or 4-cell batteries. Both configurations allow the battery to work with the adapter together to supply the system load when it exceeds the adapter capability, referred to as system Turbo mode. The HPB charger configuration reverse-boosts battery energy to the system bus to help the adapter provide the system power in Turbo mode. The NVDC charger configuration quickly turns on BGATE to enable the battery to help the adapter provide the system power in Turbo mode.

The ISL95521A uses N-channel MOSFETs (NFETs) for all the switches to achieve the best performance and lowest BOM cost. The internal charge pump is capable of turning on all the NFETs fast or slow depending on the circumstance or the need. The ability to quickly turn on NFETs prevents system bus voltage drop when the battery is suddenly removed in Turbo mode or in Battery Learn mode.

The ISL95521A provides many protection features including a PROCHOT# indicator for system low voltage, adapter overcurrent, battery overcurrent or overheating, with an array of SMBus programmable parameters for maximum flexibility. It also features hardware based adapter current limit and battery-current limit in addition to SMBus programmable limits.

The ISL95521A provides a high accuracy adapter current monitor, battery current monitor, and system power monitor outputs. To provide maximum flexibility for working with high power and low power systems, the ISL95521A provides several configurable current-sense resistor value options to achieve the best trade-off of current sensing accuracy vs power loss.

The ISL95521A uses the Renesas Robust Ripple Regulator (R3™) modulation scheme to provide excellent light-load efficiency and fast dynamic response. The ISL95521A is available in a 32 Ld 4x4mm² QFN package.

Features

- Configurable as HPB charger or NVDC charger
- Compliant with Intel PROCHOT# and PSYS requirements
- Adapter current monitor and battery discharging current monitor
- Uses NFET for all the switches
 - Supports battery removal during Battery Learn mode
 - Actively controlled inrush current to prevent FET damage
- SMBus programmable settings and high accuracy
- Comprehensive protection features:
 - PROCHOT# indicator for system low voltage, adapter overcurrent, battery overcurrent, and system overheating
 - Hardware-based adapter current and battery current limits
 - Supports sudden battery removal in system Turbo mode
- 16 switching frequency options from 350kHz to 1MHz
- Low quiescent current
- SMBus and auto-increment I²C compatible
- Robust Ripple Regulator (R3) modulation scheme provides excellent light-load efficiency and fast dynamic response
- 32 Ld 4x4mm² QFN package
- Pb-free (RoHS compliant)

Applications

- Devices with rechargeable 2-, 3-, or 4-cell batteries

Related Literature

For a full list of related documents, visit our website:

- [ISL95521A](#) device page

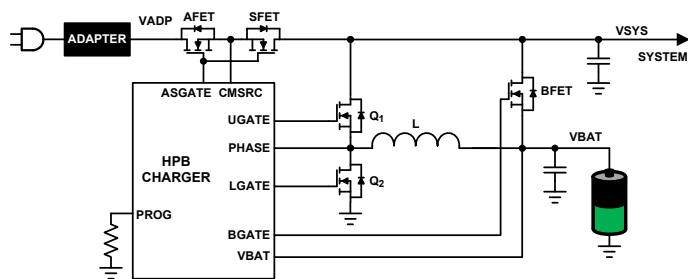


FIGURE 1. HPB CHARGER CONFIGURATION

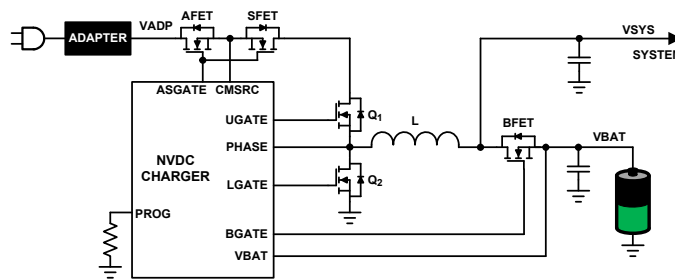


FIGURE 2. NVDC CHARGER CONFIGURATION

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Simplified Application Circuits

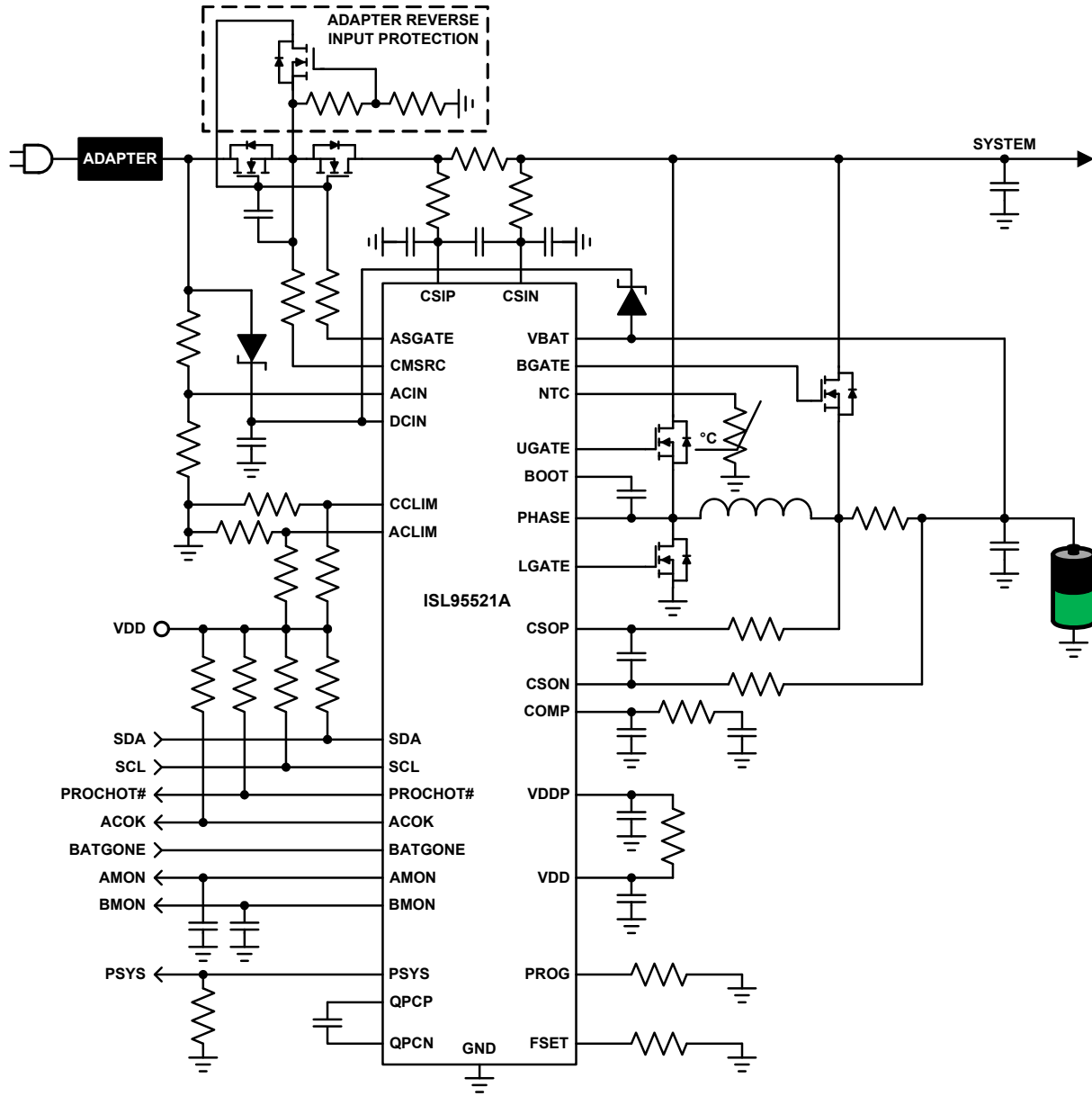


FIGURE 3. TYPICAL APPLICATION CIRCUIT: HPB CHARGER CONFIGURATION WITH TWO NMOS SELECTORS

Simplified Application Circuits (Continued)

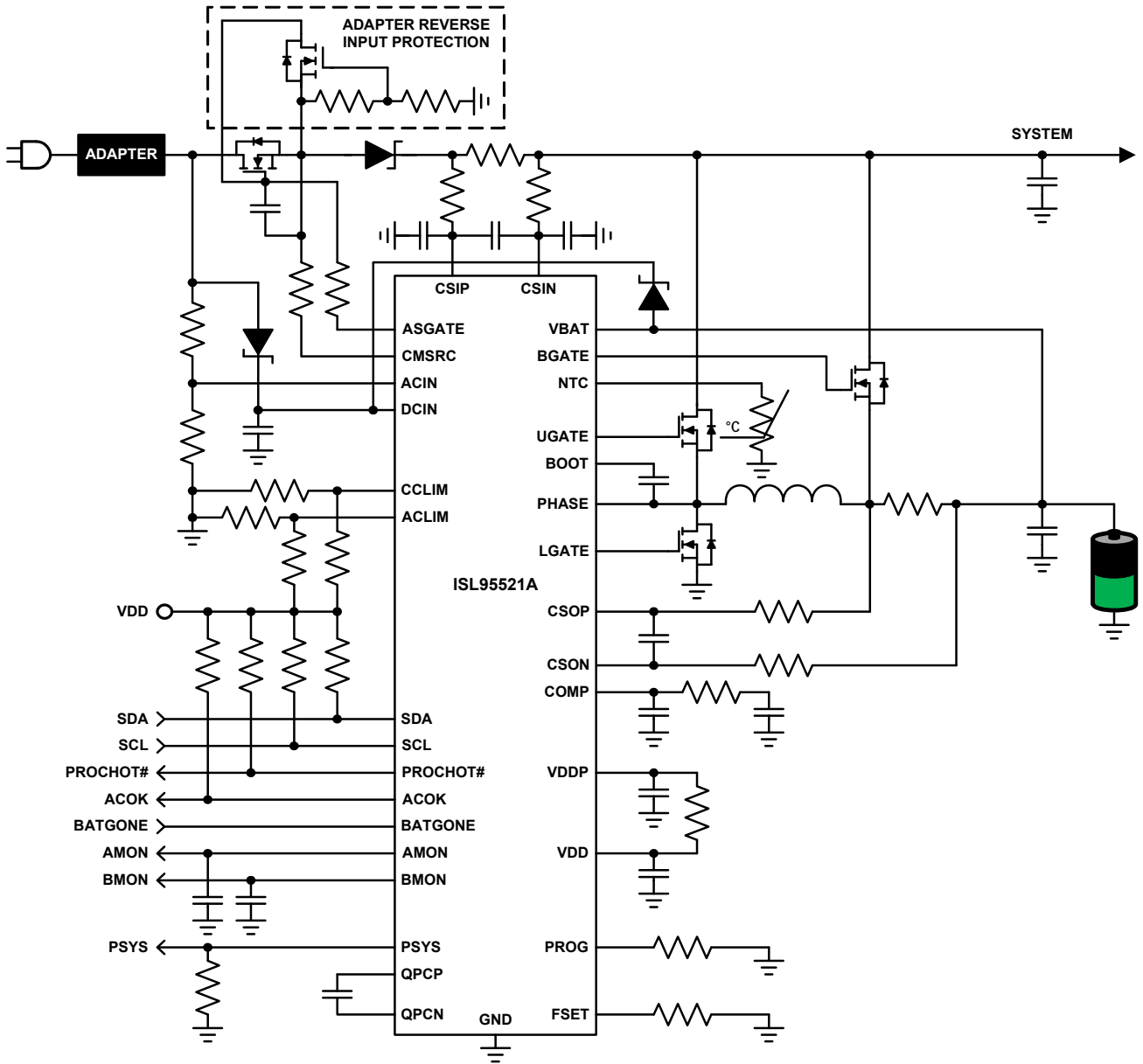


FIGURE 4. TYPICAL APPLICATION CIRCUIT: HPB CHARGER CONFIGURATION WITH ONE NMOS SELECTOR AND SCHOTTKY DIODE

Simplified Application Circuits (Continued)

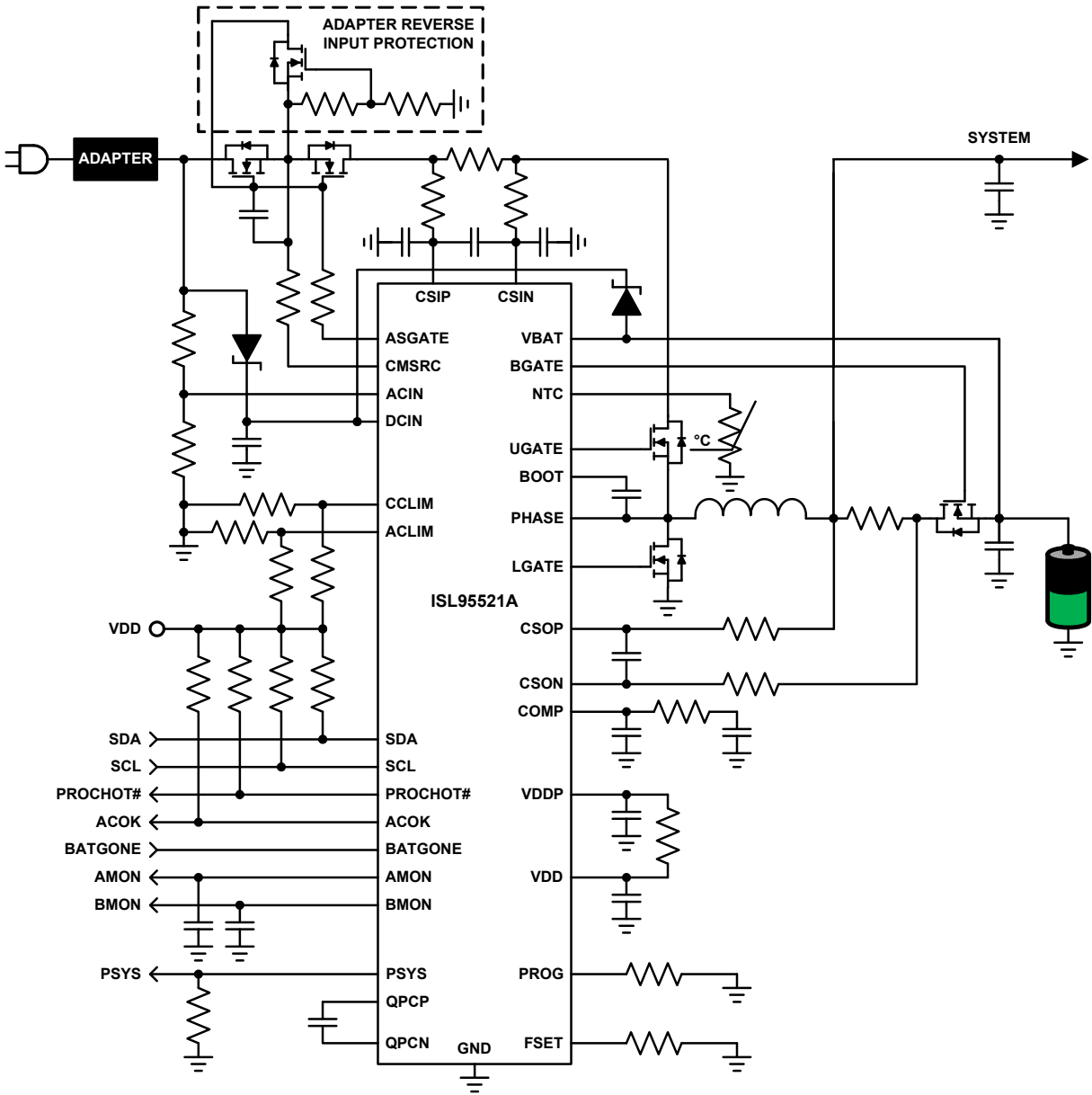


FIGURE 5. TYPICAL APPLICATION CIRCUIT: NVDC CHARGER CONFIGURATION WITH TWO NMOS SELECTORS

Simplified Application Circuits (Continued)

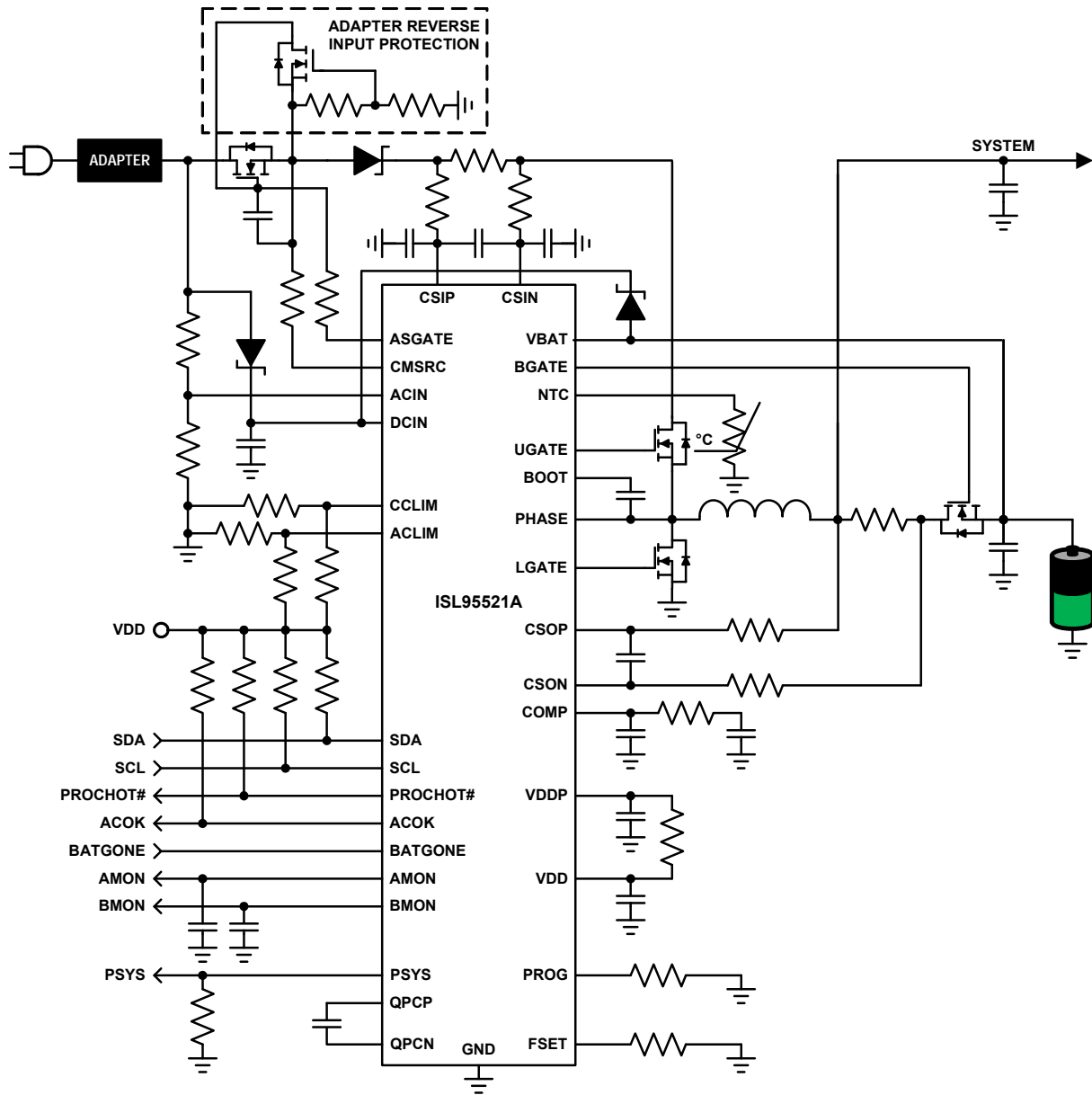


FIGURE 6. TYPICAL APPLICATION CIRCUIT: NVDC CHARGER CONFIGURATION WITH ONE NMOS SELECTOR AND SCHOTTKY DIODE

Block Diagram

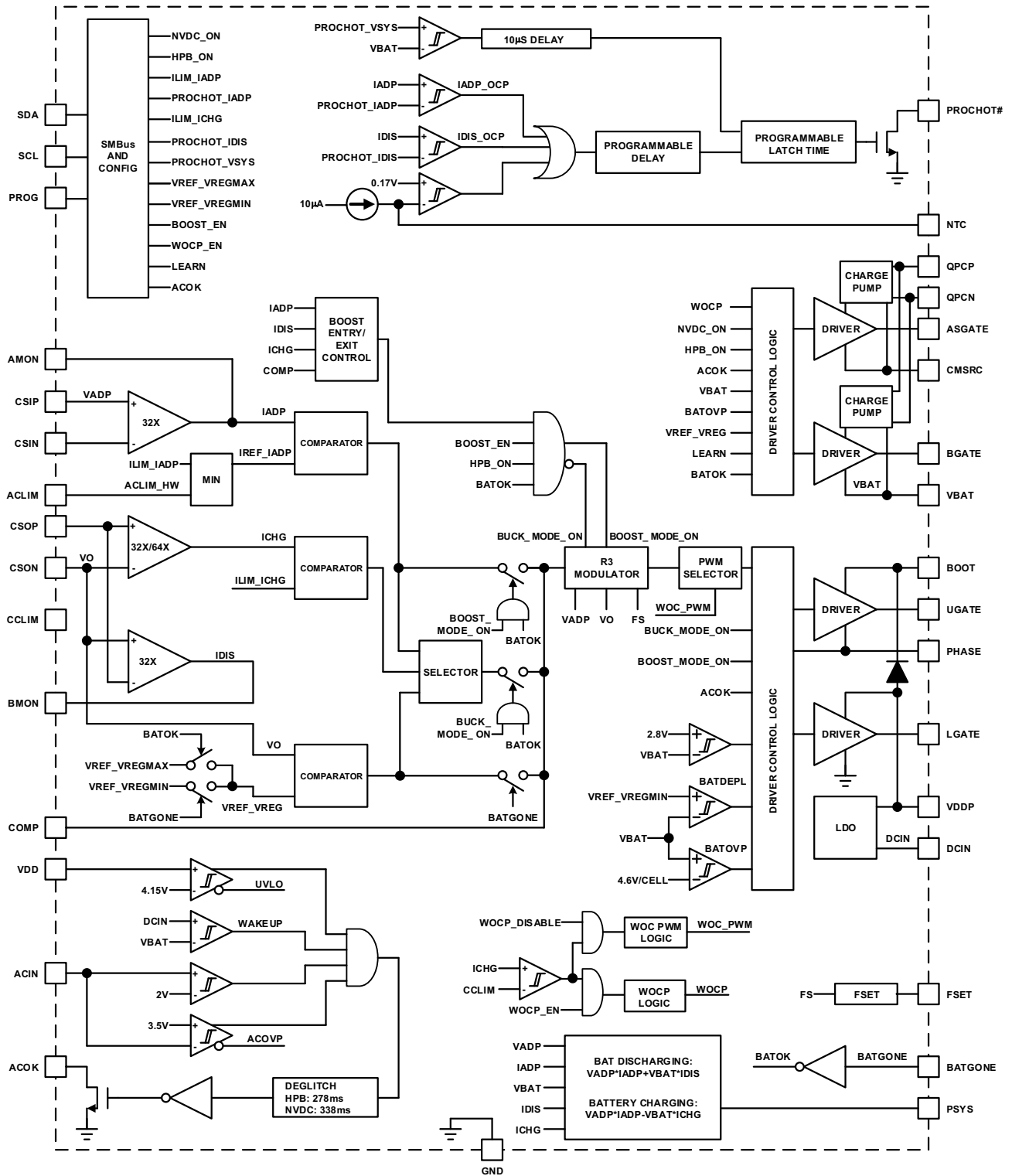


FIGURE 7. BLOCK DIAGRAM

Ordering Information

PART NUMBER (Notes 2, 3)	PART MARKING	TEMP. RANGE (°C)	TAPE AND REEL (UNITS) (Note 1)	PACKAGE (RoHS COMPLIANT)	PKG. DWG. #
ISL95521AHRZ	955 21AHRZ	0 to +85	-	32 Ld 4x4 QFN	L32.4x4A
ISL95521AHRZ-T	955 21AHRZ	0 to +85	6k	32 Ld 4x4 QFN	
ISL95521AIRZ	955 21AIRZ	-40 to +100	-	32 Ld 4x4 QFN	L32.4x4A
ISL95521AIRZ-T	955 21AIRZ	-40 to +100	6k	32 Ld 4x4 QFN	
ISL95521ACOMBO-HYBEVZ	HPB Configuration Evaluation Board				
ISL95521ACOMBONVDCEVZ	NVDC Configuration Evaluation Board				

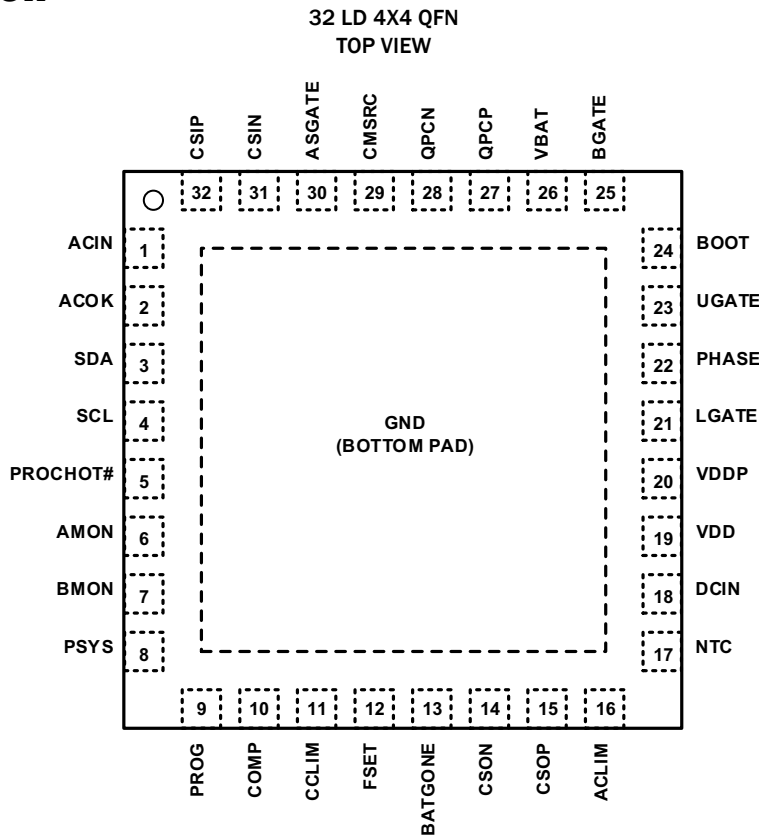
NOTES:

- See [TB347](#) for details on reel specifications.
- 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.
- For Moisture Sensitivity Level (MSL), see the [ISL95521A](#) device page. For more information about MSL see [TB363](#).

TABLE 1. KEY DIFFERENCES BETWEEN FAMILY OF PARTS

	ISL95521A	ISL88739	ISL88750
Charger Type	HPB and NVDC combo	HPB and NVDC combo	NVDC
PSYS	Yes	No	No
PROCHOT# and NTC	Yes	Yes	No

Pin Configuration



Pin Descriptions

PIN #	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 removal.
1	ACIN	Adapter voltage sense. The adapter voltage is "valid" if the ACIN pin voltage is between 2V and 3.5V. If the ACIN pin voltage exceeds 3.5V, the adapter voltage is in the overvoltage condition and turns off the ASGATE MOSFETs to isolate the adapter from the system.
2	ACOK	Open-drain output to indicate adapter voltage is ready. Pulled low if the adapter voltage is not ready.
3	SDA	SMBus data I/O. Connect to the data line from the host controller or smart battery. Connect a 10kΩ pull-up resistor according to the SMBus specification.
4	SCL	SMBus clock I/O. Connect to the clock line from the host controller or smart battery. Connect a 10kΩ pull-up resistor according to the SMBus specification.
5	PROCHOT#	Open-drain output. Pull low with SMBus programmable debounce time if any of the four conditions occur: <ol style="list-style-type: none"> 1. Adapter current reaches PROCHOT_IADP. 2. Battery discharging current reaches PROCHOT_IDIS. 3. System bus voltage is below the low system voltage detection threshold (programmable through SMBus). 4. NTC pin voltage is below 170mV. When asserted, it latches on for a minimum SMBus programmable time before it can be cleared.
6	AMON	Adapter current monitor output. $V_{AMON} = 32 \times (V_{CSIP} - V_{CSIN})$. Leave AMON pin floating if not used.
7	BMON	Battery discharging current monitor. $V_{BMON} = 32 \times (V_{CSOP} - V_{CSIN})$. Leave BMON pin floating if not used.
8	PSYS	System power monitor output. Connect the PSYS pin to GND if not used.
9	PROG	A resistor to GND sets the following configurations: <ol style="list-style-type: none"> 1. HPB charger or NVDC charger. 2. Default number of the battery cells in series. 3. Adapter current sense resistor and battery current sense resistor values. See Table 17 on page 39 for programming options. After POR, pulling the PROG pin to 5V enables learn mode.
10	COMP	Error amplifier output. Connect compensation network externally from COMP to GND.
11	CCLIM	The voltage on this pin sets the WOCP threshold for the current flowing into the battery.
12	FSET	A resistor from this pin to GND programs the default switching frequency. See Table 20 on page 41 for programming options.
13	BATGONE	Battery presence indicator input pin to the ISL95521A. Logic high indicates the battery has been removed. Logic low indicates the battery is present.
14	CSON	Battery current sense "-" input. Also used to sense NVDC charger system voltage.
15	CSOP	Battery current sense "+" input.
16	ACLIM	The voltage on this pin sets the hardware-based adapter current limit. The lower value of the hardware-set adapter current limit and the SMBus set adapter current limit is the actual limit of the adapter current. The hardware-based adapter current limit also sets the regulated inrush current level for ASGATE MOSFET protection.
17	NTC	10μA current source output. Connect an NTC thermistor network from this pin to GND. If the NTC pin voltage is below 170mV, the ISL95521A pulls PROCHOT# low. Other than connecting an NTC thermistor network, this NTC pin comparator can be used as a general purpose comparator for the platform to use.
18	DCIN	Input of an internal 5V output LDO. Renesas recommends connecting a diode-OR from adapter and battery. The DCIN pin voltage needs to be higher than the VBAT pin voltage for ASGATE to soft-start turning on. Connect a 10Ω DCIN resistor between the DCIN pin and the VADP/VSYS diodes, and connect a 4.7μF (50V) DCIN capacitor to GND. The capacitor must have an effective capacitance higher than 0.4μF at 20V.
19	VDD	5V power supply input for the ISL95521A control circuitry. Connect a 2.2μF (10V) MLCC capacitor to GND. The capacitor must have an effective capacitance higher than 0.4μF at 5V and x1.6 effective capacitance at the BOOT pin at 5V.
20	VDDP	Output of the internal 5V output LDO. The ISL95521A uses it as a FET driver power supply. Connect a 2.2μF (10V) MLCC capacitor to GND. The capacitor must have an effective capacitance higher than 0.4μF at 5V and x1.6 effective capacitance at the BOOT pin at 5V.
21	LGATE	Output of the low-side switching FET gate drive. Connect this pin to the gate of the low-side switch FET.

Pin Descriptions (Continued)

PIN #	PIN NAME	DESCRIPTION
22	PHASE	Current return path for the high-side switching FET gate drive. Connect this pin to the node consisting of the high-side switch FET source, the low-side switch FET drain, and the output inductor.
23	UGATE	Output of the high-side switch FET gate drive. Connect this pin to the gate of the high-side switching FET.
24	BOOT	Connect an MLCC capacitor across the BOOT pin and the PHASE pin. The boot capacitor is charged through an internal bootstrap switch connected from the VDDP pin to the BOOT pin, when the PHASE pin drops below VDDP minus the voltage drop across the internal bootstrap switch. Connect a 0.47 μ F (25V) bootstrap capacitor, which must have an effective capacitance higher than 0.25 μ F at 5V and x50 effective high side MOSFET gate capacitance.
25	BGATE	Output of the gate drive for the NFET connecting the system voltage and the battery. The behavior of the BGATE depends on whether the ISL95521A is in HPB charger configuration or NVDC charger configuration.
26	VBAT	Current return path for the BGATE gate drive. Also used to sense battery voltage. Renesas recommends connecting an RC filter at the VBAT pin.
27	QPCP	Internal charge pump "+" input. Connect an MLCC capacitor across the QPCP pin and the QPCN pin.
28	QPCN	Internal charge pump "-" input. Connect an MLCC capacitor across the QPCP pin and the QPCN pin.
29	CMSRC	Common source node of the two back-to-back ASGATE NFETs.
30	ASGATE	Output of the gate drive for the two back-to-back NFETs.
31	CSIN	Adapter current sense "-" input.
32	CSIP	Adapter current sense "+" input. Also used to sense input voltage.

Absolute Maximum Ratings

CSIP, CSIN, DCIN, CMSRC, QPCN	-0.3V to +28V
VBAT, CSOP, CSON	-0.3V to +28V
ASGATE, BGATE, QPCP	-0.3V to +33V
VDD, VDDP	-0.3V to +7V
CSIP-CSIN, CSOP-CSON	-0.3V to +0.3V
QPCP-QPCN	-0.3V to +7V
UGATE-PHASE	-0.3V to +7V
BOOT Voltage (BOOT)	-0.3V to +33V
BOOT to PHASE Voltage (BOOT-PHASE)	-0.3V to +7V (DC)
	-0.3V to +9V (<10ns)
PHASE Voltage (PHASE)	-0.3V to 28V
	-7V (<20ns Pulse Width, 10μJ)
UGATE Voltage (UGATE)	(PHASE - 0.3V) (DC) to BOOT
	(PHASE - 5V) (<20ns Pulse Width, 10μJ) to BOOT
LGATE Voltage	-2.5V (<20ns Pulse Width, 5μJ) to VDDP+0.3V
Open-Drain Outputs, ACOK, PROCHOT#	-0.3V to +7V
All Other Pins	-0.3V to (VDD +0.3V)
ESD Rating	
Human Body Model (Tested per JESD22-A114E)	2.5kV
Charged Device Model (Tested per JESD22-C101A)	750V
Latch-Up (Tested per JESD-78B)	Class 2, Level A

Thermal Information

Thermal Resistance (Typical)	θ_{JA} (°C/W)	θ_{JC} (°C/W)
32 Ld QFN Package (Notes 4, 5)	39	3
Maximum Junction Temperature	+150°C	
Maximum Storage Temperature Range	-65°C to +150°C	
Pb-Free Reflow Profile	see TB493	

Recommended Operating Conditions

Ambient Temperature HRZ	0°C to +85°C
Ambient Temperature IRZ	-40°C to +100°C
Junction Temperature	0°C to +125°C

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:

- θ_{JA} is measured in free air with the component mounted on a high effective thermal conductivity test board with “direct attach” features. See [TB379](#).
- For θ_{JC} , the “case temp” location is the center of the exposed metal pad on the package underside.

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$.**

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
QUIESCENT CURRENT AND POR						
Battery Current	$I_{BAT_BGATE_OFF\ NVDC}$	Adapter present, BGATE off, $V_{BAT} = 16.8V$, DCIN current does not come from battery, $I_{BAT} = I_{VBAT}$		40	75	μA
	$I_{BAT_BGATE_ON\ NVDC}$	Battery only, BGATE on, $V_{BAT} = 16.8V$, DCIN current comes from battery, $I_{BAT} = I_{PHASE} + I_{VBAT} + I_{CSOP} + I_{CSON} + I_{DCIN} + I_{CMSRC}$		130	190	μA
	$I_{BAT_BGATE_OFF\ HPB}$	Adapter present, BGATE off, $V_{BAT} = 16.8V$, DCIN current does not come from battery, $I_{BAT} = I_{PHASE} + I_{VBAT} + I_{CSOP} + I_{CSON} + I_{CMSRC}$		43	75	μA
	$I_{BAT_BGATE_ON\ HPB}$	Battery only, BGATE on, $V_{BAT} = 16.8V$, DCIN current comes from battery, $I_{BAT} = I_{PHASE} + I_{VBAT} + I_{CSOP} + I_{CSON} + I_{DCIN} + I_{CSIP} + I_{CSIN} + I_{CMSRC}$		130	190	μA
Quiescent Current	$I_{DCIN_STANDBY\ HPB}$	VADP = 19.2V, AMON, BMON, PSYS all OFF		160	220	μA
	$I_{DCIN_NOSW_1\ HPB}$	VADP = 19.2V, no switching, AMON, BMON, PSYS all OFF		785	900	μA
	$I_{DCIN_NOSW_2\ HPB}$	VADP = 19.2V, no switching, AMON, BMON, PSYS all ON		1070	1250	μA
	$I_{DCIN_SW_H\ HPB}$	VADP = 19.2V, charge enabled, AMON, BMON, PSYS all OFF		1.52	1.82	mA
	$I_{DCIN_SW_N\ NVDC}$	VADP = 19.2V, charge enabled, AMON, BMON, PSYS all OFF		1.45	1.75	mA
VDD Power-On Reset (POR)	POR_{VDD_R}	VDD rising		4.66	4.75	V
	POR_{VDD_F}	VDD falling	4.35	4.44		mV

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
CHARGING VOLTAGE LIMIT						
Maximum Charging Voltage Accuracy	V_{CHG_MAX}	MaxChargeVoltage = 0x41A0H (16.8V) $T_A = 0^\circ C$ to $+85^\circ C$		16.79		V
			-0.75		0.75	%
		MaxChargeVoltage = 0x41A0H (16.8V) $T_A = -40^\circ C$ to $+100^\circ C$	-0.85		0.85	%
		MaxChargeVoltage = 0x3140H (12.608V) $T_A = 0^\circ C$ to $+85^\circ C$		12.6		V
			-0.75		0.75	%
		MaxChargeVoltage = 0x3140H (12.608V) $T_A = -40^\circ C$ to $+100^\circ C$	-0.85		0.85	%
		MaxChargeVoltage = 0x20D0H (8.4V) $T_A = 0^\circ C$ to $+85^\circ C$		8.4		V
	-0.75		0.75	%		
	-0.85		0.85	%		
Minimum Charging Voltage Accuracy (NVDC 450mV + MinChargeVoltage register setting)	V_{CHG_MIN}	MinChargeVoltage = 0x2A00H (10.752V) $T_A = 0^\circ C$ to $+85^\circ C$	11.02	11.20	11.40	V
		MinChargeVoltage = 0x2A00H (10.752V) $T_A = -40^\circ C$ to $+100^\circ C$	11.02		11.43	V
		MinChargeVoltage = 0x2000H (8.192V) $T_A = 0^\circ C$ to $+85^\circ C$	8.48	8.64	8.84	V
		MinChargeVoltage = 0x2000H (8.192V) $T_A = -40^\circ C$ to $+100^\circ C$	8.48		8.86	V
		MinChargeVoltage = 0x1500H (5.376V) $T_A = 0^\circ C$ to $+85^\circ C$	5.680	5.825	6	V
		MinChargeVoltage = 0x1500H (5.376V) $T_A = -40^\circ C$ to $+100^\circ C$	5.680		6.010	V
BATTERY CURRENT LIMIT						
Battery Current Sense Amplifier Input Differential Voltage Range	V_{IBAT_RGE5}	$R_{S2} = 5m\Omega$, charging current ($V_{CSOP} - V_{CSON}$)	0		40.5	mV
	V_{IBAT_RGE10}	$R_{S2} = 10m\Omega$ or $R_{S2} = 20m\Omega$, charging current ($V_{CSOP} - V_{CSON}$)	0		81	mV
	V_{IBAT_RGED}	Discharging current ($V_{CSOP} - V_{CSON}$)	-81		0	mV

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$ or -40°C to $+100^\circ\text{C}$ unless otherwise noted. **Boldface limits apply across the operating temperature range, 0°C to $+85^\circ\text{C}$ or -40°C to $+100^\circ\text{C}$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT	
Charging Current Limit $R_{S2} = 10\text{m}\Omega$ $V_{BAT} > 4.5V$	$I_{\text{CHG_ACC10}}$	ChargeCurrentLimit = 0x1F20H (7968mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		8000		mA	
			-2.1	0.4	3.4	%	
		ChargeCurrentLimit = 0x1F20H (7968mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$				3.5	%
			-2.2				
		ChargeCurrentLimit = 0x0FA0H (4000mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		4025			mA
			-2.4	0.6	3.8	%	
		ChargeCurrentLimit = 0x0FA0H (4000mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$				4	%
			-2.6				
		ChargeCurrentLimit = 0x07E0H (2016mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		2030			mA
			-3.6	0.7	5.4	%	
		ChargeCurrentLimit = 0x07E0H (2016mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$				5.9	%
			-4.1				
		ChargeCurrentLimit = 0x03E0H (992mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		1006			mA
			-5	1.4	7.9	%	
		ChargeCurrentLimit = 0x03E0H (992mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$				8.9	%
	-6						
ChargeCurrentLimit = 0x0200H (512mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		525			mA		
	-8.4	2.5	12.3	%			
ChargeCurrentLimit = 0x0200H (512mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$				14.3	%		
	-10						
ChargeCurrentLimit = 0x0100H (256mA) (Not trickle charging mode current) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		256			mA		
	-22.7	0	21.1	%			
ChargeCurrentLimit = 0x0100H (256mA) (Not trickle charging mode current) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$				25.1	%		
	-27						

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT	
Charging Current Limit $R_{S2} = 5m\Omega$ $V_{BAT} > 4.5V$	I_{CHG_ACC5}	ChargeCurrentLimit = 0x1F20H (7968mA) $T_A = 0^\circ C$ to $+85^\circ C$		8015		mA	
			-2.4	0.6	3.8	%	
		ChargeCurrentLimit = 0x1F20H (7968mA) $T_A = -40^\circ C$ to $+100^\circ C$	-2.6		4	%	
		ChargeCurrentLimit = 0x0FA0H (4000mA) $T_A = 0^\circ C$ to $+85^\circ C$		4030		mA	
			-3.2	0.8	4.3	%	
		ChargeCurrentLimit = 0x0FA0H (4000mA) $T_A = -40^\circ C$ to $+100^\circ C$	-3.7		4.8	%	
		ChargeCurrentLimit = 0x07E0H (2016mA) $T_A = 0^\circ C$ to $+85^\circ C$		2035		mA	
			-5	0.9	6.3	%	
		ChargeCurrentLimit = 0x07E0H (2016mA) $T_A = -40^\circ C$ to $+100^\circ C$	-6		7.3	%	
		ChargeCurrentLimit = 0x03E0H (992mA) $T_A = 0^\circ C$ to $+85^\circ C$		1008		mA	
			-9.1	1.6	10.3	%	
		ChargeCurrentLimit = 0x03E0H (992mA) $T_A = -40^\circ C$ to $+100^\circ C$	-11		12.3	%	
		ChargeCurrentLimit = 0x0200H (512mA) $T_A = 0^\circ C$ to $+85^\circ C$		523		mA	
			-17.4	2.1	16.8	%	
ChargeCurrentLimit = 0x0200H (512mA) $T_A = -40^\circ C$ to $+100^\circ C$	-21		20.8	%			
ChargeCurrentLimit = 0x0100H (256mA) (Not trickle charging mode current) $T_A = 0^\circ C$ to $+85^\circ C$		248		mA			
	-42	-3	27	%			
ChargeCurrentLimit = 0x0100H (256mA) (Not trickle charging mode current) $T_A = -40^\circ C$ to $+100^\circ C$	-50		35	%			
Trickle Charging Current Limit	$I_{TRKL_ACC10_256}$	$R_{S2} = 10m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = 0^\circ C$ to $+85^\circ C$	210	265	310	mA	
		$R_{S2} = 10m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = -40^\circ C$ to $+100^\circ C$	200		315	mA	
	$I_{TRKL_ACC10_128}$	$R_{S2} = 10m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = 0^\circ C$ to $+85^\circ C$	85	135	180	mA	
		$R_{S2} = 10m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = -40^\circ C$ to $+100^\circ C$	75		185	mA	
	$I_{TRKL_ACC5_256}$	$R_{S2} = 5m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = 0^\circ C$ to $+85^\circ C$	165	255	330	mA	
		$R_{S2} = 5m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = -40^\circ C$ to $+100^\circ C$	145		340	mA	
	$I_{TRKL_ACC5_128}$	$R_{S2} = 5m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = 0^\circ C$ to $+85^\circ C$	32	120	208	mA	
		$R_{S2} = 5m\Omega$, $V_{BAT} < \text{MinChargeVoltage}$ $T_A = -40^\circ C$ to $+100^\circ C$	12		215	mA	
	V_{BAT} Trickle Charging Threshold	$V_{TRKL_TH_R}$	MinChargeVoltage = 4.096V, exit trickle charging mode		4.39	4.57	V
		$V_{TRKL_TH_F}$	MinChargeVoltage = 4.096V, enter trickle charging mode	3.85	4.03		V

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$ or -40°C to $+100^\circ\text{C}$ unless otherwise noted. **Boldface limits apply across the operating temperature range, 0°C to $+85^\circ\text{C}$ or -40°C to $+100^\circ\text{C}$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
Discharging Current PROCHOT# Threshold $R_{S2} = 5\text{m}\Omega$	$I_{DIS_HOT_TH5}$	DCProchot = 0x2A00H (10752mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		10848		mA
			-3.5	0.9	5.3	%
		DCProchot = 0x2A00H (10752mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-3.6		5.3	%
		DCProchot = 0x1500H (5376mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		5450		mA
		$T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	-6.4	1.4	9.2	%
		DCProchot = 0x1500H (5376mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-6.5		9.2	%
ADAPTER CURRENT LIMIT						
Adapter Current Sense Amplifier Input Differential Voltage Range	V_{IADP_RGE}	$R_{S1} = 10\text{m}\Omega$ or $R_{S1} = 20\text{m}\Omega$, adapter current ($V_{CSIP} - V_{CSIN}$)	0		81	mV
Adapter Current Limit $R_{S1} = 10\text{m}\Omega$	I_{ADP_10}	AdapterCurrentLimit = 0x1F20H (8064mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		8115		mA
			-1.2	0.6	2.5	%
		AdapterCurrentLimit = 0x1F20H (8064mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-1.2		2.6	%
		AdapterCurrentLimit = 0x1000H (4096mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		4140		mA
			-1.3	1.1	3.5	%
		AdapterCurrentLimit = 0x1000H (4096mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-1.3		3.7	%
		AdapterCurrentLimit = 0x0800H (2048mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		2075		mA
			-2.5	1.3	5.2	%
		AdapterCurrentLimit = 0x0800H (2048mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-2.5		5.7	%
		AdapterCurrentLimit = 0x0400H (1024mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		1055		mA
			-4	3	10	%
		AdapterCurrentLimit = 0x0400H (1024mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-4		11	%
		AdapterCurrentLimit = 0x0200H (512mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		545		mA
			-6	6.5	19	%
AdapterCurrentLimit = 0x0200H (512mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-6		21	%		
AdapterCurrentLimit = 0x0100H (256mA) $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$		290		mA		
	-12.0	13.3	40.0	%		
AdapterCurrentLimit = 0x0100H (256mA) $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-12.0		44	%		
Adapter Current PROCHOT# Threshold $R_{S1} = 10\text{m}\Omega$	$I_{ADP_HOT_TH10}$	ACProchot = 0x1500H (5376mA)		5389		mA
			-3.50	0.25	4	%
		ACProchot = 0x0A80H (2688mA)		2728		mA
		$T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	-7.0	1.5	10.0	%

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
MONITOR						
AMON Accuracy $V_{AMON} = 32x(V_{CSIP} - V_{CSIN})$ $R_{s1} = 10m\Omega$	V_{AMON}	$V_{CSIP} - V_{CSIN} = 80mV$ $T_A = 0^\circ C$ to $+85^\circ C$		2544		mV
			-2.5	-0.6	1.3	%
		$V_{CSIP} - V_{CSIN} = 80mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-2.7		1.5	%
		$V_{CSIP} - V_{CSIN} = 40mV$ $T_A = 0^\circ C$ to $+85^\circ C$		1269		mV
			-3.50	-0.85	1.80	%
		$V_{CSIP} - V_{CSIN} = 40mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-3.9		2.2	%
		$V_{CSIP} - V_{CSIN} = 20mV$ $T_A = 0^\circ C$ to $+85^\circ C$		632		mV
			-6.00	-1.25	3.50	%
		$V_{CSIP} - V_{CSIN} = 20mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-6.8		4.3	%
		$V_{CSIP} - V_{CSIN} = 10mV$ $T_A = 0^\circ C$ to $+85^\circ C$		313		mV
			-10.0	-2.2	6.6	%
	$V_{CSIP} - V_{CSIN} = 10mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-11.6		8.2	%	
	$V_{CSIP} - V_{CSIN} = 5mV$ $T_A = 0^\circ C$ to $+85^\circ C$		154		mV	
		-19.50	-3.75	12.50	%	
	$V_{CSIP} - V_{CSIN} = 5mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-22.5		15.5	%	
AMON Current Sourcing Capability	$I_{AMON_MAX_SR}$	$T_A = 0^\circ C$ to $+85^\circ C$	255	515	800	μA
		$T_A = -40^\circ C$ to $+100^\circ C$	205		850	μA
AMON Current Sinking Capability	$I_{AMON_MAX_SK}$		12	22	32	μA
BMON Accuracy $V_{BMON} = 32x(V_{CSON} - V_{CSOP})$ $R_{s2} = 10m\Omega$	V_{BMON}	$V_{CSON} - V_{CSOP} = 80mV$ $T_A = 0^\circ C$ to $+85^\circ C$		2562		mV
			-3.70	0.08	3.70	%
		$V_{CSON} - V_{CSOP} = 80mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-3.70		4.10	%
		$V_{CSON} - V_{CSOP} = 40mV$ $T_A = 0^\circ C$ to $+85^\circ C$		1284		mV
			-4.2	0.3	4.7	%
		$V_{CSON} - V_{CSOP} = 40mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-4.2		5.1	%
		$V_{CSON} - V_{CSOP} = 20mV$ $T_A = 0^\circ C$ to $+85^\circ C$		645		mV
			-5.70	0.75	7.40	%
		$V_{CSON} - V_{CSOP} = 20mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-5.70		7.9	%
	$V_{CSON} - V_{CSOP} = 10mV$ $T_A = 0^\circ C$ to $+85^\circ C$		325		mV	
		-7.5	1.7	11.5	%	
	$V_{CSON} - V_{CSOP} = 10mV$ $T_A = -40^\circ C$ to $+100^\circ C$	-7.5		12.5	%	
BMON Current Sourcing Capability	$I_{BMON_MAX_SR}$	$T_A = 0^\circ C$ to $+85^\circ C$	120	285	460	μA
		$T_A = -40^\circ C$ to $+100^\circ C$	90		490	μA
BMON Current Sinking Capability	$I_{BMON_MAX_SK}$		5.5	11.4	17.5	μA

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT	
PSYS Output Current $R_{s1} = 10m\Omega$ $R_{s2} = 10m\Omega$ PSYS Current Gain = $1.14\mu A/W$	I_{PSYS}	$V_{CSIP} = 19V$, $V_{CSIP} - V_{CSIN} = 80mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = 0mV$ $T_A = 0^\circ C$ to $+85^\circ C$		174		μA	
			-8.3	0.4	9.1	%	
		$V_{CSIP} = 19V$, $V_{CSIP} - V_{CSIN} = 80mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = 0mV$ $T_A = -40^\circ C$ to $+100^\circ C$				9.1	%
				146.5			μA
		$V_{CSIP} = 19V$, $V_{CSIP} - V_{CSIN} = 80mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = 20mV$ $T_A = 0^\circ C$ to $+85^\circ C$		-8.2	0.4	9	%
		$V_{CSIP} = 19V$, $V_{CSIP} - V_{CSIN} = 80mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = 20mV$ $T_A = -40^\circ C$ to $+100^\circ C$		-9.6		9	%
		$V_{CSIP} = 19V$, $V_{CSIP} - V_{CSIN} = 80mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = -20mV$ $T_A = 0^\circ C$ to $+85^\circ C$			199.5		μA
			-8.4	-0.6	7.2	%	
		$V_{CSIP} = 19V$, $V_{CSIP} - V_{CSIN} = 80mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = -20mV$ $T_A = -40^\circ C$ to $+100^\circ C$		-13.2		7.2	%
		$V_{CSIP} = 0V$, $V_{CSIP} - V_{CSIN} = 0mV$, $V_{BAT} = 12V$, $V_{CSOP} - V_{CSON} = -20mV$ $T_A = 0^\circ C$ to $+85^\circ C$			26.2		μA
	-15.2	-4.2	6.8	%			
	-15.6			6.8	%		
Maximum PSYS Output Voltage	V_{PSYS_MAX}	$I_{PSYS} = 200\mu A$		2.25		V	
NTC Source Current	I_{NTC}	NTC = $1V$	9.71	10.08	10.44	μA	
NTC_PROCHOT# Trip Threshold	V_{NTC_TH}	V_{NTC} falling $T_A = 0^\circ C$ to $+85^\circ C$	161	171	182	mV	
		V_{NTC} falling $T_A = -40^\circ C$ to $+100^\circ C$	161		183	mV	
NTC_PROCHOT# Hysteresis	V_{NTC_HYS}	$T_A = 0^\circ C$ to $+85^\circ C$	18	27	36	mV	
		$T_A = -40^\circ C$ to $+100^\circ C$	18		37	mV	
ACIN/ACOK COMPARATOR							
ACIN Threshold Rising	$V_{ACIN_TH_R}$	V_{ACIN} rising $T_A = 0^\circ C$ to $+85^\circ C$		2.041	2.070	V	
		V_{ACIN} rising $T_A = -40^\circ C$ to $+100^\circ C$			2.075	V	
ACIN Threshold Falling	$V_{ACIN_TH_F}$	V_{ACIN} falling $T_A = 0^\circ C$ to $+85^\circ C$	1.995	2.024		V	
		V_{ACIN} falling $T_A = -40^\circ C$ to $+100^\circ C$	1.990			V	
ACIN OVP Rising	$V_{ACIN_OVP_TH_R}$	V_{ACIN} rising $T_A = 0^\circ C$ to $+85^\circ C$		3.5	3.7	V	
		V_{ACIN} rising $T_A = -40^\circ C$ to $+100^\circ C$			3.705	V	
ACIN OVP Falling	$V_{ACIN_OVP_TH_F}$	V_{ACIN} falling $T_A = 0^\circ C$ to $+85^\circ C$	3.30	3.45		V	
		V_{ACIN} falling $T_A = -40^\circ C$ to $+100^\circ C$	3.295			V	
ACIN Input Leakage Current	I_{ACIN_LEAK}		-1		1	μA	
ACOK Input Leakage Current	I_{ACOK_LEAK}		-1		1	μA	
ACOK Output Low Current	I_{ACOK}	$V_{ACOK} = 0.3V$		240		μA	

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface** limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$. (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
ACLIM, CCLIM						
ACLIM Current Limit		$V_{ACLIM} = 2.56V$, $R_{S1} = 10m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	7970	8075	8175	mA
		$V_{ACLIM} = 2.56V$, $R_{S1} = 10m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	7970		8185	mA
		$V_{ACLIM} = 1.92V$, $R_{S1} = 10m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	5970	6060	6150	mA
		$V_{ACLIM} = 1.92V$, $R_{S1} = 10m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	5970		6160	mA
		$V_{ACLIM} = 1.28V$, $R_{S1} = 10m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	3975	4050	4125	mA
		$V_{ACLIM} = 1.28V$, $R_{S1} = 10m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	3975		4135	mA
CCLIM Current Limit		$V_{CCLIM} = 2.56V$, $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	7855	8070	8265	mA
		$V_{CCLIM} = 2.56V$, $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	7835		8285	mA
		$V_{CCLIM} = 1.92V$, $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	5875	6050	6205	mA
		$V_{CCLIM} = 1.92V$, $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	5865		6215	mA
		$V_{CCLIM} = 1.28V$, $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	3900	4035	4155	mA
		$V_{CCLIM} = 1.28V$, $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	3890		4165	mA
		$V_{CCLIM} = 2.56V$, $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	7860	8065	8250	mA
		$V_{CCLIM} = 2.56V$, $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	7850		8270	mA
		$V_{CCLIM} = 1.92V$, $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	5895	6045	6185	mA
		$V_{CCLIM} = 1.92V$, $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	5890		6195	mA
		$V_{CCLIM} = 1.28V$, $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	3930	4035	4135	mA
		$V_{CCLIM} = 1.28V$, $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	3925		4145	mA
		$V_{CCLIM} = 2.56V$, $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	3930	4030	4130	mA
		$V_{CCLIM} = 2.56V$, $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	3925		4135	mA
		$V_{CCLIM} = 1.92V$, $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	2945	3025	3100	mA
		$V_{CCLIM} = 1.92V$, $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	2940		3105	mA
		$V_{CCLIM} = 1.28V$, $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$ $T_A = 0^\circ C$ to $+85^\circ C$	1960	2015	2075	mA
		$V_{CCLIM} = 1.28V$, $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$ $T_A = -40^\circ C$ to $+100^\circ C$	1955		2080	mA

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$ or -40°C to $+100^\circ\text{C}$ unless otherwise noted. **Boldface limits apply across the operating temperature range, 0°C to $+85^\circ\text{C}$ or -40°C to $+100^\circ\text{C}$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
PROCHOT#						
PROCHOT# Leakage Current	$I_{\text{PROCHOT\#_LEAK}}$		-1		1	μA
PROCHOT# Output Low Current	$I_{\text{PROCHOT\#}}$	$V_{\text{PROCHOT\#}} = 0.3V$		42		mA
Low VSYS PROCHOT# Trip Threshold	$V_{\text{LOW_VSYS_HOT}}$	Control1 register Bit<9:8> = 00 $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	5.48	5.62	5.76	V
		Control1 register Bit<9:8> = 00 $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	5.470		5.765	V
		Control1 register Bit<9:8> = 01 $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	5.97	6.11	6.25	V
		Control1 register Bit<9:8> = 01 $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	5.960		6.255	V
		Control1 register Bit<9:8> = 10 $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	6.44	6.59	6.73	V
		Control1 register Bit<9:8> = 10 $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	6.430		6.735	V
		Control1 register Bit<9:8> = 11 $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	6.90	7.05	7.20	V
		Control1 register Bit<9:8> = 11 $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	6.890		7.205	V
PROCHOT# Debounce Time		PROCHOT# debounce register Bit<1:0> = 01		102		μs
		PROCHOT# debounce register Bit<1:0> = 10		510		μs
PROCHOT# Duration Time		PROCHOT# duration register Bit<2:0> = 010		15.3		ms
		PROCHOT# duration register Bit<2:0> = 101		1.02		ms
BATGONE THRESHOLD						
BATGONE Threshold Rising	$V_{\text{BATGONE_TH_R}}$	V_{BATGONE} rising (battery removal)		2.58	2.75	V
BATGONE Threshold Falling	$V_{\text{BATGONE_TH_F}}$	V_{BATGONE} falling (battery insertion)	1.80	2.12		V
LDO						
Output Voltage		$V_{\text{DCIN}} = 6V$ to $25V$, $I_{\text{VDDP}} = 1\text{mA}$ $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	4.80	5.24	5.75	V
		$V_{\text{DCIN}} = 6V$ to $25V$, $I_{\text{VDDP}} = 1\text{mA}$ $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	4.75		5.80	V
		$V_{\text{DCIN}} = 6V$, $I_{\text{VDDP}} = 30\text{mA}$ $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	4.65	5.12	5.65	V
		$V_{\text{DCIN}} = 6V$, $I_{\text{VDDP}} = 30\text{mA}$ $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	4.55		5.65	V
		$V_{\text{DCIN}} = 25V$, $I_{\text{VDDP}} = 30\text{mA}$ $T_A = 0^\circ\text{C}$ to $+85^\circ\text{C}$	4.75	5.22	5.70	V
		$V_{\text{DCIN}} = 25V$, $I_{\text{VDDP}} = 30\text{mA}$ $T_A = -40^\circ\text{C}$ to $+100^\circ\text{C}$	4.70		5.75	V
GATE DRIVER						
UGATE Pull-up Resistance (Note 7)	R_{UGPU}	200mA source current		1.0	1.5	Ω
UGATE Source Current	I_{UGSRC}	UGATE - PHASE = 2.5V		2.0		A
UGATE Sink Resistance (Note 7)	R_{UGPD}	250mA sink current		1.0	1.5	Ω
UGATE Sink Current	I_{UGSNK}	UGATE - PHASE = 2.5V		2.0		A
LGATE Pull-up Resistance (Note 7)	R_{LGPU}	250mA source current		1.0	1.5	Ω
LGATE Source Current	I_{LGSRC}	LGATE - GND = 2.5V		2.0		A
LGATE Sink Resistance (Note 7)	R_{LGPD}	250mA sink current		0.5	0.9	Ω
LGATE Sink Current	I_{LGSNK}	LGATE - GND = 2.5V		4.0		A

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^\circ C$ to $+85^\circ C$ or $-40^\circ C$ to $+100^\circ C$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
UGATE to LGATE Dead Time	t_{UGFLGR}	UGATE falling to LGATE rising, no load		17		ns
LGATE to UGATE Dead Time	t_{LGFUGR}	LGATE falling to UGATE rising, no load		29		ns
ASGATE Pull-Up Resistance	R_{ASGPU}	1mA source current		500		Ω
ASGATE Sink Resistance	R_{ASGPD}	1mA sink current		1300		Ω
BGATE Pull-Up Resistance	R_{BGPU}	1mA source current		500		Ω
BGATE Sink Resistance	R_{BGPD}	1mA sink current		1300		Ω
BOOTSTRAP SWITCH						
ON-Resistance	R_F			20		Ω
Reverse Leakage	I_R	$V_R = 25V$		0.2		μA
AMPLIFIERS						
Adapter Current Sense Amplifier Input Offset	V_{ACSNS_OFFSET}			0.4		mV
Battery Charging Current Sense Amplifier Input Offset	$V_{ICHGSNS_OFFSET}$			0.4		mV
Battery Discharging Current Sense Amplifier Input Offset	$V_{IDISSNS_OFFSET}$			0.4		mV
Error Amplifier DC Gain	A_{VO_EA}			80		dB
Error Amp Gain-bandwidth Product	GBW_EA	$C_L = 20pF$		5		MHz
COMP Lower Clamp	$V_{COMP_L_CLP}$			1.24	1.40	V
COMP Upper Clamp	$V_{COMP_U_CLP}$		4.90	4.99		V
OVER-TEMPERATURE PROTECTION						
Over-Temperature Threshold	T_{OTP_R}	Temperature rising		155		$^\circ C$
	T_{OTP_F}	Temperature falling		128		$^\circ C$
SMBUS						
SDA/SCL Input Low Voltage					0.8	V
SDA/SCL Input High Voltage			2			V
SDA/SCL Input Bias Current		SDA, SCL = 0V, 5V	-1		1	μA
SDA, Output Sink Current (Note 8)		SDA = 0.4V		19		mA
SMBus Frequency	f_{SMB}	(Note 8)	10		400	kHz
Bus Free Time	t_{BUF}	100kHz, (Note 8)	4.7			μs
		400kHz, (Note 8)	1.3			μs
Start Condition Hold Time from SCL	t_{HD_STA}	100kHz, (Note 8)	4			μs
		400kHz, (Note 8)	0.6			μs
Start Condition Set-Up Time from SCL	t_{SU_STA}	100kHz, (Note 8)	4.7			μs
		400kHz, (Note 8)	0.6			μs
Stop Condition Set-Up Time from SCL	t_{HD_STO}	100kHz, (Note 8)	4			μs
		400kHz, (Note 8)	0.6			μs
SDA Hold Time from SCL	t_{HD_DAT}	100kHz, (Note 8)	300			ns
		400kHz, (Note 8)	300			ns
SDA Set-Up Time from SCL	t_{SU_DAT}	100kHz, (Note 8)	250			ns
		400kHz, (Note 8)	100			ns
SCL Low Period	t_{LOW}	100kHz, (Note 8)	4.7			μs
		400kHz, (Note 8)	1.3			μs
SCL High Period	t_{HIGH}	100kHz, (Note 8)	4			μs
		400kHz, (Note 8)	0.6			μs

Electrical Specifications Operating Conditions: $V_{DD} = 5V$, $T_A = 0^{\circ}C$ to $+85^{\circ}C$ or $-40^{\circ}C$ to $+100^{\circ}C$ unless otherwise noted. **Boldface limits apply across the operating temperature range, $0^{\circ}C$ to $+85^{\circ}C$ or $-40^{\circ}C$ to $+100^{\circ}C$.** (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN (Note 6)	TYP	MAX (Note 6)	UNIT
SDA/SCL Rise Time	t_{RISE}	100kHz, 400pF, maximum load, (Note 8)			1000	ns
		400kHz, 400pF, maximum load, (Note 8)			300	ns
SDA/SCL Fall Time	t_{FALL}	100kHz, 400pF, maximum load, (Note 8)			300	ns
		400kHz, 400pF, maximum load, (Note 8)			300	ns
SMBus Inactivity Time-Out (Note 8)		Maximum period without a SMBus write to MaxChargeVoltage or ChargeCurrent register		175		s

NOTES:

- Parameters with MIN and/or MAX limits are 100% tested at $+25^{\circ}C$, unless otherwise specified. Temperature limits established by characterization and are not production tested.
- Limits established by characterization and are not production tested.
- Compliance to datasheet limits is assured by one or more methods: production test, characterization, and/or design.

Gate Driver Timing Diagram

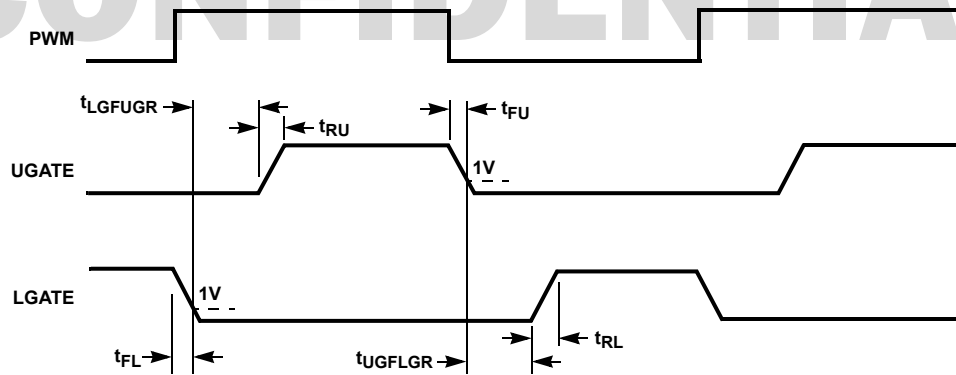


FIGURE 8. GATE DRIVER TIMING DIAGRAM

Typical Performance

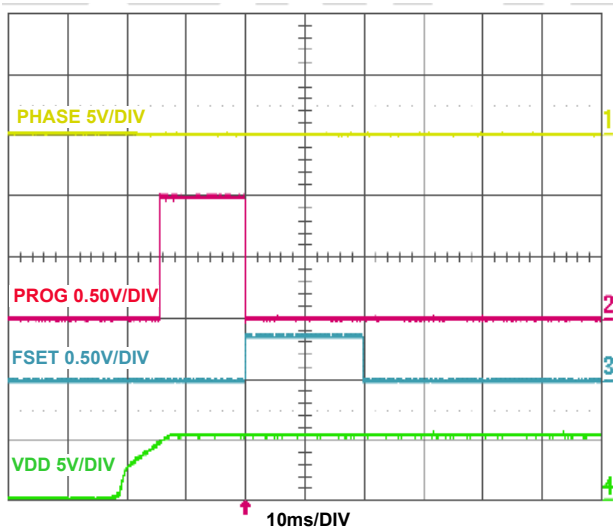


FIGURE 9. POWER-UP, READ PROG, AND FSET RESISTORS

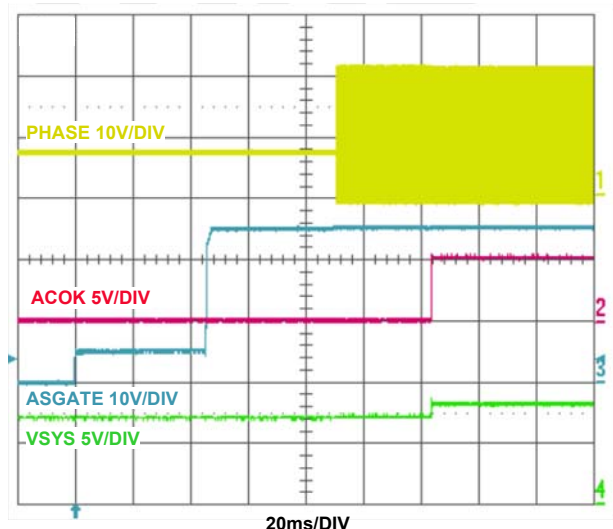


FIGURE 10. NVDC: ADAPTER INSERTION START-UP SEQUENCE

Typical Performance (Continued)

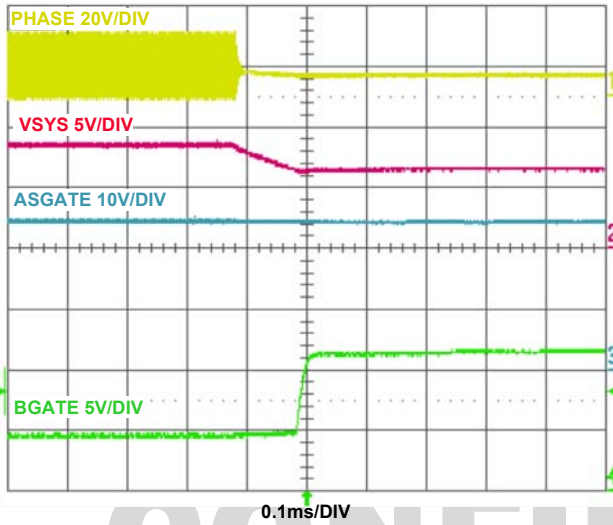


FIGURE 11. NVDC: ENTER LEARN MODE

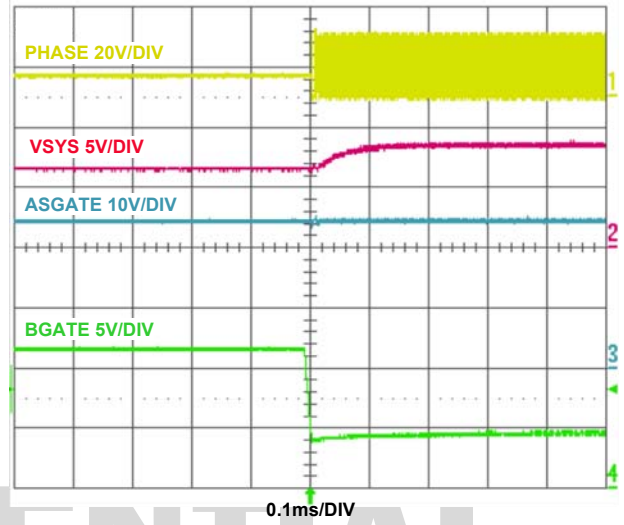


FIGURE 12. NVDC: EXIT LEARN MODE

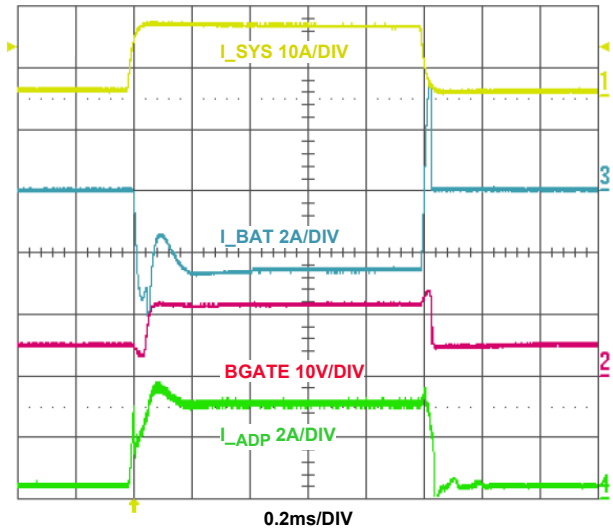


FIGURE 13. NVDC: SYSTEM VOLTAGE REGULATION LOOP AND TURBO MODE TRANSIENT. VADP = 20V, ADAPTERCURRENTLIMIT1 = 3.072A, V_{BAT} = 7V, MAXCHARGEVOLTAGE = 8.192V, 1A TO 12A SYSTEM LOAD STEP

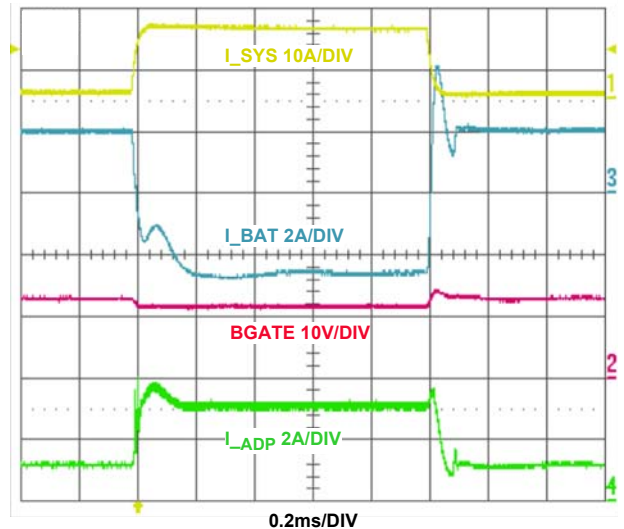


FIGURE 14. NVDC: CHARGING CURRENT LIMIT LOOP AND TURBO MODE TRANSITION. VADP = 20V, ADAPTERCURRENTLIMIT1 = 3.072A, V_{BAT} = 7V, MAXCHARGEVOLTAGE = 8.192V, CHARGECURRENT = 2.016A, 1A TO 12A SYSTEM LOAD STEP

Typical Performance (Continued)

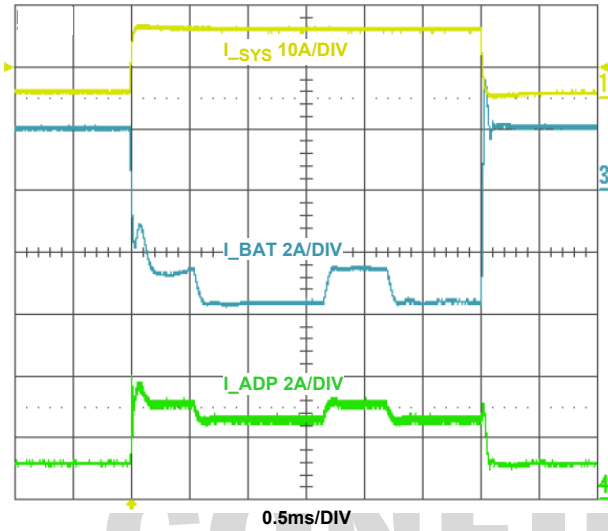


FIGURE 15. TWO LEVEL ADAPTER CURRENT LIMIT. VADP = 20V, ADAPTERCURRENTLIMIT1 = 2.56A, ADAPTERCURRENTLIMIT2 = 3.072A, T2 = 500 μ s, T1 = 1ms, V_{BAT} = 7V, MAXCHARGEVOLTAGE = 8.192V, CHARGECURRENT = 2.016A, 1A TO 12A SYSTEM LOAD STEP

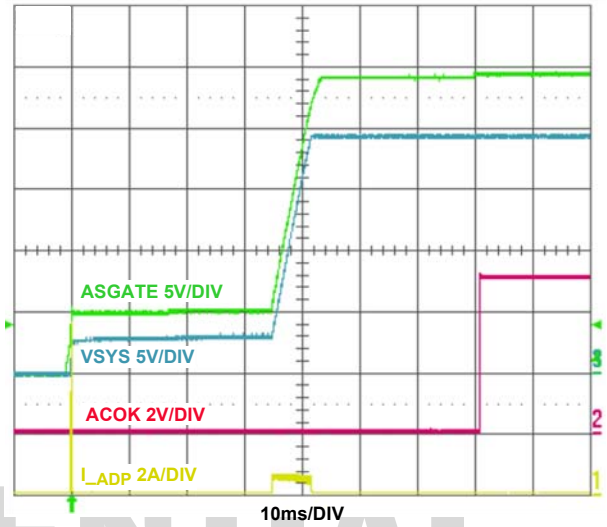


FIGURE 16. HPB: ADAPTER INSERTION ASGATE INRUSH CURRENT CONTROL. NO BATTERY, VADP = 20V, 330 μ F SYSTEM RAIL CAPACITANCE

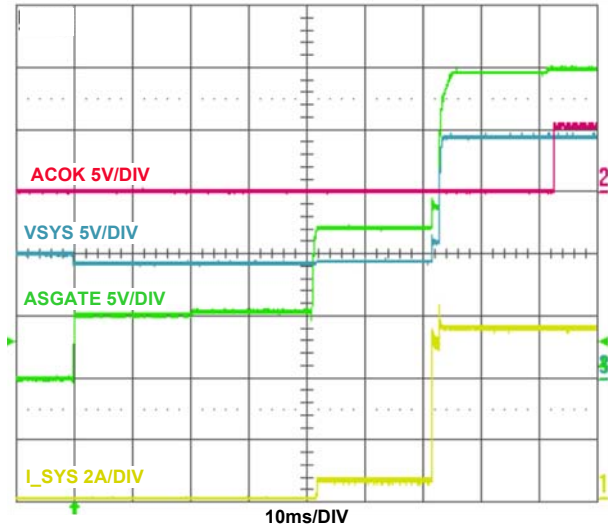


FIGURE 17. HPB: ADAPTER INSERTION ASGATE INRUSH CURRENT CONTROL. V_{BAT} = 10V, VADP = 20V, ACLIM SETTING = 5A, SYSTEM LOAD = 5.5A

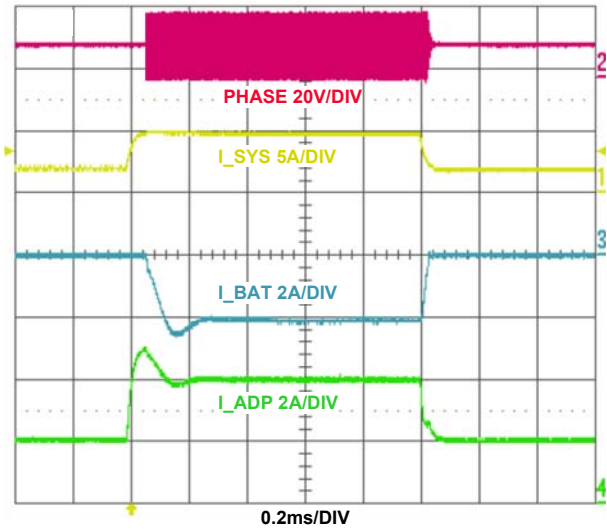


FIGURE 18. HPB: CHARGE DISABLED, ENTER TURBO MODE. VADP = 20V, V_{BAT} = 10V, ADAPTERCURRENTLIMIT1 = 4.096A, 2A TO 5A LOAD STEP

Typical Performance (Continued)

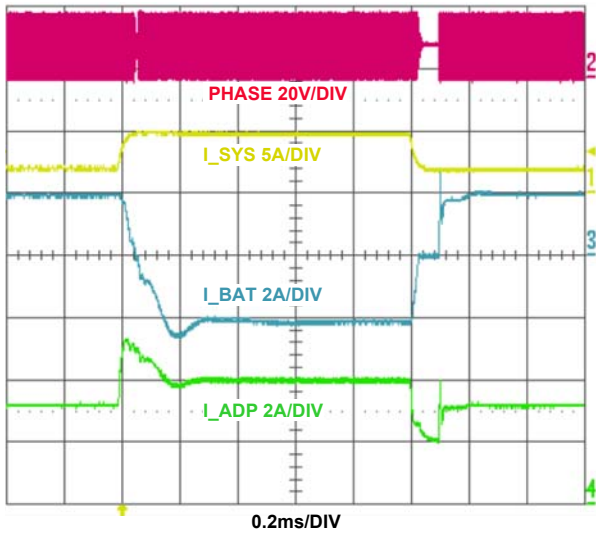


FIGURE 19. HPB: CHARGE ENABLED, ENTER TURBO MODE. VADP = 20V, V_{BAT} = 10V, ADAPTERCURRENTLIMIT1 = 4.096A, CHARGECURRENT = 2.016A, 2A TO 5A LOAD STEP

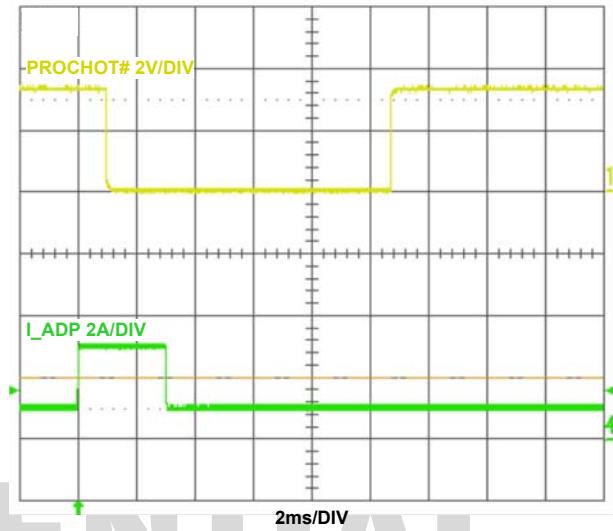


FIGURE 20. ACPROCHOT# ASSERTION. ACPROCHOT = 2.048A, PROCHOTDEBOUNCE = 1ms, PROCHOTDURATION = 10ms

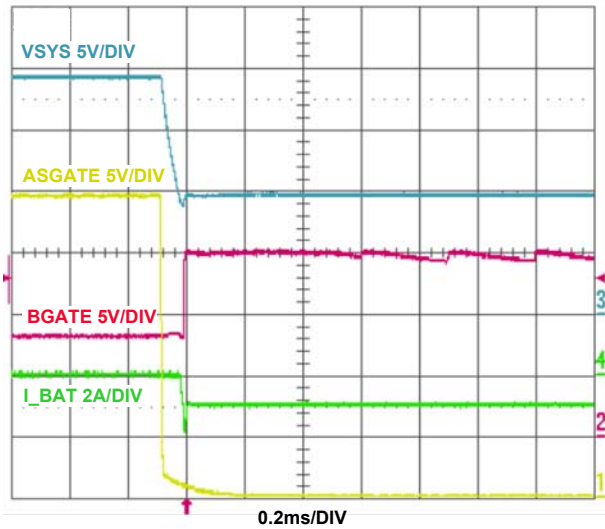


FIGURE 21. HPB: ENTER LEARN MODE

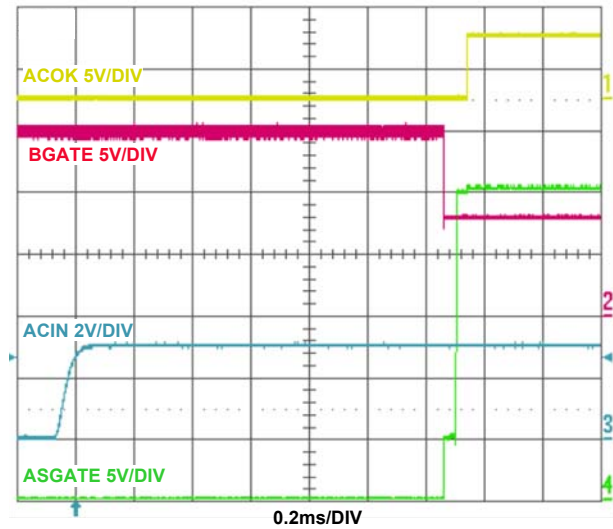


FIGURE 22. HPB: ASGATE TURNING ON DELAY AFTER ADAPTER INSERTION. VADP = 20V, V_{BAT} = 10V, CONTROL2 REGISTER BIT<5> = 0

Typical Performance (Continued)

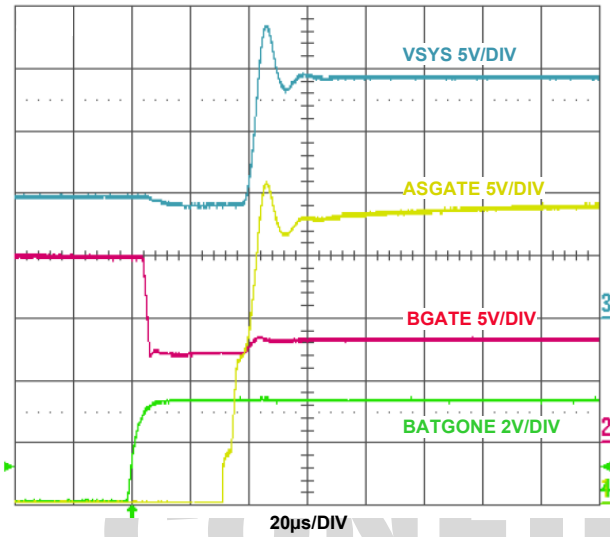


FIGURE 23. HPB: BATTERY SUDDEN REMOVAL IN LEARN MODE BY PULLING BATGONE TO HIGH

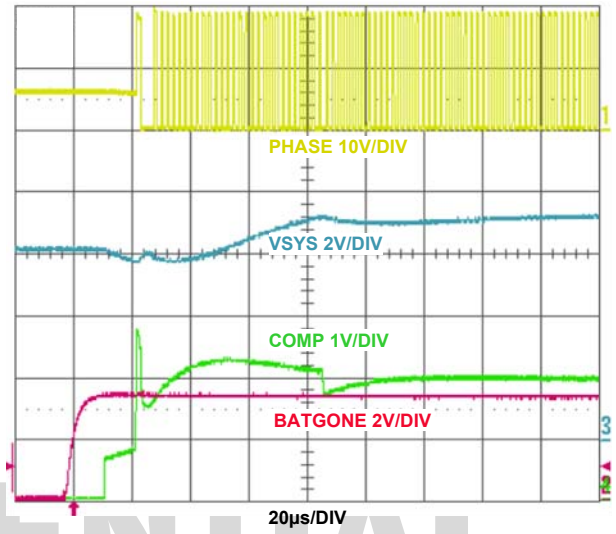


FIGURE 24. NVDC: BATTERY SUDDEN REMOVAL IN LEARN MODE BY PULLING BATGONE TO HIGH

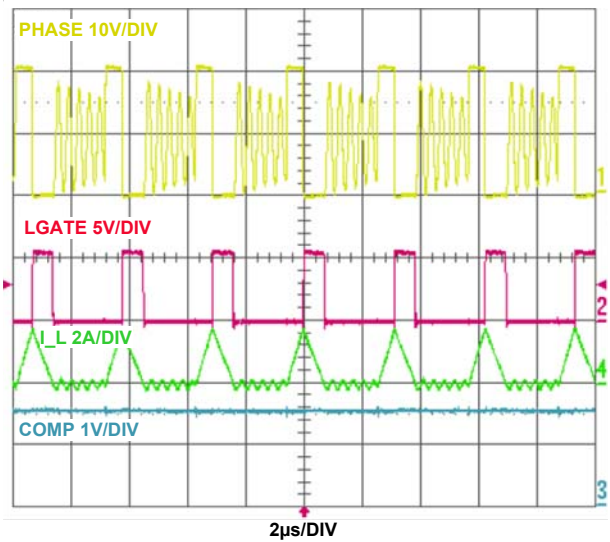


FIGURE 25. DISCONTINUOUS CONDUCTION MODE (DCM) SWITCHING

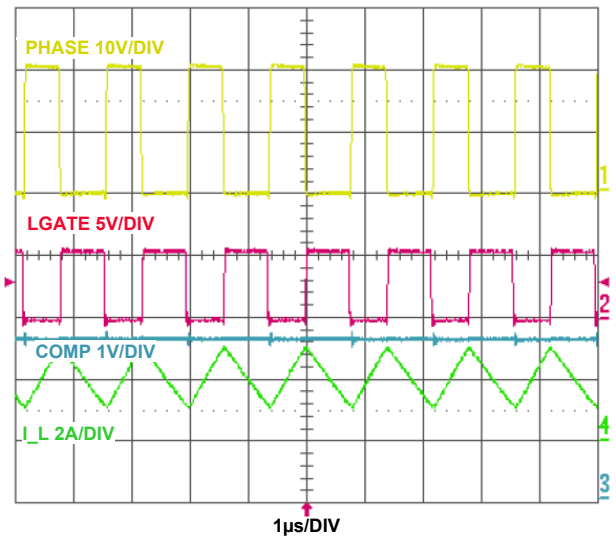


FIGURE 26. CONTINUOUS CONDUCTION MODE (CCM) SWITCHING

Typical Performance (Continued)

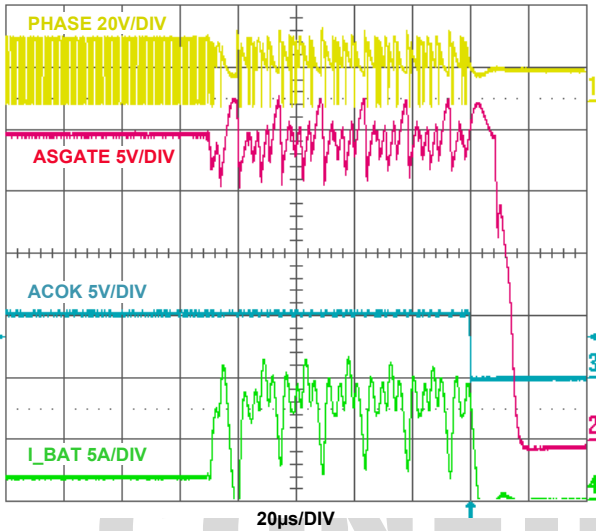


FIGURE 27. WOCIP: INDUCTOR SHORT DURING CHARGING.
 $V_{ADP} = 20V$, $V_{BAT} = 10V$, CHARGE CURRENT = 2A,
 $CCLIM = 2V$

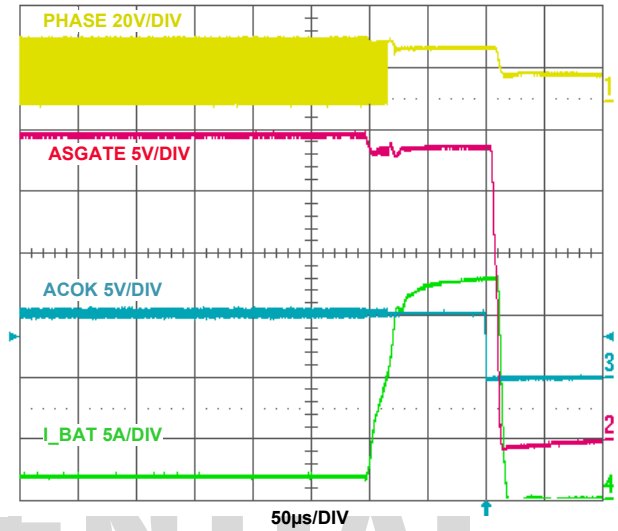


FIGURE 28. WOCIP: HIGH-SIDE MOSFET SHORT DURING CHARGING.
 $V_{ADP} = 20V$, $V_{BAT} = 10V$, CHARGE CURRENT = 2A,
 $CCLIM = 2V$

General SMBus Architecture

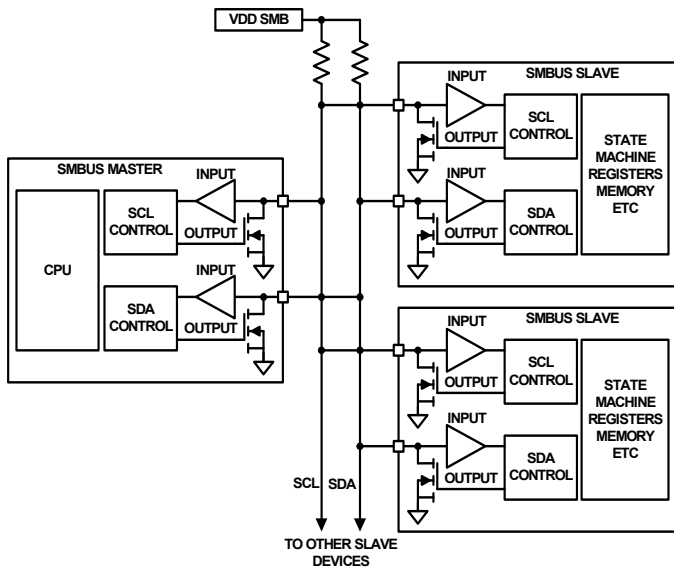


FIGURE 29. GENERAL SMBus ARCHITECTURE

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. See [Figure 30](#).

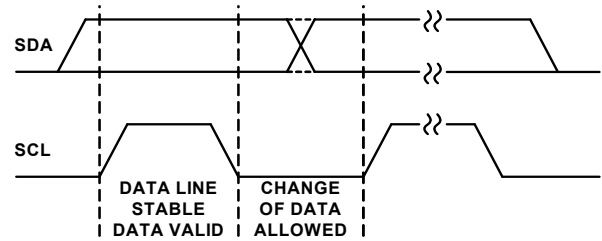


FIGURE 30. DATA VALIDITY

START and STOP Conditions

See [Figure 31](#). The 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.

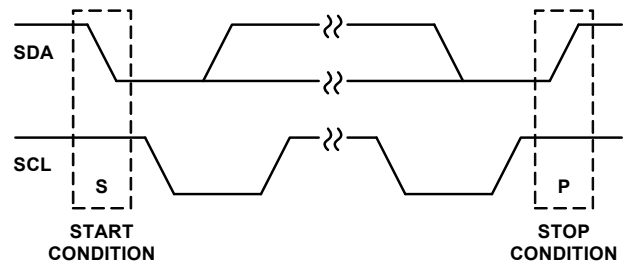


FIGURE 31. START AND STOP WAVEFORMS

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/W bit during the next 8-clock pulses. During the 9-clock pulse, the device that recognizes its own address holds the data line low to acknowledge (as shown in [Figure 32](#)). Both the master and the slave use the ACK bit.

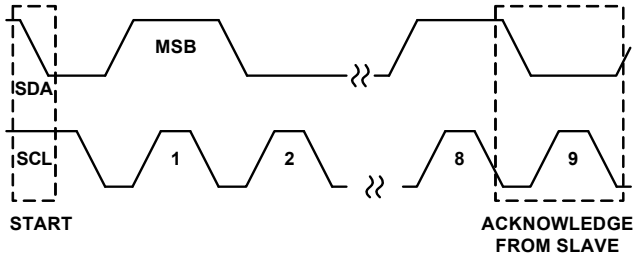


FIGURE 32. ACKNOWLEDGE ON THE SMBus

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 seven bits of slave address (0001001 for the ISL95521A) and the R/W bit. The R/W bit is 0 for a WRITE or 1 for a READ. If any slave device on the SMBus bus recognizes its address, it acknowledges 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 is 1, indicating a Not Acknowledge condition.

When the control byte is sent and the ISL95521A 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 ISL95521A which register the master writes or reads. See [Table 2](#) for details of the registers. When the ISL95521A receives a register address byte, it responds with an acknowledge.

Byte Format

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

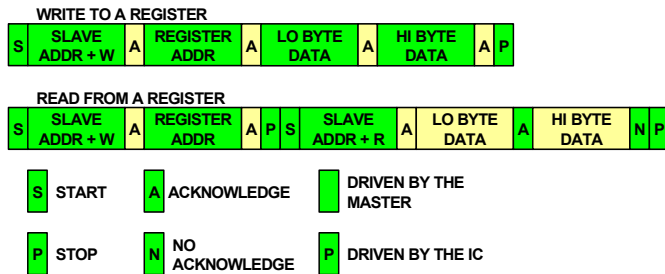


FIGURE 33. SMBus READ AND WRITE PROTOCOL

SMBus and I²C Compatibility

The ISL95521A SMBus minimum input logic high voltage is 2V, so it is compatible with I²C with higher than 2V pull-up power supply.

The ISL95521A SMBus registers are 16 bits, so it is compatible with 16 bits I²C or 8 bits I²C with auto-increment capability.

ISL95521A SMBus Commands

The ISL95521A 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 ISL95521A uses the SMBus Read Word and Write Word protocols shown in [Figure 33](#) to communicate with the host system and a smart battery. The ISL95521A is an SMBus slave device and does not initiate communication on the bus. It responds to the 7-bit address 0b0001001_:

Read address = 0b00010011 (0X13H) and

Write address = 0b00010010 (0X12H).

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 ISL95521A allows you to change the SMBus registers to change some functions and options, as shown in [Table 2](#).

The illustration in this datasheet is based on current sensing resistors R_{s1} = 10mΩ and R_{s2} = 10mΩ unless specified otherwise. For other current sensing resistor specifications, see [Tables 18](#) and [19](#) for more information.

TABLE 2. REGISTERS SUMMARY ($R_{s1} = 10m\Omega$ AND $R_{s2} = 10m\Omega$)

REGISTER NAMES	REGISTER ADDRESS	READ/WRITE	NUMBER OF BITS	DESCRIPTION	POR BIT STATE
ChargeCurrentLimit	0x14H	R/W	8	Bits<12:5> are used. If Bit<0> is interpreted as 1mA, the resolution is 32mA and the POR default value is 0A.	<12:5> 00000000
AdapterCurrentLimit1	0x3FH	R/W	6	Bits<12:7> are used. If Bit<0> is interpreted as 1mA, the resolution is 128mA and the POR default value is 8.064A.	<12:7> 111111
AdapterCurrentLimit2	0x3BH	R/W	6	Bits<12:7> are used. If Bit<0> is interpreted as 1mA, the resolution is 128mA and the POR default value is 8.064A.	<12:7> 111111
T1	0x37H	R/W	3	Bits<2:0> are used. If 2-level adapter current limit function is enabled and is tripped, T1 configures the effective duration of AdapterCurrentLimit1 register. POR default value is 500 μ s.	<2:0> 110
T2	0x38H	R/W	3	Bits<2:0> are used. If 2-level adapter current limit function is enabled and is tripped, T2 configures the effective duration of AdapterCurrentLimit2 register. POR default value is 100 μ s.	<2:0> 001
MaxChargeVoltage	0x15H	R/W	11	Bits<14:4> are used. If Bit<0> is interpreted as 1mV, the resolution is 16mV. The POR default value is based on PROG pin cell number programming: 2-cell: 8.192V 3-cell: 12.288V 4-cell: 16.4V The MaxChargeVoltage register should always be programmed higher than the MinChargeVoltage register.	
MinChargeVoltage	0x3EH	R/W	6	Bits<13:8> are used. If Bit<0> is interpreted as 1mV, the resolution is 256mV. The POR default value is based on PROG pin cell number programming: 2-cell: 5.376V 3-cell: 8.064V 4-cell: 10.752V The MinChargeVoltage register should always be programmed lower than the MaxChargeVoltage register.	
ProchotDebounce	0x39H	R/W	2	Bits<1:0> are used. Set the debounce time before asserting the PROCHOT# signal for NTC_Prochot#, ACProchot#, and DCProchot#. POR default value is 100 μ s.	<1:0> 01
ProchotDuration	0x3AH	R/W	3	Bits<2:0> are used. Set the minimum duration of PROCHOT# signal latch-up when asserted. POR default value is 10ms.	<2:0> 011
ACProchot	0x47H	R/W	6	Bits<12:7> are used. Set the PROCHOT# threshold for adapter overcurrent condition. If Bit<0> is interpreted as 1mA, the resolution is 128mA and the POR default value is 6.144A.	<12:7> 110000
DCProchot	0x48H	R/W	6	Sets the PROCHOT# threshold for battery over-discharging current condition. Bits<12:7> are used. If Bit<0> is interpreted as 1mA, the resolution is 128mA and the POR default value is 4.096A.	<12:7> 100000
Control1	0x3DH	R/W	16	See Control1 register Table 13 .	
Control2	0x3CH	R/W	12	See Control2 register Table 14 .	
Information1	0x46H	R	8	Various information reported over SMBus. See Information1 register Table 15 .	
Information2	0x45H	R/W	8	PROG pin resistor reading result report. Also configures the 20m Ω current sensing resistor option. See Information2 register Table 16 .	
ManufacturerID	0xFEH	R		ASCII for "I".	0x49H
DeviceID	0xFFH	R			0x09H

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 33 on page 27](#) and the data format shown in [Table 3](#).

The ISL95521A limits the charging current by limiting the $V_{CSOP} - V_{CSIN}$ voltage. By using the recommended current sense resistor values shown in [Table 17](#), the register's LSB always translates to 1mA of charging current. The ChargeCurrentLimit register accepts any charging current command however, only the valid register bits are written to the register. It is not recommended to set the charging current limit lower than 96mA.

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

[Tables 21](#) and [22](#) show the conditions to enable fast charging according to the ChargeCurrentLimit register setting for HPB configuration and NVDC configuration respectively.

TABLE 3. CHARGECURRENTLIMIT REGISTER 0x14H ($R_{S1} = 10m\Omega$ AND $R_{S2} = 10m\Omega$). (SEE [Table 18 on page 40](#) FOR OTHER CONFIGURATIONS)

BIT	DESCRIPTION
<4:0>	Not used
<5>	0 = Add 0mA of charging current limit. 1 = Add 32mA of charging current limit.
<6>	0 = Add 0mA of charging current limit. 1 = Add 64mA of charging current limit.
<7>	0 = Add 0mA of charging current limit. 1 = Add 128mA of charging current limit.
<8>	0 = Add 0mA of charging current limit. 1 = Add 256mA of charging current limit.
<9>	0 = Add 0mA of charging current limit. 1 = Add 512mA of charging current limit.
<10>	0 = Add 0mA of charging current limit. 1 = Add 1024mA of charging current limit.
<11>	0 = Add 0mA of charging current limit. 1 = Add 2048mA of charging current limit.
<12>	0 = Add 0mA of charging current limit. 1 = Add 4096mA of charging current limit.
<15:13>	Not used

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 33](#) and the data format shown in [Table 4](#).

The ISL95521A limits the adapter current by limiting the $V_{CSIP} - V_{CSIN}$ voltage. By using the recommended current sense resistor value as [Table 17](#) shows, the register's LSB always translates to 1mA adapter current. Any adapter current limit command is accepted however, only the valid register bits are written to the AdapterCurrentLimit1 and AdapterCurrentLimit2

registers. The minimum adapter current limit command is 128mA and a 0A command is rejected.

After POR, the AdapterCurrentLimit1 and AdapterCurrentLimit2 register are reset to 0x1F80. 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 33](#) and the data format as shown in [Table 4](#).

The AdapterCurrentLimit2 register has the same specification as the AdapterCurrentLimit1 register. See [“Two-Level Adapter Current Limit” on page 45](#) for detailed operation.

TABLE 4. ADAPTERCURRENTLIMIT1 REGISTER 0x3FH AND ADAPTERCURRENTLIMIT2 REGISTER 0x3BH ($R_{S1} = 10m\Omega$ AND $R_{S2} = 10m\Omega$)

BIT	DESCRIPTION
<6:0>	Not used
<7>	0 = Add 0mA of adapter current limit. 1 = Add 128mA of adapter current limit.
<8>	0 = Add 0mA of adapter current limit. 1 = Add 256mA of adapter current limit.
<9>	0 = Add 0mA of adapter current limit. 1 = Add 512mA of adapter current limit.
<10>	0 = Add 0mA of adapter current limit. 1 = Add 1024mA of adapter current limit.
<11>	0 = Add 0mA of adapter current limit. 1 = Add 2048mA of adapter current limit.
<12>	0 = Add 0mA of adapter current limit. 1 = Add 4096mA of adapter current limit.
<15:13>	Not used

Setting Two-Level Adapter Current Limit Duration

For a two-level adapter current limit, write a 16-bit T1 command (0x37H or 0b00110111) using the Write Word protocol shown in [Figure 33](#) and the data format shown in [Table 5](#) to set the AdapterCurrentLimit1 duration as the adapter current limit. Write a 16-bit T2 command (0x38H or 0b00111000) to set AdapterCurrentLimit2 duration as the adapter current limit. T1 register and T2 register accept any command however, only the valid register bits are written. See [“Two-Level Adapter Current Limit” on page 45](#) for detailed operation.

TABLE 5. T1 REGISTER 0x37H

BIT	DESCRIPTION
<2:0>	000 = 0ms 001 = 20ms 010 = 15ms 011 = 10ms 100 = 5ms 101 = 1ms 110 = 0.5ms 111 = 0.1ms
<15:3>	Not used

TABLE 6. T2 REGISTER 0x38H

BIT	DESCRIPTION
<2:0>	000 = 15µs 001 = 100µs 010 = 500µs 011 = 1ms 100 = 300µs 101 = 750µs 110 = 3ms 111 = 10ms
<15:3>	Not used

Setting Maximum Charging Voltage

To set the maximum charging voltage, write a 16-bit MaxChargeVoltage command (0X15H or 0b00010101) using the Write Word protocol shown in [Figure 33 on page 27](#) and the data format as shown in [Table 7](#).

The maximum charging voltage range is 7.168V to 18.432V. The MaxChargeVoltage register accepts any voltage command however, only the valid register bits are written to the register.

The MaxChargeVoltage register sets the battery full charging voltage limit. For NVDC configuration, MaxChargeVoltage register setting also is the system bus voltage regulation point when the battery is present but is not in charge. See [“NVDC Charger System Voltage Regulation” on page 46](#) for details.

The CSON pin is used to sense the battery voltage for maximum charging voltage regulation. For NVDC configuration, the CSON pin is also the system bus voltage regulation sense point.

TABLE 7. MAXCHARGEVOLTAGE REGISTER 0x15H

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

Setting Minimum Charging Voltage

To set the minimum charging voltage, write a 16-bit MinChargeVoltage command (0x3EH or 0b00111110) using the Write Word protocol shown in [Figure 33](#) and the data format as shown in [Table 8](#).

The minimum charging voltage range is 2.048V to 16.128V. The MinChargeVoltage register accepts any voltage command however, only the valid register bits are written to the register. The MinChargeVoltage register value should be set lower than the MaxChargeVoltage register value.

The MinChargeVoltage register sets the battery voltage threshold for entry and exit of the trickle charge mode. The VBAT pin is used to sense the battery voltage to compare with the MinChargeVoltage register setting. See [“Trickle Charging” on page 46](#) for details.

For NVDC configuration, the MinChargeVoltage register setting is also the system voltage regulation point when the battery is not present. The CSON pin is the system voltage regulation sense point. See [“NVDC Charger System Voltage Regulation” on page 46](#) for details.

TABLE 8. MINCHARGEVOLTAGE REGISTER 0x3EH

BIT	DESCRIPTION
<7:0>	Not used
<8>	0 = Add 0mV of charging voltage. 1 = Add 256mV of charging voltage.
<9>	0 = Add 0mV of charging voltage. 1 = Add 512mV of charging voltage.
<10>	0 = Add 0mV of charging voltage. 1 = Add 1024mV of charging voltage.
<11>	0 = Add 0mV of charging voltage. 1 = Add 2048mV of charging voltage.
<12>	0 = Add 0mV of charging voltage. 1 = Add 4096mV of charging voltage.
<13>	0 = Add 0mV of charging voltage. 1 = Add 8192mV of charging voltage.
<15:14>	Not used

Setting PROCHOT# Debounce Time

To set the PROCHOT# signal debounce time before its assertion for ACProchot, DCProchot and NTC_Prochot, write a 16-bit PROCHOT# debounce time (0x39H or 0b00111001) using the Write Word protocol shown in [Figure 33](#) and the data format as shown in [Table 9](#). PROCHOT# Debounce Time register accepts any command however, only the valid register bits are written.

The low system voltage PROCHOT# has a fixed debounce time of 10µs.

TABLE 9. PROCHOTDEBOUNCE REGISTER 0x39H

BIT	DESCRIPTION
<1:0>	00 = 10µs 01 = 100µs 10 = 500µs 11 = 1ms
<15:2>	Not used

Setting PROCHOT# Duration

To set the PROCHOT# signal latch-up duration when asserted for ACProchot, DCProchot and NTC_Prochot and low system voltage Prochot, write a 16-bit PROCHOT# Duration command (0x3AH or 0b01111010) using the Write Word protocol shown in [Figure 33](#) and the data format shown in [Table 10](#). Prochot# Duration register accepts any command however, only the valid register bits are written.

TABLE 10. PROCHOT# DURATION REGISTER 0x3Ah

BIT	DESCRIPTION
<2:0>	000 = 0ms 001 = 20ms 010 = 15ms 011 = 10ms 100 = 5ms 101 = 1ms 110 = 500µs 111 = 100µs
<15:3>	Not used

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 [Figure 33 on page 27](#) and the data format shown in [Table 11](#). By using the recommended current sense resistor value as [Table 17 on page 39](#) shows, the register's LSB always translates to 1mA adapter current. The ACProchot register accepts any command however, only the valid register bits are written to the register.

After POR, the ACProchot register is reset to 0x1800H. The ACProchot register can be read back to verify its content.

If the adapter current exceeds the ACProchot register setting, the PROCHOT# signal asserts after the debounce time is programmed by the ProchotDebounce register and latches on for a minimum time programmed by the ProchotDuration register.

For HPB configuration, the ACProchot function is disabled when it is in standby mode because the standby mode turns off the internal comparator reference, which is indicated by Information1 register Bit<8>.

TABLE 11. ACPROCHOT REGISTER 0x47H ($R_{s1} = 10m\Omega$ AND $R_{s2} = 10m\Omega$). (SEE [Table 18 on page 40](#) FOR OTHER CONFIGURATIONS)

BIT	DESCRIPTION
<6:0>	Not used
<7>	0 = Add 0mA of ACProchot threshold. 1 = Add 128mA of ACProchot threshold.
<8>	0 = Add 0mA of ACProchot threshold. 1 = Add 256mA of ACProchot threshold.
<9>	0 = Add 0mA of ACProchot threshold. 1 = Add 512mA of ACProchot threshold.
<10>	0 = Add 0mA of ACProchot threshold. 1 = Add 1024mA of ACProchot threshold.
<11>	0 = Add 0mA of ACProchot threshold. 1 = Add 2048mA of ACProchot threshold.
<12>	0 = Add 0mA of ACProchot threshold. 1 = Add 4096mA of ACProchot threshold.
<15:13>	Not used

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 33](#) and the data format shown in [Table 12](#). By using the recommended current sense resistor value as [Table 17 on page 39](#) shows, the register's LSB always translates to 1mA adapter current. The DCProchot register accepts any command however, only the valid register bits are written to the register.

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 asserts after the debounce time is programmed by the ProchotDebounce register and latches on for a minimum time programmed by the ProchotDuration register.

In battery only mode, the DCProchot function works only when PSYS or NTC is enabled, because enabling PSYS or NTC activates the internal comparator reference. The Information1 register bit<8> indicates if the internal comparator reference is active or not.

When the adapter is present, the internal comparator reference is always active unless it is in standby mode for HPB configuration.

TABLE 12. DCPROCHOT REGISTER 0x48H (R_{s1} = 10mΩ AND R_{s2} = 10mΩ. (SEE Table 18 on page 40 FOR OTHER CONFIGURATIONS)

BIT	DESCRIPTION
<6:0>	Not used
<7>	0 = Add 0mA of DCProchot threshold. 1 = Add 128mA of DCProchot threshold.
<8>	0 = Add 0mA of DCProchot threshold. 1 = Add 256mA of DCProchot threshold.
<9>	0 = Add 0mA of DCProchot threshold. 1 = Add 512mA of DCProchot threshold.
<10>	0 = Add 0mA of DCProchot threshold. 1 = Add 1024mA of DCProchot threshold.
<11>	0 = Add 0mA of DCProchot threshold. 1 = Add 2048mA of DCProchot threshold.
<12>	0 = Add 0mA of DCProchot threshold. 1 = Add 4096mA of DCProchot threshold.
<15:13>	Not used

Control Registers

To change certain functions or options after POR, write a 16-bit control command to Control1 register (0x3DH or 0b00111101) or Control2 register (0x3CH or 0b00111100) using the Write Word protocol shown in Figure 33 on page 27 and the data format shown in Tables 13 and 14, respectively.

TABLE 13. CONTROL1 REGISTER 0x3DH

BIT	BIT NAME	DESCRIPTION	POR STATE
<0>	Standby Mode	1 = The charger enters Standby mode. 0 = The charger exits Standby mode. The Standby mode control bit is valid for HPB configuration only and is valid only when an adapter is present; it has no effect for NVDC configuration. When ISL95521A enters Standby mode, it turns off the internal references (indicated by Information1 register Bit<8>) and stops switching to enter a low power consumption mode with minimum quiescent current. If PSYS is already enabled, it cannot enter Standby mode.	0
<1>	Learn Mode	1 = The charger enters Learn mode. 0 = The charger exits Learn mode. The SMBus learn mode control is valid only when the PROG pin is not pulled to 5V after POR.	0
<2>	AMON	1 = Turn on adapter current monitor AMON function. 0 = Turn off adapter current monitor AMON function.	0
<3>	BMON	1 = Turn on battery discharging current monitor BMON function. 0 = Turn off battery discharging current monitor BMON function. BMON function is disabled if battery voltage is less than 3.5V to avoid battery over discharged.	0
<4>	PSYS	1 = Turn on system power monitor PSYS function. 0 = Turn off system power monitor PSYS function. PSYS function does not include the power provided by battery if battery voltage is less than 3.5V. For HPB configuration, when adapter is present, if it enters Standby mode already, PSYS cannot be turned on.	0

TABLE 13. CONTROL1 REGISTER 0x3DH (Continued)

BIT	BIT NAME	DESCRIPTION	POR STATE
<5>	Low System Voltage Detection	<p>1 = Turn on low system voltage detect function. 0 = Turn off low system voltage detect function.</p> <p>Bit<5> is valid only when the internal comparator reference is active, which is indicated by Information1 register Bit<8>.</p> <p>In battery only mode, low system voltage detection function works only when PSYS or NTC is enabled, because enabling PSYS or NTC activates the internal comparator reference.</p> <p>When adapter is present, the internal comparator reference is always active unless it is in standby mode for HPB configuration.</p> <p>For HPB configuration, ISL95521A senses the system voltage through CSIP pin. For NVDC configuration, ISL95521A senses the system voltage through CSON pin.</p>	0
<6>	NTC	<p>1 = Turn on NTC function. 0 = Turn off NTC function.</p> <p>When turned on, if the NTC pin voltage is less than 170mV, the PROCHOT# signal asserts after the debounce time programmed by the ProchotDebounce register and latches on for a minimum time programmed by the ProchotDuration register.</p> <p>For NTC function to work, the internal reference indicated by Information1 register bit<8> needs to be active.</p> <p>When the adapter is present, NTC function is always turned on unless it is in Standby mode then Bit<6> is invalid.</p> <p>In battery only mode, Bit<6> is valid to turn on or off NTC function only when PSYS is turned off; NTC function is always turned on automatically if PSYS is turned on.</p>	0
<7>	Fast Learn Mode Exit	<p>1 = Fast Learn Mode Exit. 0 = Slow Learn Mode Exit.</p> <p>For Fast Learn Mode Exit, it turns on ASGATE MOSFETs instantly without going through the ASGATE soft-start turning on procedure when BATGONE pin voltage goes from logic LOW to HIGH.</p> <p>For slow learn mode exit, it goes through the ASGATE soft-start turning on procedure 163ms after BATGONE pin voltage goes from logic LOW to HIGH.</p> <p>This Fast Learn Mode Exit control bit is valid only when battery is removed during learn mode and it only works for HPB configuration and has no effect for NVDC configuration.</p>	0
<9:8>	Threshold for Low System Voltage Detection	<p>If the Control register Bit<5> = 1, Bits<9:8> programs the low system voltage detection threshold. If the system voltage is below this threshold, the PROCHOT# signal asserts after a fixed 10μs debounce time and latches on for a minimum time programmed by the ProchotDuration register.</p> <p>00 = 5.6V threshold. 01 = 6.06V threshold. 10 = 6.53V threshold. 11 = 7V threshold.</p> <p>Valid only when Control1 register Bit<5> = 1.</p>	00
<10>	Turbo/Boost Mode	<p>1 = Disable Turbo/Boost mode. 0 = Enable Turbo/Boost mode.</p>	1
<11>	Charging Current WOCF	<p>1 = Disable charging current way overcurrent protection function. 0 = Enable charging current way overcurrent protection function.</p>	0
<12>	Enable Charging	<p>0 = Disable charging. 1 = Enable charging.</p>	1

TABLE 13. CONTROL1 REGISTER 0x3DH (Continued)

BIT	BIT NAME	DESCRIPTION	POR STATE
<14:13>	Force The Number Of Battery Cells In Series	<p>Bits<14:13> can overwrite the number of battery cells in series that are programmed by PROG pin. When Bit<14:13> is written, only the POR default MaxChargeVoltage register value and MinChargeVoltage register value change according to the cell number. The battery 4.6V/cell overvoltage protection threshold also changes according to the cell number.</p> <p>The MaxChargeVoltage register setting should be always smaller than battery overvoltage threshold $4.6V * \text{cell\#}$.</p> <p>If Bits<14:13> are not used, keep its POR code based on PROG pin cell# setting.</p> <p>00 = Not available and is ignored if written. 01 = 2-cell. 10 = 3-cell. 11 = 4-cell.</p>	PROG cell#
<15>	SMBus Timeout	<p>The ISL95521A includes a timer to ensure the SMBus master is active and to prevent overcharging the battery. If the adapter is present and if the ISL95521A does not receive a write to the MaxChargeVoltage or ChargeCurrentLimit register within 175s, the ISL95521A terminates charging. If a timeout occurs, writing the MaxChargeVoltage or ChargeCurrentLimit register re-enables charging.</p> <p>0 = Enable the SMBus timeout function. 1 = Disable the SMBus timeout function.</p>	0

TABLE 14. CONTROL2 REGISTER 0x3CH

BIT	BIT NAME	DESCRIPTION	POR STATE
<3:0>	Frequency Setting	<p>Overwrite the switching frequency set by FSET pin. See the default CCM switching frequency programming Table 20 for the correlation.</p> <p>1111 = 992kHz (equivalent to R_FSET = 0Ω) 1110 = 838kHz 1101 = 729kHz 1100 = 642kHz 1011 = 678kHz 1010 = 614kHz 1001 = 561kHz 1000 = 517kHz 0111 = 513kHz 0110 = 477kHz 0101 = 449kHz 0100 = 421kHz 0011 = 417kHz 0010 = 395kHz 0001 = 375kHz 0000 = Switching frequency set by FSET pin</p> <p>To keep the switching frequency set by PROG pin resistor, leave Bit<3:0> as it is or write code 0000, which sets the same frequency as the PROG pin resistor does.</p>	0000
<4>	Release Adapter Current Limit when No Battery	<p>When there is no battery, Bit<4> enables or releases the adapter current limit for NVDC configuration.</p> <p>0 = Enable adapter current limit function. 1 = Release adapter current limit function.</p>	0
<5>	ASGATE Turn-On Delay	<p>0 = Set restart ASGATE turn on delay to 1.3s. 1 = Set restart ASGATE turn on delay to 163ms.</p> <p>Bit<5> only configures the ASGATE restart delay in a fault condition (adapter OVP and WOCP). In normal operation after adapter plugged in, the ASGATE turn on delay is always 163ms, regardless of the Bit<5> setting.</p>	0

TABLE 14. CONTROL2 REGISTER 0x3CH (Continued)

BIT	BIT NAME	DESCRIPTION	POR STATE
<6>	Two-level Adapter Current Limit Function	0 = Disable two-level adapter current limit function. 1 = Enable two-level adapter current limit function.	1
<7> <12>	Trickle Charging Current	Bit<12> and Bit<7> can be combined together to change the trickle charging current value. Bit <12>:<7> = <0>:<0> = 256mA trickle charging current. <0>:<1> = 128mA trickle charging current. <1>:<0> = 128mA trickle charging current. <1>:<1> = 64mA trickle charging current. 64mA trickle charging current option is valid only for "R _{s1} = 10mΩ, R _{s2} = 10mΩ" and "R _{s1} = 20mΩ, R _{s2} = 20mΩ" configurations for both NVDC charger and HPB charger.	0:1
<8>	Adapter OVP	0 = Enable adapter OVP function; 1 = Disable adapter OVP function. If adapter OVP function is enabled, the ISL95521A turns off ASGATE and pulls down ACOK when ACIN>3.5V.	0
<9>	PSYS Current Gain	For "R _{s1} = 10mΩ, R _{s2} = 5mΩ" and "R _{s1} = 10mΩ, R _{s2} = 10mΩ" configuration: 0 = 1.14μA/W 1 = 0.285μA/W For "R _{s1} = 20mΩ, R _{s2} = 10mΩ" and "R _{s1} = 20mΩ, R _{s2} = 20mΩ" configuration: 0 = 2.28μA/W 1 = 0.57μA/W	0
<10>	ACLIM Inrush Current Limit Time	0 = Set soft-start ACLIM inrush current limit period as 1ms when adapter plugged in. 1 = Set soft-start ACLIM inrush current limit period as 4ms when adapter plugged in.	0
<11>	BGATE OFF Timing	Bit<11> is valid for HPB configuration only. It changes the BGATE FET turning off timing when adapter is plugged in. 0 = Turn OFF BGATE FET according to battery voltage (see "Soft-Start" on page 41 for details). 1 = Turn OFF BGATE FET before turning on ASGATE FETs.	0
<13>	ACLIM Function	Bit<13> configures ACLIM to be functional all the time or only during ASGATE turning on procedure to limit the inrush current. 0 = ACLIM function is ON all the time. 1 = ACLIM function is OFF after ACOK assertion.	0
<15:14>	DCM LGATE Turning OFF Timing	Bit<15:14> adjusts the LGATE turning OFF timing when the buck switcher is in DCM operation to minimize the MOSFETs body diode conduction time. By default, LGATE turns OFF when the inductor current is positive (from PHASE node to output). 00 = Earliest LGATE turning OFF when PHASE pin voltage is about -6mV. 01 = Earlier LGATE turning OFF when PHASE pin voltage is about -4mV. 10 = Early LGATE turning OFF when PHASE pin voltage is about -2mV. 11 = Late LGATE turning OFF when PHASE pin voltage is about 0mV.	00

Information Registers

To read the information register, write a 16-bit Information1 command (0x46H or 0b01000110) or Information2 command (0x45H or 0b01000101) using the Read Word protocol shown in [Figure 33](#) and the data format shown in [Tables 15](#) and [16](#), respectively.

TABLE 15. INFORMATION1 REGISTER 0x46H

BIT	BIT NAME	W/R	DESCRIPTION
<0>	Adapter Present	R	0 = The adapter is not present. 1 = The adapter is present.
<1>	ASGATE ON	R	0 = ASGATE is OFF. 1 = ASGATE is ON.
<2>	VBAT<MinChargeVoltage	R	0 = VBAT>MinChargeVoltage. 1 = VBAT<MinChargeVoltage. Valid only when Information1 register Bit<8> = 1.
<3>	VSYS<Low System Voltage Setting	R	0 = VSYS>Low System Voltage Setting programmed by Control1 register Bit<9:8>. 1 = VSYS<Low System Voltage Setting programmed by Control1 register Bit<9:8>. Valid only when Information1 register Bit<8> = 1.
<4>	NTC_PROCHOT#	R	0 = NTC_PROCHOT# not asserted. 1 = NTC_PROCHOT# asserted. Valid only when Information1 register Bit<8> = 1.
<5>	In trickle charge mode	R	0 = Not in trickle charge mode. 1 = In trickle charge mode. Bit<5> is valid for NVDC configuration only.
<6>	In Turbo/Boost mode	R	0 = Not in Turbo/Boost mode. 1 = In Turbo/Boost mode. For NVDC configuration, if BGATE is already ON before entering Turbo mode, BGATE stays ON after entering Turbo mode; Bit<6> does not indicate the Turbo mode in this case.
<7>	ACProchot	R	0 = ACProchot# not asserted. 1 = ACProchot# asserted.
<8>	Reference Active	R	0 = Reference is not active. 1 = Reference is active. When Bit<8> = 1, Information Register Bits <4:2> are valid. When adapter is present, the internal comparator reference is always active; unless it is in standby mode for HPB charger configuration. In battery only mode, the default internal reference is not active, unless PSYS or NTC is enabled.

TABLE 16. INFORMATION2 REGISTER 0x45H

BIT	BIT NAME	W/R	DESCRIPTION	POR STATE
<0> <8>	R _{s1}	W/R	If R _{s1} = 20mΩ (R _{s1} = 20mΩ and R _{s2} = 10mΩ or R _{s1} = 20mΩ and R _{s2} = 20mΩ), both Bit<8> and Bit<0> need to be programmed as 1 to have correct internal current sensing scaling. Bit<8>:<0>: <0>:<0> = R _{s1} = 10mΩ <0>:<1> = R _{s1} = 10mΩ <1>:<0> = R _{s1} = 10mΩ <1>:<1> = R _{s1} = 20mΩ	0:0
<3:1>			Not used. Internally hardwired as <3:1> = 010.	
<5:4>	Cell number	R	00 = Not available. 01 = 2-cell 10 = 3-cell 11 = 4-cell	
<6>	Current sensing resistor	R	0 = "R _{s1} :R _{s2} = 2:1" (R _{s1} = 10mΩ and R _{s2} = 5mΩ or R _{s1} = 20mΩ and R _{s2} = 10mΩ) 1 = "R _{s1} :R _{s2} = 1:1" (R _{s1} = 10mΩ and R _{s2} = 10mΩ or R _{s1} = 20mΩ and R _{s2} = 20mΩ) Together with Bit<8> and Bit<0> R _{s1} setting, it can be figured out that R _{s1} = 10mΩ or R _{s1} = 20mΩ.	
<7>	Charger Configuration	R	0 = HPB charger configuration 1 = NVDC charger configuration	
<15:9>			Not used.	

Application Information

R3 Modulator

The ISL95521A uses the Renesas R3 (Robust Ripple Regulator) modulation scheme. The R3 modulator combines the best features of fixed frequency PWM and hysteric PWM while eliminating many of their shortcomings. [Figure 34](#) conceptually shows the R3 modulator circuit and [Figure 35](#) shows the operation principles in steady state.

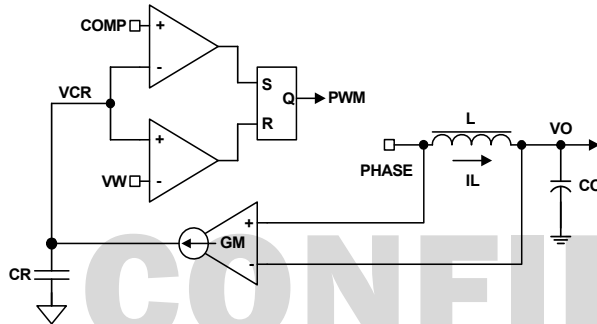


FIGURE 34. R3 MODULATOR

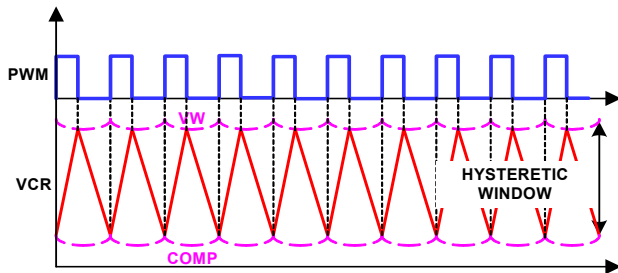


FIGURE 35. R3 MODULATOR OPERATION PRINCIPLES IN STEADY STATE

There is a fixed voltage window between VW and COMP 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 $g_m V_o$, 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 a large amplitude and noise free synthesized signal, it achieves lower phase jitter than conventional hysteric mode modulator.

[Figure 36](#) 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.

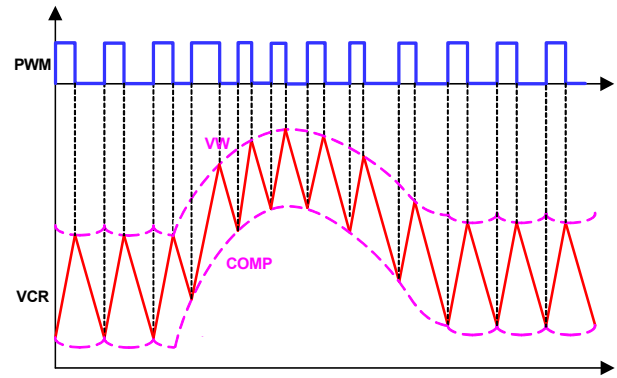


FIGURE 36. R3 MODULATOR OPERATION PRINCIPLES IN DYNAMIC RESPONSE

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 37](#), 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 37](#) shows, the inductor current reaches and stays 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 never reaches 0A and therefore, the regulator is in CCM although the controller is in DE mode.

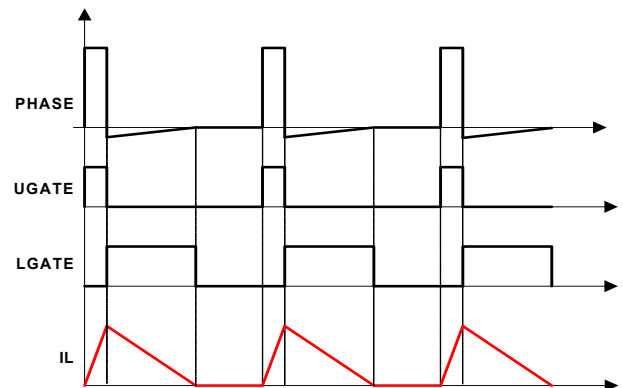


FIGURE 37. DIODE EMULATION

In DCM operation, to turn off LGATE when the inductor current reaches near zero, the ISL95521A provides Control2 register Bit<15:14> to adjust the LGATE turning off timing. The default timing purposely turns off LGATE a little earlier than the inductor current zero crossing. The SMBus bit can adjust the timing more aggressively towards the precise zero-crossing point to minimize the MOSFET's body diode conduction time for higher efficiency at light load. However, it is not recommended to turn off LGATE after the inductor current zero crossing, which may feed energy back to the adapter side.

[Figure 38 on page 39](#) shows the operation principle in DE 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. The COMP voltage takes longer to reach V_{CR} which naturally stretches the switching period. The inductor current triangles move farther 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.

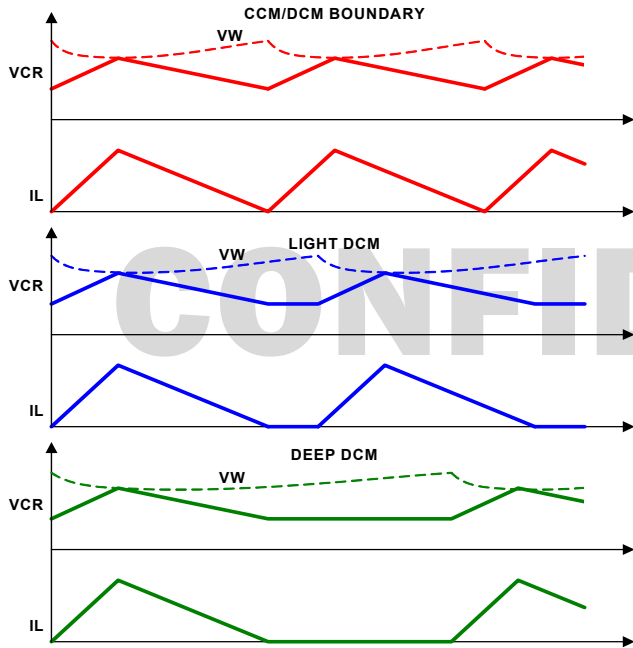


FIGURE 38. PERIOD STRETCHING

Programming Charger Options

TABLE 17. PROG PIN PROGRAMMING OPTIONS

PROG-GND RESISTANCE (kΩ)	CHARGER TYPE	CURRENT SENSE RESISTOR VALUE	DEFAULT # OF BATTERY CELLS IN SERIES	
TYP (1% STANDARD RESISTOR)				
0	NVDC	$R_{S1}:R_{S2} = 2:1$ $R_{S1} = 10m\Omega$ $R_{S2} = 5m\Omega$	3	
22.6			4	
38.3			2	
69.8		HPB	$R_{S1}:R_{S2} = 1:1$ $R_{S1} = 10m\Omega$ $R_{S2} = 10m\Omega$	3
86.6				4
102				2
150				4
165				2
182				3
215	HPB	$R_{S1}:R_{S2} = 2:1$ $R_{S1} = 10m\Omega$ $R_{S2} = 5m\Omega$	4	
237			2	
255			3	
			3	

The resistor from the PROG pin to GND programs the configuration of the ISL95521A as a HPB charger or NVDC charger, as well as the default number of battery cells in series and the default values of the adapter and battery current sense resistors R_{S1} and R_{S2} . [Table 17](#) shows the programming options.

Before soft-start and when V_{DD} voltage reaches its POR value, the ISL95521A sources $10\mu A$ current out of the PROG pin and reads 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 $40\mu s$, so the PROG pin voltage can rise to steady state before the ISL95521A reads it.

The ISL95521A can be programmed in two different battery charger configurations.

[Figure 1 on page 1](#) shows the typical application circuit for a HPB charger. In this configuration, the ISL95521A connects the system voltage rail to either the adapter or the battery. In turbo event, which means the system is drawing more power than the adapter's power rating, the ISL95521A operates as a boost converter to reverse-boost the battery energy to the system voltage rail, so the battery works with the adapter together to supply the system power.

[Figure 5 on page 5](#) shows the typical application circuit for the NVDC charger. In this configuration, the ISL95521A connects the system voltage rail to either the output of the buck switcher or the battery. In a Turbo event, the ISL95521A turns on the BGATE to discharge the battery so the battery works with the adapter together to supply the system power.

The PROG pin resistor programs the ratio of the current sensing resistor values R_{S1} and R_{S2} as 2:1 or 1:1. Therefore, four sets of R_{S1} and R_{S2} current sensing resistor values can be used, for example:

1. $R_{S1} = 10m\Omega$, $R_{S2} = 5m\Omega$
2. $R_{S1} = 10m\Omega$, $R_{S2} = 10m\Omega$
3. $R_{S1} = 20m\Omega$, $R_{S2} = 10m\Omega$
4. $R_{S1} = 20m\Omega$, $R_{S2} = 20m\Omega$

If $20m\Omega$ R_{S1} is used, the SMBus Information2 register Bit<0> and Bit<8> both need to be set as 1 for the appropriate internal current sensing scaling.

Smaller current sense resistor values reduce the power loss while larger current sense resistor values give better accuracy.

The PROG pin resistor configures the internal current sense gain automatically for different R_{S1} and R_{S2} , such that the SMBus command remains the same for $20m\Omega$ or $10m\Omega$ R_{S1} and for $10m\Omega$ or $5m\Omega$ R_{S2} . For example, the AdapterCurrentLimit1 register, AdapterCurrentLimit2 register and the ACProchot register can be programmed with the same SMBus command value, regardless of whether R_{S1} is $20m\Omega$ or $10m\Omega$, to obtain the same current. The ChargeCurrent register and DCProchot register can be programmed with the same SMBus command value, regardless of whether R_{S2} is $10m\Omega$ or $5m\Omega$, to obtain the same current. Using any option results in 1mA/LSB correlation in the SMBus commands.

If the R_{S1} and R_{S2} values are different from the PROG pin programming table, the SMBus command needs to be scaled accordingly to obtain the correct current.

Upon POR, the ISL95521A uses the default number of cells in series as [Table 17](#) shows and sets the default MaxChargeVoltage register value and defaults MinChargeVoltage register value accordingly. When SMBus communication is established, the

SMBus can program a different number of battery cells in series through SMBus Control1 register Bit<14:13>.

[Tables 18](#) and [19](#) show the adapter current and battery current related settings according to different R_{s1} and R_{s2} options.

TABLE 18. CURRENT SENSING RESISTOR CONFIGURATIONS

CURRENT SENSING RESISTORS		REGISTERS			K _{PSYS} (µA/W)	
		CHARGE CURRENT	DCPROCHOT	ADAPTERCURRENTLIMIT1* ADAPTERCURRENTLIMIT2* ACPROCHOT**	CONTROL2 Bit<9> = 0	CONTROL2 Bit<9> = 1
1	$R_{s1} = 10m\Omega$ $R_{s2} = 5m\Omega$	Bit<12:5> Max = 1FE0h, 8.160A Min = 0020h, 32mA Default = 0000h, 0A	Bit<13:8> Max = 3F00h, 16.128A Min = 0100h, 256mA Default = 2000h, 8.192A	Bit<12:7> Max = 1F80h, 8.064A Min = 0080h, 128mA *Default = 1F80h, 8.064A **Default = 1800h, 6.144A	1.14	0.285
2	$R_{s1} = 10m\Omega$ $R_{s2} = 10m\Omega$	Bit<12:5> Max = 1FE0h, 8.160A Min = 0020h, 32mA Default = 0000h, 0A	Bit<12:7> Max = 1F80h, 8.064A Min = 0080h, 128mA Default = 1000h, 4.096A	Bit<12:7> Max = 1F80h, 8.064A Min = 0080h, 128mA *Default = 1F80h, 8.064A **Default = 1800h, 6.144A	1.14	0.285
3	$R_{s1} = 20m\Omega$ $R_{s2} = 10m\Omega$	Bit<11:4> Max = 0FF0, 4.080A Min = 0010, 16mA Default = 0000h, 0A	Bit<12:7> Max = 1F80h, 8.064A Min = 0080h, 128mA Default = 1000h, 4.096A	Bit<11:6> Max = 0FC0h, 4.032A Min = 0040h, 64mA *Default = 0FC0h, 4.032A **Default = 0C00h, 3.072A	2.28	0.57
4	$R_{s1} = 20m\Omega$ $R_{s2} = 20m\Omega$	Bit<11:4> Max = 0FF0, 4.080A Min = 0010, 16mA Default = 0000h, 0A	Bit<11:6> Max = 0FC0h, 4.032A Min = 0040h, 64mA Default = 0800h, 2.048A	Bit<11:6> Max = 0FC0h, 4.032A Min = 0040h, 64mA *Default = 0FC0h, 4.032A **Default = 0C00h, 3.072A	2.28	0.57

TABLE 19. CURRENT SENSING RESISTOR CONFIGURATIONS

CURRENT SENSING RESISTORS		ADAPTER CURRENT LIMITED BY ACLIM	CHARGING CURRENT LIMITED BY CCLIM	TRICKLE CHARGE		NVDC PRE-CHARGE PERIOD CURRENT LIMIT (mA)	HPB t1-t2 PERIOD CURRENT LIMIT (mA)	AMON	BMON
				128mA	256mA				
1	$R_{s1} = 10m\Omega$ $R_{s2} = 5m\Omega$	$V_{ACLIM}/(32 \cdot R_{s1})$	$V_{CCLIM}/(64 \cdot R_{s2})$	128	256	256	625	$32 \cdot R_{s1} \cdot I_{ADP}$	$32 \cdot R_{s2} \cdot I_{BAT}$
2	$R_{s1} = 10m\Omega$ $R_{s2} = 10m\Omega$	$V_{ACLIM}/(32 \cdot R_{s1})$	$V_{CCLIM}/(32 \cdot R_{s2})$	128	256	256	625	$32 \cdot R_{s1} \cdot I_{ADP}$	$32 \cdot R_{s2} \cdot I_{BAT}$
3	$R_{s1} = 20m\Omega$ $R_{s2} = 10m\Omega$	$V_{ACLIM}/(32 \cdot R_{s1})$	$V_{CCLIM}/(64 \cdot R_{s2})$	128	256	128	312.5	$32 \cdot R_{s1} \cdot I_{ADP}$	$32 \cdot R_{s2} \cdot I_{BAT}$
4	$R_{s1} = 20m\Omega$ $R_{s2} = 20m\Omega$	$V_{ACLIM}/(32 \cdot R_{s1})$	$V_{CCLIM}/(32 \cdot R_{s2})$	128	256	128	312.5	$32 \cdot R_{s1} \cdot I_{ADP}$	$32 \cdot R_{s2} \cdot I_{BAT}$

Programming Switching Frequency

TABLE 20. DEFAULT CCM SWITCHING FREQUENCY OPTIONS

FSET-GND RESISTANCE (k Ω)	SWITCHING FREQUENCY (kHz)	
	TYP (1% STANDARD RESISTOR)	4-CELL WITH PERIOD STRETCH
0	992	500
22.6	838	430
38.3	729	375
54.9	642	335
69.8	678	460
86.6	614	420
102	561	390
118	517	360
133	513	420
150	477	390
165	449	370
182	421	350
200	417	360
215	395	340
237	375	330
255	350	310

The resistor from the FSET pin to GND programs the default CCM switching frequency, as shown in [Table 20](#). Before soft-start, the ISL95521A sources 10 μ A current out of the FSET pin and reads the FSET pin voltage to determine the resistor value. However, application environmental noise may pollute the FSET pin voltage and cause incorrect reading. If noise is a concern, it is recommended to connect a capacitor from the FSET pin to GND to provide filtering. The resistor and the capacitor RC time constant should be less than 40 μ s, so the FSET pin voltage can rise to steady state before the ISL95521A reads it.

In DE mode of operation, the ISL95521A employs a phase comparator to monitor the PHASE node voltage during low-side switching FET on-time 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 ISL95521A may lose diode emulation ability. To prevent such scenario, the ISL95521A 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 ISL95521A stretches the switching period 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. This effect is only pronounced in applications using 4-cell battery and high switching frequency setting.

The switching frequency can be changed through SMBus Control2 register Bit<3:0> after POR. See SMBus Control2 register programming table for detailed description.

Soft-Start

When the DCIN pin voltage is higher than 5V, an internal LDO starts to regulate and outputs 5V on the VDDP pin, which is the power supply for the gate drives.

The VDD pin is the 5V power supply for the ISL95521A control circuitry. It is recommended to use an R-C filter to generate the VDD pin voltage from the VDDP pin voltage. When the VDD pin voltage exceeds its POR, the ISL95521A sources 10 μ A current out of the PROG pin and reads the pin voltage to determine the PROG resistor value; it sources 10 μ A current out of the FSET pin and reads the pin voltage to determine the FSET resistor value. The PROG resistor and the FSET resistor values programs the configurations of the ISL95521A.

Soft-start begins when the VDD pin voltage exceeds its POR, the ACIN pin voltage exceeds 2V, the DCIN pin voltage is higher than the VBAT pin voltage, and after the 163ms delay.

Note: after the adapter is plugged in, the ASGATE turn-on delay is always 163ms, regardless of the Control2 register Bit<5> setting. Control2 register Bit<5> only sets the ASGATE turn-on delay during restart in a fault condition.

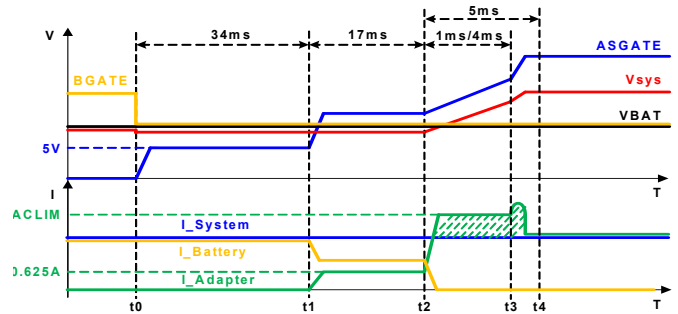


FIGURE 39. SOFT-START WITH $V_{BAT} < 4.5V$ OR $V_{BAT} > 7V$

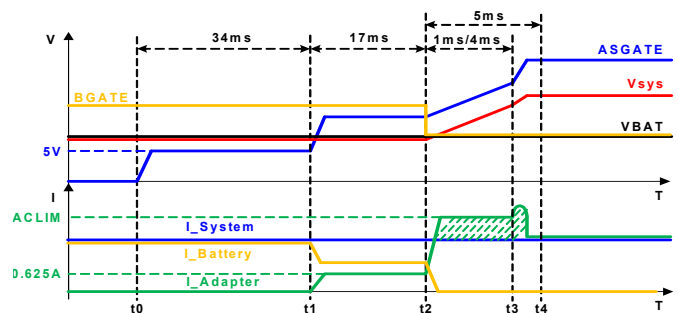


FIGURE 40. SOFT-START WITH $4.5V < V_{BAT} < 7V$

In both HPB charger and NVDC charger configurations, during soft-start, the ISL95521A limits the adapter current in several steps. See [Figure 39](#), at t_0 , the ISL95521A outputs 20 μ A current source to charge the ASGATE pin voltage to 5V and then holds the ASGATE pin voltage at 5V for 34ms until t_1 . From t_1 to t_2 , the ISL95521A limits the adapter current at 0.625A ($R_{S1} = 10m\Omega$) for 17ms. From t_2 to t_3 , the ISL95521A limits the adapter current at the value set by the ACLIM pin voltage for the next 1ms (default, 4ms option is available through SMBus Control2 register Bit<10>). From t_3 to t_4 , the ISL95521A outputs 20 μ A for another 4ms (or 1ms) to fully turn on ASGATE without actively limiting the adapter current. ACOK is asserted high after the ASGATE is fully turned

on. The stepped soft-start scheme carefully bias up the system and protects the back-to-back ASGATE FETs against potential damage caused by the inrush current.

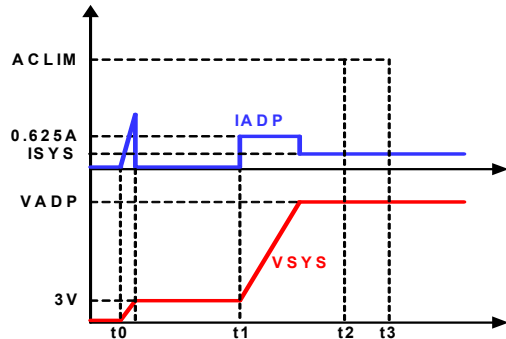


FIGURE 41. NO BATTERY SOFT-START WITH $I_{SYS} < 0.625A$

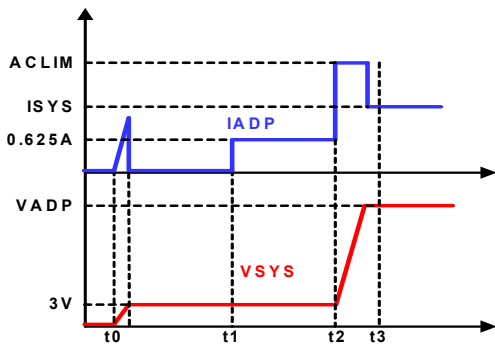


FIGURE 42. NO BATTERY SOFT-START WITH $0.625A < I_{SYS} < ACLIM$

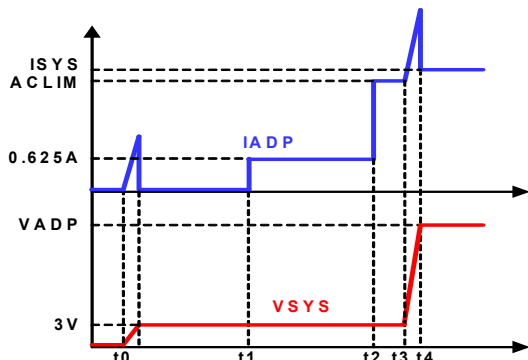


FIGURE 43. NO BATTERY SOFT-START WITH $I_{SYS} > ACLIM$

Figure 41 shows HPB configuration without battery soft-start waveform when the system load is less than 0.625A. During t_1 through t_2 , the ISL95521A charges the system bus capacitor with (0.625A - system load) current and reaches the adapter voltage level by t_2 . There is not inrush current after t_2 .

Figure 42 shows HPB configuration without battery soft-start waveform when the system load is greater than 0.625A but less than the ACLIM-set current level. During t_1 through t_2 , the system bus voltage stays at 3V because there is not enough current to overcome the load to charge the system bus capacitors. During t_2 through t_3 , the ISL95521A charges the system bus capacitor with (ACLIM - system load) current and reaches the adapter voltage by t_3 . There is not inrush current after t_3 .

Figure 43 shows HPB configuration without battery soft-start waveform when the system load is greater than the ACLIM-set current level, which is not a recommended mode of operation. During t_1 through t_3 , the system bus voltage stays at 3V because there is not enough current to overcome the load to charge the system bus capacitors. During t_3 through t_4 , the ISL95521A fully turns on the ASGATE and lets the adapter charge the system bus capacitor without current limit.

In HPB charger configuration, the ISL95521A can smartly determine when to turn off the BGATE MOSFET to prevent system voltage disturbance. BGATE MOSFET turns off at t_0 before ASGATE ramps up if $V_{BAT} < 4.5V$ or $V_{BAT} > 7V$ as shown in Figure 39 on page 41 and remains on until t_2 if $4.5V < V_{BAT} < 7V$ as shown in Figure 40 on page 41. Such a scheme prevents the system bus voltage from dropping by MOSFET body-diode voltage drop caused by BGATE MOSFET turning off early. There is a period of time when BGATE and ASGATE are both on, during which a maximum 0.625A ($R_{S1} = 10m\Omega$) current flows into the battery if system load current is zero. This should not pose any danger to the battery. However, if this scheme is not desired, Control2 register Bit<11> can turn off BGATE before ASGATE ramps up regardless the battery voltage.

In NVDC charger configuration, after fully turning on ASGATE, the ISL95521A starts the switcher. If $V_{BAT} > 3.5V$, BGATE MOSFET remains on for about 28ms after the buck regulator starts switching to prevent the system bus from dropping by a MOSFET body-diode voltage drop caused by BGATE MOSFET turning off early. This 28ms switching is called precharging switching. During the 28ms, the current that flows into battery is controlled at 256mA or 128mA based on the current sensing resistor configuration (see Table 19). If $V_{BAT} < 3.5V$, BGATE MOSFET turns off before the 28ms precharging switching to avoid the charging current to the depleted battery. ACOK signal is asserted high after the precharging switching period.

Adapter Presence Detection and ACOK

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 ISL95521A actively pulls low ACOK in the absence of the adapter.

Use a voltage divider from the adapter voltage to set the ACIN pin voltage. The ISL95521A monitors the ACIN pin voltage to determine the presence of the adapter. When the ACIN pin voltage exceeds 2V, the DCIN pin voltage is higher than the VBAT pin voltage and ASGATE is fully turned on, the ISL95521A allows the external circuit to pull-up the ACOK pin. For NVDC configuration, the ISL95521A allows the external circuit to pull up the ACOK pin after the precharging switching period.

For the buck converter to work properly to charge the battery, the ACIN pin voltage divider should be selected such that the minimum adapter voltage set by the ACIN pin voltage divider is higher than the maximum battery voltage. There is a delay between the ACIN pin voltage rising above 2V and ASGATE starting to turn on. The delay is 163ms.

Depending on different operation scenarios, the total de-glitch time from the ACIN pin voltage rising above 2V to ACOK asserted high varies. For HPB configuration, this de-glitch time is about 278ms with PROG pin resistor reading and about 247ms without

PROG pin resistor reading. For NVDC configuration, this de-glitch time is about 338ms with the PROG pin resistor reading and about 307ms without the PROG pin resistor reading. These typical numbers can have an ±1% variation.

Adapter Overvoltage Protection

If the ACIN voltage exceeds 3.5V, the ISL95521A considers an adapter overvoltage condition has occurred. It turns off ASGATE MOSFETs to isolate the adapter from the system and deasserts the ACOK signal by pulling it low.

When the ACIN voltage drops below 3.5V, after the 1.3s or 163ms debounce time set by Control2 register Bit<5>, it goes through the ASGATE soft-start to turn on ASGATE.

The adapter OVP function can be disabled through the SMBus Control2 register Bit<8>.

Power Source Selection

The ISL95521A automatically selects the adapter and/or the battery as the source for system power.

The BGATE pin drives an NFET that connects/disconnects the battery from the system and the switcher.

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

If the adapter is present, the ISL95521A turns on ASGATE to connect the adapter to the system. In HPB charger configuration, it also turns off BGATE to disconnect the battery from the system when it turns on ASGATE.

If the adapter is absent, the ISL95521A turns off ASGATE and turns on BGATE to connect the battery to the system. If system bus voltage is higher than the battery voltage, the ISL95521A waits until the system bus voltage decays to battery voltage before turning on BGATE to avoid inrush current into the battery.

Battery Learn Mode

The ISL95521A supports Battery Learn mode. The ISL95521A enters Battery Learn mode when it receives SMBus Control command (see [Table 13 on page 32](#)), or when the PROG pin voltage is externally pulled to 5V after POR. It is not possible to pull up the PROG pin to 5V if the PROG pin to GND resistor value is chosen to be 0Ω. The ISL95521A exits Battery Learn mode when it receives the SMBus control command as [Table 13](#) shows, or when the PROG pin voltage is no longer pulled to 5V.

HPB Charger Battery Learn Mode Entry/Exit

In HPB charger configuration Battery Learn mode, the ISL95521A turns off ASGATE and turns on BGATE regardless of whether the adapter is present or not. 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". The Information1 register Bit<1> indicates ASGATE on or off.

Upon entering Battery Learn mode, the ISL95521A only turns on BGATE when the system bus voltage decays to battery voltage to avoid inrush current from system bus to battery.

There are three ways of exiting HPB charger configuration Battery Learn mode:

1. Receive Battery Learn Mode Exit command through SMBus.
2. The PROG pin voltage drops below 5V.
3. BATGONE pin voltage goes from logic LOW to HIGH.

In cases 1 and 2, after the ASGATE turn on delay of 163ms, the ISL95521A goes through the soft-start process to turn on ASGATE and turn off BGATE as described in ["Soft-Start" on page 41](#).

In case 3, the ISL95521A uses its maximum gate drive strength to turn on ASGATE quickly to prevent system voltage collapse. This action can be completed within ~35μs after the BATGONE pin voltage level goes to logic high. If the soft-start process is still preferred in this case, use SMBus Control1 register Bit<7> to configure the preference.

NVDC Charger Battery Learn Mode Entry/Exit

In NVDC charger configuration Battery Learn mode, the ISL95521A turns on BGATE, keeps ASGATE on but turns off the switcher regardless of whether the adapter is present or not.

Upon entering Battery Learn mode, the ISL95521A only turns on BGATE when the system bus voltage decays to battery voltage to avoid inrush current from system bus to battery.

The three ways of exiting NVDC charger configuration Battery Learn mode are the same as for HPB charger configuration Battery Learn mode listed as follows:

1. Receive Battery Learn Mode Exit command through SMBus.
2. The PROG pin voltage drops below 5V.
3. BATGONE pin voltage goes from logic LOW to HIGH.

In all these cases, the ISL95521A resumes switching immediately to supply power to the system bus from the adapter to prevent system voltage collapse.

Hardware-Based Adapter Current Limit

The ACLIM pin voltage set hardware-based adapter current limit provides an extra level of protection in the unlikely event of SMBus communication failure.

[Equation 1](#) gives the relationship between the ACLIM pin voltage and the hardware-based adapter current limit, where $V_{ACLIMHW}$ is ACLIM pin voltage in volts and $I_{ACLIMHW}$ is the hardware-based adapter current limit in amperes.

$$I_{ACLIMHW} = \frac{V_{ACLIMHW}}{32 \times R_{s1}} \quad (\text{EQ. 1})$$

[Equation 1](#) is true for all current sensing resistor configurations.

The ISL95521A uses the lower value of the hardware-set adapter current limit and the SMBus programmed adapter current limit as the actual adapter current limit.

The ACLIM pin voltage also sets the ASGATE soft-start current limit level from t2 to t3. The ACLIM current limit function can be disabled through SMBus Control2 register Bit<13> after ACOK assertion, such that ACLIM pin is only used for ASGATE soft-start current limit from t2 to t3 as shown in ["Soft-Start" on page 41](#).

HPB Charger Turbo Mode Support

Turbo mode refers to the scenario when the system draws more power than the adapter's power rating. It prompts the need for the switcher to change from forward buck mode of operation to reverse-boost mode of operation to reverse the energy flow. Such mode of operation enables the battery to help the adapter provide the required system power. Such operation has been widely used in many systems, such as "sun mode" and "eclipse mode" for bidirectional battery charger/discharger used on satellites with solar panels as the power source acting as the adapter (see "A zero voltage switching bidirectional battery charger/discharger for the NASA EOS Satellite", Dan M. Sable, Fred C. Lee and Bo H. Cho, APEC 1992 Conference Proceedings).

In HPB charger configuration, the ISL95521A normally operates the switcher as a synchronous buck converter with diode emulation. When the buck converter is in light-load condition, it enters DCM operation with reduced switching frequency to increase efficiency. From the description of the R3 modulator operational principle, the COMP pin voltage is lower at lighter load and may reach the low clamp.

In Turbo mode, the ISL95521A operates the switcher in reverse-boost mode to boost energy from the battery to the adapter voltage rail, such that the adapter current is limited at the adapter current limit set point while the battery supplies the additional power required by the system.

The Control1 register Bit<10> enables/disables the Turbo/Boost function. See [Table 13](#) for details.

The ISL95521A enters Turbo mode when all of the following three criteria are met:

1. Adapter current is within 80mA of AdapterCurrentLimit1 (or AdapterCurrentLimit2 if two-level adapter current limit function is enabled) register setting.
2. Battery charging current is less than 150mA.
3. COMP pin voltage is lower than 1.4V.

Meeting these three criteria means that the ISL95521A only enters Turbo mode precisely when it is absolutely necessary. For example, assuming the adapter voltage is 20V, the adapter

current limit is 4A (80W rating) and the ISL95521A is charging an 8V battery at a 5A rate (40W charging power). If the system load increases from 0W to 79W instantaneously, the adapter current increases from 2A to 5.95A instantaneously, exceeding the 4A current limit level. However, the adapter current loop takes control and decreases the charging current to limit the adapter current at 4A, eventually providing 79W of system power and 1W of battery charging power. In such case, the ISL95521A does not need to enter Turbo mode adapter and can conserve battery energy. In the same example, if the system load increases from 0W to 81W instantaneously, the adapter current increases from 2A to 6.05A instantaneously, exceeding the 4A current limit level. The adapter current loop takes control and decreases the charging current to limit the adapter current at 4A. Thus, the ISL95521A eventually determines that it needs to enter Turbo mode so the adapter provides 80W and the battery provides 1W, to provide 81W to the system.

The interaction of the control loops within the ISL95521A, including the adapter current loop, the charging current loop and the battery full charging voltage loop, determines the timing of the Turbo mode entry. The timing strongly depends on the control loop compensation design and the interaction among the loops. In the previous example, compared with system power instantaneously increasing from 0W to 81W, system power instantaneously increasing from 0W to 160W causes the ISL95521A to enter Turbo mode much faster because the loops drive the circuit parameters to meet the three Turbo mode entry criteria much quicker when the adapter is more severely overloaded.

The ISL95521A exits Turbo mode when one of the following three criteria are met:

1. Battery charging current exceeds 150mA ($R_{S2} = 10m\Omega$).
2. Adapter current is less than AdapterCurrentLimit register setting and COMP voltage is lower than 1.4V.
3. Battery discharging current is less than 140mA (for $R_{S2} = 10m\Omega$) for 140ms.

[Table 21](#) shows the ISL95521A HPB configuration charge function and Turbo/Boost function control truth table.

TABLE 21. HPB CHARGER BEHAVIOR TRUTH TABLE

TURBO/BOOST MODE CONTROL BIT	ENABLECHARGING CONTROL BIT	CHARGECURRENT REGISTER		
0 = ENABLE BOOST 1 = DISABLE BOOST	0 = DISABLE CHARGING 1 = ENABLE CHARGING	0 = 0A COMMAND 1 = NON-ZERO VALID COMMAND	CHARGE?	BOOST?
0	0	0	NO	YES
0	0	1	NO	YES
0	1	0	NO	YES
0	1	1	YES (Fast charge and trickle charge enabled)	YES
1	0	0	NO	NO
1	0	1	NO	NO
1	1	0	NO	NO
1	1	1	YES (Fast charge and trickle charge enabled)	NO

TABLE 22. NVDC CHARGER BEHAVIOR TRUTH TABLE

TURBO/BOOST MODE CONTROL BIT	ENABLECHARGING CONTROL BIT	CHARGE CURRENT REGISTER	BGATE ON/OFF	
0 = ENABLE TURBO 1 = DISABLE TURBO	0 = DISABLE CHARGING 1 = ENABLE CHARGING	0 = 0A COMMAND 1 = NON-ZERO VALID COMMAND	SYSTEM LOAD NOT IN TURBO MODE RANGE	SYSTEM LOAD IN TURBO MODE RANGE
0	0	0	OFF	ON
0	0	1	OFF	ON
0	1	0	OFF	ON
0	1	1	ON for fast charge; trickle charge enabled	ON
1	0	0	OFF	OFF
1	0	1	OFF	OFF
1	1	0	OFF	OFF
1	1	1	ON for fast charge; trickle charge enabled	ON

NVDC Charger Turbo Mode Support

In NVDC charger configuration and Turbo mode, the ISL95521A turns on the BGATE FET to limit the adapter current at the adapter current limit set point while the battery supplies the rest of the power required by the system. To turn on BGATE in Turbo mode, the CSON pin voltage needs to be 175mV lower than the VBAT pin voltage. If the ISL95521A detects 150mA charging current or if the battery discharging current is less than 140mA for 140ms, it turns off BGATE to exit Turbo mode. See [Table 22](#) for BGATE operation.

Two-Level Adapter Current Limit

In a real system, a 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 ISL95521A employs two-level adapter current limit to fully take advantage of adapter's surge capability and minimize the power draw from the battery.

[Figure 44](#) 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 reaches 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.

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

The two-level adapter current limit function can be enabled and disabled through SMBus Control2 register Bit<6>. 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.

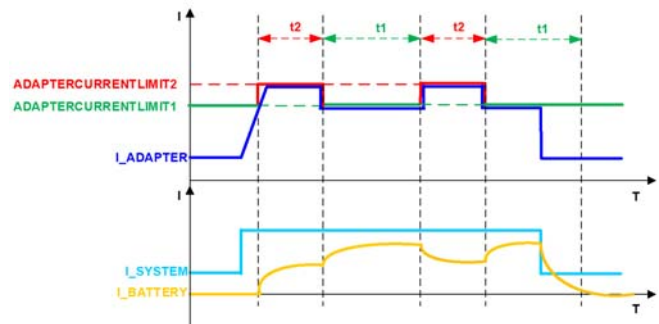


FIGURE 44. TWO-LEVEL ADAPTER CURRENT LIMIT

Current Monitor

The ISL95521A provides an adapter current monitor through the AMON pin and a battery discharging current monitor through BMON pin. The AMON pin voltage is 32x the (V_{CSIP}-V_{CSIN}) voltage and the BMON pin voltage is 32x the (V_{CSON}-V_{CSOP}) voltage.

AMON and BMON function can be enabled or disabled through SMBus Control1 register Bit<2> and Bit<3> respectively, as [Table 13 on page 32](#) shows.

PSYS Monitor

The ISL95521A PSYS pin provides a measure of the instantaneous power consumption of the entire platform. The PSYS pin outputs a current source described by [Equation 2](#).

$$I_{PSYS} = K_{PSYS} \times (V_{ADP} \times I_{ADP} + V_{BAT} \times I_{BAT}) \quad (\text{EQ. 2})$$

K_{PSYS} is based on the current sensing resistors R_{S1} and R_{S2} configuration and is selectable through SMBus Control2 register Bit<9>. See [Table 18](#) for details. 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 the CSON pin to maximize the power monitor accuracy in NVDC configuration trickle charge mode.

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, convert the PSYS information from current to voltage.

The PSYS function can be enabled or disabled through SMBus Control1 register Bit<4> as shown in [Table 13](#).

Charger Timeout

The ISL95521A includes a timer to insure the SMBus master is active and to prevent overcharging the battery. The ISL95521A terminates charging if the charger has not received a write to the MaxChargeVoltage or ChargeCurrent register within 175s. If a time-out occurs, MaxChargeVoltage or ChargeCurrent register must be written to re-enable charging.

The ISL95521A allows you to disable the charger timeout function through SMBus Control1 register Bit<15> as [Table 13](#) shows.

Trickle Charging

The ISL95521A supports trickle charge to an overly discharged battery. It can activate the trickle charge function when the battery voltage is lower than MinChargeVoltage setting. The VBAT pin is the battery voltage sense point for trickle charge mode.

To enable trickle charge, set EnableCharging control bit to 1 and set ChargeCurrent register to a valid non-zero value. To disable trickle charge, either set EnableCharging control bit to 0 or set ChargeCurrent register to 0. [Table 21 on page 44](#) shows the condition to enable HPB configuration trickle charge mode. [Table 22](#) shows the condition to enable the NVDC configuration trickle charge mode.

The trickle charging current can be programmed to be 256mA, 128mA or 64mA through SMBus Control2 register Bit<7> and Bit<12> as shown in [Table 14 on page 34](#).

In HPB charger configuration, the ISL95521A charges the battery at 256mA, 128mA, or 64mA in trickle charge mode.

In NVDC charger configuration trickle charge mode, the ISL95521A regulates the system voltage at 450mV above the MinChargeVoltage register value. An independent control loop regulates BGATE FET gate voltage to regulate the battery charging current at 256mA, 128mA or 64mA.

When the battery voltage is charged to 175mV above MinChargeVoltage register value, the ISL95521A enters fast charging mode by limiting the charging current at the ChargeCurrentLimit register setting.

The ISL95521A CSON pin sinks about 20 μ A current and the CSOP pin sinks about 35 μ A current to provide the bias power for the battery current sensing amplifier. If there is a resistor series in CSON pin, the voltage drop on this resistor creates a small offset such that the actual battery charging current becomes slightly smaller. If there is a resistor series in CSOP pin, the voltage drop on this resistor creates a small offset so that the actual battery charging current becomes slightly larger. These two resistors can be used to slightly tweak the actual battery charging current.

NVDC Charger System Voltage Regulation

If the battery is absent, the ISL95521A regulates the system bus voltage at the higher value of 7.168V and the MinChargeVoltage register setting.

If the battery is present but BGATE is turned off, the ISL95521A regulates the system bus voltage at the higher value of 7.168V and the MaxChargeVoltage register setting.

The CSON pin is used to sense the system bus voltage.

When the battery is absent, in order not to collapse the system voltage, the ISL95521A does not limit the adapter current if the system power draw causes the adapter current to exceed the adapter current limit. This function can be enabled or disabled through SMBus Control2 register Bit<4>.

Charging Current WOCP

The ISL95521A provides the WOCP (Way-Overcurrent Protection) function for the current flowing into to the battery against the high-side MOSFET short and inductor short scenarios. It employs the CCLIM pin to set the WOCP threshold. ISL95521A monitors the CSOP-CSON voltage and compares it with the WOCP threshold. When the WOC comparator is tripped, it either terminates the PWM switching pulse, or turns off ASGATE and deassert ACOK, configurable through SMBus Control1 register Bit<11>.

When the WOCP function is enabled through the Control1 register Bit<11>, if the WOC comparator is tripped, the ISL95521A counts once within every 20 μ s. Whenever ISL95521A counts to 7 times in 656ms, it turns off ASGATE and deassert ACOK immediately. After the 1.3s or 163ms debounce time set by Control2 register Bit<5>, it goes through the ASGATE soft-start to retry.

When the WOCP function is disabled through Control1 register Bit<11>, as long as the WOC comparator is tripped within every 20 μ s, it terminates the PWM switching pulse immediately for the rest of the time of the 20 μ s.

The CCLIM pin voltage sets the charging current WOCP threshold. [Equations 3](#) and [4](#) give the relationship between the CCLIM pin voltage and the WOCP threshold, where $V_{CCLIMHW}$ is the CCLIM pin voltage in volts and I_{WOCP} is the WOCP threshold in amperes.

$$I_{WOCP} = 1.23 \times \frac{V_{CCLIMHW}}{64 \times R_{s2}} \quad (\text{EQ. 3})$$

[Equation 3](#) is true for $R_{s1}:R_{s2} = 2:1$ ($R_{s1} = 10\text{m}\Omega$ and $R_{s2} = 5\text{m}\Omega$ or $R_{s1} = 20\text{m}\Omega$ and $R_{s2} = 10\text{m}\Omega$).

$$I_{WOCP} = \frac{V_{CCLIMHW}}{32 \times R_{s2}} \quad (\text{EQ. 4})$$

[Equation 4](#) is true for $R_{s1}:R_{s2} = 1:1$ ($R_{s1} = 10\text{m}\Omega$ and $R_{s2} = 10\text{m}\Omega$ or $R_{s1} = 20\text{m}\Omega$ and $R_{s2} = 20\text{m}\Omega$).

The WOC comparator monitors the peak current crossing the battery current sensing resistor R_{s2} , so the WOCP threshold needs to be set at least half of the inductor ripple current higher than the SMBus-programmed charging current command to avoid the false tripping in normal charging.

For the WOCP function to work properly, it needs to connect an RC filter from CSON pin to ground to increase the overcurrent detection sensitivity. This RC filter time constant should be selected carefully and cannot be too large, otherwise the WOCP could be falsely tripped by the current overshoot flowing into the battery when ISL95521A exits Turbo mode after system bus load release. Meanwhile, the WOCP threshold should be set high enough to avoid the false trip by the current overshoot flowing into the battery.

The current spike flowing into the battery could cause a voltage spike at the battery connector due to the battery current path impedance. For the NVDC charger, one should pay attention to this voltage spike at VBAT pin so as not to trip the battery 4.6V/cell OVP function, otherwise the BGATE FET turns off due to the battery OVP such that the current flowing on R_{S2} is gone. Adding an RC filter at VBAT is recommended in this scenario.

Over-Temperature Protection

The ISL95521A turns off the internal LDO for self-protection when the junction temperature exceeds $+155^{\circ}\text{C}$. The internal LDO stays off until the junction temperature falls below $+128^{\circ}\text{C}$.

In HPB charger configuration, the ISL95521A puts the charger in standby mode after declaring over-temperature protection.

In NVDC charger configuration, the ISL95521A stops switching after declaring over-temperature protection.

When the temperature falls below $+128^{\circ}\text{C}$, the ISL95521A enables the internal LDO and the ISL95521A resumes operation.

Battery Overvoltage Protection

The battery overvoltage protection function prevents the battery from being overcharged.

In HPB charger configuration, the ISL95521A stops switching if battery voltage is higher than MaxChargeVoltage register setting. If the battery voltage is higher than 4.6V/cell, it stops charging.

In NVDC charger configuration, the ISL95521A stops switching if the system bus voltage is higher than MaxChargeVoltage register value; if the battery voltage is higher than 4.6V/cell, it turns off BGATE to stop charging.

The MaxChargeVoltage register setting should be less than 4.6V/cell.

System Bus Short-Circuit Detection

If the ACIN pin is pulled below 2V by the system bus excessive current or short-circuit, the ISL95521A turns off ASGATE to isolate the adapter from the system bus. When the ACIN pin voltage rises above 2V again and after 163ms delay, ASGATE turns on again with soft-start.

An external circuit, as shown in [Figure 45 on page 47](#), can be used to detect the system bus short-circuit. If the system bus short-circuits, the ACIN pin is pulled below 2V by diode D_1 , so ASGATE cannot turn on. While in normal operation, ASGATE still can turn on when the system bus is charged up above 2V through D_1 .

In normal operation, to charge up the system bus above 2V through D_1 quickly, the ACIN pin voltage divider resistor values need to be small, which in sequence causes a larger constant power consumption on the ACIN pin voltage divider resistors. Two optional circuits as shown in [Figure 45](#) can be dedicated to charge up the system bus. It is recommended to use option 1 circuit for HPB configuration and option 2 circuit for NVDC configuration.

For option 2 circuit, the R_3 and R_4 voltage divider voltage, (the Q_1 gate voltage) needs to be 2V higher than the Q_1 gate source threshold voltage such that Q_1 can be turned on and the system bus can be charged up above 2V through R_2 and Q_1 . Meanwhile, the R_3 and R_4 voltage divider voltage needs to be less than the final system bus voltage such that Q_1 can be turned off in normal operation to avoid the leakage current through Q_1 . The D_3 can be used to block the leakage current from system bus to the adapter side through Q_1 body diode in battery only mode.

Note: with option 1 circuit there is leakage current through R_1 and D_2 when the adapter voltage is higher than the system bus voltage such as in Learn mode or for NVDC configuration.

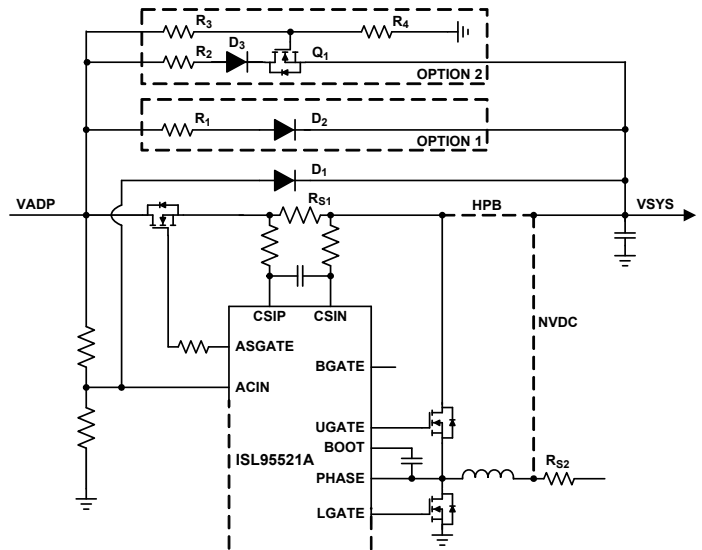


FIGURE 45. EXTERNAL SYSTEM BUS SHORT DETECTION CIRCUIT

Adapter Input Filter

The adapter cable parasitic inductance and capacitance can cause some voltage ring or overshoot spike at adapter connector node when the adapter is hot plugged in. This voltage spike can damage the ASGATE MOSFET or the ISL95521A 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 46](#). A practical value of the RC snubber is 2.2Ω to $2.2\mu\text{F}$ 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.

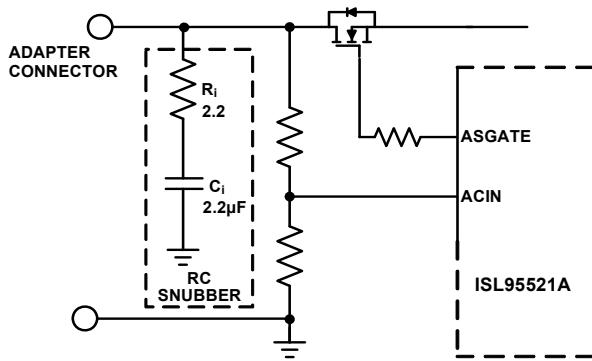


FIGURE 46. ADAPTER INPUT RC SNUBBER CIRCUIT

Test with e-Load Constant Voltage Mode

An electronic load in constant voltage mode (e-Load in CV mode) is often used to emulate a battery in testing a battery charger. However, an e-Load in CV mode does not accurately emulate the characteristics of a real battery, particularly the ESR. Such discrepancy may result in much more exaggerated output voltage switching ripple observed by the battery charger and present inaccurate test results. It is recommended to add a capacitor, such as 680 μ F, at the terminal of the e-Load to better match the impedance of a real battery, such that the test result better represents that with a real battery. As a precaution for potentially testing with an e-load with large ESR, it is recommended to add an R-C filter at the VBAT pin to smooth the switching ripple observed by the ISL95521A. The recommended range of the R-C time constant is 200 μ s to 1ms.

General Application Information

This design guide provides 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, Renesas 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 5](#):

$$D = \frac{V_{OUT}}{V_{IN}} \quad (\text{EQ. 5})$$

The output inductor peak-to-peak ripple current is written by [Equation 6](#):

$$I_{P-P} = \frac{V_{OUT} \cdot (1-D)}{f_{SW} \cdot L} \quad (\text{EQ. 6})$$

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

DC copper loss of the inductor can be estimated by [Equation 7](#):

$$P_{COPPER} = I_{LOAD}^2 \cdot DCR \quad (\text{EQ. 7})$$

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-P} can flow. Current I_{P-P} develops a corresponding ripple voltage V_{P-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 8](#) and [9](#):

$$\Delta V_{ESR} = I_{P-P} \cdot ESR \quad (\text{EQ. 8})$$

$$\Delta V_C = \frac{I_{P-P}}{8 \cdot C_O \cdot f_{SW}} \quad (\text{EQ. 9})$$

If the output of the converter has to support a load with high pulsating current, several capacitors need to be paralleled to reduce the total ESR until the required V_{P-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-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 47 on page 49](#) 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 10](#):

$$I_{IN(RMS,NORMALIZED)} = \frac{I_{MAX} \cdot \sqrt{D \cdot (1-D) + \frac{D \cdot k^2}{12}}}{I_{MAX}} \quad (\text{EQ. 10})$$

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 percentage of I_{MAX} (0% to 100%)
- D is the duty cycle that is adjusted to take into account the efficiency of the converter, which is written as [Equation 11](#):

$$D = \frac{V_{OUT}}{V_{IN} \cdot EFF} \quad (EQ. 11)$$

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.

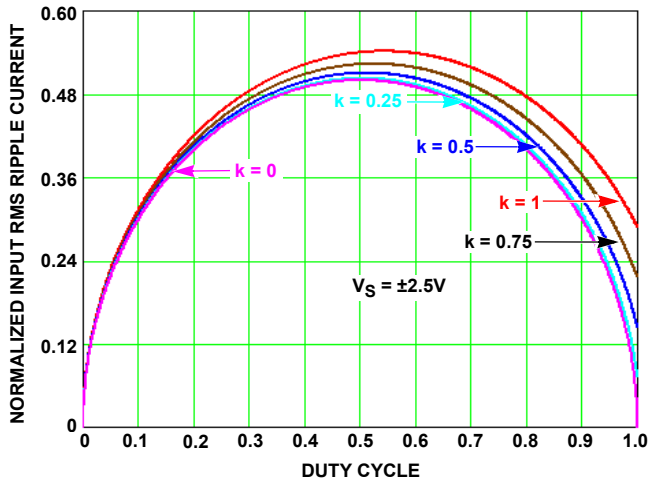


FIGURE 47. NORMALIZED RMS INPUT CURRENT AT EFF = 1

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 $V_{IN} - V_{OUT}$, 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-side 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 12](#):

$$P_{CON_LS} \approx I_{LOAD}^2 \cdot r_{DS(ON)_LS} \cdot (1 - D) \quad (EQ. 12)$$

For the High-Side (HS) MOSFET, conduction loss is written by [Equation 13](#):

$$P_{CON_HS} = I_{LOAD}^2 \cdot r_{DS(ON)_HS} \cdot D \quad (EQ. 13)$$

For the high-side MOSFET, the switching loss is written as [Equation 14](#):

$$P_{SW_HS} = \frac{V_{IN} \cdot I_{VALLEY} \cdot t_{ON} \cdot f_{SW}}{2} + \frac{V_{IN} \cdot I_{PEAK} \cdot t_{OFF} \cdot f_{SW}}{2} \quad (EQ. 14)$$

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_{ON} is the time required to drive the device into saturation
- t_{OFF} is the time required to drive the device into cut-off

Renesas recommends using a 2.2 μ F (10V) VDD/VDDP capacitor, which has an effective capacitance higher than 0.4 μ F at 5V and x1.6 effective cap at the BOOT pin at 5V.

Select the Bootstrap Capacitor

The selection of the bootstrap capacitor is written by [Equation 15](#):

$$C_{BOOT} = \frac{Q_g}{\Delta V_{BOOT}} \quad (EQ. 15)$$

where:

- Q_g is the total gate charge required to turn on the high-side MOSFET
- ΔV_{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 ΔV_{BOOT} of 200mV. The calculated bootstrap capacitance is 0.125 μ F; for a comfortable margin, select a capacitor that is double the calculated capacitance. In this example, 0.22 μ F is sufficient. Use an X7R or X5R ceramic capacitor.

Renesas recommends using a bootstrap capacitor of 0.47 μ F (25V), which has an effective capacitance higher than 0.25 μ F at 5V and x50 effective high side MOSFET gate capacitance.

Select the DCIN Filter

An RC filter is connected at the DCIN pin. Renesas recommends connecting a 10 Ω DCIN resistor between the DCIN pin and the VADP/VSYS diodes, and connecting a 4.7 μ F (50V) DCIN capacitor to GND, which has an effective capacitance higher than 0.4 μ F at 20V.

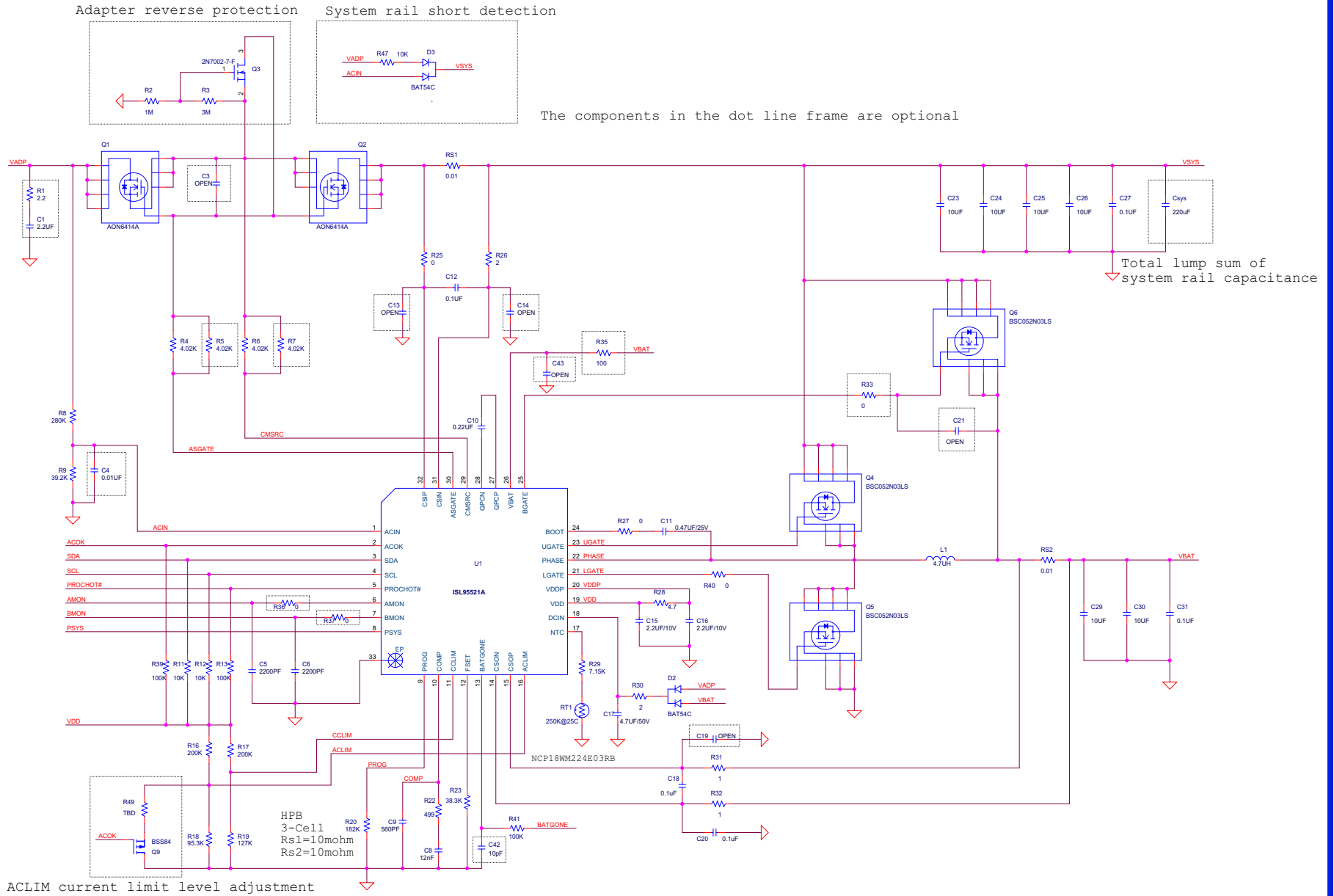


FIGURE 48. ISL95521A HPB CONFIGURATION REFERENCE DESIGN

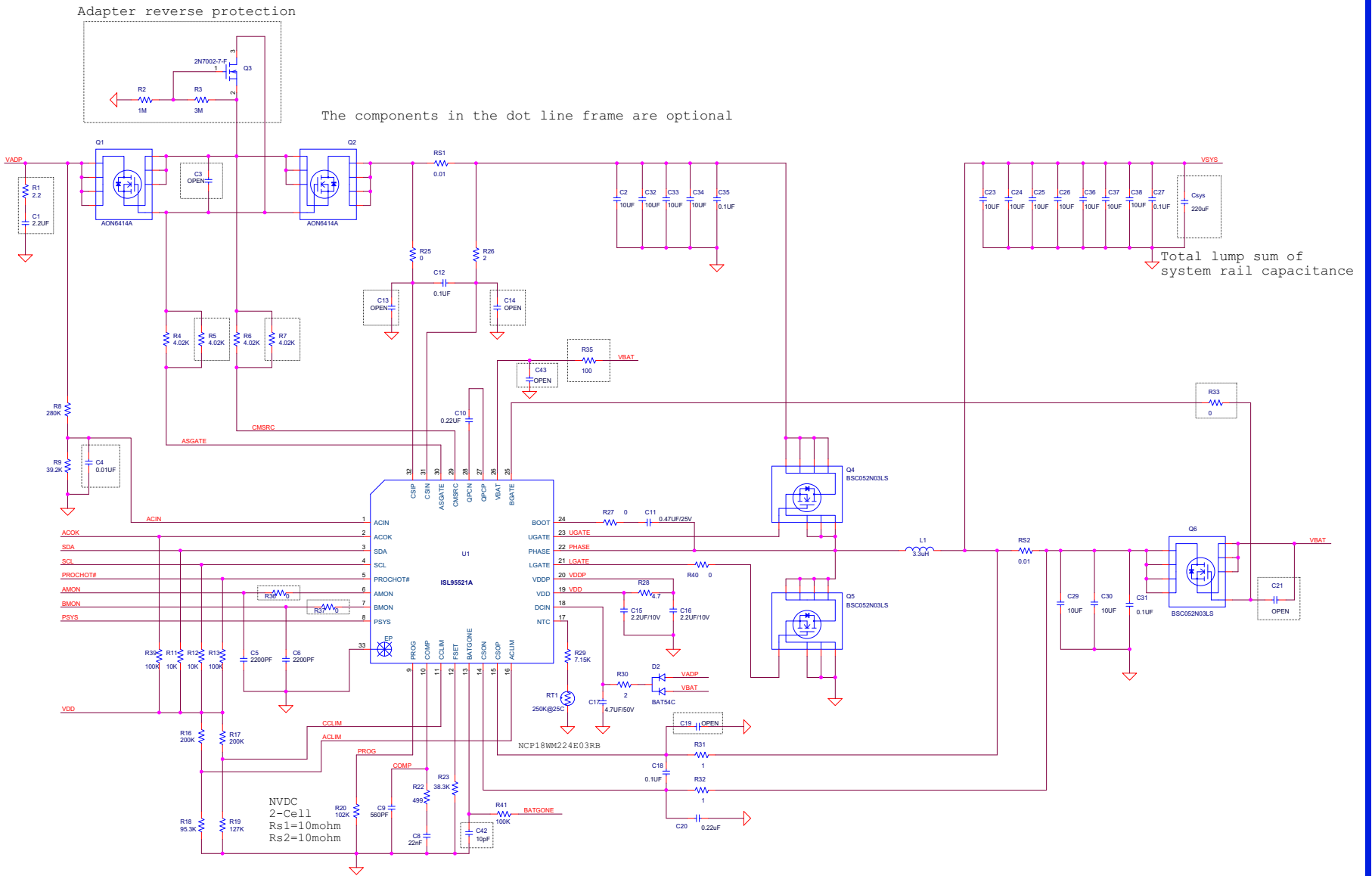
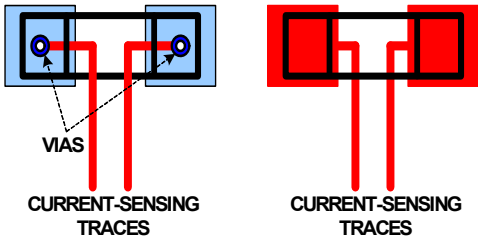


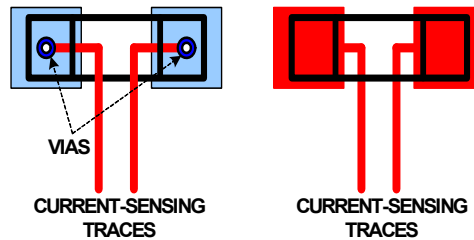
FIGURE 49. ISL95521A NVDC CONFIGURATION REFERENCE DESIGN

Layout Guidelines

PIN #	SYMBOL	LAYOUT GUIDELINES
BOTTOM PAD	GND	Connect this ground pad to the ground plane through the low impedance path. Renesas recommends using of at least 5 vias to connect to ground planes in PCB to ensure there is sufficient thermal dissipation directly under the IC.
1	ACIN	Place the voltage divider resistors and the optional decoupling capacitor in general proximity of the controller.
2	ACOK	No special consideration.
3	SDA	
4	SCLK	
5	PROCHOT#	
6	AMON	
7	BMON	No special consideration.
8	PSYS	
9	PROG	Place the PROG programming resistor in general proximity of the controller.
10	COMP	Place the compensation components in general proximity of the controller.
11	CCLIM	Place the CCLIM voltage divider resistors in general proximity of the controller.
12	FSET	Place the FSET programming resistor in general proximity of the controller.
13	BATGONE	Place the 100kΩ resistor series in the BATGONE signal trace and the optional decoupling capacitor in general proximity of the controller.
14	CSOP	Run two dedicated traces 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.
15	CSOP	<p>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.</p> 
16	ACLIM	Place the ACLIM voltage divider resistors in general proximity of the controller.
17	NTC	Place the resistor series with the NTC thermistor in general proximity of the controller. Place the NTC thermistor at the point where the temperature is to be monitored. Note if the NTC thermistor is too close to the switching components, it may couple the switching noise to the NTC pin.
18	DCIN	Place the OR diodes and the RC filter in general proximity of the controller.
19	VDD	Place the RC filter from VDDP pin in general proximity of the controller.
20	VDDP	Place the decoupling capacitor in general proximity of the controller.
21	LGATE	Run LGATE trace in parallel with UGATE and PHASE traces on the same PCB layer. Use decent width. Avoid any sensitive analog signal trace from crossing over or getting close.

Layout Guidelines (Continued)

PIN #	SYMBOL	LAYOUT GUIDELINES
22	PHASE	Run these two traces in parallel fashion with decent width. Avoid any sensitive analog signal trace from crossing over or getting close. Recommend routing PHASE trace to high-side MOSFET source pin instead of general copper.
23	UGATE	<p>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.</p> <p>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.</p> <p>Place the inductor input 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.</p>
24	BOOT	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.
25	BGATE	Use decent width trace from the IC to the BGATE MOSFET gate.
26	VBAT	Place the RC filter in general proximity of the controller. Run a dedicated trace from the battery positive connection point to the IC. In HPB configuration, separate this trace with the trace connecting the CSON pin.
27	QPCP	Place the charge pump flying capacitor in general proximity of the controller. Route trace with decent width.
28	QPCN	
29	CMSRC	Run these two traces in parallel fashion with decent width.
30	ASGATE	
31	CSIN	
32	CSIP	<p>Place the battery current sensing resistor right next to the inductor output. 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.</p> <p>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.</p>



Revision History The revision history provided is for informational purposes only and is believed to be accurate, but not warranted. Please go to web to make sure you have the latest revision.

DATE	REVISION	CHANGE
Jul 19, 2019	FN8841.2	Updated links throughout. Updated Ordering information table by adding tape and reel information and updating notes. Updated the ACIN, DCIN, VDD, VDDP, and BOOT pin descriptions. Added the last paragraph to "Select the Switching Power MOSFET" and "Select the Bootstrap Capacitor" sections on page 49. Added "Select the DCIN Filter" on page 49. Updated Figures 48 and 49. Removed About Intersil section. Updated disclaimer.
Aug 12, 2016	FN8841.1	Ordering information table on page 8: Added ISL95521AIRZ. Recommended Operating Conditions on page 11: Added "Ambient Temperature IRZ: -40°C to +100°C" Added industrial version throughout the datasheet.
May 11, 2016	FN8841.0	Initial Release

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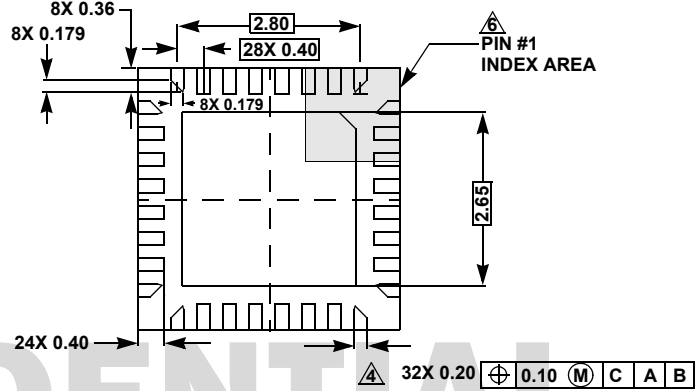
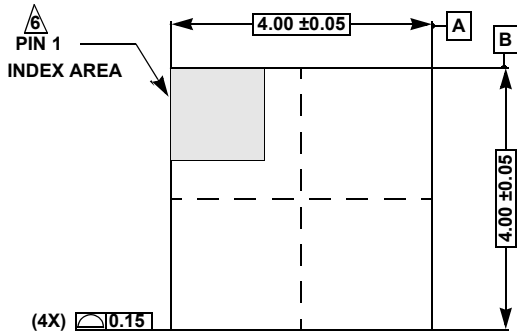
Package Outline Drawing

For the most recent package outline drawing, see [L32.4x4A](#).

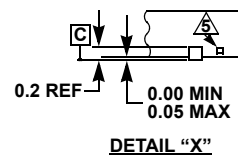
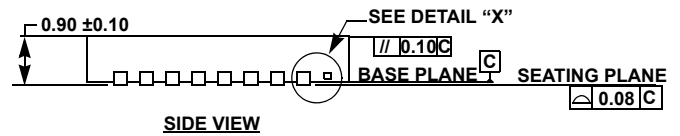
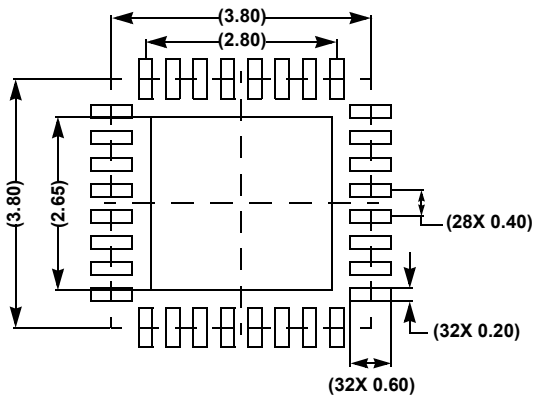
L32.4x4A

32 LEAD QUAD FLAT NO-LEAD PLASTIC PACKAGE

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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. \triangle Dimension applies to the metallized terminal and is measured between 0.15mm and 0.25mm from the terminal tip.
5. \triangle Tiebar shown (if present) is a non-functional feature.
6. \triangle 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.

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