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EVALUATION KIT AVAILABLE

MAX8971

Industry's Smallest 1.55A 1-Cell Li+ DC-DC Charger

General Description

The MAX8971 is a compact, high-frequency, high-efficiency switch-mode charger for a one-cell lithium-ion (Li+) battery. It delivers up to 1.55A of current to the battery from inputs up to 7.5V and withstands transient inputs up to 22V. The 4MHz switch-mode charger is ideally suited for small portable devices, such as headsets and ultra-portable media players. It minimizes component size and heat.

Battery-protection features include: low-voltage prequalification, charge fault timer, die temperature monitoring, and battery temperature monitoring. The battery temperature monitoring adjusts the charge current and termination voltage for safe use of secondary lithium-ion batteries.

The IC accepts either a general DC input or USB. It has programmable automatic input-current limiting to protect upstream charging sources such as USB.

Charge parameters are easily adjustable through an I²C interface. Charge is terminated based on user-selectable minimum current level. A safety timer with reset control provides a safety backup for I²C interface. Charge status is provided to the application processor through an interrupt pin.

The IC is available in a space-saving, 20-bump, 2.18mm x 1.62mm WLP package.

Applications

- USB Charging
- Headsets and Media Players
- Smartphones
- Digital Cameras
- GPS, PDAs

Benefits and Features

- **Switch-Mode Charger**
  - **High-Efficiency**
  - **Low Heat**
  - **Fast Charge Time**
- **Small and Simple**
- **Precise**
  - **Up to ±5% Current Regulation and 0.5% Voltage Regulation**
- **Safe**
  - **JEITA Battery Temperature Monitor**
  - **Over/Undervoltage Protection, Safety Timers, Temperature Regulation**
  - **USB Friendly**
- **Flexible**
  - **Programmable Voltage/Current**
  - **Status/Interrupts Through I²C**
  - **Automatic Input Current Limit**
- **I²C Interface**
  - **Input Current Limit (100mA to 1500mA)**
  - **Fast-Charge/Termination Current (250mA to 1550mA)**
  - **Charge Voltage (4.1V, 4.15V, 4.2V, 4.35V)**
  - **Safety Timer**
  - **Termination Enable**
- **+22V Absolute Maximum Input Voltage Rating**
- **Up to 7.5V Maximum Operating Input Voltage**
- **5V USB/Safeout LDO for USB PHY**
- **2.3A GSM RF Test Mode (Factory Testing)**
- **Charge Current to Voltage Conversion (V_{ICHG}) for Baseband ADC**
- **Reverse Battery Leakage Protection**
- **Input/Output Overvoltage Protection**
- **Interrupt Status Output**

***Ordering Information* appears at end of data sheet.**

For related parts and recommended products to use with this part, refer to www.maxim-ic.com/MAX8971.related.

Simplified Applications Circuit appears at end of data sheet.

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LIST OF TABLES

LIST OF FIGURES

ABSOLUTE MAXIMUM RATINGS

BYP to PG_ ....-0.3V to +22V
DC_ to BYP ....-6V to +0.3V
I2CIN, V_{ICHG}, IRQB, SDA, SCL to GND ....-0.3V to +6V
BST to AVL ....-0.3V to +16V
BST to LX_..-0.3V to +6V
PVL, SFO, BAT, CS to PG_ ....-0.3V to +6V
AVL, THM to GND ....-0.3V to +6V
PG_ to GND..-0.3V to +0.3V
DC_, LX_, CS, BAT, BYP Continuous Current ....1.6A_{RMS}

Continuous Power Dissipation (T_A = +70°C)
WLP derate 21.7mW/°C above +70°C 1736mW
Operating Temperature Range..........................-40°C to +85°C
Junction Temperature..+150°C
Storage Temperature Range............................-65°C to +150°C
Soldering Temperature (reflow) ....+260°C

*This device is constructed using a unique set of packaging techniques that impose a limit on the thermal profile the device can be exposed to during board-level solder attach and rework. This limit permits only the use of the solder profiles recommended in the industry-standard specification, JEDEC 020A, paragraph 7.6, Table 3 for IR/VPR and Convection reflow. Preheating is required. Hand or wave soldering is not allowed.

PACKAGE THERMAL CHARACTERISTICS (Note 1)

WLP
Junction-to-Ambient Thermal Resistance (θ_{JA}) ....46°C/W
Junction-to-Case Thermal Resistance (θ_{JC}) ....2°C/W

Note 1: Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maxim-ic.com/thermal-tutorial.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{DC} = 5V, C_{BYP} = 1µF, I_{FCHG} = 500mA, C_{AVL} = 4.7µF, V_{THM} = AVL/2, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
DC INPUT						
DC Operating Voltage Range			4.0		V_{OVP}	V
DC Undervoltage Lockout	DC rising, 500mV hysteresis		3.6	3.8	4.0	V
DC Overvoltage Threshold (V_{OVP})*	DC rising, 250mV hysteresis		7.25	7.5	7.75	V
DC OVP Interrupt Delay				16		ms
DC to BAT Shutdown Threshold	When charging stops, V_{DC} falling, 150mV hysteresis		0	50	100	mV
DC Supply Current	Charger enabled, V_{DC} = 5.5V			2		mA
BST Leakage Current	V_{BST} = 5.5V, LX_ = PG_	T_A = +25°C		0.01	10	µA
		T_A = -40°C to +85°C		0.1		
LX_ Leakage Current	$V_{LX\_}$ = 0 or 5.5V	T_A = +25°C		0.01	10	
		T_A = -40°C to +85°C		0.1		
BAT Reverse Leakage Current	V_{DC} = 0V, V_{BAT} = 4.2V			1	5	µA
Input-Current Limit Range			0.1		1.5	A

ELECTRICAL CHARACTERISTICS (continued)

(V_{DC} = 5V, C_{BYP} = 1µF, I_{FCHG} = 500mA, C_{AVL} = 4.7µF, V_{THM} = AVL/2, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input-Current Limit Accuracy	USB 100mA mode	90	95	100	mA
	USB 500mA mode	450	475	500	
	Input limit programmed to 1.5A, I_{FCHG} = 1500mA	1350	1500	1650	
Adaptive Input-Current Limit (AICL) (Note 4)	DC voltage where charge current is regulated		4.5		V
	DC voltage where charge current is set to 75mA		4.4		
Input Limit Switch	V_{DC} = 5.5V, I_{BYP} = 100mA		35	80	mΩ
BUCK OPERATION					
Switching Frequency	V_{BAT} = 3.6V		4		MHz
Maximum Duty Cycle			99.5		%
Minimum On-Time			55		ns
Maximum On-Time			10		µs
Minimum Off-Time			65		ns
Soft-Start Time			1.5		ms
High-Side Resistance	I_{LX} = 100mA, V_{DC} = 5.5V		120	250	mΩ
Low-Side Resistance	I_{LX} = 100mA, V_{DC} = 5.5V		150	220	mΩ
Thermal Regulation Temperature (T_{REG})	I^2C programmable 2-bits (90, 105, 120, and disable selections, 105 default)		105		°C
Thermal Regulation Gain	Percentage decrease in I_{FCHG} above the thermal regulation temperature		5		%/°C
BATTERY CHARGER PRECHARGE					
Battery-Prequalification Lower Threshold (V_{PQLTH})	V_{BAT} rising, 130mV hysteresis		2.1		V
Dead-Battery Charge Current (I_{DBAT})	0V ≤ V_{BAT} ≤ 2.1V		45		mA
Battery-Prequalification Upper Threshold (V_{PQUTH})**	V_{BAT} rising, 150mV hysteresis		2.5		V
Prequalification Charge Current (I_{PQ})	Percentage of fast-charge current programmed		10		%
CONSTANT-CURRENT MODE					
BAT Fast-Charge Current Range (I_{FC})	5 bits–50mA steps, R_{CS} = 47mΩ	250		1550	mA
Fast-Charge Current Accuracy	T_A = +15°C to +45°C	-5		+5	%
	JEITA safety region (Figure 6)	-65	-50	-35	%

ELECTRICAL CHARACTERISTICS (continued)

(V_{DC} = 5V, C_{BYP} = 1µF, I_{FCHG} = 500mA, C_{AVL} = 4.7µF, V_{THM} = AVL/2, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
CONSTANT VOLTAGE MODE						
Battery Regulation Voltage (V_{BATREG})	I_{BAT} = 100mA, operating in voltage-regulation mode, I^2C-programmable 4.1V, 4.15V, 4.2V, and 4.35V selection	T_A = +25°C	-0.5		+0.5	%
		T_A = -40°C to +85°C	-1		+1	
		JEITA safety region, percentage of battery regulation voltage (Note 6)	96	97	98	
Battery Refresh Threshold	(Below regulation point), 100mV and 150mV selection, default 150mV (Note 5)		120	150	185	mV
Battery Overvoltage Protection	V_{BAT} threshold over regulation voltage to turn off charger during charge (% of regulation voltage) (Note 7)		102	103.5	105	%
	Hysteresis (V_{BAT} falling) at 4.2V			1.4		
Charge-Current Termination Threshold (I_{TOPOFF})	Programmable topoff current independent of JEITA functionality, default 50mA, 200mA hysteresis		50		200	mA
	Deglitch time			16		ms
Charge-Current Termination Accuracy	I_{TOPOFF} = 200mA		-20		+20	%
GSM TEST MODE						
GSM Test-Mode Output Pulse Current	V_{BAT} capacitance ≥ 60µF, peak current pulse frequency = 217Hz, on-duty cycle 12.5%			2.3		A
GSM Test-Mode Minimum Output	V_{BAT} capacitance ≥ 60µF, current pulse frequency = 217Hz, on-duty cycle 12.5% (Note 3)		3.7			V
CHARGER TIMER						
Prequalification Time (t_{PQ})	V_{BAT} < V_{BATPQ_UT}			45		Mins
Fast-Charge Time (t_{FC})	Default 5 hours, I^2C programmable (4–10 hours and disabled selection)			5		hrs
Timer Accuracy				20		%
Top-Off Time (t_{TOPOFF})	I^2C programmable 0 to 70 mintues, 10-minute steps, default 30 mintues		0		70	Mins
Top-Off Timer Accuracy				20		%
Timer-Extend Current Threshold (Note 3)	Percentage of fast-charge current below which the timer clock operates at half speed			50		%

ELECTRICAL CHARACTERISTICS (continued)

(V_{DC} = 5V, C_{BYP} = 1µF, I_{FCHG} = 500mA, C_{AVL} = 4.7µF, V_{THM} = AVL/2, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
THERMISTOR MONITOR						
THM Threshold, Cold, No Charge (0°C)	$V_{THM/AVL}$ rising, 1% hysterisis (thermistor temperature falling)		71.06	74.56	78.06	%
THM Threshold, Cold, Current Foldback (+15°C)	$V_{THM/AVL}$ rising, 1% hysterisis (thermistor temperature falling)		57.00	60.00	63.00	%
THM Threshold, Hot, Voltage Foldback (+45°C)	$V_{THM/AVL}$ falling, 1% hysterisis (thermistor temperature rising)		32.68	34.68	36.68	%
THM Threshold, Hot, No Charge (+60°C)	$V_{THM/AVL}$ falling, 1% hysterisis (thermistor temperature rising)		21.24	22.54	23.84	%
THM Input Bias Current	V_{THM} = V_{AVL} or 0V	T_A = +25°C	-0.2	0.01	+0.2	µA
		T_A = +85°C		0.01		
V_{ICHG}						
V_{ICHG} Output Voltage	I_{BAT} = 100mA			150		mV
	I_{BAT} = 1000mA		1260	1400	1540	mV
	I_{BAT} = 1500mA			2100		mV
IRQB OUTPUT						
Low-Level Output Saturation Voltage	I_{IRQB} =10mA, sinking current				0.4	V
High-Level Leakage Current	V_{IRQB} = 5V	T_A = +25°C	-1	0.01	+1	µA
		T_A = +85°C		0.1		µA
SAFEOUT OUTPUT						
Regulated Output	I_{SFO} = 30mA, V_{DC} = 5.5V		4.75	5	5.25	V
Dropout Voltage	I_{SFO} = 30mA			45		mV
Current Limit				590		mA
Maximum Output Current			100			mA
POK Output Threshold				2.7		V
PVL/AVL OUTPUT						
PVL Output Voltage	5.5V < V_{DC} < 7.5V, no load			5.05		V
AVL Output Voltage	5.5V < V_{DC} < 7.5V, no load			5.05		V
LOGIC LEVELS AND TIMING CHARACTERISTICS (SCL, SDA)						
Output Low Threshold	I_o = 3mA, sink current (SDA)				0.4	V
Input Low Threshold	V_{I2CIN} = 1.8V				0.4	V
Input High Threshold	V_{I2CIN} = 1.8V		1.4			V

ELECTRICAL CHARACTERISTICS (continued)

(V_{DC} = 5V, C_{BYP} = 1µF, I_{FCHG} = 500mA, C_{AVL} = 4.7µF, V_{THM} = AVL/2, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 2)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input Bias Current	V_{I2CIN} = 1.8V, T_A = +25°C			1	µA
SCL Clock Frequency		100		400	kHz
Bus Free Time Between START and STOP (Note 3)		1.3			µs
Hold Time REPEATED START Condition (Note 3)		0.6			µs
SCL Low Period (Note 3)		1.3			µs
SCL High Period (Note 3)		0.6			µs
Setup Time REPEATED START Condition (Note 3)		0.6			µs
SDA Hold Time (Note 3)		0			µs
SDA Setup Time (Note 3)		100			ns
Maximum Pulse Width of Spikes (must be suppressed by the input filter of both SDA and SCL signals) (Note 3)			50		ns
Setup Time for STOP Condition (Note 3)		0.6			µs
THERMAL REGULATION AND SHUTDOWN					
Thermal Shutdown Temperature (Note 3)			+160		°C
Thermal Shutdown Hysteresis (Note 3)			15		°C

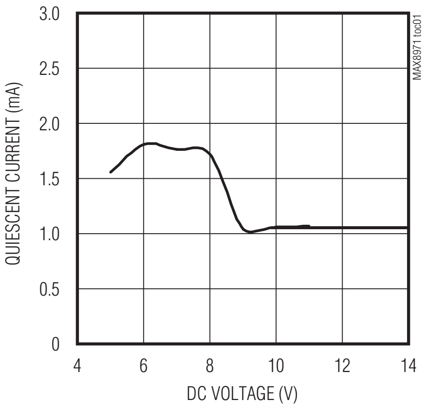
Note 2: Parameters are production tested at T_A = +25°C. Limits over the operating temperature range are guaranteed through correlation using statistical quality control (SQC) methods.
Note 3: Guaranteed by design, not production tested.
Note 4: Voltage for 4.35V battery mode increases by 100mV.
Note 5: Refresh voltage for 4.15V increases by 50mV.
Note 6: JEITA decreases by 1% for 4.15V termination voltage.
Note 7: Battery overvoltage increases by 1% for 4.15V termination voltage.

** = Contact factory for alternate thresholds (6.7V, 9.7V, and 14V available).*
*** = Contact the factory for 3.0V.*

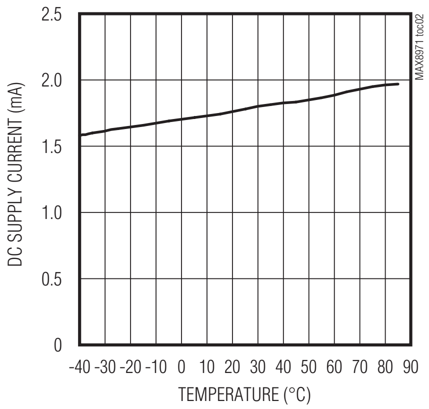
Typical Operating Characteristics

(V_{DC} = 5V, C_{BYP} = 1µF, C_{AVL} = 4.7µF, V_{THM} = 2.5V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.)

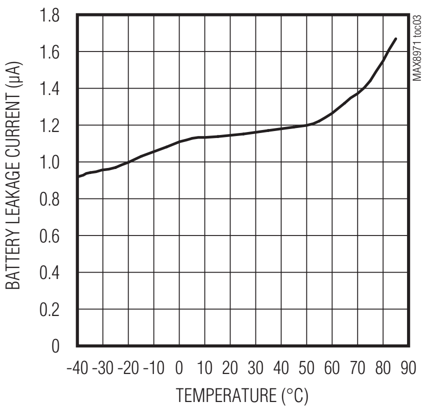
DC QUIESCENT CURRENT vs. DC SUPPLY VOLTAGE



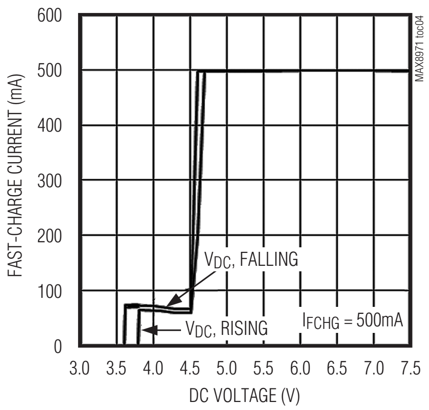
DC SUPPLY CURRENT vs. TEMPERATURE



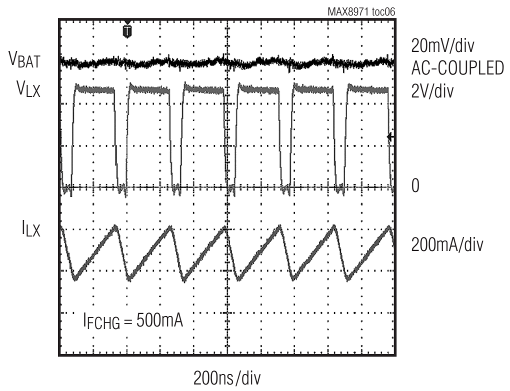
BATTERY LEAKAGE CURRENT vs. TEMPERATURE



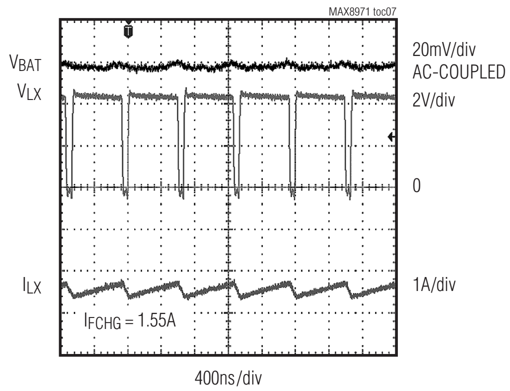
FAST-CHARGE CURRENT vs. DC SUPPLY VOLTAGE



MEDIUM LOAD SWITCHING WAVEFROMS



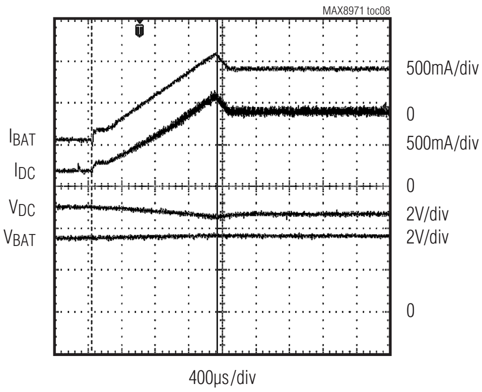
HEAVY LOAD SWITCHING WAVEFROMS



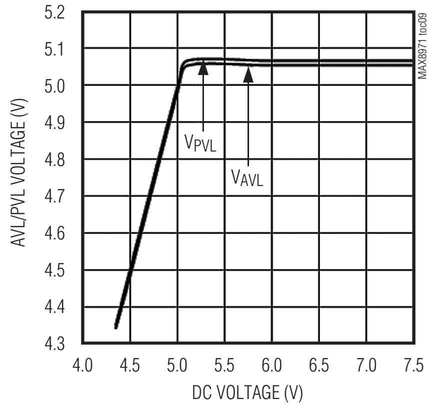
Typical Operating Characteristics (continued)

(V_{DC} = 5V, C_{BYP} = 1μF, C_{AVL} = 4.7μF, V_{THM} = 2.5V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.)

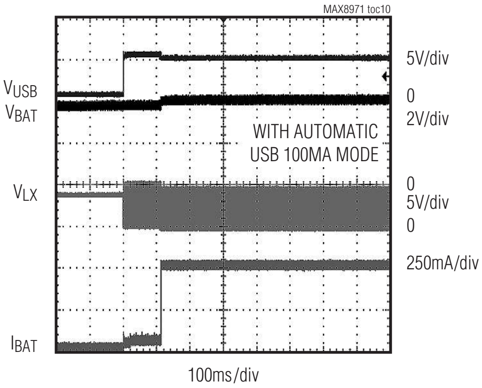
CHARGER ENABLE SOFT-START TIME



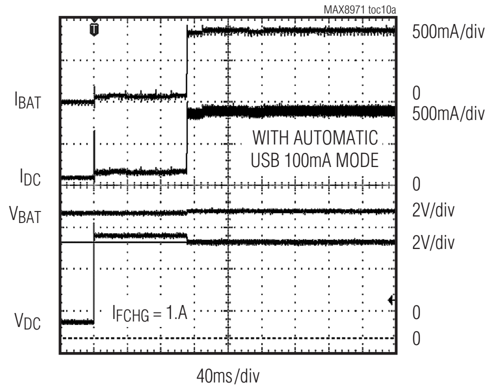
AVL/PVL VOLTAGE vs. DC SUPPLY VOLTAGE



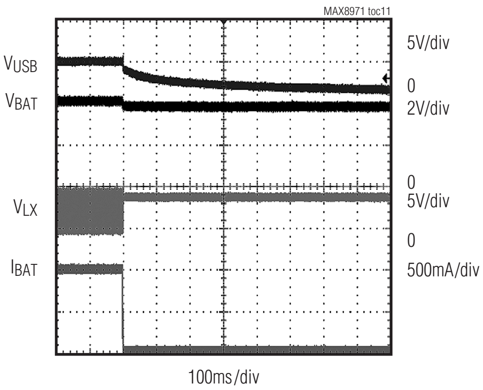
USB INSERTION INTO 500mA DEFAULT FAST-CHARGE CURRENT



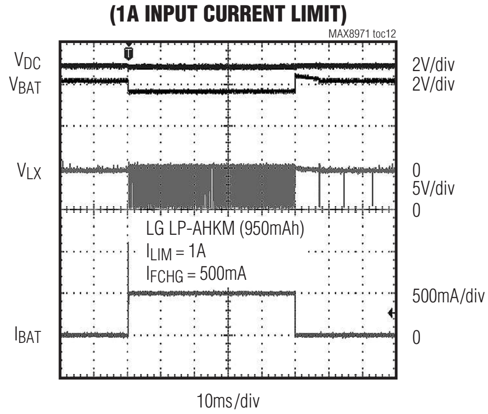
DC PLUG-IN TO 1A DEFAULT FAST-CHARGE CURRENT



USB REMOVAL



BATTERY INSERTION/REMOVAL (1A INPUT CURRENT LIMIT)

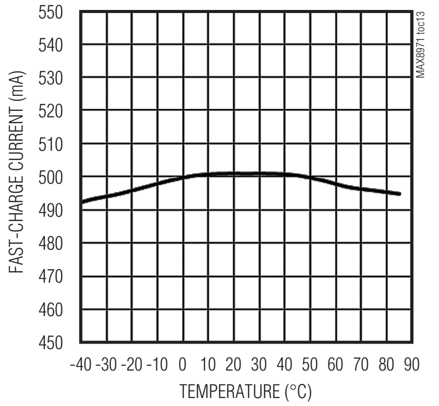


Industry's Smallest 1.55A 1-Cell Li+ DC-DC Charger

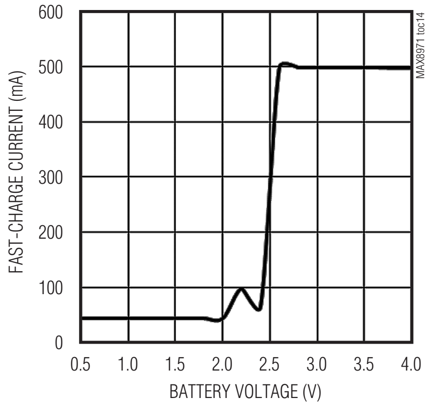
Typical Operating Characteristics

(V_{DC} = 5V, C_{BYP} = 1µF, C_{AVL} = 4.7µF, V_{THM} = 2.5V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.)

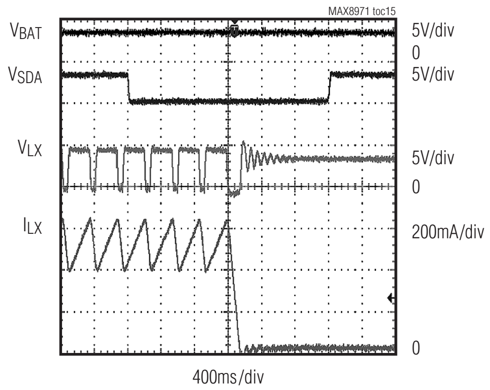
FAST-CHARGE CURRENT vs. TEMPERATURE



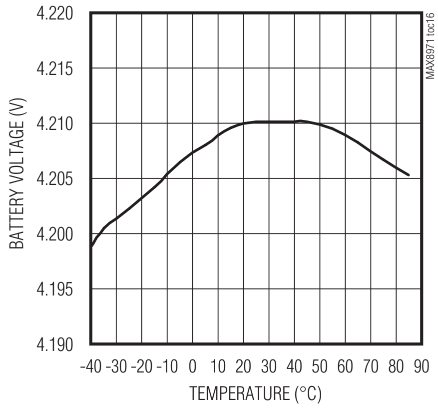
FAST-CHARGE CURRENT vs. BATTERY VOLTAGE



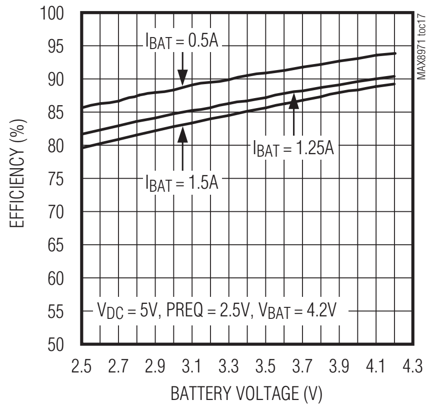
FAST CHARGE TO SUSPEND



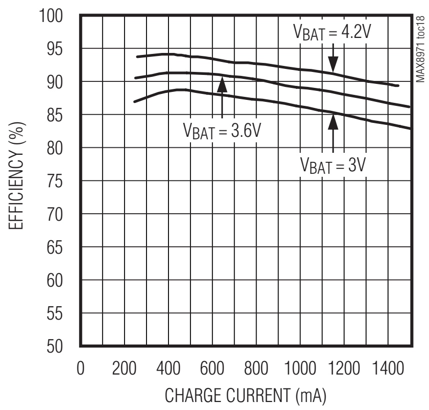
BATTERY REGULATION VOLTAGE vs. TEMPERATURE



BATTERY CHARGER EFFICIENCY vs. BATTERY VOLTAGE



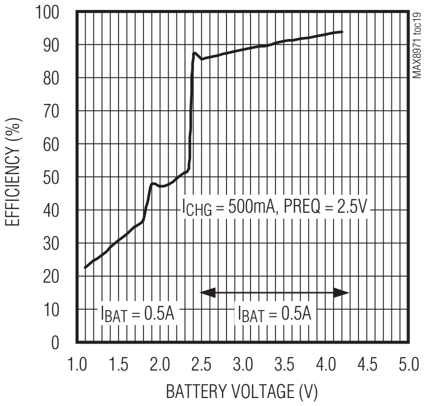
BATTERY CHARGER EFFICIENCY vs. CHARGE CURRENT



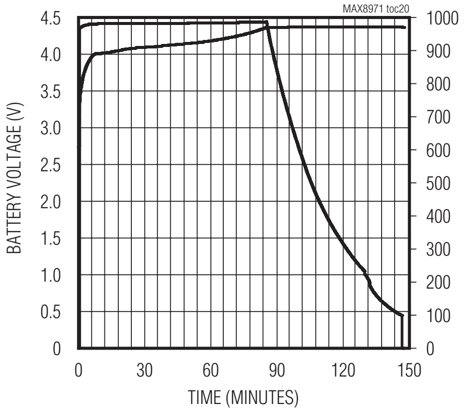
Typical Operating Characteristics

(V_{DC} = 5V, C_{BYP} = 1µF, C_{AVL} = 4.7µF, V_{THM} = 2.5V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.)

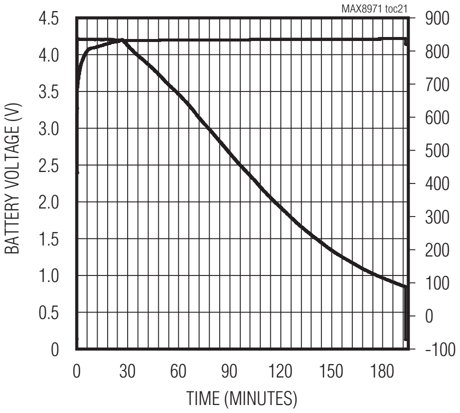
BATTERY CHARGER EFFICIENCY vs. BATTERY VOLTAGE



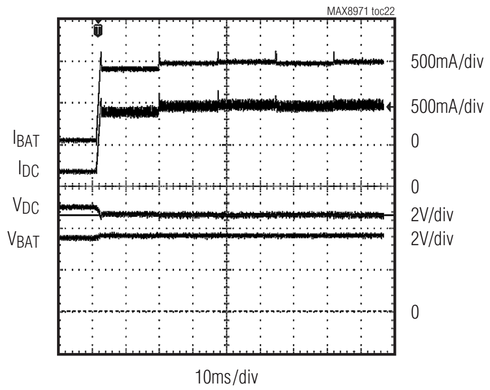
CHARGE PROFILE FOR 1830mAh 4.35V BATTERY CHARGED AT 0.55C



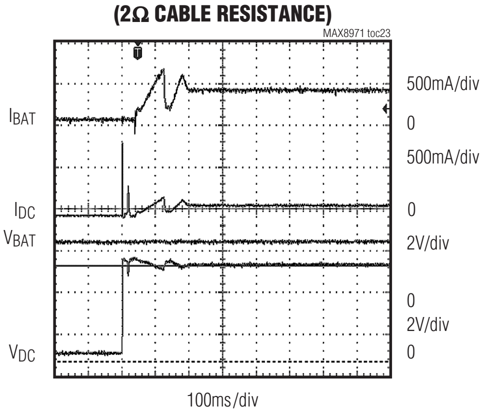
CHARGE PROFILE FOR 1500mAh 4.2V BATTERY WITH 70mA CONSTANT LOAD CHARGED AT 0.6C



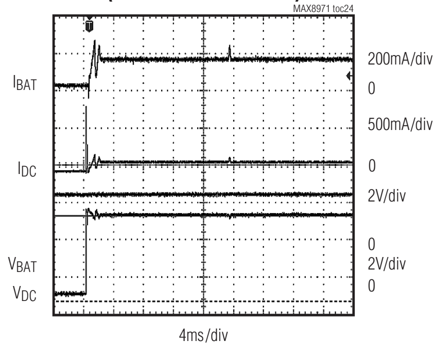
AUTOMATIC INPUT CURRENT LIMIT



AUTOMATIC INPUT CURRENT LIMIT (2Ω CABLE RESISTANCE)



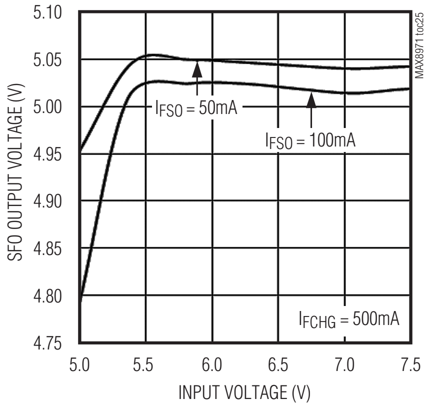
AUTOMATIC INPUT CURRENT LIMIT (1Ω CABLE RESISTANCE)



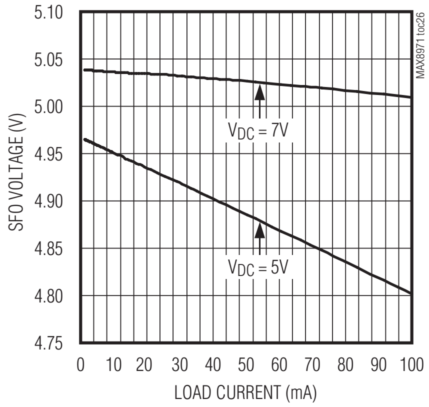
Typical Operating Characteristics

(V_{DC} = 5V, C_{BYP} = 1µF, C_{AVL} = 4.7µF, V_{THM} = 2.5V, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.)

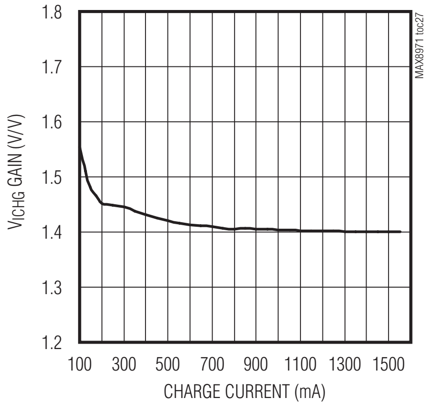
SFO OUTPUT VOLTAGE vs. INPUT VOLTAGE



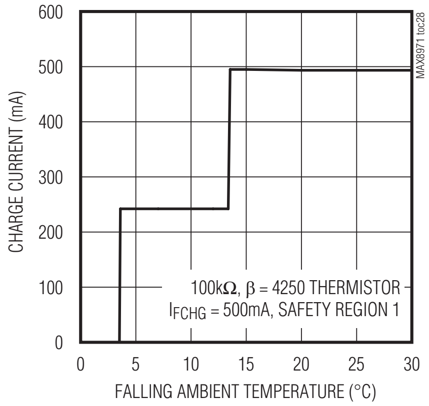
SFO OUTPUT VOLTAGE vs. LOAD CURRENT



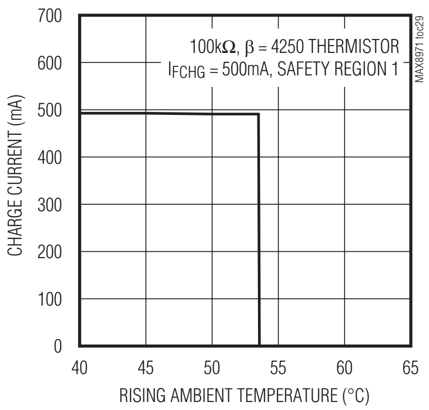
V_{ICHG} GAIN vs. CHARGE CURRENT



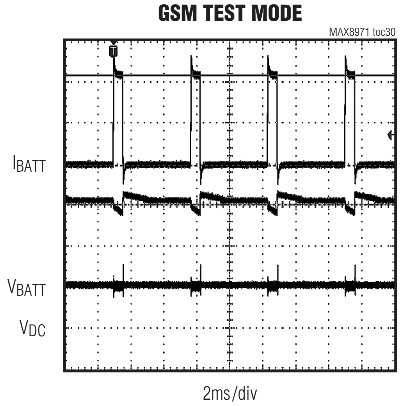
CHARGE CURRENT vs. AMBIENT TEMPERATURE



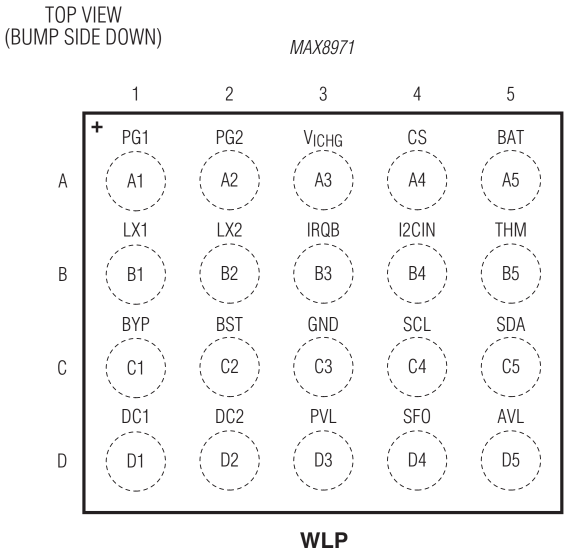
CHARGE CURRENT vs. AMBIENT TEMPERATURE



GSM TEST MODE



Bump Configuration



Bump Description

PIN	NAME	FUNCTION
A1, A2	PG1, PG2	Power Ground for Step-Down Low-Side FET
A3	V_{ICHG}	Battery-Charging Current Monitor Output. This pin is an analog representation of the charger current at 1.4mV/mA.
A4	CS	Current-Sense Input Power Pin
A5	BAT	Battery Connection. Connect to a single-cell Li+ battery.
B1, B2	LX1, LX2	Buck Inductor Connection. Connect the inductor between LX_ and CS. The LX1 and LX2 pins must be connected together externally.
B3	IRQB	Open-Drain Host Processor Interrupt Pin
B4	I2CIN	I^2C Interface Supply
B5	THM	Thermistor Input. Connect a negative temperature coefficient (NTC) thermistor from THM to GND. Connect a resistor equal to the thermistor +25°C resistance from THM to AVL. Charging is suspended when the thermistor is outside the hot and cold limits. Connect THM to GND to disable the thermistor temperature sensor. If the thermistor function is disable through I^2C, connect THM to GND.
C1	BYP	Connection Point Between Reverse Blocking MOSFET and High-Side Switching MOSFET. Bypass to PG_ with a minimum 1µF ceramic capacitor.
C2	BST	High-Side FET Driver Supply. Bypass BST to LX with a 0.1µF ceramic capacitor.
C3	GND	Analog Ground. GND is the low-noise ground connection for the internal circuitry.

Bump Description (continued)

PIN	NAME	FUNCTION
C4	SCL	I²C Interface Clock. Connect a 10kΩ resistor from SCL to I2CIN.
C5	SDA	I²C interface Data. Connect a 10kΩ resistor from SDA to I2CIN.
D1, D2	DC1, DC2	High-Current Charger Input Supply Pin(s). Bypass to PG_ with a 2.2µF ceramic capacitor. DC is capable of delivering up to 1.5A to BYP. DC supports both AC adapter and USB inputs. Short DC1 and DC2 together externally.
D3	PVL	Internal Bias Regulator High-Current Output Bypass Pin. Supports internal noisy and high-current gate drive loads. Bypass to PGND with a minimum 1µF ceramic capacitor. Do not use PVL to power external loads.
D4	SFO	5V Regulated LDO Output. Bypass SFO to GND with a 1µF or larger ceramic capacitor. SFO can be used to supply low-voltage rated USB systems.
D5	AVL	Internal-Bias-Regulator Quiet Analog Bypass Pin. Internal 10Ω connection between PVL and AVL forms a lowpass filter with external bypass capacitor to GND. Do not use AVL to power external loads.

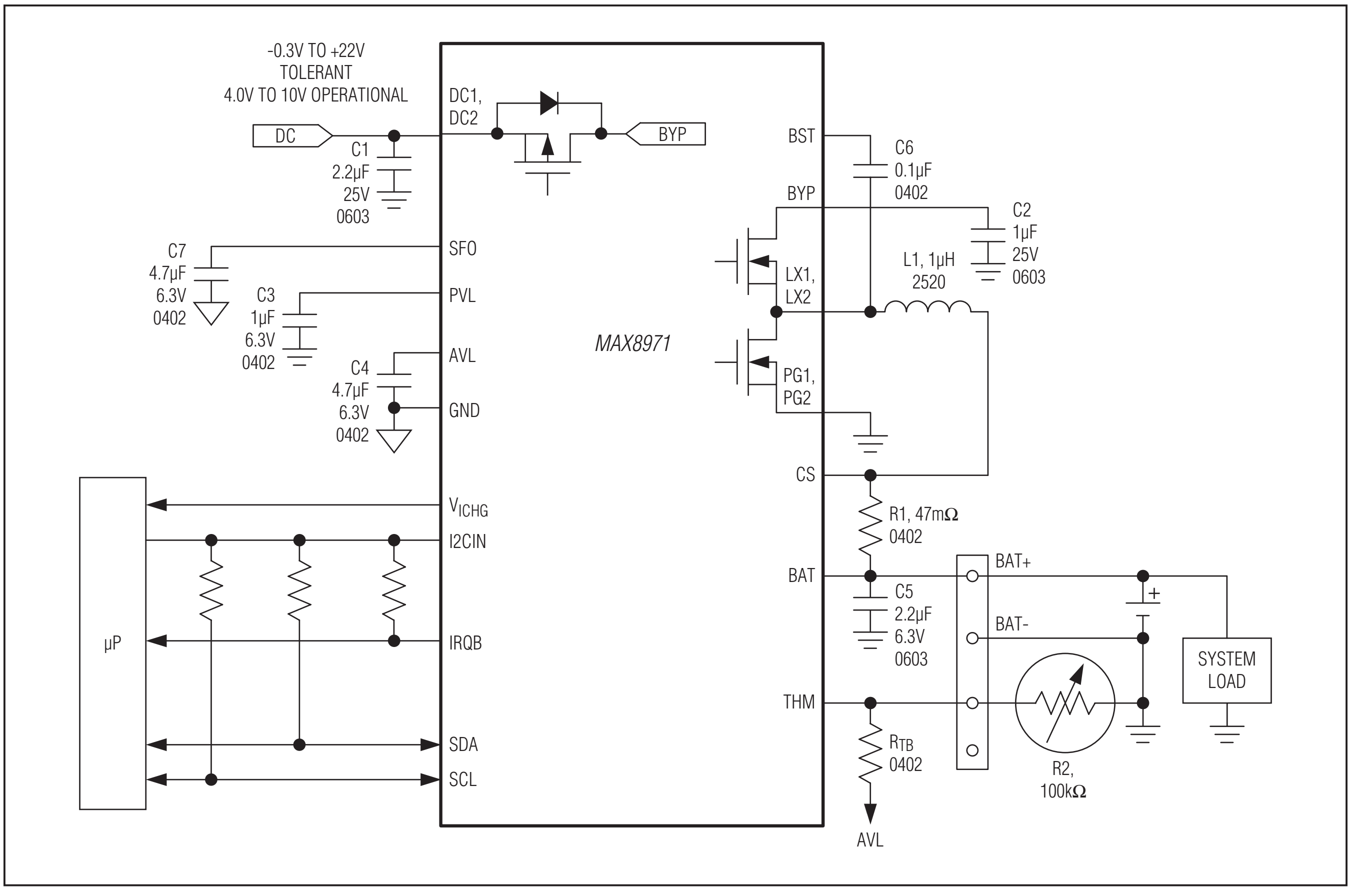


Figure 1. Typical Application Circuit

Detailed Description

The MAX8971 is a JEITA-compliant Li+ switching battery charger that safely charges a single Li+ cell in accordance with JEITA specifications. The IC accepts an input supply range from 4V to 7.5V, but disables charging if the supply voltage exceeds +7.5V, protecting against unqualified or faulty AC adapters. The step-down converter supplies up to 1.5A to the battery. The IC includes charger features thermistor monitor, charger status and fault outputs. Also included are interrupt signals to the processor. Flexibility is maintained with adjustable charge current, input current limit, and a minimum battery voltage (when charging is scaled back to hold the battery voltage up) through an I²C interface.

DC Input—Fast-Hysteretic Step-Down Regulator

If a valid DC input is present, battery charging is supplied by the high-frequency step-down regulator from DC. The step-down regulation point is then controlled by three feedback signals: maximum step-down output current programmed by the input current limit, maximum charger current programmed for the fast-charge current, and maximum die temperature. The feedback signal requiring the smallest current controls the average output current in the inductor. This scheme minimizes total power dissipation for battery charging, and allows the battery to absorb any load transients with minimum voltage disturbance.

A proprietary hysteretic current PWM control scheme ensures fast switching and physically tiny external components. The feedback control signal that requires the smallest input current, controls the center of the peak and valley currents in the inductor. The ripple current is internally set to provide 4MHz operation. When the input voltage decreases near the output voltage, very high duty cycle occurs. Due to minimum off-time, 4MHz operation is not achievable. The controller then provides minimum off-time, peak current regulation. Similarly, when the input voltage is too high to allow 4MHz operation due to the minimum off-time, the controller becomes a minimum on-time, valley current regulator. In this way, ripple current in the inductor is always as small as possible to reduce ripple voltage-on battery for a given capacitance. The ripple current is made to vary with input voltage and output voltage in a way that reduces frequency variation. However, the frequency still varies somewhat with operating conditions.

Soft-Start

To prevent input current transients, the rate of change of the input current (di/dt) and charge current is limited. When the input is valid the charge current ramps from 0mA to the fast-charge current value in 1.5ms. Charge current also soft-starts when transitioning from the prequalification state to the fast-charge state. There is no di/dt limiting when transitioning from the done state to the fast-charge state.

PVL and AVL

PVL is a 5V linear regulator that the IC uses to power the gate drivers for its step-down charger. PVL also charges the BST capacitor. The PVL linear regulator is on when DC is greater than ~2.5V, otherwise it is off. Bypass PVL with a 1µF ceramic capacitor to PG. Powering external loads from PVL is not recommended.

As shown in Figure 1, AVL is a filtered output from the PVL linear regulator that the IC uses to power its internal analog circuits. The filter consists of an internal 10Ω resistor, and the AVL external bypass capacitor (4.7µF). This filter creates a 100kHz lowpass filter that cleans the 4MHz switching noise from the analog portion of the IC. Connect a 4.7µF ceramic capacitor from AVL to GND. Powering external loads with AVL is not recommended.

Thermistor Input (THM)

The THM input connects to an external negative temperature coefficient (NTC) thermistor to monitor battery or system temperature. Charging is suspended when the thermistor temperature is out of range. The charge timers are suspended and hold their state, but no fault is indicated. When the thermistor comes back into range, charging resumes and the charge timer continues from where it left.

Since the thermistor monitoring circuit employs an external bias resistor from THM to AVL, the thermistor is not limited only to 10kΩ (at +25°C). Any resistance thermistor can be used as long as the value is equivalent to the thermistors +25°C resistance. For example, with a

10kΩ at R_{TB} resistor, the charger enters a temperature suspend state when the thermistor resistance falls below 3.97kΩ (too hot) or rises above 28.7kΩ (too cold). This corresponds to the 0°C to +50°C range when using a 10kΩ NTC thermistor with a beta of 3500. The general relation of thermistor resistance to temperature is defined by the following equation:

$$R_T = R_{25} \times e\{ß((1/(T+273)) \times (1/298))\}$$

where:

R_T = the resistance in Ω of the thermistor at temperature T in celsius

R_{25}= the resistance in Ω of the thermistor at +25°C

ß = the material constant of the thermistor, which typically ranges from 3000k to 5000k

T = the temperature of the thermistor in °C

Some designs might prefer other thermistor temperature limits. Threshold adjustment can be accommodated by changing R_{TB}, connecting a resistor in series and/or in parallel with the thermistor, or using a thermistor with different ß. For example, a +45°C hot threshold and 0°C cold threshold can be realized by using a thermistor with a ß to 4250, and connecting 120kΩ in parallel. Since the thermistor resistance near 0°C is much higher than it is near +50°C, a large parallel resistance lowers the cold threshold, while only slightly lowering the hot threshold. Conversely, a small series resistance raises the cold threshold, while only slightly raising the hot threshold. Raising R_{TB}, lowers both the hot and cold threshold, while lowering R_{TB} raises both thresholds.

Note that since AVL is active whenever valid input power is connected at DC, thermistor bias current flows at all times. Using a 10kΩ thermistor and a 10kΩ pullup to AVL, results in an additional 250µA load. This load can be reduced to 25µA by instead using a 100kΩ thermistor and 100kΩ pullup resistor.

Thermal Foldback

Thermal foldback maximizes the battery charge current while regulating the IC's junction temperature. When the die temperature exceeds T_{REG}, a thermal limiting circuit reduces the battery charge-current target until the charge current reaches 10% of the fast-charge current setting. The charger maintains 10% of the fast-charge current until the die temperature reaches T_{SHDN}. Please note that the IC is rated for a maximum ambient temperature of +85°C. Furthermore, although the maximum die temperature of the MAX8971 is +150°C, it is common industry practice to design systems in such a way that the die temperature never exceeds +125°C. Limiting the maximum die temperature to +125°C extends long-term reliability.

Charger States

The IC utilizes several charging states to safely and quickly charge batteries as shown in Figure 3.

Figure 2 shows an exaggerated view of a Li+/Li-Poly battery progressing through the following charge states when the die and battery are close to room temperature: dead battery → prequalification → fast charge → top-off → done.

Table 1. Trip Temperatures for Different Thermistors

THERMISTOR	TEMPERATURE						
R_{THM} at T_A=+25°C	10,000	10,000	10,000	47,000	47,000	100,000	100,000
Thermistor Beta (ßΩ)	3380	3940	3940	4050	4050	4250	4250
RTB (Ω)	10,000	10,000	10,000	47,000	47,000	100,000	100,000
RTP (Ω)	Open	Open	301,000	Open	1,200,000	Open	1,800,000
RTS (Ω)	Short	Short	499	Short	2,400	Short	6,800
Resistance at T1_n15 (Ω)	61,788	61,788	77,248	290,410	380,716	617,913	934,027
Resistance at T1_0(Ω)	29,308	29,308	31,971	137,750	153,211	293,090	343,283

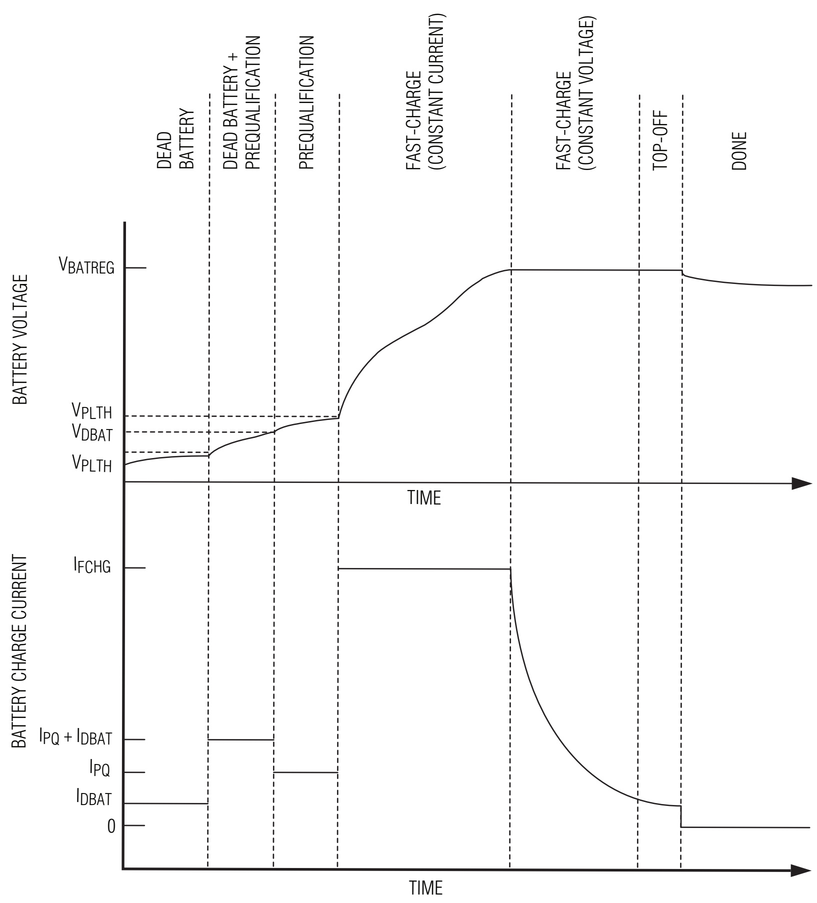


Figure 2. Li/Li-Poly Charge Profile

Industry's Smallest 1.55A 1-Cell Li+ DC-DC Charger

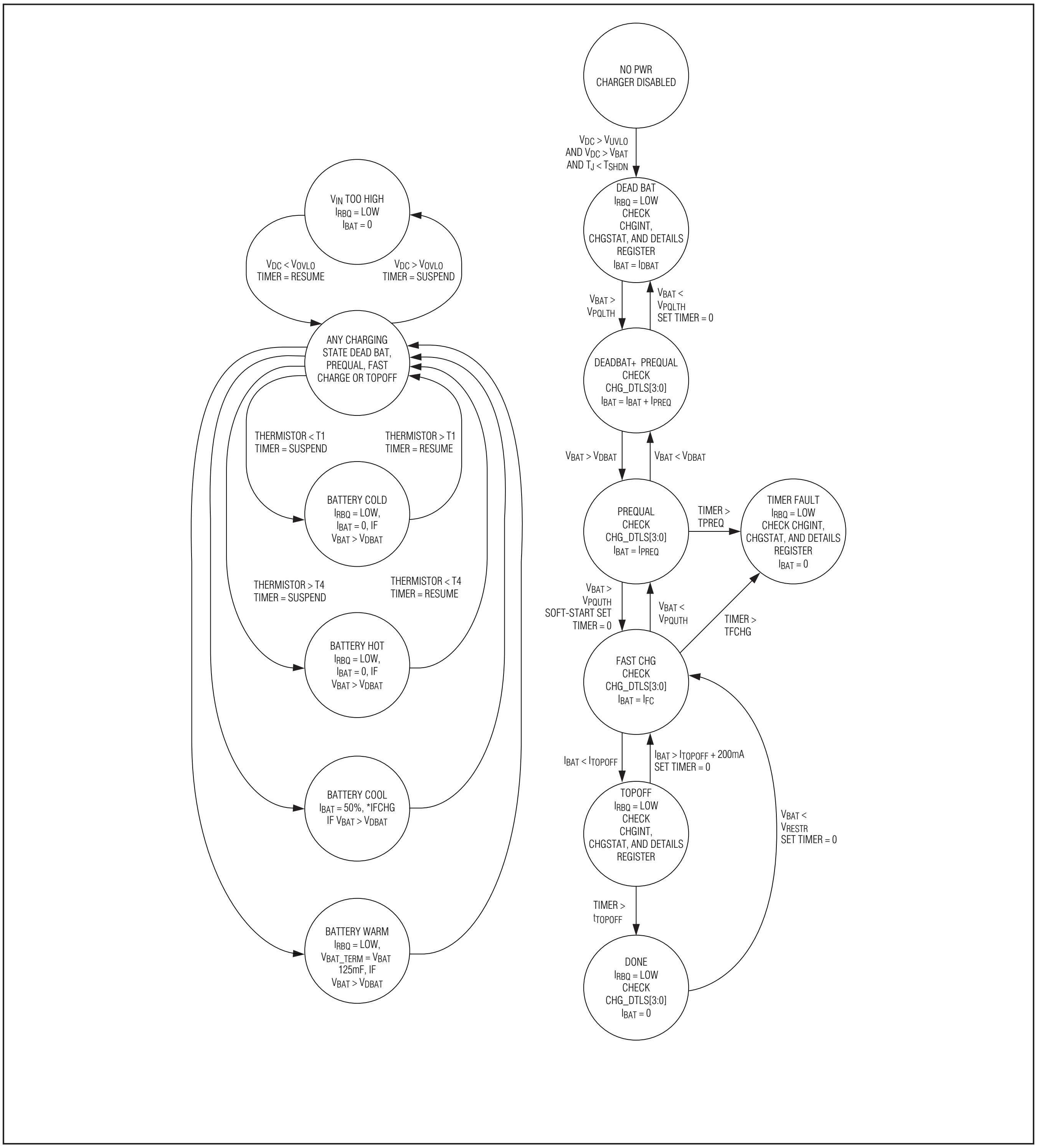


Figure 3. Functional State Diagram

Charger-Disabled State

When DC is low or the input voltage is out of range, the IC disables the charger. To exit this state, the input voltage must be within its valid range.

Dead-Battery State

When a deeply discharged battery is inserted with a voltage of less than V_{PQLTH}, the IC disables the switching charger and linearly charges with I_{DBAT}. Once V_{BAT} increases beyond V_{PQLTH}, the IC clears the prequalification timer, and transitions to the dead battery + prequalification state. This state prevents the IC from dissipating excessive power in the event of a shorted battery. The dead-battery linear charge remains on, except when in the charger disabled state, timer fault state, thermal shutdown and $V_{BAT} > V_{DBAT}$.

Dead-Battery + Prequalification State

The dead battery + prequalification state occurs when the battery voltage is greater than V_{PQLTH}, and less than V_{DBAT}. In this state, both the linear dead-battery charger and the switching charger are on, delivering current to the battery. The total battery current is I_{DBAT} + I_{PQ}. If the IC remains in this state for longer than t_{PQ}, the IC transitions to the timer fault state. A normal battery typically stays in this state for several minutes or less. When the battery voltage rises above V_{DBAT} the IC transitions to the prequalification states. The dead-battery linear charger remains on except when in the charger disabled state, timer fault state, thermal shutdown and $V_{BAT} > V_{DBAT}$.

Prequalification State

The prequalification state occurs when the battery voltage is greater than V_{DBAT} and less than V_{PQUTH}. In this state, the linear dead-battery charger is turned off. Only the switching charger is on and delivering current to the battery. The total battery current is I_{PQ}. If the IC remains in this state for longer than t_{PQ}, then the IC transitions to the timer fault state. A normal battery typically stays in the prequalification state for several minutes or less. When the battery voltage rises above V_{PQUTH}, the IC transitions to the fast-charge constant-current state.

Fast-Charge Constant-Current State

The fast-charge constant-current state occurs when the battery voltage is greater than V_{PQUTH} and less than V_{BATREG}. In this state, the switching charger is on and delivering current to the battery. The total battery current is I_{FC}. If the IC remains in this state and the fast-charge constant voltage state for longer than t_{FC}, then the IC transitions to the timer fault state. When the battery voltage rises to V_{BATREG}, the IC transitions to the fast-charge constant voltage state. The fast-charge constant-current is set to 50% of programmed value when 0°C < THM <+15°C, and 100% of programmed value when +15°C < THM <+60°C.

The MAX8971 dissipates the most power in the fast-charge constant-current state. This power dissipation causes the internal die temperature to rise. If the die temperature exceeds T_{REG}, I_{FC} is reduced.

If there is low input-voltage headroom (V_{IN} - V_{BAT}), then I_{FC} decreases due to the impedance from IN to BAT.

Fast-Charge Constant Voltage State

The fast-charge constant voltage state occurs when the battery voltage is at the V_{BATREG}, and the charge current is greater than I_{TOPOFF}. In this state, the switching charge is on and delivering current to the battery. The IC maintains V_{BATREG} and monitors the charge current to detect when the battery consumes less than the TOPOFF current. When the charge current decreases below the TOPOFF threshold, the IC transitions to the top-off state. If the IC remains in the fast-charge constant-current state for longer than t_{FC}, then it transitions to the timer fault state.

Top-Off State

The top-off state occurs when the battery voltage is at V_{BATREG} and the battery current decreases below TOPOFF current. In this state, the switching charger is on and delivers current to the battery. The IC maintains V_{BATREG} for a specified time. When this time expires, the IC transitions to the DONE state. If the charging current increases to I_{TOPOFF} + 200mA before this time expires, then the charge reenters the fast-charge constant voltage state.

Done State

The IC enters its done state after the charge has been in the top-off state for t_{TOPOFF}. In this state, the switching charger is off and no current is delivered to the battery. If the system load presented to the battery is low << 10µA, then a typical system can remain in the done state for many days. If left in the done state long enough, the battery voltage decays below the restart threshold and the IC transitions back into the fast-charge state. There is no soft-start (di/dt limiting) during the done-to-fast-charge state transition.

Timer Fault State

The timer fault state occurs when either the prequalification or fast-charge timers expire. In this state, the charger is off. The charger can exit this timer fault state by cycling input power.

Overvoltage and Protection

The IC provides for a +22V absolute maximum positive input voltage, and a -0.3V absolute maximum negative input voltage. Excursions to the absolute maximum voltage levels should be on a transient basis only, but can be withstood by the IC indefinitely.

Situations that typically require extended input voltage ratings include, but are not limited to the following:

- Inductive kick
- Charge source failure
- Power surge
- Improperly wired wall adapter
- Improperly set universal wall adapter
- Wall adapter with the correct plug, but wrong voltage
- Home-built computer with USB wiring harness connected backwards (negative voltage)
- USB connector failure
- Excessive ripple voltage on a switch-mode wall charger
- USB-powered hub that is powered by a wall charger (typically through a barrel connector) that has any of the aforementioned issues
- Unregulated charger

Automatic Input Current Limit Protection

The IC includes an input-current-limiting feature. The amplifiers required for sensing the currents and associated logic circuitry for making decisions and changing the battery-charger current are fully integrated in the ICs. This not only helps in reducing cost, but also improves the speed of system response.

The IC works by monitoring the current being drawn from the AC adapter and comparing it to the programmed current limit. The current limit should be set based on the current-handling capability of the AC adapter. Generally, this limit is chosen to optimally fulfill the system-power requirements while achieving a satisfactory charging time for the batteries. If the AC-adapter current exceeds its output capability, the charger responds by cutting back on the charger current, thereby keeping the current drawn from the AC adapter within its capability. With such a battery charger, the AC adapter doesn't need to be oversized to meet maximum system and battery-charging requirements simultaneously, thereby reducing AC adapter cost.

The input current limit has two control inputs, one based on voltage and one based on current. The voltage input monitors the input voltage, and when it drops below the desired input (4.5V), it generates a flag (AICL) to decrement the fast-charge current.

When the voltage comparator initially trips at 4.5V, fast-charge current decrements at a slow rate, allowing the charger output to settle until the voltage on DC returns above this voltage threshold. Once the DC voltage resolves itself, the current delivery of the adapter is maximized. In the event of a limited input current source, an example being a 500mA adaptor plugged into a 1A input current limit setting, a second voltage comparator set at 4.4V triggers and throttles the fast-charge current to a minimum of 75mA. Once the DC voltage corrects itself to above 4.5V, the fast-charge level is checked every 16ms to allow the system to recover if the available input power increases.

The current-limit input monitors the current through the input FET and generates a flag (DC_I) to decrement the fast-charge current when the input limit is exceeded. The fast-charge current is slowly decremented until the input-limit condition is cleared. At this point, the fast-charge current is maintained for 16ms and is then sampled again.

V_{ICHG} Charging Current Monitor

V_{ICHG} is a buffered output that can be interpreted to the charge current (V_{ICHG} = 1400mV/I_{FCHG}). See the *Typical Operating Characteristics* section for the V_{ICHG} curve.

SAFEOUT

SAFEOUT is a linear regulator that provides an output voltage of 5V and can be used to supply low-voltage rated USB systems. The SFO linear regulator turns on when V_{IN} > 2.5V.

JEITA Description

The IC JEITA-compliant switching Li+ battery charger safely charges a single Li+ cell in accordance with JEITA specifications. The IC monitors the battery temperature while charging, and automatically adjusts the fast-charge current and/or charge termination voltage as the battery temperature varies.

In safety region 1, the IC automatically reduces the fast-charging current for T_{BAT} < +10°C, and reduces the charge termination voltage from 4.200V (±25mV) to 4.075V (±25mV) for T_{BAT} > +45°C. The fast-charge current is reduced to 50% of the nominal fast-charge current with options for 25% and 75%. JEITA never specifically states one or the other. When battery charge current is reduced by 50%, the timer is doubled.

In safety region 2, the IC automatically reduces the charge termination voltage from 4.200V (±25mV) to 4.075V (±25mV) for T_{BAT} < +10°C and for T_{BAT} > +45°C. The fast-charge current is not changed in safety region 2.

Maxim Model Gauge M3 Support

Figure 5 illustrates how the IC can easily integrate with Maxim's Model gauge M3 MAX17047 chip. The user just needs to add a Schottky diode between V_{BATT} and V_{TT} on the MAX17047.

Factory-Mode GSM Test Mode Support

The IC supports GSM pulse programming scheme. When DC is inserted with no battery operation, the IC soft-starts and cycles through dead-battery, prequalification, and fast charge, settling at constant voltage-mode operation, and regulating to the termination voltage (4.2V default). At this time, when B4 of register 0x08 is sent, the part can now support GSM pulse. See the *Typical Operating Characteristics* section.

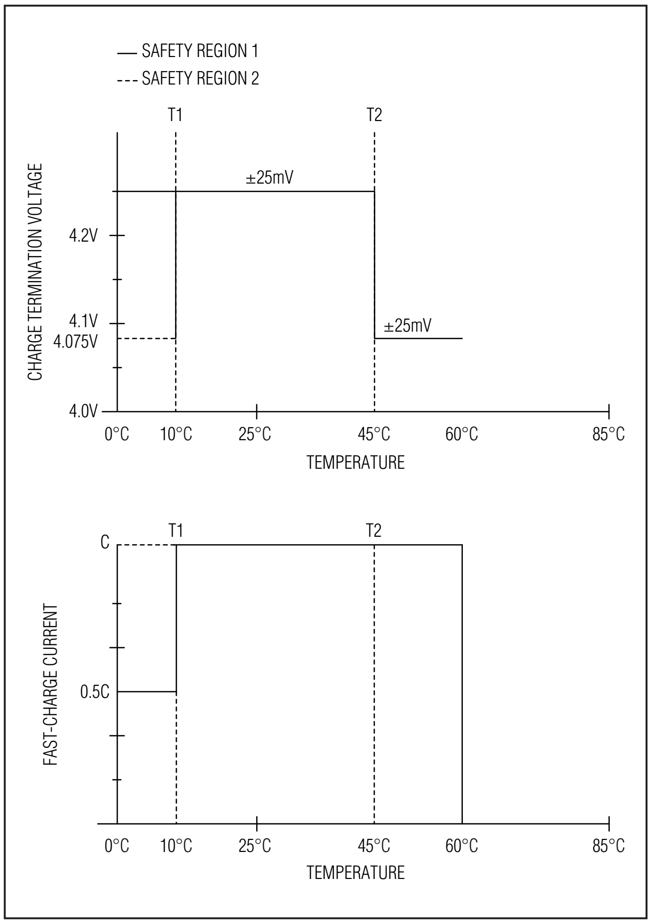


Figure 4. JEITA Safety Region

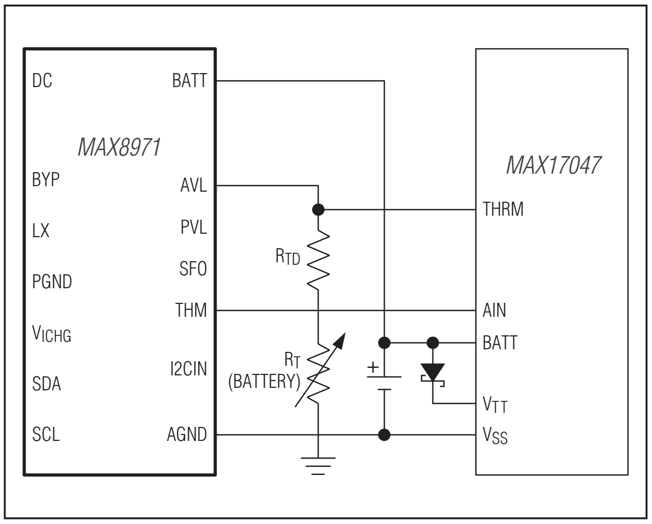


Figure 5. MAX8971 with MAX17047

The battery node should have enough capacitance to hold the battery voltage to some minimum acceptable system value (V_{SYS}) during the done to fast-charge state transition time of 100us ($t_{DONE2FC}$).

$$C_{BAT} \geq I_{LOAD} \times t_{DONE2FC}/(V_{BATREG} - V_{SYS})$$

For example, if the maximum system load without a battery is 400mA (I_{LOAD}), and the minimum acceptable system voltage is 3.4V (V_{SYS}), then the battery node should have at least 40µF.

$$C_{BAT} \geq 400mA \times 100\mu s/(4.2V - 3.4V) = 40\mu F.$$

Applications Information

Inductor Selection

The charger operates with a switching frequency of 4MHz and uses a 1µH or 2.2µH inductor. This operating frequency allows the use of physically small inductors while maintaining high efficiency.

The inductor's DC current rating only needs to match the maximum load of the application because the IC features zero current overshoot during startup and load transients. For optimum transient response and high efficiency, choose an inductor with DC series resistance in the 40mΩ to 120mΩ range. See Table 2 for suggested inductors and manufacturers.

Input Capacitor Selection

The input capacitor reduces the current peaks drawn from the input power source and reduces switching noise in the IC. The impedance of the input capacitor at the switching frequency should be kept very low. Ceramic capacitors with X5R or X7R temperature characteristics are highly recommended due to their small size, low ESR, and small temperature coefficients. A 4.7FF capacitor is recommended. For optimum noise immunity and low input ripple, the input capacitor value can be increased.

Note that some ceramic dielectrics exhibit large capacitance and ESR variation with temperature and DC bias. Ceramic capacitors with Z5U or Y5V temperature characteristics should be avoided.

Output Capacitor Selection

For the charger, the output capacitor keeps the output voltage ripple small and ensures regulation loop stability. The output capacitor must have low impedance at the switching frequency. Ceramic capacitors with X5R or X7R temperature characteristics are highly recommended due to their small size, low ESR, and small temperature coefficients. A 4.7µF capacitor is recommended. For optimum load-transient performance and very low output ripple, increase the output capacitor value.

Charge Current Resistor Selection

Both the top-off current range and fast-charge current range depends on the sensing resistor (R_{SNS}). The default resistor recommended is a 47mΩ, 0.125W resistor. Select a 0.125W,47mΩ 2% sense resistor, e.g., Panasonic ERJ2BWGR047. This is a standard value.

$P_{RSNS} = I_{CHARGE}^2 \times R_{SNS}$

$P_{RSNS} = 1.5^2 \times 0.047$

$P_{RSNS} = 0.105W$

The charge current step (I_{CHARGE}) is calculated using equation below:

$$I_{CHARGE\_STEP} = V_{(CHGCC<>)}/R_{SNS}$$

Table 3 below shows the charge current settings for two sensing resistors.

$$I_{CHARGE\_CURRENT\_STEP} = V_{(TOPOFF<>)}/R_{SNS}$$

Table 2. Suggested Inductors

MANUFACTURER	SERIES	INDUCTANCE (µH)	ESR (Ω)	CURRENT RATING (mA)	DIMENSIONS
FDK	MIPSA2520D1R0	1.0	0.08	1500	2.5mm x 2.0mm x 1.2mm = 6mm^3
Murata	LQM2HPN_G0	1.0	0.05	1600	2.5mm x 2.0mm x 0.6mm = 3mm^3
Coilcraft	EPL2014	1.0	0.059	1600	2.0mm x 2.0mm x 1.4mm = 5.6mm^3
TDK	MLP2520S	1.0	0.06	1500	2.0mm x 2.5mm x 1.0mm = 5mm^3
TOKO	MIPF2520	2.2	0.05	1500	2.5mm x 2.0mm x 1.0mm = 5mm^3
TOKO	DFE252012C	1	0.06	2500	2.5 x 2.0 x 1.2 = 6mm^3
Murata	LQM32PN1R0MG0	1	0.06	1800	3.2 x 2.5 x 0.9 = 7.2mm3

Table 3. Charge Current Settings for 47mΩ and 68mΩ Sense Resistors

BIT	VI_{REG} (mV)	I_{CHARGE} (mA) R_{SNS} = 47mΩ	I_{CHARGE} (mA) R_{SNS} = 68mΩ
$V_{(CHGCC<11110>)}$	70.5	1500	1037
$V_{(CHGCC<10100>)}$	47	1000	691
$V_{(CHGCC<01010>)}$	23.5	500	345

Table 4. Topoff Current Settings for 47mΩ and 68mΩ Sense Resistors

BIT	$V_{(TOPOFF)}$	$I_{(TOPOFF)}$ (mA) R_{SNS} = 47mΩ	$I_{(TOPOFF)}$ (mA) R_{SNS} = 68mΩ
$V_{(TOPOFF<>)}$	9.4	200	138.2
$V_{(TOPOFF<>)}$	4.7	100	69.1
$V_{(TOPOFF<>)}$	2.35	50	34.5

Table 5. High-Level I^2C Register Map

REGISTER NAME	REGISTER ADDRESS	R/W	RESET CONDITION	B7	B6	B5	B4	B3	B2	B1	B0
CHGINT	0x0F	R	VSTBY or rising edge of SFO_POK	AICL_I	TOPOFF	DC_ OVP	DC_ UVP	CHG_I	BAT_I	THM_I	POWERUP
CHGINT_MSK	0x01	R/W	VSTBY or rising edge of SFO_POK	AICL_M	TOPOFF_ M	DC_ OVP_M	DC_ UVP_M	CHG_M	BAT_M	THM_M	—
CHG_STAT	0x02	R	VSTBY or rising edge of SFO_POK	DCV_OK	DCI_OK	DCOVP_ OK	DCUVP_ OK	CHG_OK	BAT_ OK	THM_ OK	—
DETAILS1	0x03	R	VSTBY or rising edge of SFO_POK	DC_V	DC_I	DC_OVP	DC_UVP	RSVD	THM_D[2:0]		
DETAILS2	0x04	R	VSTBY or rising edge of SFO_POK	RSVD	RSVD	BAT_DT[1:0]			CHG_D[2:0]		

Table 5. High-Level I2C Register Map (continued)

REGISTER NAME	REGISTER ADDRESS	R/W	RESET CONDITION	B7	B6	B5	B4	B3	B2	B1	B0
CHGCNTL1	0x05	R/W	VSTBY or rising edge of SFO_POK	RSVD	RSVD	RSVD	RSVD	RSVD	RSVD	DCMON_ DIS	USB_ SUS
FCHGCRNT	0x06	R/W	VSTBY or rising edge of SFO_POK	FCHGT[2:0]			CHGCC[3:0]				
DCCRNT	0x07	R/W	VSTBY or rising edge of SFO_POK	RSVD	CHGR STRT	DCILMT[5:0]					
TOPOFF	0x08	R/W	VSTBY or rising edge of SFO_POK	TOPOFFT[2:0]			IFST2P8	TOFFS[1:0]		CHGCV[1:0]	
TEMPREG	0x09	R/W	VSTBY or rising edge of SFO_POK	RTEMP[1:0]		THM CNFG	RSVD	RSVD	THMRES		SAFE REG
PROTCMD	0x0A	R/W	VSTBY or rising edge of SFO_POK	RSVD	RSVD	RSVD	RSVD	C_PROT[1:0]		RSVD	RSVD