

Lithium-Ion Battery Pulse Charger with Overcurrent Protection

July 2002

FEATURES

- Complete Standalone Pulse Charger for 1-Cell Lithium-Ion Batteries
- Requires No Microcontroller
- Internal 0.35Ω NMOS Switch
- Sense Resistor Limits Maximum Current for Safety
- Programmable Charge Termination Timer for Maximum Capacity Charging
- No Blocking Diode Required
- 1% Float Voltage Accuracy
- Near End-of-Charge (C/10) Detection Output
- Low Battery Drain when Input Supply Is Removed
- Automatic Trickle Charge for Low Battery
- Automatic Battery Refresh
- Thermal Shutdown Protection
- Small 8-Pin Thermally Enhanced MSOP Package

APPLICATIONS

- Standalone Lithium-Ion Battery Charger
- Personal Information Appliances
- Cellular Telephones
- Cradle Chargers

DESCRIPTION

The LTC[®]4052 is a complete standalone pulse charger with integrated MOSFET for 1-cell lithium-ion batteries.

An external sense resistor provides maximum charge current limiting as a safety precaution against a user connecting a wall adapter with the incorrect or no current limit. The internal MOSFET prevents reverse battery current from flowing if the input voltage is shorted to ground, eliminating the need for a blocking diode.

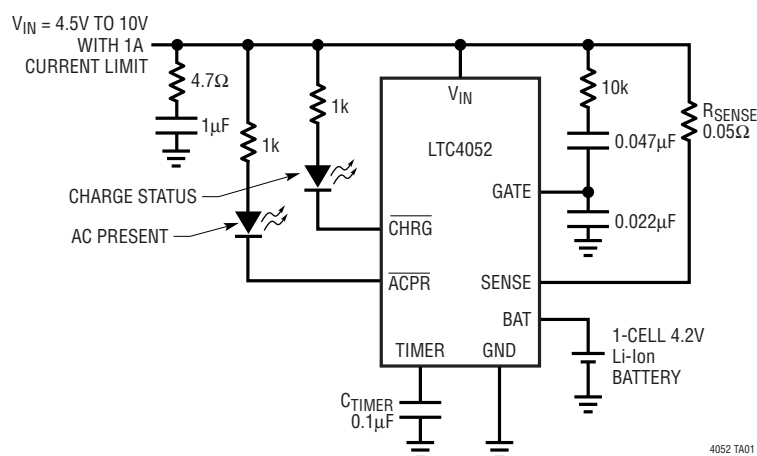
As the battery accepts charge and approaches the programmed float voltage, the internal MOSFET begins switching off and on with the duty cycle gradually decreasing as the battery approaches a fully charged condition. A programmable timer ends the charge cycle. The near end-of-charge C/10 condition is indicated at the $\overline{\text{CHRG}}$ pin when the average charge current falls to one-tenth of the wallpack current. Removing the input voltage puts the LTC4052 into a sleep mode, dropping the battery current drain to less than $1\mu\text{A}$ (maximum).

The LTC4052 is available in a tiny 8-pin thermally enhanced MSOP package.

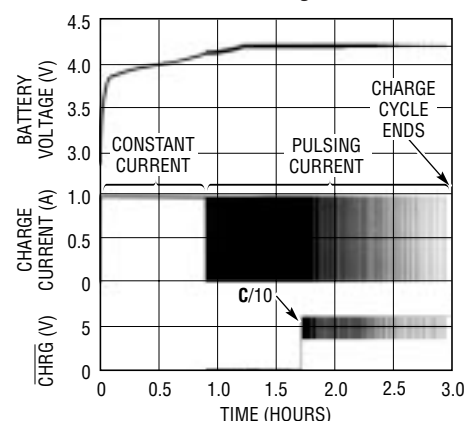
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TYPICAL APPLICATION

Single Cell 4.2V, 1A, Standalone Li-Ion Battery Charger



LTC4052 Charge Profile



4052 TA01

4052 • TA01b

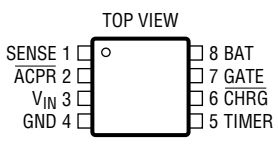
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ABSOLUTE MAXIMUM RATINGS

(Note 1)

Input Supply Voltage (V_{IN})	12V
BAT Voltage	-0.3V to 12V
GATE (Note 2)	-0.3V to 8V
SENSE, TIMER	-0.3V to $V_{IN} + 0.3V$
CHRG, ACPR	-0.3V to 12V
SENSE, BAT Peak Current	1.5A
Operating Temperature Range (Note 3)	-40°C to 85°C
Junction Temperature (Note 4)	125°C
Storage Temperature Range	-65°C to 150°C
Lead Temperature (Soldering, 10 sec)	300°C

PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER
	LTC4052EMS8E-4.2
	MS8 PART MARKING
	LTTY

Consult LTC Marketing for parts specified with wider operating temperature ranges.

DC ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A = 25^\circ\text{C}$. $V_{IN} = 6V$ unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{IN}	Supply Voltage	Wall Adapter Open Circuit Voltage	● 4.5		10	V
I_{IN}	Supply Current	Fast Charge Mode	●	0.7	1.4	mA
V_{BAT}	Battery Float Voltage	$0^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$	● 4.158 4.137	4.200	4.242	V V
V_{RECHRG}	Recharge Battery Voltage Threshold	Battery Voltage Falling $0^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$	● 3.990 3.969	4.050	4.110	V V
V_{MARGIN}	$V_{BAT} - V_{RECHRG}$ Margin		● 75	150	225	mV
V_{IMAX}	Overcurrent Trip Voltage		● 90	105	120	mV
I_{TRICKL}	Trickle Charge Current	$V_{BAT} = 2V$	● 14	24	34	mA
V_{TRICKL}	Trickle Charge Trip Threshold	V_{BAT} Rising	● 2.35	2.45	2.55	V
$R_{DS(ON)}$	Internal Switch On-Resistance	$V_{BAT} = 2.6V$ $V_{BAT} = 4V$		0.45 0.35	0.7 0.5	Ω Ω
V_{GATE}	GATE Pin Voltage	$V_{BAT} = 2.6V$ $V_{BAT} = 4V$		6.5 10.5		V V
T_{TIMER}	TIMER Period Accuracy	$C_{TIMER} = 0.1\mu F$, Fast Charge Mode			± 10	%
I_{LEAK}	Battery Leakage Through Charger	$V_{BAT} = 4V$, $V_{IN} = 0V$	●		1	μA
V_{SLEEP}	Sleep Threshold	$(V_{IN} - V_{BAT})$ Low to High $(V_{IN} - V_{BAT})$ High to Low	20 0	45 15	70	mV mV
V_{ACPR}	ACPR Pin Output Low Voltage	$I_{ACPR} = 3mA$	●	0.5	0.8	V
$I_{LEAKACPR}$	ACPR Pin Leakage Current	$V_{IN} = 0$, $V_{ACPR} = 6V$	●		1	μA
V_{CHRG}	CHRG Pin Output Low Voltage	$I_{CHRG} = 3mA$, Charging, C/10 Not Reached	●	0.5	0.8	V
$I_{LEAKCHRG}$	CHRG Pin Leakage Current	$V_{IN} = 0$, $V_{CHRG} = 6V$	●		1	μA
I_{CHRG}	CHRG Pin Pull-Down Current	$V_{CHRG} = 1V$, Charging, C/10 Reached	20	40	70	μA
T_{SHDN}	Thermal Shutdown Temperature			140		$^\circ\text{C}$
ΔT_{SHDN}	Thermal Shutdown Hysteresis			5		$^\circ\text{C}$

ELECTRICAL CHARACTERISTICS

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: Absolute Maximum Rating for GATE pin applies only to externally applied voltage. During normal operation the LTC4052-4.2's internal charge pump can generate GATE pin voltage exceeding absolute maximum but it is internally current limited.

Note 3: The LTC4052EMS8E-4.2 is guaranteed to meet performance specifications from 0°C to 70°C. Specifications over the –40°C to 85°C operating temperature range are assured by design, characterization and correlation with statistical process controls.

Note 4: Junction temperature T_J is calculated from the ambient temperature T_A and power dissipation P_D according to the following formula: $T_J = T_A + (P_D \cdot \theta_{JA}^{\circ}\text{C/W})$

PIN FUNCTIONS

SENSE (Pin 1): Overcurrent Sense Input. A sense resistor (R_{SENSE}) should be connected from V_{IN} to the SENSE pin to program the current limit level. When current limit is tripped, the pass transistor immediately turns off and turns back on after a 640ms time-out period ($C_{\text{TIMER}} = 0.1\mu\text{F}$). The on-off cycle will continue as long as the overcurrent condition persists or until the timer runs out. If overcurrent protection is not needed, short SENSE to V_{IN} .

ACPR (Pin 2): Wall Adapter AC Present Open-Drain Output. When the input voltage (wall adapter) is applied to the LTC4052, this pin is pulled to ground by an internal N-channel MOSFET capable of driving an LED.

V_{IN} (Pin 3): Positive Input Supply Voltage ($4.5\text{V} \leq V_{\text{IN}} \leq 10\text{V}$). Bypass this pin with a $1\mu\text{F}$ capacitor in series with a 4.7Ω resistor.

GND (Pin 4): Electrical Ground Connection and provides a thermal path from the IC to the PC board copper. Use large copper pads and traces for maximum heat transfer.

TIMER (Pin 5): Timer Set Pin. The timer period is set by a capacitor (C_{TIMER}) to ground. The timer period is: $t_{\text{TIMER}} = (C_{\text{TIMER}} \cdot 3\text{Hr}) / (0.1\mu\text{F})$. The minimum ON time, minimum OFF time and the overcurrent time-out period all scale with t_{TIMER} .

CHRG (Pin 6): Charge Status Open-Drain Output. When a depleted battery is being charged, the $\overline{\text{CHRG}}$ pin is pulled to ground by an internal N-channel MOSFET capable of driving an LED. Once the duty cycle at the GATE pin drops

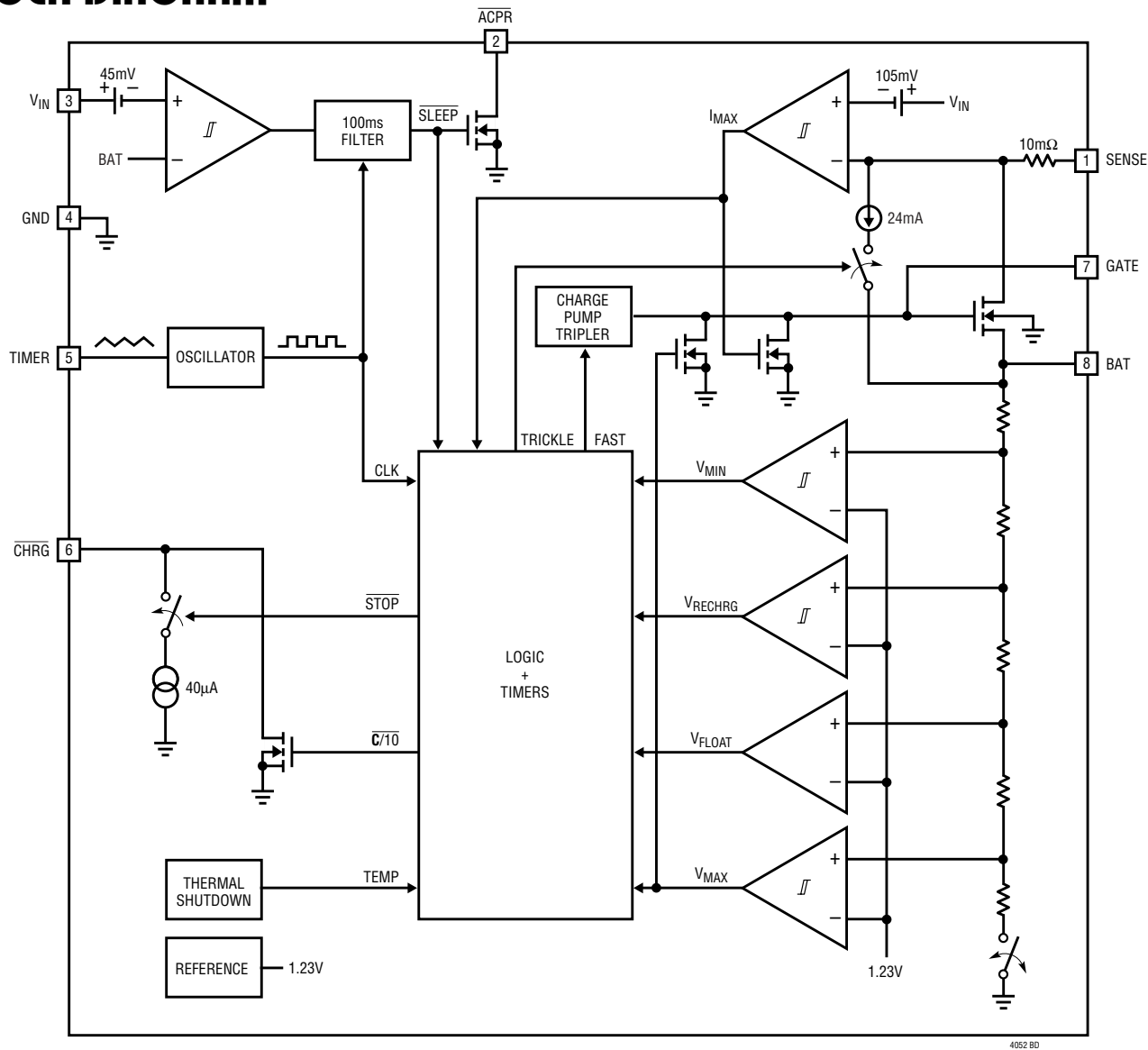
below 10%, the N-MOSFET turns off and a weak $40\mu\text{A}$ current source to ground turns on to indicate a near end-of-charge C/10 condition. When a time-out occurs or the input supply is removed, the $\overline{\text{CHRG}}$ pin becomes high impedance.

GATE (Pin 7): Gate Drive Output Pin for Internal and External Pass Transistors. An external N-MOSFET transistor can be connected in parallel with the internal transistor to reduce the on-resistance for higher charge current. In this case, an external blocking diode is required to prevent damage to the battery if V_{IN} is shorted to ground. A $10\mu\text{A}$ current source pulls this pin up to the charge pump potential when turned on and a $40\mu\text{A}$ current source pulls it down to ground to turn it off. If an overcurrent condition is detected, the GATE pin is immediately pulled to ground. The voltage at this pin is internally clamped to 12V above the GND pin.

A series RC network from the GATE to the V_{IN} pin is required to control the slew rate at the V_{IN} pin when the switch is turned on or off. The slew rate control prevents excessive current from the capacitor located in the wall adapter from flowing into the battery when the pass transistor is turned on.

BAT (Pin 8): Battery Sense Input Pin. This pin is clamped to 4.7V if the battery is disconnected while charging. An internal resistor divider presets the final float voltage to 4.2V. If the BAT pin drops below 4.05V after the charge cycle has ended, the timer resets and a new charge cycle begins.

BLOCK DIAGRAM



OPERATION

The LTC4052 is a complete lithium-ion battery pulse charger with an internal 0.35Ω N-MOSFET switch driven by an internal charge pump. **The charge current is set by the current limit of the input supply (wall adapter).** An external R_{SENSE} sets the maximum allowable charge overcurrent and prevents a wall adapter with the wrong current limit from damaging the battery. If the current limit of the input supply is above I_{MAX} , the charger will immediately terminate charging and will retry after 640ms ($C_{TIMER} = 0.1\mu F$). If the battery is disconnected while in

fast charge mode, the charge pump will be turned off when the voltage at the BAT pin rises above 4.7V and turned back on when the voltage drops below the float voltage.

A charge cycle begins when the voltage at the V_{IN} pin rises above the BAT pin by 45mV. The charger will go into trickle charge mode if the battery voltage is below 2.45V. The trickle charge current is preset to 24mA and is provided by an internal current source. In trickle mode, both the pass transistor and charge pump are off.

OPERATION

When the cell voltage exceeds 2.45V, the charger goes into fast charge mode. In this mode, the charge pump turns on and ramps up the gate voltage of the pass transistor turning it on. The voltage at the V_{IN} pin then ramps down to V_{BAT} plus the voltage drop across the pass transistor and R_{SENSE} , thus reducing the power dissipation in the pass transistor. **The charge current is determined by the current limit of the input supply.**

When the battery voltage reaches the final float voltage, the pass transistor turns off for 100ms (minimum off-time). It remains off as long as the battery voltage stays above the float voltage after the 100ms off-time. After the minimum off-time, if the battery voltage drops below the float voltage, the pass transistor turns back on for at least 400ms (minimum on-time). As the battery approaches full charge, the off-time will get longer and the on-time will

stay at 400ms. The voltage at the BAT pin will be slightly higher than the final float voltage due to the ESR associated with the battery pack. This voltage level should not turn on the overvoltage protection circuitry often located in the battery pack. When the duty cycle at the GATE pin drops below 10%, a comparator turns off the N-FET at the $\overline{CHRG}$ pin and connects a weak current source (40 μ A) to ground to indicate a near end-of-charge C/10 condition. The pulse charging will continue until the timer stops.

An external capacitor at the TIMER pin sets the total charge time, the minimum on- and off-time and the overcurrent retry period. After a time-out has occurred, the charge cycle terminates and the $\overline{CHRG}$ pin is forced high impedance. After the charging stops, if the battery voltage drops below 4V, due to external loading or internal leakage, a new charge cycle will automatically resume.

APPLICATIONS INFORMATION

Input Voltage (Wall Adapter)

The input voltage to the LTC4052 must have some method of current limit capability. The current limit level of the input power source must be lower than the overcurrent limit (I_{MAX}) set by the sense resistor $I_{MAX} = 105\text{mV}/(R_{SENSE} + 10\text{m}\Omega)$. The 10m Ω represents bond wire resistance internal to the IC. If a wall adapter without current limit is used, or the current limit level is above I_{MAX} , the charger will turn on briefly and then immediately turn off after the overcurrent condition is detected. This cycle will be resumed every 640ms ($C_{TIMER} = 0.1\mu\text{F}$) until the total charge time has run out. If overcurrent protection is not needed, short the SENSE pin to V_{IN} .

Trickle Charge and Defective Battery Detection

At the beginning of the charge cycle, if the cell voltage is low (less than 2.45V) the charger goes into a 24mA trickle charge mode. If the low cell voltage persists for one quarter of the total charge time, the battery is considered defective and the charge cycle is terminated. The $\overline{CHRG}$ pin output is then forced to a high impedance state.

Battery Charge Current

The battery charge current is determined by the current limit of the input supply (wall adapter). However, this current must not exceed the maximum charge current, I_{MAX} . If an overcurrent condition is detected, the charging is immediately terminated, the GATE pin is pulled to ground and the charge pump turns off. The charging will resume after a 640ms time off ($C_{TIMER} = 0.1\mu\text{F}$).

Programming the Timer

The programmable timer is used to terminate the charge cycle and sets the minimum ON/OFF time and the overcurrent time-off period. The length of the timer is programmed by an external capacitor from the TIMER pin to ground. The total charge time is:

$$\text{Time (Hours)} = (3 \text{ Hours})(C_{TIMER}/0.1\mu\text{F}) \text{ or}$$

$$C_{TIMER} = 0.1\mu\text{F} \cdot \text{Time (Hours)}/3 \text{ (Hours)}$$

The timer starts when the input voltage (at least 40mV greater than V_{BAT}) is applied. After a time-out has occurred, the charging stops and the $\overline{CHRG}$ pin becomes high impedance.

APPLICATIONS INFORMATION

CHRG Status Output Pin

This open-drain output can report three different charger conditions:

Charger Status	CHRG Pin Behavior
Not Charging	High Impedance
Charging	Strong Pulldown
Charging, C/10 Reached	Weak 40 μ A Pulldown

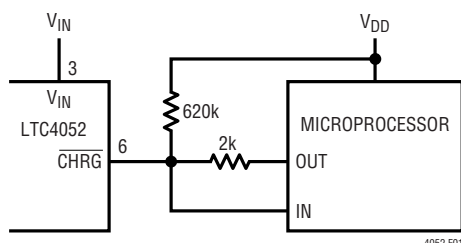


Figure 1. Interfacing with Microprocessor

Using a simple two-resistor network a microprocessor can distinguish all three states. See Figure 1.

When the LTC4052 is charging a battery, an internal N-MOSFET pulls the $\overline{\text{CHRG}}$ pin to ground. When C/10 is reached, the strong NMOS pulldown is replaced by a weak 40 μ A current source pulldown. When the LTC4052 is not charging a battery, the $\overline{\text{CHRG}}$ pin is high impedance.

Using the network in Figure 1, the microprocessor can determine charger state using the following procedure:

1. Force the digital output pin, OUT, high and read the logic value at the digital input, IN. If IN reads low, a charger cycle is in progress.
2. If the IN pin is high, force the OUT pin to be high impedance, then read the logic level at the IN pin again. If IN is low, the charge cycle is still in progress, the timer is still running, but the charge current has dropped below 10% of the programmed value indicating that the charge cycle is nearly complete.
3. If the logic level at the IN pin is high, the charge cycle has ended.

Near End-of-Charge C/10 Detection

The LTC4052 includes a comparator to monitor the duty cycle at the GATE pin to detect when the battery is nearing

full charge. When the duty cycle falls below 10%, the comparator trips and turns off the N-MOSFET at the $\overline{\text{CHRG}}$ pin and switches in a weak (40 μ A) current source to ground. The 40 μ A turns off when the charge cycle terminates. C/10 detection is disabled in trickle charge mode.

Internal Pass Transistor

An N-channel MOSFET (0.35 Ω) is included in the LTC4052 as the pass transistor. The gate of the MOSFET is controlled by an internal charge pump. The body is connected to ground instead of source terminal. There is no body diode from the BAT pin back to the V_{IN} pin; therefore, no blocking diode is required in series with the battery or the input supply. This will not only reduce cost but also reduce the heat generated while in fast charge mode. An internal thermal shutdown circuit turns the pass transistor off when the die temperature exceeds approximately 140°C with 5°C of thermal hysteresis.

Gate Drive

The MOSFET gate drive consists of a regulated 10 μ A current source charge pump. A series RC network is required from the GATE pin to the V_{IN} pin. When the MOSFET is turned on, the voltage at the V_{IN} pin will start slewing down to a voltage equal to V_{BAT} plus the voltage drop across the pass transistor and R_{SENSE} . The slew rate is equal to 10 μ A/C. By ramping the V_{IN} pin down slowly, the inrush current is reduced. The resistor in series with the capacitor is required to limit the transient current when the input supply is first applied.

When the charge pump is turned off, a 50 μ A current source to ground will start pulling the GATE voltage down. Once the pass transistor is off, the voltage at the V_{IN} pin will begin slewing up with the rate equal to 50 μ A/C. With this external capacitor, the voltage at the V_{IN} pin is ramping at a controlled manner (Figure 2).

For higher current applications an external power N-channel MOSFET can be connected in parallel with the internal pass transistor. Because the charge pump output is clamped to 12V above GND, the external MOSFET gate to source breakdown voltage should be rated for 16V or more.

APPLICATIONS INFORMATION

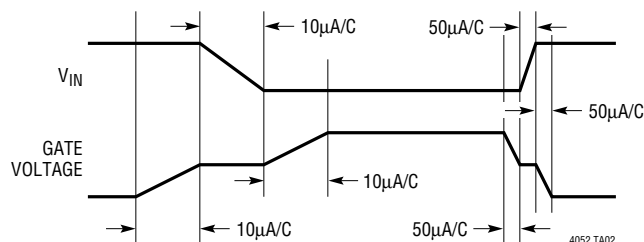


Figure 2. Slew Rate at GATE and V_{IN} Pins with the RC Network from GATE to V_{IN}

Thermal Considerations

The power handling capability is limited by the maximum rated junction temperature (125°C) and the amount of PC board copper used as a heat sink. The power dissipated by the device consists of two components:

1. Input supply current multiplied by the input voltage
2. The voltage drop across the switch (SENSE pin to BAT pin) multiplied by the charge current

The LTC4052 has internal thermal shutdown designed to protect the IC from overtemperature conditions. For continuous charging in the fast charge mode, the maximum junction temperature must not be exceeded. It is important to give careful consideration to all sources of thermal resistance from junction to ambient. Additional heat sources mounted nearby must also be considered.

Surface mount packages rely primarily on the PC board copper to dissipate the heat generated by the package to the surrounding air. Since the PC board copper is the heat sink, generous amounts of copper surrounding the package are recommended to increase the effectiveness of the heat sink. In addition, feedthrough vias or plated through holes (located directly beneath the package and elsewhere) connecting internal copper and backside copper layers help transfer and spread the heat generated by the package.

Calculating Junction Temperature

Example: Find the maximum junction temperature for a battery voltage of 4V (V_{IN} will collapse to around V_{BAT} in the fast charge mode), charge current of 1A and a maximum ambient temperature of 75°C.

The power dissipated by the IC is:

$$\begin{aligned} P &= (I_{BAT} \cdot I_{BAT} \cdot R_{DS(ON)}) + (V_{IN} \cdot I_{IN}) \\ &= (1A \cdot 1A \cdot 0.35\Omega) + (4V \cdot 1mA) \\ &= 0.35 + 0.004 \\ &= 0.354W \end{aligned}$$

The LTC4052 is available in an enhanced 8-pin MSOP package which features an exposed copper pad on the bottom of the package allowing it to be soldered directly to the PC board copper for maximum heat transfer. This greatly reduces the thermal resistance and increases the power handling capability when compared to a standard MSOP package. The junction to ambient thermal resistance of this package is approximately 35°C/W depending on the copper area. The junction temperature rise above ambient will be approximately:

$$(0.354W)(35^{\circ}C/W) = 12.39^{\circ}C$$

The maximum junction temperature will be equal to the maximum junction temperature rise above ambient plus the maximum ambient temperature or:

$$T_{JMAX} = 85^{\circ}C + 12.39^{\circ}C = 97.39^{\circ}C$$

ACPR Output Pin

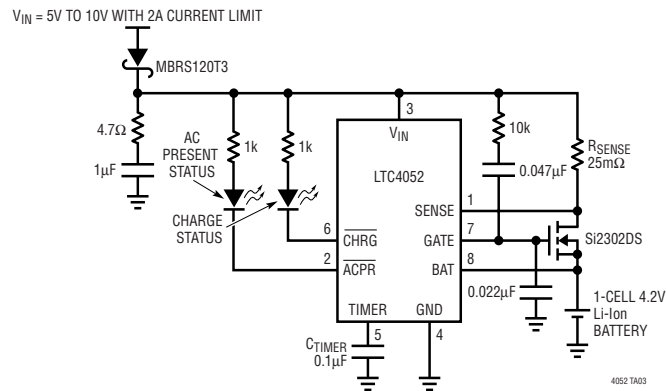
When the input voltage is 45mV higher than the voltage at the BAT pin, the ACPR pin is pulled to ground to indicate that the input supply (wall adapter) is applied. After the input supply is removed, this pin will become high impedance. An internal 100ms filter prevents the LTC4052 from turning off if the voltage at the V_{IN} pin rings and gets too close to V_{BAT} due to parasitic inductance.

Stop Charging

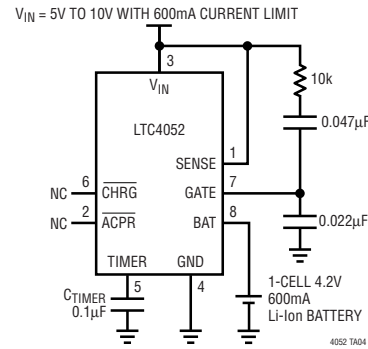
The charger is off when the voltage at the V_{IN} pin is less than 45mV above V_{BAT} (sleep mode). The charge pump and the internal pass transistor are turned off, and the internal resistor divider is disconnected to reduce the current drain on the battery in the sleep mode.

TYPICAL APPLICATIONS

External N-MOSFET for Higher Charge Current



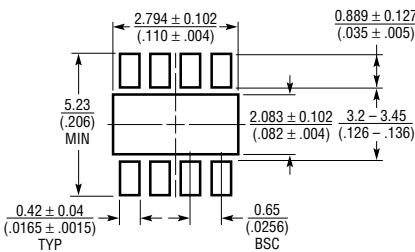
Minimum Component Count 4.2V Li-Ion Battery Charger



PACKAGE DESCRIPTION

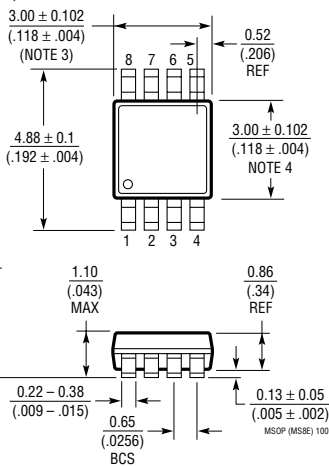
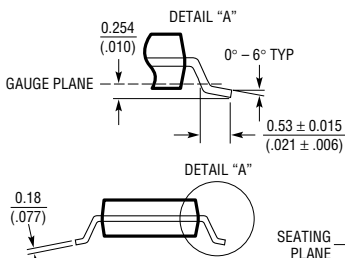
MS8E Package
8-Lead Plastic MSOP

(Reference LTC DWG # 05-08-1662)

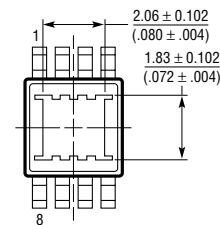


- NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
 2. DRAWING NOT TO SCALE
 3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
 4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
 5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

RECOMMENDED SOLDER PAD LAYOUT



BOTTOM VIEW OF
EXPOSED PAD OPTION



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1510-5	500kHz CC/CV Battery Charger	Most Compact, Up to 1.5A, Charges NiCd, NiMH, Li-Ion Cells
LTC1729	Termination Controller for Li-Ion	Time or Charge Current Termination, Automatic Charger/Battery Detection Status Output, Preconditioning, 8-Lead MSOP
LTC1730	Li-Ion Battery Pulse Charger with Thermistor Interface	Battery Temperature Sensing, FAULT Output, SO-8 and SSOP-16 Packages
LTC1731	Li-Ion Battery Charger Controller	CC/CV Charges Li-Ion Cells, 8-Lead MSOP
LTC1732	Li-Ion Battery Charger Controller	CC/CV Charges Li-Ion Cells, Automatic Battery Detection, 10-Lead MSOP
LTC1733	Li-Ion Battery Charger with Thermal Regulation	Standalone Charger, Constant-Current/Constant-Voltage/Constant-Temperature, Integrated MOSFET, No External Sense Resistor or Blocking Diodes
LTC1734	ThinSOT™ Li-Ion Battery Charger	Only Two External Components, Up to 700mA I _{CHARGE} , No Reverse Current Diode Required, No Sense Resistor Required
LTC4050	Li-Ion Battery Charger Controller with Thermistor Interface	Drives External MOSFET, 10-Lead MSOP

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