## Li-ion/Li Polymer Battery Charger

The ISL6297 is a Dual-Mode Lithium Ion battery charger optimized for cellular phone travel charger applications. It uses Intersil's **patent-pending** dual-mode charge technology to minimize the heat normally generated in a linear charger. By minimizing the heat generation, the ISL6297 can be placed inside the connector of the travel charger to completely remove the influence of the adapter cable on the charging performance.

The ISL6297 is an enhancement of the original ISL6292B. New features include improved accuracy, pre-charge circuit verification, and enhanced LED indicator function.

Working with a current-limited AC/DC converter, the dual-mode charger charges a Li-ion battery with the same current profile as a traditional linear charger. The constant charge current is determined by the current limit of the AC/DC converter. The constant output voltage is fixed at 4.2V. When the battery voltage is below 2.8V, the charger preconditions the battery with a low trickle-charge current. The charge status is indicated by a bi-color LED. A safety timer prevents charging a dead battery for an excessively long period.

The ISL6297 also features THERMAGUARD™, a thermal foldback function that automatically reduces the charge current when the internal die temperature exceeds a +100°C limit to prevent further temperature rise. This function removes the concern of thermal failure in the targeted space-limited applications. An ambient temperature monitoring circuit allows users to set two separate temperature limit levels, for charge and non-charge conditions. The thermally-enhanced QFN package further improves the thermal performance of the ISL6297 in space-limited applications.

Pinout

ISL6297
(16 LD QFN)
TOP VIEW
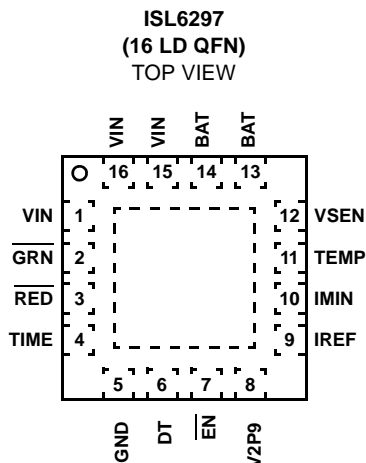
Features

- Complete Charger for Single-Cell Li-ion Batteries
- Integrated Pass Element and Current Sensor
- No External Blocking Diode Required
- Very Low Thermal Dual-Mode Operation
- 0.7% Voltage Accuracy with Remote Sense
- Pre-charge circuit verification with LED status indication
- Drives a bi-color LED
- Programmable Safety Timer
- Programmable Current Limit up to 1.5A
- Programmable End-of-Charge Current
- THERMAGUARD™ Charge Current Thermal Foldback
- NTC Thermistor Interface for Battery Temperature Monitor
- Two-Level Ambient Temperature Setting
- Guaranteed to Operate at 2.65V After Start-Up
- Ambient Temperature Range: -20°C to +70°C
- Thermally-Enhanced QFN Packages
- QFN Package:
  - Compliant to JEDEC PUB95 MO-220 QFN - Quad Flat No Leads - Package Outline
  - Near Chip Scale Package footprint, which improves PCB efficiency and has a thinner profile
- Pb-Free Plus Anneal Available (RoHS Compliant)

Applications

- PDAs, Cell Phones and Smart Phones
- Portable Instruments, MP3 Players
- Medical Handhelds
- Self-Charging Battery Packs
- Stand-Alone Chargers

Ordering Information

PART NUMBER	PART MARKING	TEMP. RANGE (°C)	PACKAGE	PKG. DWG. #
ISL6297CR*	ISL 6297CR	-20 to +70	16 Ld 4x4 QFN	L16.4x4
ISL6297CRZ* (Note)	62 97CRZ	-20 to +70	16 Ld 4x4 QFN (Pb-free)	L16.4x4

Add "-T" suffix for tape and reel.

NOTE: Intersil Pb-free plus anneal products employ special Pb-free material sets; molding compounds/die attach materials and 100% matte tin plate termination finish, which are RoHS compliant and compatible with both SnPb and Pb-free soldering operations. Intersil 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.

Absolute Maximum Ratings

Supply Voltage (V_{IN}) . . . . -0.3 to 7V
All Other Pins . . . . -0.3 to 5.5V

Recommended Operating Conditions

Ambient Temperature Range. -20°C to +70°C
Supply Voltage, V_{IN} . . . . 4.3V to 6.5V
Maximum Pin Voltage (Except VIN). 5.25V

Thermal Information

Thermal Resistance (Notes 1, 2)	θ_{JA} (°C/W)	θ_{JC} (°C/W)
4x4 QFN Package	41	4

Junction Temperature Range . . . . -55°C to +150°C
Operating Temperature Range . . . . -40°C to +85°C
Storage Temperature Range . . . . -65°C to +150°C
Maximum Lead Temperature (Soldering 10s) . . . . +300°C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

+150°C max junction temperature is intended for short periods of time. Constantly operated at +150°C may shorten the life of the part.

NOTES:

1. θ_{JA} is measured in free air with the component mounted on a high effective thermal conductivity test board with "direct attach" features. See Tech Brief TB379.

2. θ_{JC}, "case temperature" location is at the center of the exposed metal pad on the package underside. See Tech Brief TB379.

Electrical Specifications   Typical values are tested at V_{IN} = 5V and +25°C ambient temperature. Maximum and minimum values are guaranteed over recommended operating conditions, unless otherwise noted.

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
POWER-ON RESET, OVER VOLTAGE PROTECTION, PRE-REGULATOR						
Rising VIN Threshold			2.9	3.4	4.0	V
Falling VIN Threshold			2.3	2.4	2.65	V
2.9V Reference Output Voltage	V2P9	I_{LOAD} = 2mA	-	2.9	-	V
2.9V Reference Output Current			-	-	30	mA
VIN-BAT Comparator Offset			30	-	-	mV
STANDBY CURRENT						
VBAT Pin Sink Current	$I_{STANDBY}$	VIN floating or $\overline{EN}$ pin is floating	-	-	3.0	μA
VIN Pin Supply Current	I_{VIN1}	BAT Pin floating, $\overline{EN}$ = LOW	-	1.0	1.5	mA
VIN Pin Supply Current	I_{VIN2}	BAT Pin floating, $\overline{EN}$ = HIGH	-	0.5	1.0	mA
Charger Reverse Current		VIN = 4.3V, VSEN = BAT= 4.5V, $\overline{EN}$ = HIGH	-	-	6.0	μA
VOLTAGE REGULATION						
Output Voltage	V_{CH}		4.17	4.20	4.23	V
Dropout Voltage		V_{BAT} = 3.7V, I_{CHARGE} = 0.65A	-	250	300	mV
CHARGE CURRENT						
Charge/Protection Current	I_{CHARGE}	R_{IREF} = 80kΩ, V_{BAT} = 3.7V, V_{IN} = 5V	900	1000	1100	mA
Trickle Charge Current	$I_{TRICKLE}$	R_{IREF} = 80kΩ, V_{BAT} = 2.0V, V_{IN} = 5V	85	110	135	mA
End-of-Charge Current		R_{IMIN} = 133kΩ	56	63	70	mA
CHARGE VOLTAGE THRESHOLDS						
Short-Circuit Threshold	V_{SC}		0.9	1.0	1.1	V
Trickle Charge Threshold - Rising	V_{MIN}		2.7	2.9	3.2	V
Trickle Charge Threshold - Falling	V_{MIN}		2.6	2.7	3.0	V
Recharge Threshold - Falling	V_{RECHRG}		3.90	4.00	4.08	V
Difference from Final Battery Voltage			-	-210	-	mV
Open Circuit Test Threshold- Rising	V_{OCR}		-	4.4	-	V

Electrical Specifications   Typical values are tested at V_{IN} = 5V and +25°C ambient temperature. Maximum and minimum values are guaranteed over recommended operating conditions, unless otherwise noted. **(Continued)**

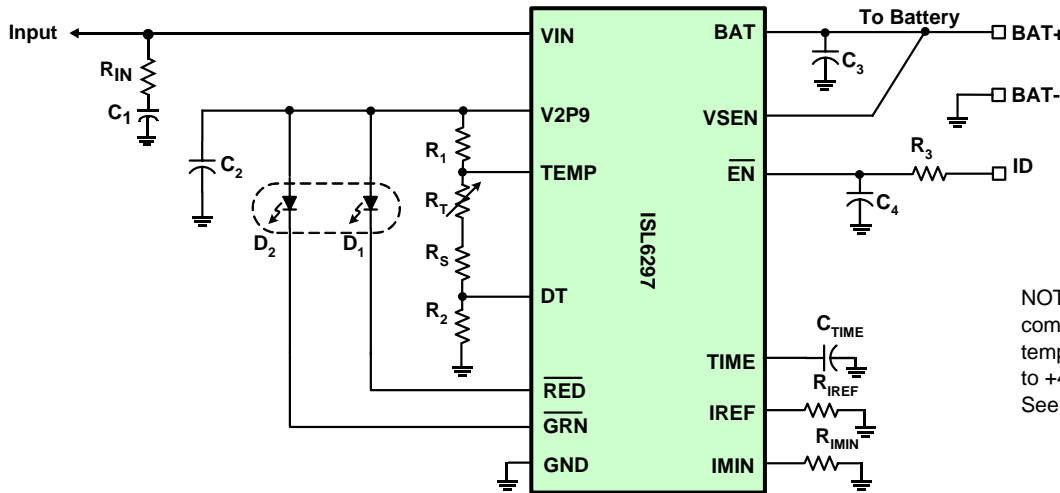| PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
BATTERY TEMPERATURE MONITORING						
Low Temperature Threshold	V_{TMIN}	V2P9 = 2.88V	1.94	2.0	2.06	V
Low Temperature Hysteresis			135	167	199	mV
High Temperature Threshold	V_{TMAX}	V2P9 = 2.88V	.704	.718	.732	V
High Temperature Hysteresis			160	185	200	mV
DT Pin MOSFET On Resistance	R_{DT}		-	25	-	Ω
Charge Current Foldback Threshold (Note 4)	T_{FOLD}		-	100	-	°C
Current Foldback Gain (Note 5)	G_{FOLD}		-	100	-	mA/°C
OSCILLATOR						
Oscillation Period	T_{OSC}	C_{TIME} = 15nF	2.7	3.0	3.3	ms
LOGIC INPUT AND OUTPUT						
$\overline{EN}$ Input Low			-	-	0.8	V
$\overline{EN}$ Pin External Pull Down to Disable			-	-	50	kΩ
LED Sink Current ($\overline{RED}$, $\overline{GRN}$)		Pin Voltage = 1.0V	5	10	-	mA
LED Leakage Current			-	-	1	μA

NOTES:

3. The actual current may be lower due to the thermal foldback.

4. Guaranteed by design and characterization to be typically +100°C ±15%.

5. Guaranteed by design and characterization.

Pin Description

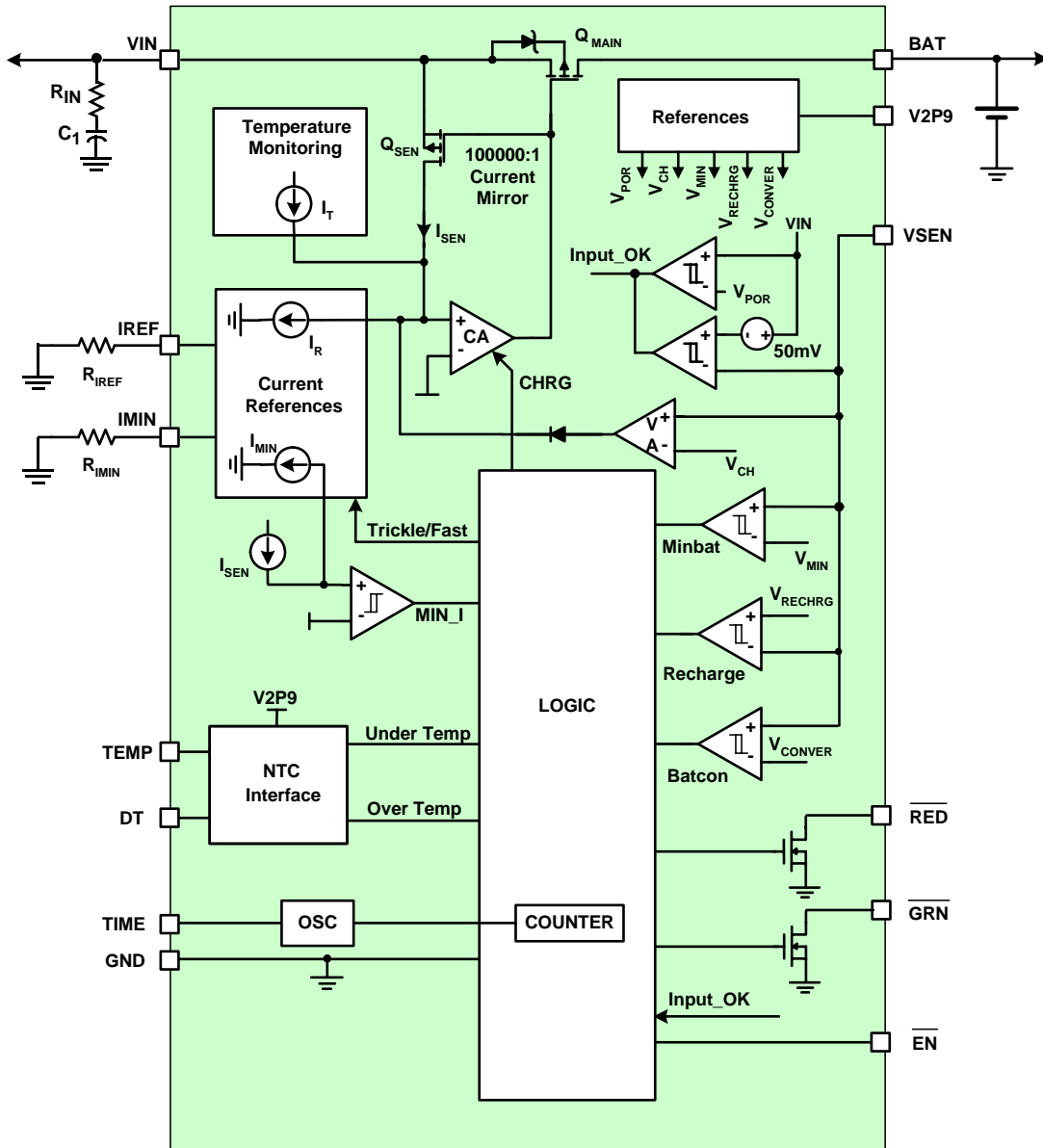| PIN #	PIN NAME	DESCRIPTION
1, 15, 16	VIN	VIN is the input power source. It is recommended to have a 1Ω resistor in series with the input decoupling capacitor to prevent an over-shoot voltage when the input cable is plugged in.
2	$\overline{\text{GRN}}$	Open-drain LED drive pin. This pin sinks a constant-current 10mA to drive a **green** LED in a bi-color LED pack.
3	$\overline{\text{RED}}$	Open-drain LED drive pin. This pin sinks a constant-current 10mA to drive a **red** LED in a bi-color LED pack.
4	TIME	Timer Programming Input. The TIME pin determines the oscillation period by connecting a timing capacitor between this pin and GND. The oscillator provides a time reference for the charger.
5	GND	GND is the connection to system ground.
6	DT	Delta Temperature Setting Input. This pin sets the temperature difference before and after the charging starts. This pin can also be used as an indication whether or not the charger is charging.
7	$\overline{\text{EN}}$	Enable Input. Connect $\overline{\text{EN}}$ LOW to enable the charger. Pull it HIGH or leave it floating to disable the charger. This pin is pulled up to 2.9V when left floating.
8	V2P9	Untrimmed 2.9V voltage output. This pin outputs a 2.9V voltage source when the input voltage is above POR threshold, independent on the $\overline{\text{EN}}$ pin input. The V2P9 output is used to power the LEDs, the NTC circuit, or for other functions. The maximum output current is 30mA. This output can also be used as an indication for adapter presence.
9	IREF	This is the programming input for the constant charging current in a linear charger. In the typical application of a dual-mode charger, the IREF pin programs the trickle charge current as well as the protection current level.
10	IMIN	IMIN is the programmable input for the end-of-charge current.
11	TEMP	Temperature setting input. An external NTC thermistor is connected to this pin for ambient temperature sensing.
12	VSEN	Battery remote voltage sensing feedback pin. This pin allows remote sense of the battery pack voltage. Connect this pin as close as possible to the battery positive terminal with a separate trace to minimize the impact of parasitic resistance. This pin also serves the function of compensating for voltage drop caused by the connector contact resistance.
13, 14	BAT	BAT is the charger output.
-	EPAD	Exposed Pad. This pad is internally connected to GND. Connect as much copper as possible to this pad on the component or other layers through thermal vias to maximize the thermal performance.

Typical Application

C$_1$: 1μF X5R ceramic capacitor
C$_3$: 10μF X5R ceramic capacitor
C$_2$, C$_4$: 0.1μF X5R ceramic capacitor
C$_{\text{TIME}}$: 22nF X5R or better timing capacitor
D$_1$, D$_2$: dual-color (red and green) LED in one package
R$_{\text{IREF}}$: 80kΩ, 1%
R$_{\text{IMIN}}$: 133kΩ, 1%

R$_1$: 15kΩ, 1%
R$_2$: TBD, value dependent on the DT (1.37kΩ for +10°C delta)
R$_T$: MuRata NCP18XH103J -- 10kΩ at +25°C, 5% (0603 size)
R$_S$: 41.2Ω
R$_3$: 10kΩ, 5% (R$_3$ and C$_4$ are for improving ESD protection)
R$_{\text{IN}}$: 1Ω (Used to prevent overshoot when connecting the cable)

NOTE: Temperature limit components selected for a temperature Range of -5°C to +45°C (not charging) See Example, page 14

Block Diagram

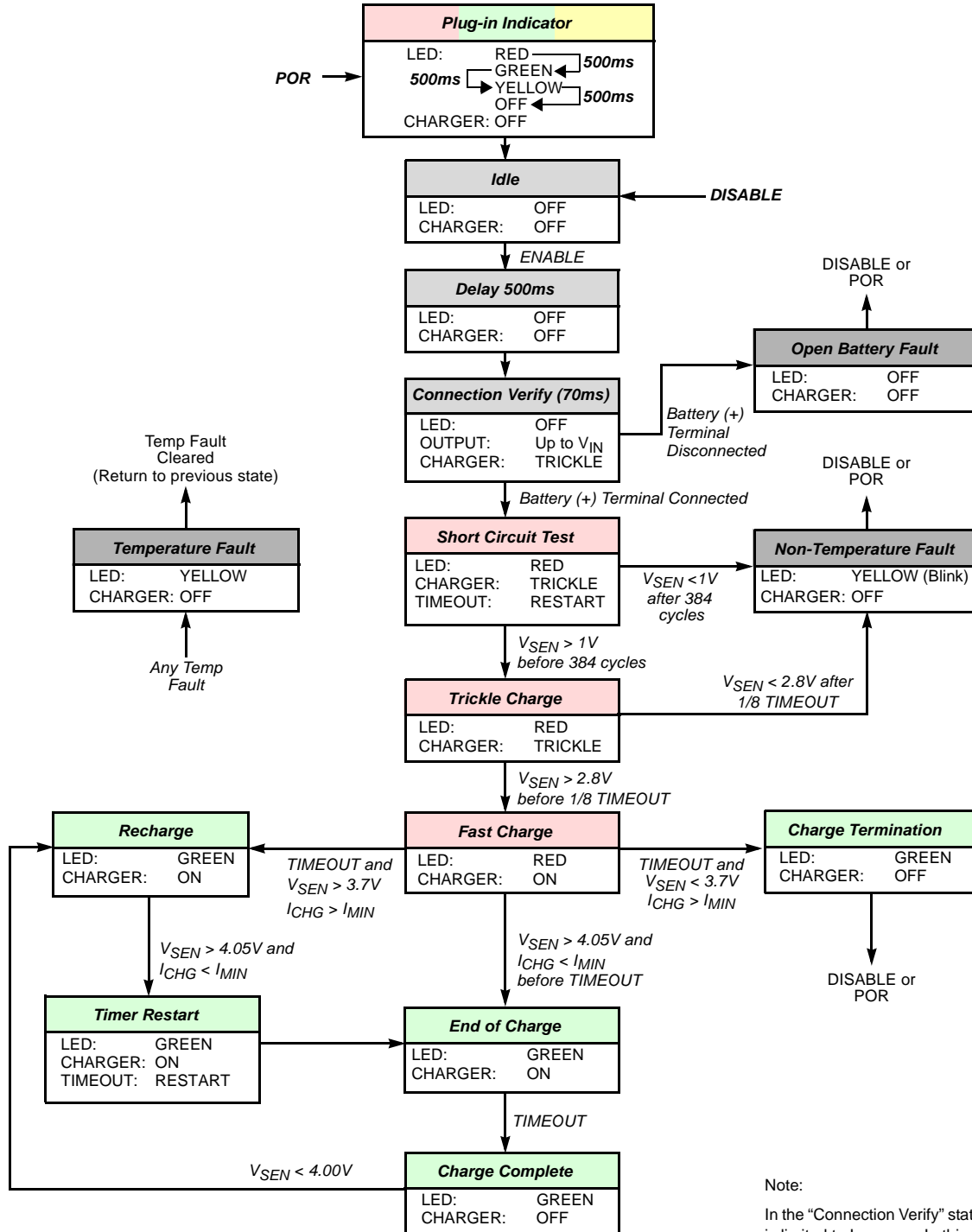## *State Diagram*

Plug-in Indicator
LED: RED
              GREEN *500ms*
500ms YELLOW
              OFF *500ms*
CHARGER: OFF

POR →

Idle
LED: OFF
CHARGER: OFF

← *DISABLE*

↓ *ENABLE*

Delay 500ms
LED: OFF
CHARGER: OFF

Connection Verify (70ms)
LED: OFF
OUTPUT: Up to V_{IN}
CHARGER: TRICKLE

→ *Battery (+) Terminal Disconnected*

Open Battery Fault
LED: OFF
CHARGER: OFF

↑ DISABLE or POR

↓ *Battery (+) Terminal Connected*

Temp Fault Cleared
(Return to previous state)

Temperature Fault
LED: YELLOW
CHARGER: OFF

↑ *Any Temp Fault*

Short Circuit Test
LED: RED
CHARGER: TRICKLE
TIMEOUT: RESTART

→ *V_{SEN} <1V after 384 cycles*

Non-Temperature Fault
LED: YELLOW (Blink)
CHARGER: OFF

↑ DISABLE or POR

↓ *V_{SEN} > 1V before 384 cycles*

Trickle Charge
LED: RED
CHARGER: TRICKLE

→ *V_{SEN} < 2.8V after 1/8 TIMEOUT*

↓ *V_{SEN} > 2.8V before 1/8 TIMEOUT*

Recharge
LED: GREEN
CHARGER: ON

← *TIMEOUT and V_{SEN} > 3.7V I_{CHG} > I_{MIN}*

Fast Charge
LED: RED
CHARGER: ON

→ *TIMEOUT and V_{SEN} < 3.7V I_{CHG} > I_{MIN}*

Charge Termination
LED: GREEN
CHARGER: OFF

↓ DISABLE or POR

V_{SEN} > 4.05V and I_{CHG} < I_{MIN}

Timer Restart
LED: GREEN
CHARGER: ON
TIMEOUT: RESTART

V_{SEN} > 4.05V and I_{CHG} < I_{MIN} before TIMEOUT

End of Charge
LED: GREEN
CHARGER: ON

↓ *TIMEOUT*

V_{SEN} < 4.00V

Charge Complete
LED: GREEN
CHARGER: OFF

Note:

In the "Connection Verify" state, the output current is limited to $I_{TRICKLE}$. In this state, **with** a battery connected, the output voltage rises no higher than the battery voltage. Also in this state, **with no** battery connected, the output voltage rises to V_{IN}. In all other states, the output voltage is limited to 4.2V (typ).

Theory of Operation

The ISL6297 is based on the **Intersil Patent-pending** dual-mode charging technology. This allows the ISL6297 to function as a traditional linear charger when powered with a voltage-source adapter. However, when powered with a current-limited adapter, the charger minimizes the thermal dissipation commonly seen in traditional linear chargers. This dual-mode technology generates very low heat, which enables the charger to be used in space-limited applications.

The ISL6297 charges a Lithium Ion battery using the constant current (CC) and constant voltage (CV) profile specified by battery cell manufacturers.

As a linear charger, the constant charge current I_{REF} is programmable up to 1.5A with an external resistor. The constant charge voltage V_{CH} is regulated by the ISL6297 at 4.2V with a 0.7% accuracy over the entire recommended operating range.

The ISL6297 always preconditions the battery with 10% of the programmed current at the beginning of a charge cycle, until the battery voltage is verified to be above the minimum fast charge voltage, V_{MIN}. This low-current preconditioning charge mode is named trickle mode.

A thermal-foldback feature removes the thermal concern typically seen in linear chargers. The charger reduces the charge current automatically as the IC internal temperature rises above +100°C to prevent further temperature rise. The thermal-foldback feature guarantees safe operation when the printed circuit board (PCB) is space limited for thermal dissipation.
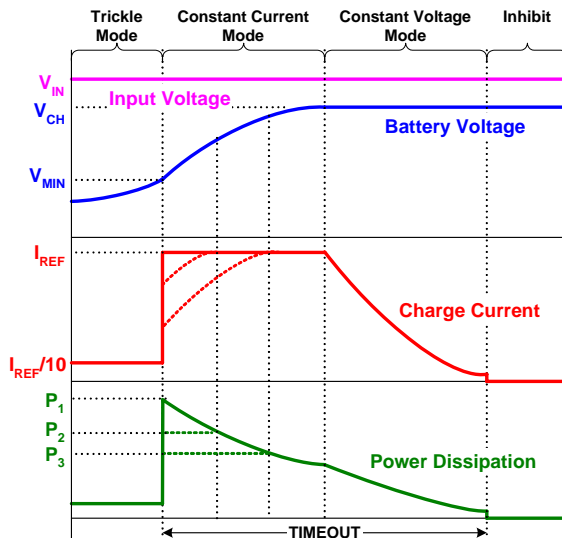
FIGURE 1. TYPICAL CHARGE CURVES USING A CONSTANT-VOLTAGE ADAPTER

Figure 1 shows the typical charge curves in a traditional linear charger powered with a constant-voltage adapter. The power dissipation P_{CH} is given by the following equations:

$$P_{CH} = (V_{IN} - V_{BAT}) \times I_{CHARGE} \qquad \text{(EQ. 1)}$$

where I_{CHARGE} is the charge current. The maximum power dissipation occurs at the beginning of the CC mode. The maximum power the IC is capable of dissipating is dependent on the thermal impedance of the printed-circuit board (PCB). Figure 1 shows, with dotted lines, two cases in which the charge currents are limited by the maximum power dissipation capability due to the thermal foldback.

To take advantage of the low-heat feature of the ISL6297, a current-limited AC/DC converter is required as the power supply to the charger. The current-limited supply has the I-V characteristics shown in Figure 2. The supply is a DC source before the load current reaches the limited current I_{LIM}. Once the current limit is reached, the supply current cannot increase further; instead, the supply voltage falls. The current-limited supply is a voltage source with an equivalent output impedance or a current source, depending on its operating region, as shown in Figure 2.
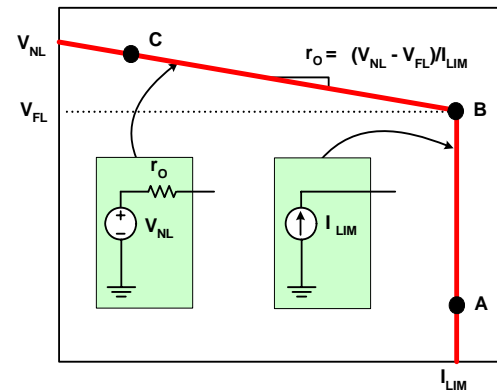

FIGURE 2. THE I-V CHARACTERISTICS OF THE CURRENT-LIMITED AC/DC CONVERTER

In this mode of operation, the constant current is determined by the current limit I_{LIM} of the supply during the constant-current charge mode. To ensure dual-mode operation, the current protection level set by the ISL6297 I_{REF} pin should be higher than I_{LIM}. In the constant-voltage charge mode, the battery voltage is regulated at 4.2V. When the battery voltage is below the specified V_{MIN} voltage, the charger preconditions the battery using trickle charge mode.

Figure 3 shows the typical waveforms in a charge cycle of the dual mode operation. When the battery voltage is below V_{MIN}, the trickle charge mode is in effect. Since the charge current is much less than the I_{LIM}, the AC/DC converter operates in the voltage source region. Once the battery voltage exceeds V_{MIN}, the charger fully turns on the internal P-channel power MOSFET. The AC/DC converter operates in the current-limitedregion and its voltage is pulled down to a level slightly higher than the battery voltage.
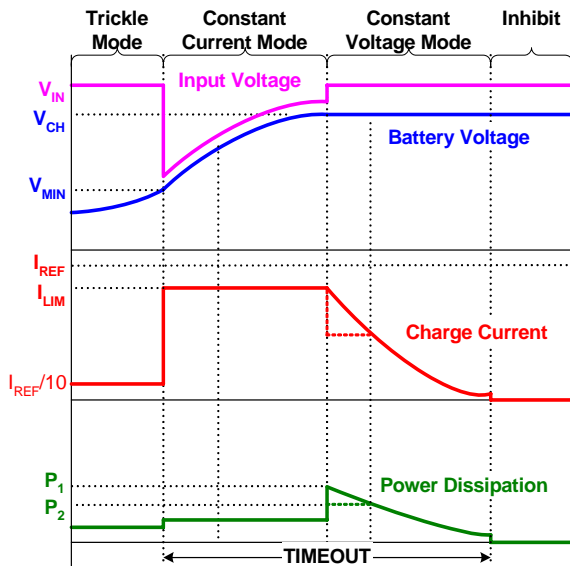
FIGURE 3. TYPICAL CHARGE CURVES USING A CURRENT-LIMITED ADAPTER

As shown in Figure 3, the charge current is I_{LIM} and is lower than I_{REF}. As the battery voltage reaches the 4.2V V_{CH} level, the charge current starts to decrease. The AC/DC supply moves out of the current-limit region and becomes a voltage source again. When the charge current reaches a programmable end-of-charge (EOC) level set by the I_{MIN} pin, the charger sends out an EOC indication.

When using a current-limited adapter, the thermal situation in the ISL6297 is totally different from the voltage limited case. Figure 3 shows the typical charge curves when a current-limited adapter is employed. The operation requires that the I_{REF} level be programmed higher than the limited current I_{LIM} of the adapter. The key difference in the charger operation under such conditions occurs during the CC mode.

The power dissipation in the CC mode becomes:

$$P_{CH} = R_{DS(ON)} \times I_{CHARGE}^2 \qquad \text{(EQ. 2)}$$

where $r_{DS(ON)}$ is the resistance when the main MOSFET is fully turned on. This power is typically much less than the peak power in the traditional linear mode.

When using a current-limited adapter, the worst power dissipation typically occurs at the beginning of the CV mode, as shown in Figure 3. The equation EQ.1 also applies to the dual mode operation during the CV mode. When using a very small PCB whose thermal impedance is relatively large, it is possible that the internal temperature can still reach the thermal foldback threshold. In that case, the IC is thermally protected by lowering the charge current, as shown with the dotted lines in the charge current and power curves.

Appropriate design of the adapter can further reduce the peak power dissipation of the ISL6297. One simple approach is to design the AC/DC converter output voltage

just high enough (normally lower than 5V) to fully charge the battery. More information can be found in the ISL6292 datasheet available at http://www.intersil.com.

Functional Overview

After applying power to the ISL6297, but before charging starts, the ISL6297 gives a "Plug-in indication" by sequentially turning on a red, a green and a yellow indicator. The indicator then turns off. This verifies that the AC/DC adapter and the ISL6297 have properly powered up.

The ISL6297 then waits in an idle mode until the enable pin indicates that the battery pack has been plugged in. A 500ms delay give time for the pins to be connected prior to the start of a connection verification operation.

In the connection verification, the ISL6297 determines if the battery positive pin is connected. If not, the charge operation does not start and the LED remains off.

If the battery is firmly connected, the ISL6297 checks to see if the battery is good and that the battery connection is not short-circuited. If no faults are detected the ISL6297 starts a trickle charge and turns on the red LED charge indicator. Once the battery voltage reaches V_{MIN}, the charger outputs a constant current until the battery voltage reaches V_{CH}. The ISL6297 then holds the voltage constant. As the battery charges, the current supplied to the battery decreases.

When the charge current drops to I_{MIN}, the ISL6297 issues an EOC indication, which consists of the LED changing colors from red to green. An end of charge indication will also occur at the end of a user programmable TIMEOUT period even if the cell is not completely charged.

If the battery voltage drops to a recharge threshold after the end of charge, the ISL6297 recharges the battery until the voltage again reaches 4.2V and the current drops below I_{MIN}. At this point, the charger again turns off. The recharge cycle continues indefinitely until the charger is turned off by disconnecting the battery, which sets the $\overline{EN}$ pin high.

An external NTC thermistor allows the ISL6297 to monitor the ambient temperature. If the ambient temperature is out range, the charger will not operate. Because the printed-circuit board (PCB) temperature rises during charge, the ISL6297 provides a higher temperature limit during the charge operation.

The ISL6297 also features a thermal-foldback function that reduces the charge current if the IC internal temperature reaches +100°C to prevent further temperature rise.

Applications Information

Power-On Reset (POR)

The ISL6297 has a 3.4V rising POR threshold. Before the input voltage reaches the POR threshold, the V2P9 pin outputs 0V and the charger is disabled. Once the POR

threshold is reached, all counters are reset to zero, the charge state machine is reset, the V2P9 pin outputs 2.9V, the open-drain MOSFET on the DT pin is turned on, and the ambient temperature monitoring circuit starts to function.

$\overline{EN}$ Pin

If all other charge conditions are met, pulling the $\overline{EN}$ pin low starts the ISL6297 charge operation. In a typical application, $\overline{EN}$ connects to the ID pin of a battery pack. Inside the battery pack the ID pin connects to ground through a resistance of less than 27kΩ. When the battery is not attached to the charger, the ISL6297 internally pulls the $\overline{EN}$ pin high to disable the charger. An RC filter on the ISL6297 $\overline{EN}$ input improves the charger ESD protection.

Table 1 summarizes the status of each pin when the $\overline{EN}$ pin disables the IC.

TABLE 1. SUMMARY OF PIN BEHAVIOR WHEN THE IC IS DISABLED BY THE EN PIN

PIN	BEHAVIOR
V2P9	Outputs 2.9V.
RED	High impedance.
GRN	High impedance.
DT	Low impedance.
IREF	Outputs 0.8V.
IMIN	Outputs 0.8V.
TEMP	The temperature monitoring circuit remains functioning.

Plug-in Indication

After power is applied to the ISL6297 and V_{IN} exceeds the POR threshold, the LEDs provide a Plug-in Indication sequence. First the RED LED turns on for 500ms, then the GREEN LED turns on for 500ms, then both turn on for 500ms (giving a YELLOW indication), and finally all the LEDs turn off.

The ISL6297 turns on an LED by pulling the output line LOW with a constant current of 10mA (typical). A typical bi-color LED needs no series resistor for the LED connection, however, current can be minimized by adding a serial resistor in each LED path.

Idle Condition and Battery Connection

Once V_{IN} is greater than (V_{BAT} + 50mV) and the temperature is within the allowed range the ISL6297 is ready to start the charge operation. Charging is initiated by plugging in the battery, which pulls the $\overline{EN}$ pin low.

Connection Verification

The $\overline{EN}$ pin going low starts a 500ms delay. After the delay, the ISL6297 turns on the charger for 70ms with a trickle charge current and an output voltage of V_{IN}. If no battery is connected, the VSEN voltage will go up to approximately VIN. If no battery is detected after the 70ms period, the

ISL6297 terminates the charge operation, turns off the output voltage, and sets the LEDs off. The device remains in this state until the $\overline{EN}$ pin is toggled or the device goes through a power cycle. (See Figure 5.)

If the battery is connected within the 70ms open battery detect period, the voltage on VSEN pin needs to drop below the (falling) threshold of about 4.3V before the end of the 70ms period. If not, then the battery has not been properly connected and an open battery connection fault condition exists, requiring a power cycle or a toggle of $\overline{EN}$.

After the 500ms delay, if a battery is connected, the VSEN voltage will remain below the 4.4V threshold and the ISL6297 assumes that the battery is connected. The device turns on the Red LED to indicate a charge operation and starts a short circuit detection. (See Figure 4.)

If the battery positive terminal comes loose and reconnects after this time, the charge operation sequence continues, but the LED indicates an end of charge condition, regardless of the state of charge.

Short Circuit Detection

To detect a short circuit condition the ISL6297 forces the trickle charge current to the battery. If, after 384 cycles, the battery voltage is below 1V, the ISL6297 considers the battery or connection to be short-circuited. In this condition, the charger turns off and a flashing yellow indicator displays the occurance of this "non-temperture" fault.

To clear a short circuit fault condition requires that the enable pin be toggled, by removing the battery pack, or by cycling the power on the charger.

Trickle Charge

If there is no short circuit the voltage is higher than 1V and the charge operation continues with a trickle charge. In the trickle charge, the ISL6297 applies 10% of the programmed current to the battery. If the voltage on the cell is greater than 2.8V after 15 clock cycles, then the ISL6297 applies the full constant current charge to the cell. However, if the voltage on the cell does not rise above 2.8V in one eighth (1/8) of the TIMEOUT period, then a non-temperature fault occurs and the charger is turned off. A flashing yellow indicator announces this condition.
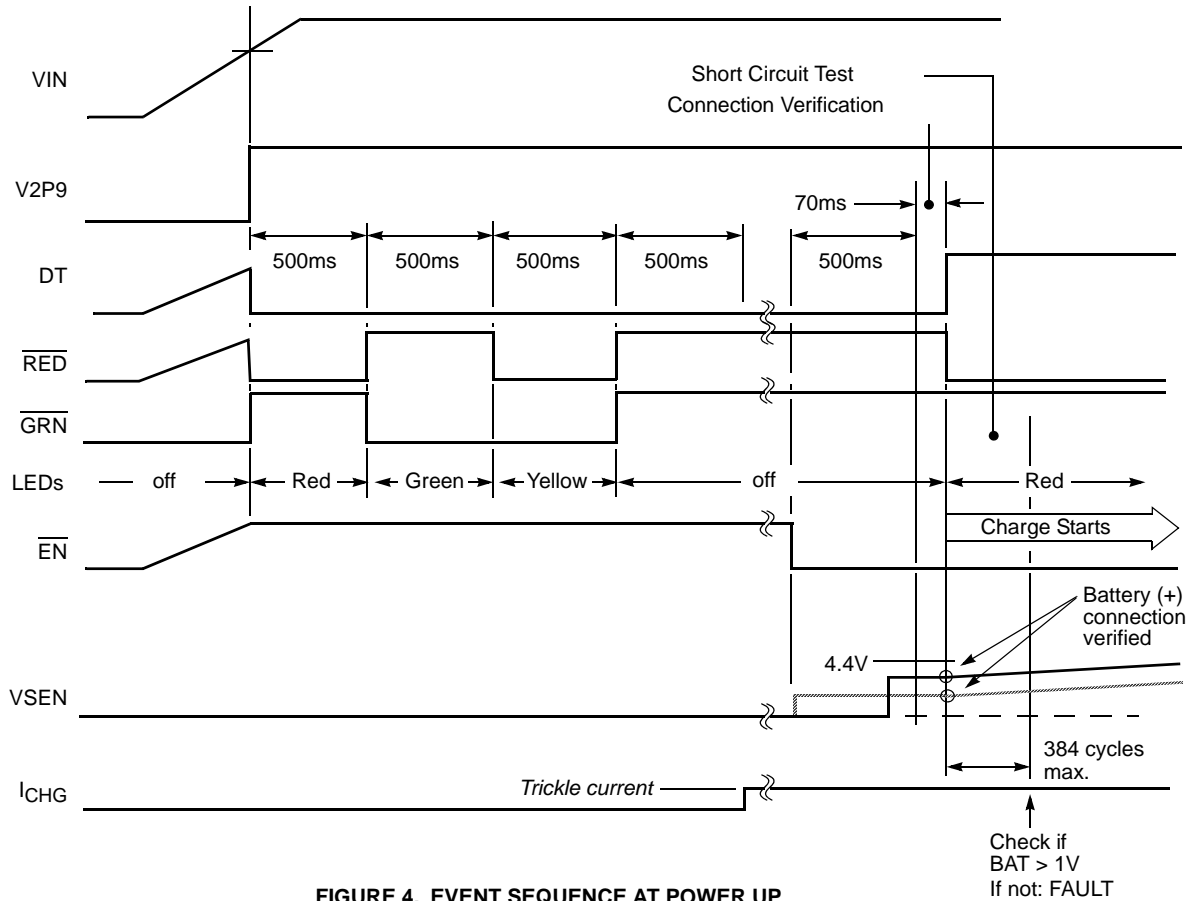
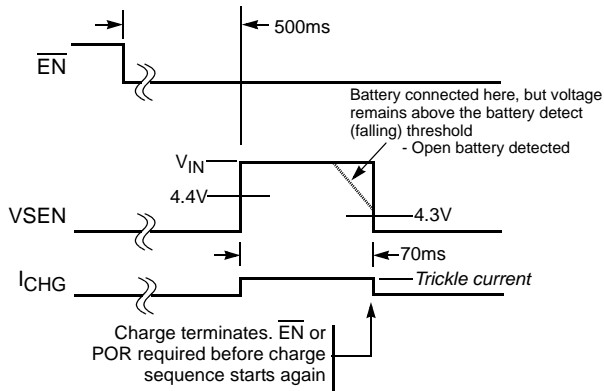**FIGURE 4. EVENT SEQUENCE AT POWER UP**

FIGURE 5. OPEN BATTERY DETECTED

Charge Current and R_{IREF} Selection

When the ISL6297 is used as a traditional linear charger, the RIREF sets the constant charge current. When working with a dual-mode, current-limited supply, the CC current is determined by the supply limited current ILIM. IREF needs to be programmed higher than ILIM and is used as an overcurrent protection. Taking into account the tolerance of both the ILIM and IREF, it is recommended the IREF be programmed at least 30% higher than the ILIM. IREF can be calculated by using the following equation:

$$I_{REF} = \frac{0.8V}{R_{IREF}} \times 10^5 (A) \tag{EQ. 3}$$

The trickle charge current is 10% of I_{REF}, that is,

$$I_{Trickle} = \frac{0.8V}{R_{IREF}} \times 10^4 (A) \tag{EQ. 4}$$

The ISL6297 has a comparator with a 50mV offset voltage to ensure the input voltage is higher than the battery voltage before charging starts (see the Block Diagram). This condition, coupled with an $R_{DS(on)}$ of about 400mΩ (max) requires I_{LIM} be higher than 125mA. The upper limit for I_{LIM} is 1.5A.

EOC Current and R_{IMIN} Selection

The EOC current level is programmed by the I_{MIN} pin and can be calculated by the following equation:

$$I_{MIN} = \frac{0.8V}{R_{IMIN}} \times 10^4 (A) \tag{EQ. 5}$$

The EOC current has a programming range up to 400mA.

To qualify as an EOC condition, the battery voltage must be above the recharge threshold given in the Electrical Specification table and the charge current needs to drop below the I_{MIN} level for 3 to 4 cycles of the internal oscillator.
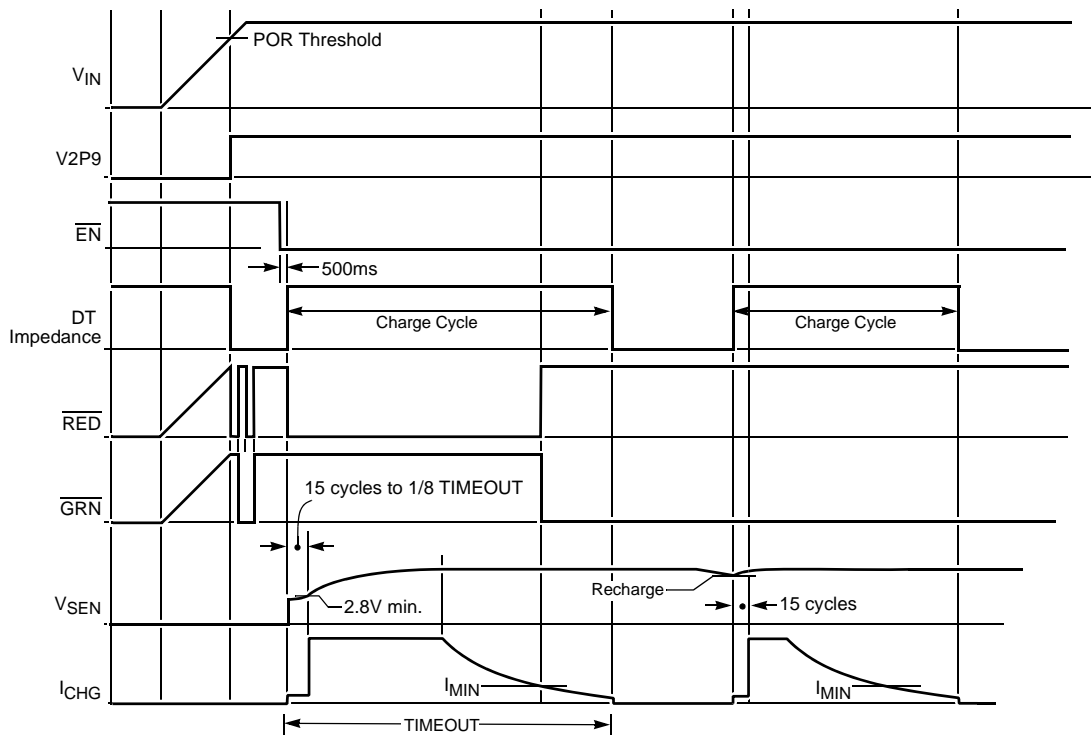
FIGURE 6. OPERATION WAVEFORMS

Internal Oscillator

The internal oscillator establishes a timing reference. The oscillation period is programmable with an external timing capacitor, C_{TIME}, as shown in Typical Applications. The oscillator charges the timing capacitor to 1.5V and then discharges it to 0.5V in one period, both with 10µA current. The period T_{OSC} is:

$$T_{OSC} = 0.2 \times 10^6 \times C_{TIME} \qquad (seconds) \qquad (EQ.\ 6)$$

A 15nF capacitor results in a 3ms oscillation period. The accuracy of the period is mainly dependent on the accuracy of the capacitance and the internal current source.

Total Charge Time and C_{TIME} Selection

The time allowed for the battery to charge before an end of charge indication is limited to the duration of the TIMEOUT counter. The TIMEOUT period can be calculated by:

$$TIMEOUT = 14 \times \frac{C_{TIME}}{1nF} \qquad (minutes) \qquad (EQ.\ 7)$$

where C_{TIME} is the timing capacitor shown in the Typical Application circuit. A 1nF capacitor leads to 14 minutes of TIMEOUT. For example, a 15nF capacitor sets the TIMEOUT to be 3.5 hours. The EOC indication goes active when the TIMEOUT counter expires, even if the battery has not reached full charge. At this point, if the voltage is above 4.05V, the recharge mechanism will continue to charge the

cell until the current drops below I_{MIN}. If the TIMEOUT counter expires before the battery reaches 4.05V, then the end of charge indication goes active, but the charger turns off. The charger cannot leave this condition without toggling the enable pin or cycling the power.

The trickle mode charge has a time limit of 1/8 TIMEOUT. If the battery voltage does not reach V_{MIN} within that time period, a TIMEOUT fault is issued and the charger turns off with a flashing Yellow LED indicator. The charger stays in trickle mode for at least 15 cycles of the internal oscillator and, at most, 1/8 of TIMEOUT.

Once the ISL6297 detects that the battery reaches the EOC condition, it resets the TIMEOUT counter. At the end of this TIMEOUT period, the charger turns off and does not start again until the battery reaches a recharge condition.

Recharge Threshold

Once the charger reaches an end of charge condition and the charger turns off, if the battery voltage drops below the recharge threshold given in the Electrical Specification table, the charger starts a re-charge cycle. This is identical to an inital charge cycle, except the indicator remains green.

LED Indications

The LED indicators show a number of conditions. On initial power on reset, the LEDs sequence through red, green and yellow. Once the charge begins, the ISL6297 pulls the $\overline{RED}$ pin low to drive a red indicator. Once the charge properly

finishes (either when the EOC condition is qualified or when the TIMEOUT completes) the ISL6297 releases the $\overline{\text{RED}}$ output and pulls the $\overline{\text{GRN}}$ pin low to drive a green indicator while the red indicator turns off. The green LED remains on unless the input power is recycled, or a fault occurs. During a recharge operation, the indicator remains green.

When a temperature fault happens, both the $\overline{\text{RED}}$ and the $\overline{\text{GRN}}$ pins turn on to indicate a yellow color. This fault is cleared automatically when the temperature again returns to the normal region. If the FAULT is non-temperature related, the yellow indicator flashes. This type of fault is latched and can only be reset by toggling the $\overline{\text{EN}}$ pin or cycling the input power. Table 2 summarizes the LED indications.

Because the LED outputs provide a constant 10mA current sink, no external resistors are necessary.

TABLE 2. LED INDICATION SUMMARY

STATUS	RED	GRN	INDICATION
Plug In Indication	L	H	Red (500ms)
	H	L	Green (500ms)
	L	L	Yellow (500ms)
	H	H	Off (500ms)
Charging	L	H	Red
Full Charge (EOC) or recharging	H	L	Green
Short circuit Error or trickle charge TIMEOUT error	L	L	Yellow (Flashing 1Hz rate)
	H	H	
Over/Under Ambient Temperature	L	L	Yellow
Idle state	H	H	Off or Battery (+) terminal not connected

VSEN Pin

When the charger is providing a large current to the cell, there can be significant voltage drop in the PCB trace between the charger output and the battery positive terminal. To minimize this effect, the VSEN pin input provides a low current monitoring path. This provides a more accurate reading of the battery voltage. Figure 7 shows the internal voltage feedback circuit.
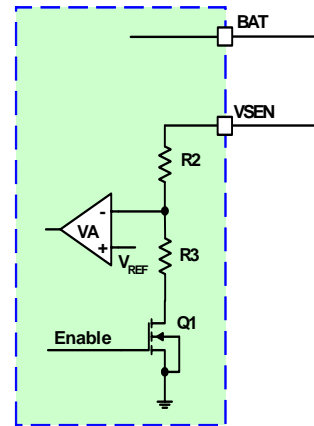
FIGURE 7. THE INTERNAL VOLTAGE FEEDBACK CIRCUIT

THERMAGUARD™ Charge Current Thermal Foldback

Over-heating is always a concern in a linear charger or in the linear region for a dual mode charger. The charge current thermal foldback function in the ISL6297 frees users from the over-heating concern.

Figure 8 shows the current signals at the summing node of the current error amplifier CA in the Block Diagram. I_R is the reference. I_T is the current from the Temperature Monitoring block. The I_T has no impact on the charge current until the internal temperature reaches approximately +100°C; then I_T rises at a rate of $1\mu A/°C$. When I_T rises, the current control loop forces the sensed current I_{SEN} to reduce at the same rate. As a mirrored current, the charge current is 100,000 times that of the sensed current and reduces at a rate of 100mA/°C. For a charger with the constant charge current set at 1A, the charge current is reduced to zero when the internal temperature rises to +110°C. The actual charge current settles between +100°C to +110°C.
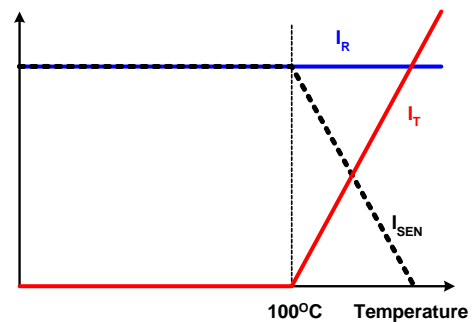

FIGURE 8. CURRENT SIGNALS AT THE AMPLIFIER CA INPUT

Usually the charge current should not drop below I_{MIN} because of the thermal foldback. If, in some extreme case this does happen, the charger does not indicate end-of-charge unless the battery voltage is already above the recharge threshold.

Ambient Temperature Sensing

The TEMP pin sets the allowable ambient temperature range for charging the battery. Typically, an NTC (negative temperature coefficient) resistor is mounted on the printed circuit board (PCB) to monitor the ambient temperature. Due to the self-heating of the PCB during charging, the ISL6297 provides the DT pin to set a higher temperature threshold during the charge operation.

Figure 9 shows the internal circuit for the ambient temperature sensing function. Two comparators form a window comparator whose high-threshold is V_{TMIN} and low-threshold is V_{TMAX}. These two thresholds are given in the Electrical Specifications. The two MOSFETs (Q1 and Q2) create a hysteresis for each comparator, respectively. The DT pin is shorted to GND via the internal Q3 MOSFET when the charger is not charging, resulting in the equivalent circuit shown in Figure 10 (A). The on-resistance of Q3 is typically 50Ω and is negligible compared to the external resistors. When the charger starts to charge, Q3 is turned off to set a higher temperature range determined by the external resistor R_D. The equivalent circuit is shown in Figure 10 (B). The DT pin provides a higher shut down ambient temperature during the charger operation.
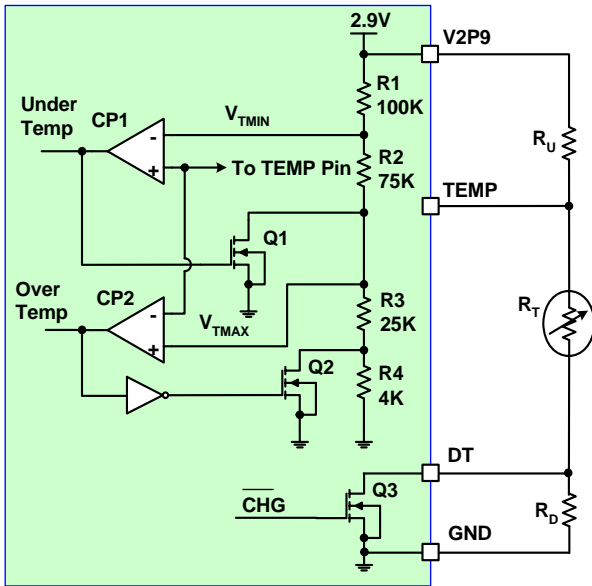
FIGURE 9. THE INTERNAL AND EXTERNAL CIRCUIT FOR THE NTC INTERFACE
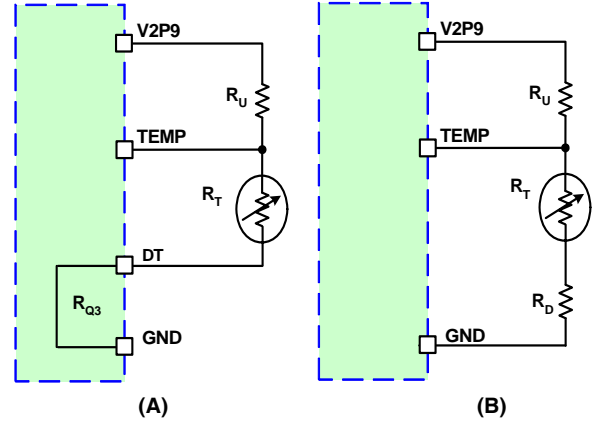
FIGURE 10. EQUIVALENT CIRCUITS FOR THE NTC DIVIDER (A) BEFORE CHARGING STARTS (B) DURING CHARGING

When the TEMP pin voltage is "out of the window," as determined by the V_{TMIN} and V_{TMAX}, the ISL6297 stops charging and indicates a fault condition. When the temperature returns to the set range, the charger continues the charge cycle.
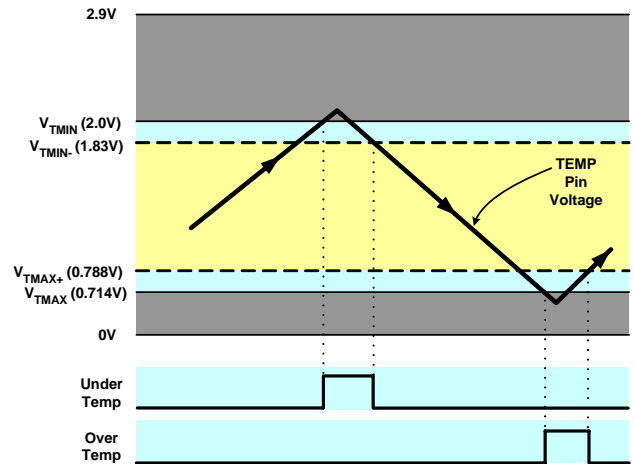

FIGURE 11. CRITICAL VOLTAGE LEVELS FOR TEMP PIN

As the temperature falls, the TEMP pin voltage rises. When it exceeds the 2.0V V_{TMIN} threshold, an under temperature condition exists. This condition does not clear until the TEMP pin voltage falls back below the threshold minus the hysteresis voltage (V_{TMIN-}). Similarly, an over-temperature condition exists when the TEMP pin voltage falls below the 0.714V V_{TMAX} threshold and does return to normal temperature operation until the voltage rises above the threshold plus the hysteresis voltage (V_{TMAX+}). The actual accuracy of the 2.9V supply voltage is **not important** because all the thresholds and the TEMP pin voltage are ratios determined by the resistor dividers, as shown in Figure 9.

The ratio, K, of the TEMP pin voltage to the bias voltage is:

$$K = \frac{R_T}{R_T + R_U} \qquad \text{(EQ. 8)}$$

and

$$R_T = \frac{K}{1-K} \times R_U \qquad \text{(EQ. 9)}$$

At V_{TMIN},

$$K = \frac{2.0}{2.88} = 0.6844 \qquad \text{(EQ. 10)}$$

Similarly, at V_{TMAX}.

$$K = \frac{0.718}{2.88} = 0.2493 \qquad \text{(EQ. 11)}$$

Using these equations to calculate the ratio of the thermistor hot to cold resistance results in:

$$\frac{R_{TCOLD}}{R_{THOT}} = \frac{2.27 R_U}{0.332 R_U} = 6.84 \qquad \text{(EQ. 12)}$$

and

$$R_U = 0.44 R_{TCOLD} \qquad \text{(EQ. 13)}$$

where R_{TCOLD} and R_{THOT} are the NTC thermistor resistance values at the cold and hot temperature limits respectively.

It is usually difficult to find an NTC thermistor that has the exact ratio given in EQ. 12. A thermistor with a ratio larger than 6.84, that is:

$$\frac{R_{TCOLD}}{R_{THOT}} \geq 6.84 \qquad \text{(EQ. 14)}$$

can be used in series with a regular resistor to form an effective thermistor that has the right ratio, as shown in Figure 12.
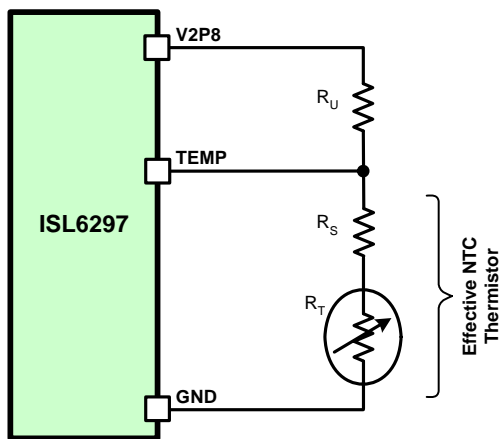
FIGURE 12. EFFECTIVE NTC THERMISTOR CIRCUIT

With the series resistor R_S, EQ. 12 can be re-written as:

$$\frac{R_S + R_{TCOLD}}{R_S + R_{THOT}} = 6.84 \qquad \text{(EQ. 15)}$$

Once the thermistor and the temperature limits are selected, R_S and R_U can be calculated using:

$$R_S = \frac{R_{TCOLD} - 6.84 R_{THOT}}{5.84} \qquad \text{(EQ. 16)}$$

and

$$R_U = 0.44 \times (R_S + R_{TCOLD}) \qquad \text{(EQ. 17)}$$

To summarize, the NTC thermistor circuit design requires three steps:

1. Find an NTC thermistor that satisfies EQ. 14. The temperature limits are determined by the application requirement.
2. Calculate the series resistance according to EQ. 16.
3. Calculate the pull-up resistance according to EQ. 17.

Example:

The charger is designed to charge the battery with the temperature range from -5°C to +45°C. The 10kΩ NTC thermistor NCP15XH103F03RC from Murata (http://www.murata.com) satisfies EQ. 14. The resistance values for this thermistor are given in Table 3. The typical resistance at -5°C and +45°C are:

R_{TCOLD} = 33.8922kΩ and
R_{THOT} = 4.9169kΩ.

Using EQ. 16 and EQ. 17 result in:

R_S = 41.6Ω and R_U = 14.931kΩ.

Selecting R_S = 41.2Ω and R_U = 15kΩ gives a low temperature threshold of -5.1°C and a high temperature threshold of +44.9°C.

TABLE 3. RESISTANCE TABLE OF NCP15XH103F03RC

TEMP (°C)	R-LOW (kΩ)	R-CENTER (kΩ)	R-HIGH (kΩ)
-10	41.4765	42.5062	43.5570
-5	33.1462	33.8922	34.6515
0	26.6780	27.2186	27.7675
6	20.7560	21.1230	21.4944
7	19.9227	20.2666	20.6143
40	5.7443	5.8336	5.9238
45	4.8333	4.9169	5.0015
50	4.0833	4.1609	4.2395
55	3.4634	3.5350	3.6076

Hysteresis Temperature Calculation

Re-arranging EQ. 8, and including the effect of R_S, gives:

$$R_T = \frac{K}{1-K} \times R_U - R_S \qquad \text{(EQ. 18)}$$

Using the K/(1-K) ratio at the hysteresis threshold, equation 18 provides the NTC thermistor resistance at the threshold. Continuing the example above, the thermistor values are found to be 26.2kΩ and 7.3kΩ respectively at the low and high hysteresis temperatures. The corresponding temperatures are found from Table 3. Cold recovery is about +1.0°C and the hot recovery is about +33.9°C. In other words, the hysteresis temperatures for the low and high limits are approximately +6.1°C and +11.0°C, respectively.

Temperature Tolerance Calculation

The temperature accuracy is affected by the accuracy of the thresholds, R_S, R_U, and the NTC thermistor. Using the maximum ratio K, maximum possible R_U, and minimum R_S results in the maximum value of R_T from EQ. 18, that is:

$$R_{TMAX} = \frac{K_{MAX}}{1-K_{MAX}} \times R_{UMAX} - R_{SMIN} \qquad \text{(EQ. 19)}$$

From the Electrical Specification table, the maximum K at cold is found to be 0.71. Assuming the resistors have 1% accuracy, the maximum R_U is 15.15kΩ and the minimum R_S is 40.8Ω. The resultant maximum R_T is then found to be 36.3kΩ and the corresponding temperature is about negative +6.4°C. Hence the temperature tolerance is +1.3°C. Similarly, at high temperature, the minimum K is 0.24, the minimum R_U value is 14.85kΩ and the maximum R_S is 41.6Ω. Hence, the highest temperature is +46.0°C and the tolerance is +1.1°C.

Charging Temperature Range

The selection of R_D follows the following equation:

$$R_D = R_T(@45^{o}C) - R_T(@45^{o}C + \Delta T) \qquad \text{(EQ. 20)}$$

where $R_T(@+45°C)$ is the thermistor resistance at 45°C and the $R_T(@+45°C + \Delta T)$ is the resistance at some desired temperature difference above +45°C. Figure 13 shows the temperature windows before, during, and after charging. From the example, before and after charging, the temperature window is -5°C to +45°C with +6°C and +4°C hysteresis. During charging, the high temperature limit changes to +45°C + ΔT. If this limit is exceeded, the charger is stopped and the temperature has to come back to below +41°C for the charging to be allowed again. The low temperature limit is also increased. However, the R_D typically has a much lower resistance than the NTC at low temperature, therefore, the influence on the temperature threshold is not as much as at high temperature. Typically, the low temperature threshold is raised by less than +2°C, as shown in Figure 13.

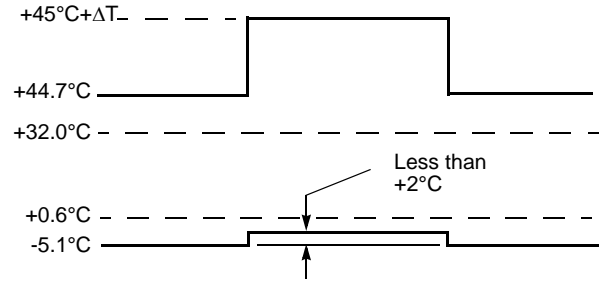**FIGURE 13. BOARD TEMPERATURE MONITORING. WHEN NOT CHARGING, THE TEMPERATURE WINDOW IS BETWEEN -5°C AND +45°C. ONCE THE CHARGER STARTS, THE TEMPERATURE WINDOW IS ~-3°C TO +45°C+ ΔT**

2.9V Bias Voltage

A pre-regulator provides a regulated 2.9V on the V2P9 pin, unless V_{IN} drops below 2.9V plus 250mV (typical). Then the output voltage tracks the input voltage with a 250mV dropout voltage. The 2.9V output turns off when V_{IN} drops below the VIN (falling) threshold. A minimum 0.1μF X5R ceramic capacitor is required for decoupling the pre-regulator.

The V2P9 output is used for biasing external circuits. The maximum loading current on this pin is 30mA. Mainly, the load current comes from the indication LEDs.

## Board Layout Recommendations

The ISL6297 is targeted for space-limited applications. In order to maximize the current capability, it is very important that the exposed pad under the package is properly soldered to the board and is connected to other layers through thermal vias. More thermal vias and more copper attached to the exposed pad usually result in better thermal performance. On the other hand, the number of vias is limited by the size of the pad. The exposed pads for the 4x4 QFN package are able to have 5 vias. As much copper as possible should be connected to the exposed pad to minimize the thermal impedance. Refer to the ISL6297 evaluation board for layout examples.

Related Literature

• Technical Brief TB363 "Guidelines for Handling and Processing Moisture Sensitive Surface Mount Devices (SMDs)"

• Technical Brief TB379 "Thermal Characterization of Packaged Semiconductor Devices"

• Technical Brief TB389 "PCB Land Pattern Design and Surface Mount Guidelines for QFN Packages"

Quad Flat No-Lead Plastic Package (QFN)
Micro Lead Frame Plastic Package (MLFP)

L16.4x4
16 LEAD QUAD FLAT NO-LEAD PLASTIC PACKAGE
(COMPLIANT TO JEDEC MO-220-VGGC ISSUE C)

TOP VIEW

SIDE VIEW

BOTTOM VIEW

SECTION "C-C"

FOR ODD TERMINAL/SIDE

FOR EVEN TERMINAL/SIDE
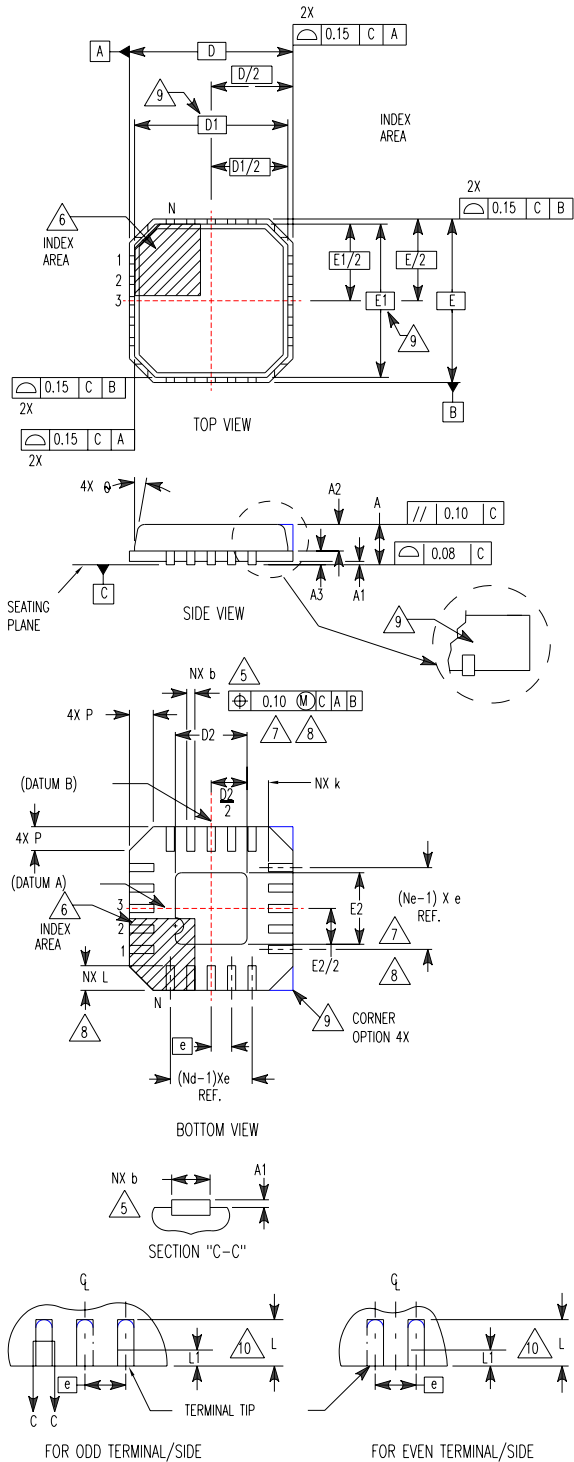
SYMBOL	MILLIMETERS			NOTES
	MIN	NOMINAL	MAX	
A	0.80	0.90	1.00	-
A1	-	-	0.05	-
A2	-	-	1.00	9
A3	0.20 REF			9
b	0.23	0.28	0.35	5, 8
D	4.00 BSC			-
D1	3.75 BSC			9
D2	1.95	2.10	2.25	7, 8
E	4.00 BSC			-
E1	3.75 BSC			9
E2	1.95	2.10	2.25	7, 8
e	0.65 BSC			-
k	0.25	-	-	-
L	0.50	0.60	0.75	8
L1	-	-	0.15	10
N	16			2
Nd	4			3
Ne	4			3
P	-	-	0.60	9
θ	-	-	12	9

Rev. 5 5/04

NOTES:

1. Dimensioning and tolerancing conform to ASME Y14.5-1994.

2. N is the number of terminals.

3. Nd and Ne refer to the number of terminals on each D and E.

4. All dimensions are in millimeters. Angles are in degrees.

5. Dimension b applies to the metallized terminal and is measured between 0.15mm and 0.30mm from the terminal tip.

6. The configuration of the pin #1 identifier is optional, but must be located within the zone indicated. The pin #1 identifier may be either a mold or mark feature.

7. Dimensions D2 and E2 are for the exposed pads which provide improved electrical and thermal performance.

8. Nominal dimensions are provided to assist with PCB Land Pattern Design efforts, see Intersil Technical Brief TB389.

9. Features and dimensions A2, A3, D1, E1, P & θ are present when Anvil singulation method is used and not present for saw singulation.

10. Depending on the method of lead termination at the edge of the package, a maximum 0.15mm pull back (L1) maybe present. L minus L1 to be equal to or greater than 0.3mm.

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