

12V Linear-Mode Battery Charger for Li+/Li-polymer Cells

FEATURES

- Internal High Voltage MOSFET
- Up to 12V Input Voltage
- $\pm 0.5\%$ Output Voltage Accuracy
- Charge Current Thermal Foldback
- Programmable Termination Voltage
- Programmable Fast Charge Current
- Programmable Charging Timer
- No Blocking Diode Required
- Low Reverse Leakage
- Preconditioning for Deeply Depleted Battery
- Low Quiescent Current Standby Mode
- Space-Saving, Thermally-Enhanced SOP-8/EP, TDFN33-8

GENERAL DESCRIPTION

The ACT3704 is a complete linear charging solution for single cell Lithium Ion and Lithium Polymer batteries. It incorporates an internal 12V power MOSFET for Constant-Current, Constant-Voltage control (CC/CV).

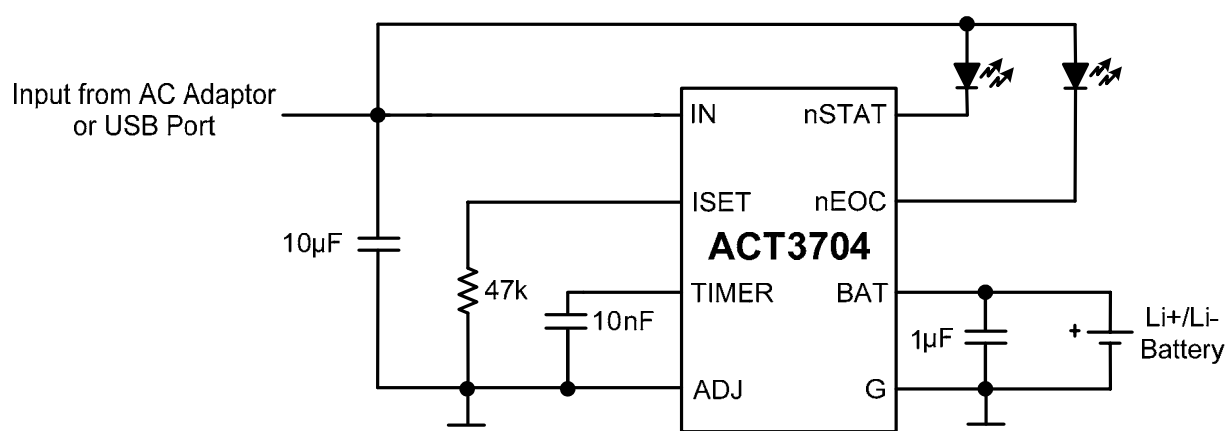
The battery regulation voltage accuracy is $\pm 0.5\%$ and can be set to either 4.1V or 4.2V. The charge current is programmed with an external resistor to a maximum of 1A to minimize total charge time.

The reverse leakage current from the battery is less than $1\mu\text{A}$ if the input adaptor is disconnected or if there is a reverse battery connection. The ACT3704 is available in thermally-enhanced SOP-8/EP, and TDFN33-8 packages to accommodate high charge current operation and minimize total charging time.

APPLICATIONS

- Mobile Phone
- Wireless Headsets
- Portable Media Players
- Cradle Chargers
- Portable Devices

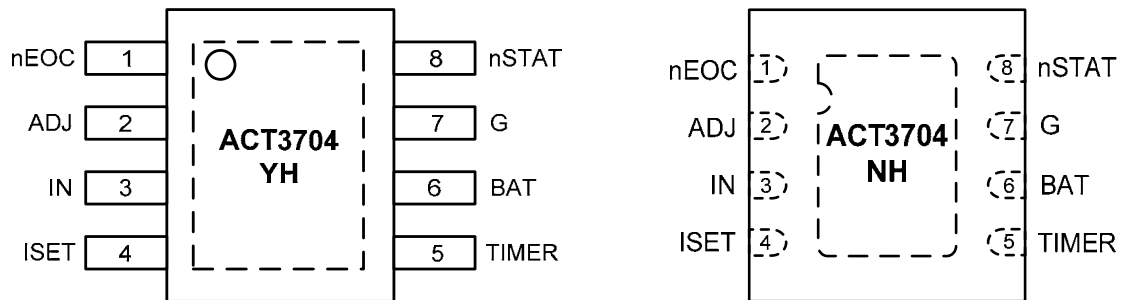
TYPICAL APPLICATION CIRCUIT



ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE	PINS	PACKING
ACT3704YH	-40°C to 85°C	SOP-8/EP	8	TUBE
ACT3704YH-T	-40°C to 85°C	SOP-8/EP	8	TAPE & REEL
ACT3704NH-T	-40°C to 85°C	TDFN33-8	8	TAPE & REEL

PIN CONFIGURATION



PIN DESCRIPTIONS

PIN NUMBER	PIN NAME	PIN DESCRIPTION
1	nEOC	Open-Drain Charge Status Indicator. nEOC is a high voltage output and can withstand up to 12V, allowing it to drive LEDs that are directly connected to IN or to a lower voltage supply. nEOC features an internal 7mA current limit, allowing this pin to directly drive an LED for a visual charge-status indicator. For a logic-level charge status indicator, simply connect a 10kΩ or greater pull-up resistor between nEOC and a suitable voltage supply.
2	ADJ	Charge Termination Voltage Adjust. Connect ADJ to G to select 4.10V termination voltage or connect ADJ to IN to select 4.20V termination voltage.
3	IN	Power Input. IN can be withstand operating voltages of up to 12V. Bypass to G with a 1μF or larger capacitor.
4	ISET	Charge Current Set. Program the maximum charge current by connecting a resistor (R_{ISET}) between ISET and G. See the <i>Charge Current Programming</i> section for more information.
5	TIMER	Safety Timer program pin. Connect to capacitor C_{TIMER} .
6	BAT	Charge Battery Output. Connect this pin to the positive terminal of the battery. Bypass this pin as close as possible to IC with 1μF ceramic capacitor.
7	G	Ground.
8	nSTAT	Open-Drain Charge Status Indicator. nSTAT can withstand up to 12V, allowing it to drive LEDs that are directly connected to IN or to a lower voltage supply, nSTAT features an internal 7mA current limit, allowing this pin to directly drive an LED for a visual charge-status indicator. For a logic-level charge status indicator, simply connect a 10kΩ or greater pullup resistor between nSTAT and a suitable voltage supply.
EP	EP	Exposed Pad. The exposed thermal pad should be connected to board ground plane and G. The ground plane should include a large exposed copper pad under the package to connect the entire pad for thermal dissipation (see package outline).

ABSOLUTE MAXIMUM RATINGS^①

PARAMETER		VALUE	UNIT
IN, ADJ, nSTAT, nEOC to G		-0.3 to 15	V
BAT to G		-0.3 to 7	V
ISET, TIMER to G		-0.3 to 6	V
ISET, TIMER Current		±5	mA
Junction to Ambient Thermal Resistance (θ_{JA})	SOP-8/EP	45	°C/W
	TDFN33-8	36.7	°C/W
Maximum Power Dissipation	SOP-8/EP	1.8	W
	TDFN33-8	2	W
Maximum Junction Temperature		125	°C
Storage Temperature		-65 to 150	°C
Lead Temperature (Soldering, 10 sec)		300	°C

①: Do not exceed these limits to prevent damage to the device. Exposure to absolute maximum rating conditions for long periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

($V_{IN} = V_{TERM} + 1V$, $V_{BAT} = 3.6V$, $T_A = 25^\circ C$, unless otherwise specified.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNIT
Input Supply Voltage, V_{IN}			4.2		12	V
Battery Termination Voltage, V_{TERM}	ADJ = G		4.079	4.1	4.121	V
		$T_A = -40^\circ C$ to $85^\circ C$	4.059		4.141	
	ADJ = IN		4.179	4.2	4.221	
		$T_A = -40^\circ C$ to $85^\circ C$	4.158		4.242	
Line Regulation	$V_{IN} = V_{TERM} + 1V$ to 12V, $I_{BAT} = 10mA$			0.03	0.1	%/V
Load Regulation	$V_{IN} = V_{TERM} + 1V$, $I_{BAT} = 10mA$ to 250mA			0.05	0.1	%
Precondition Threshold			2.55	2.75	2.95	V
Precondition Threshold Hysteresis				125		mV
Constant Current Adjust Range			100		1000	mA
Fast Charge Constant Current	$V_{BAT} = 3.8V$, $R_{ISET} = 50k$		0.45	0.51	0.57	A
Precondition Charge Current	$V_{BAT} = 2.5V$, $R_{ISET} = 50k$			51		mA
End-of-Charge Threshold	$R_{ISET} = 50k$			51		mA
Charge Restart Threshold	V_{BAT} Falling			$V_{TERM} - 0.1$		V
PMOS On Resistance	$V_{BAT} = 3.8V$, $I_{BAT} = 100mA$			0.7	1.2	Ω
UVLO Threshold	IN Rising		3.8	4.0	4.2	V
UVLO Hysteresis	IN Falling			1		V
BAT Reserve Leakage Current	Input floating or charger disabled			0.4	4	μA
IN Supply Current	Charger Standby			500	800	μA
IN Supply Current	Charger Enable			0.7	2	mA
ADJ Voltage Threshold				1.7		V
Thermal Regulation Threshold				120		°C

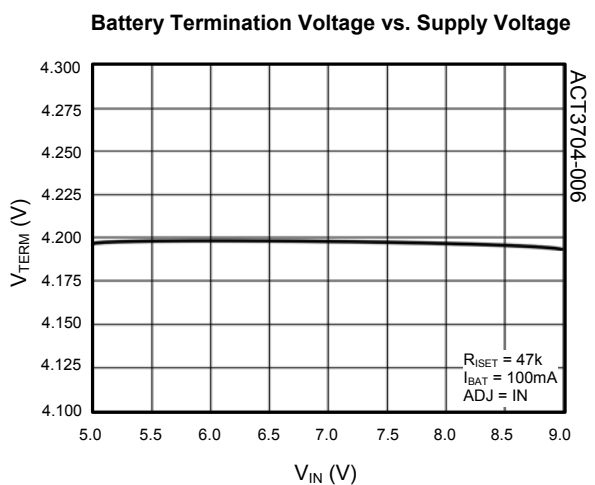
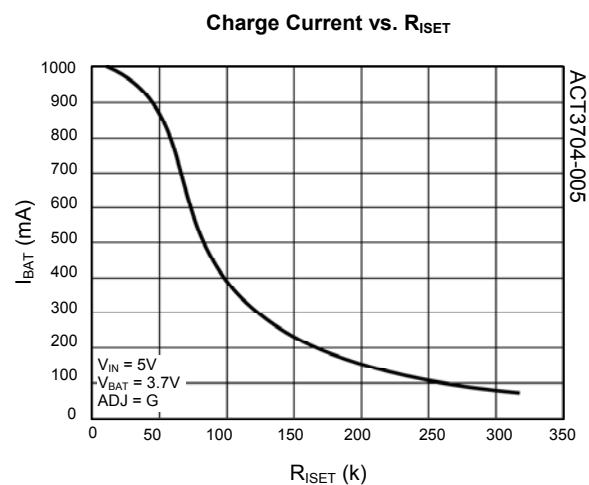
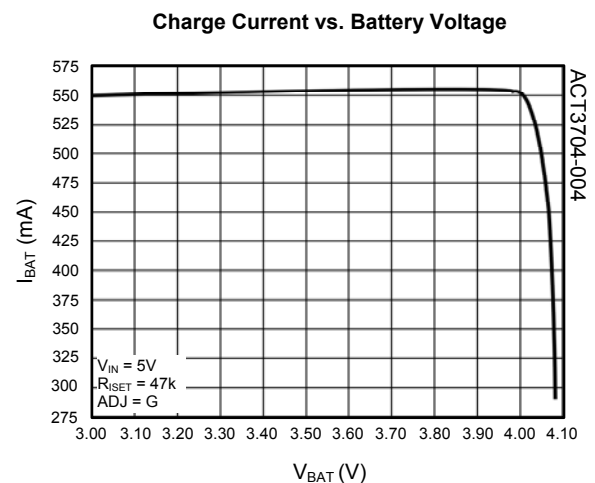
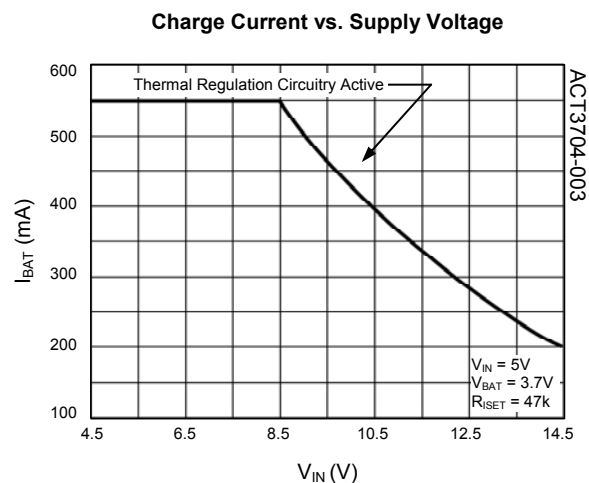
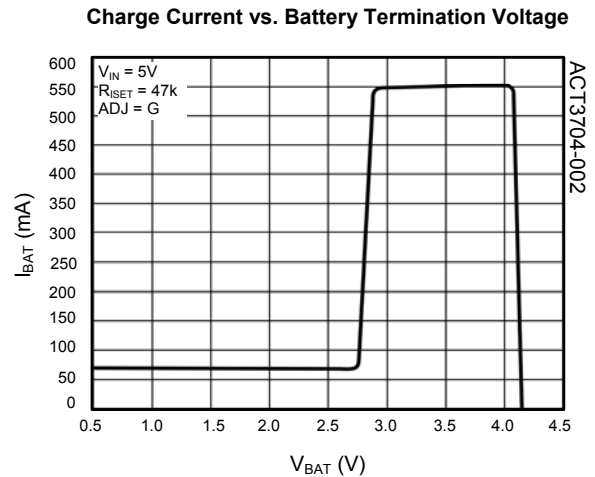
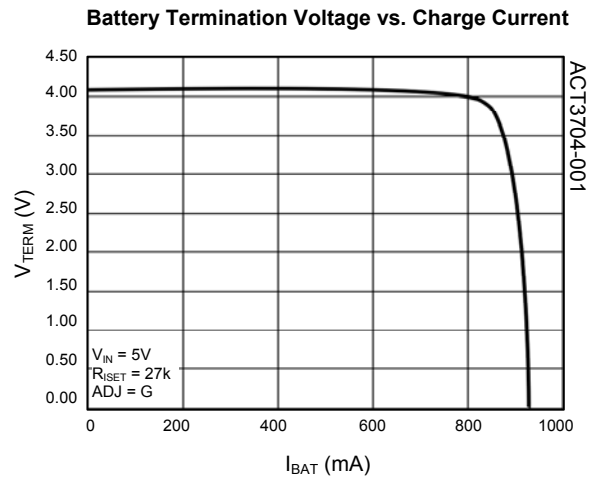
ELECTRICAL CHARACTERISTICS CONT'D

($V_{IN} = V_{TERM} + 1V$, $V_{BAT} = 3.6V$, $T_A = 25^\circ C$, unless otherwise specified.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
nSTAT, nEOC Outputs					
Sink Current	$V_{nSTAT} = V_{nEOC} = 2V$	4	7	10	mA
Output Low Voltage	$I_{SINK} = 1mA$			0.4	V
Leakage Current	$V_{nSTAT} = V_{nEOC} = 12V$			1	μA
Charge Current Setting					
ISET Pin Voltage		1.15	1.20	1.25	V
IBAT to ISET Current Ratio			22		kA/A
Charge Timers					
TIMER Frequency	TIMER Floating	0.8	1.5	2.2	kHz
POR Start Delay			1		ms
Transition Out of Preconditioning Delay			0.1		ms
Current Rise Time Out of Preconditioning			300		μs
Normal Safety Timer	$C_{TIMER} = 2.2nF$		0.5		hr
Precondition Safety Timer	$C_{TIMER} = 2.2nF$		20		mins
Total Safety Timer	$C_{TIMER} = 2.2nF$		1		hr
Time to End of Charge	$C_{TIMER} = 2.2nF$		10		mins

TYPICAL PERFORMANCE CHARACTERISTICS

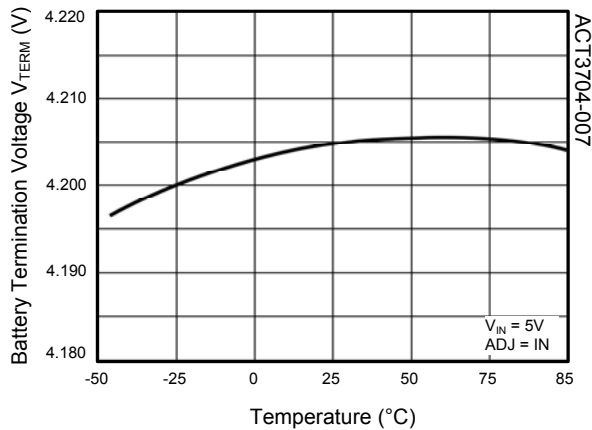
($V_{IN} = 5V$, $T_A = 25^\circ C$, unless otherwise specified.)



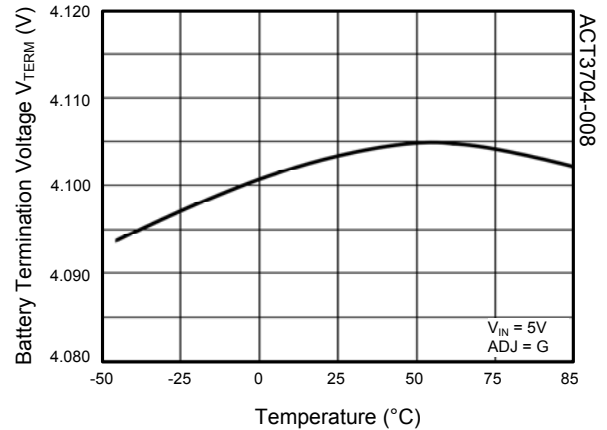
TYPICAL PERFORMANCE CHARACTERISTICS CONT'D

($V_{IN} = 5V$, $T_A = 25^\circ C$, unless otherwise specified.)

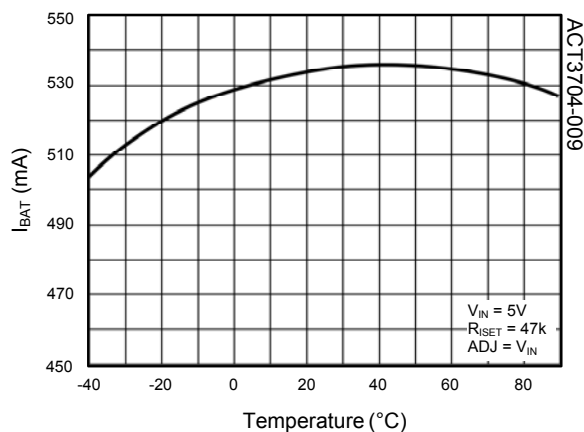
Battery Termination Voltage vs. Temperature



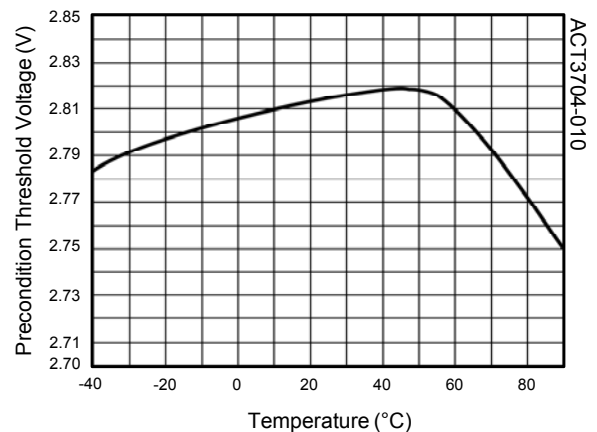
Battery Termination Voltage vs. Temperature



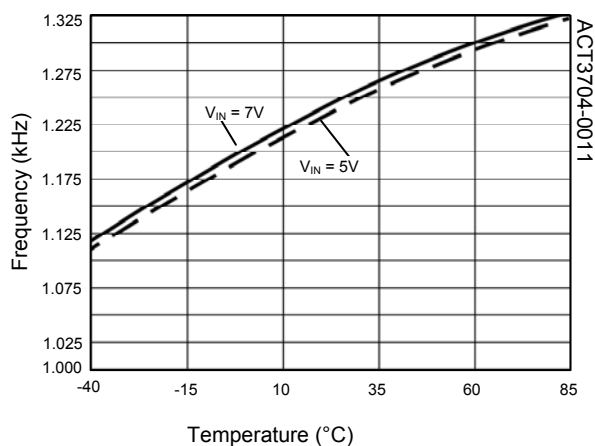
Charge Current vs. Ambient Temperature



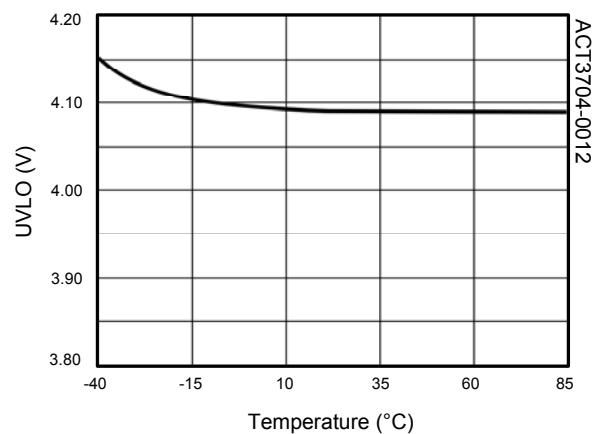
Precondition Threshold Voltage vs. Ambient Temperature



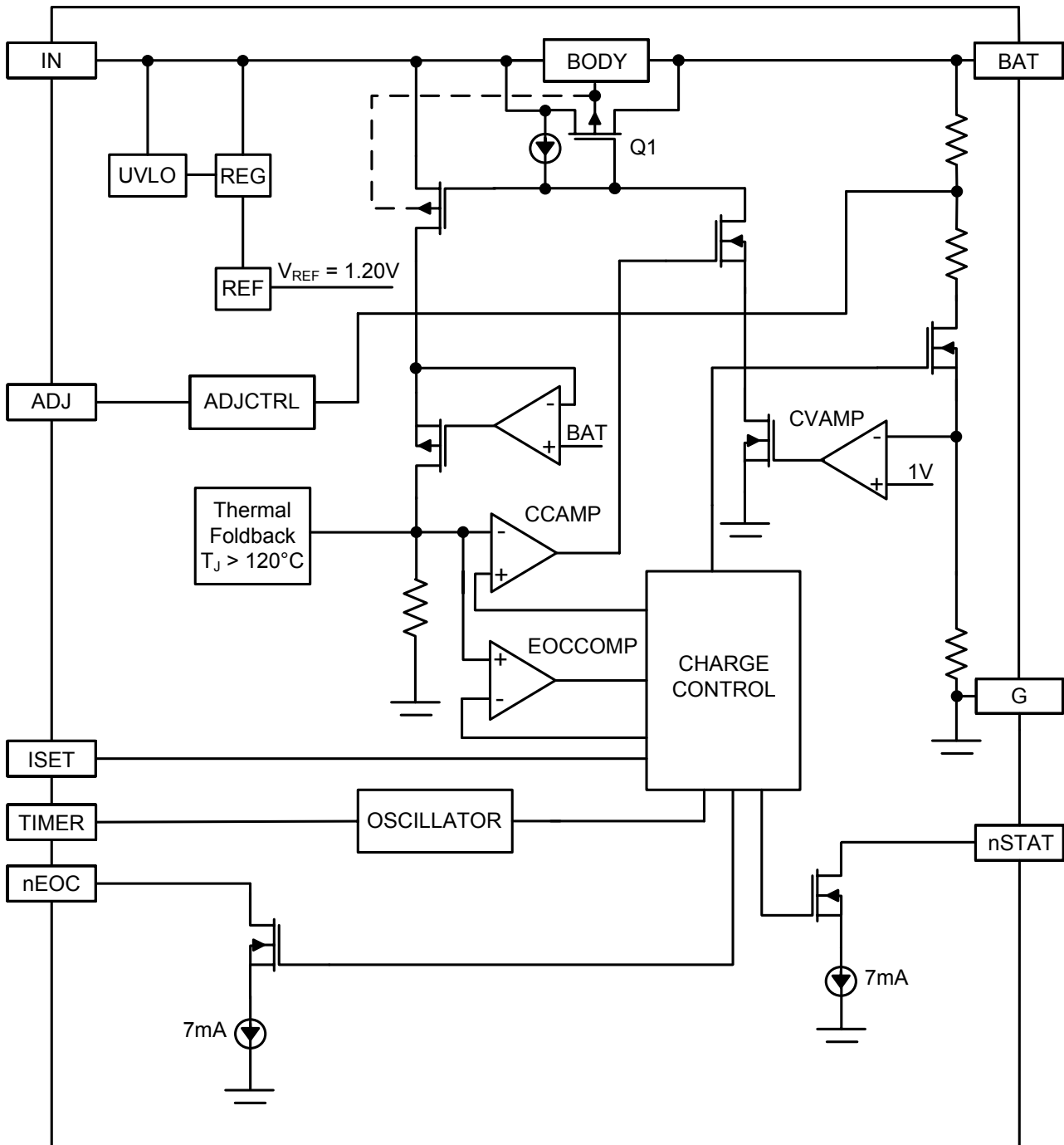
Internal Charge Timer Frequency vs. Temperature



Undervoltage Lockout Voltage vs. Temperature



FUNCTIONAL BLOCK DIAGRAM



FUNCTIONAL DESCRIPTION

The ACT3704 is an intelligent, stand-alone Constant-Current, Constant-Voltage control (CC/CV), linear-mode, single-cell charger for Lithium-Based cell chemistries. The device incorporates current and voltage sense circuitry, an internal 12V power MOSFET, a 120°C thermal-regulation loop that minimizes total charge time, a complete state-machine that implements charge safety features, and circuitry that eliminates the reverse-blocking diode required by conventional charger designs.

The ACT3704 features an accurate charge termination voltage, programmable fast-charge constant current, and a programmable charge safety timeout period. Other features include current-limited nSTAT and nEOC outputs that can directly drive LED indicators without external resistors or provide a logic-level status signal to the host microprocessor.

CC/CV Regulation Loop

At the core of the ACT3704 is a CC/CV regulation loop, which regulates either current or voltage as necessary to ensure fast and safe charging of the battery.

In a normal charge cycle, this loop regulates the current to the value set by R_{ISET} . Charging continues at this current until the battery voltage reaches the charge termination voltage. At this point the CV loop takes over, and charge current is allowed to decrease as necessary to maintain charging at the charge termination voltage.

Setting The Charge Termination Voltage

The ACT3704 offers two pin-programmable battery termination voltages; connect ADJ to G to select a 4.10V termination voltage, connect ADJ to IN (or to a voltage greater than 1.4V) to select a 4.20V termination voltage.

Charge Current Programming

The maximum charging current is programmed by an external resistor (R_{ISET}) connected from ISET to G.

Calculate R_{ISET} as follows:

$$R_{ISET} = 22k\Omega \times (1.20V / I_{BAT}) \quad (1)$$

Where I_{BAT} is Amps.

The voltage at ISET is fixed at 1.20V, and the maximum charge current at BAT is set by:

$$I_{BAT} = 22k\Omega \times (1.20V / R_{ISET}) \quad (2)$$

Table 1:
Charge Current Programming

$R_{ISET}(k\Omega)$	Charge Current (mA)
89	297
64	413
56	470
47	562
33	800
27	989

The R_{ISET} values in Table 1 are standard 1%. Note that the actual charging current may be limited to a current that is lower than the programmed fast-charge current due to the ACT3704's internal thermal-regulation loop. See the *Thermal Regulation Loop* section for more information.

Thermal Regulation Loop

The ACT3704 features an internal thermal regulation loop that reduces the charging current as necessary to ensure that the die temperature does not rise beyond the thermal regulation threshold of 120°C. This feature protects the ACT3704 against excessive junction temperature and makes the ACT3704 more accommodating to aggressive thermal designs. Note, however, that attention to good thermal designs is required to achieve the fastest possible charge time by maximizing charge current.

In order to account for the extended total charge time resulting from operation in thermal regulation mode, the charge timeout periods are extended proportionally to the reduction in charge current. In order to ensure a safe charge, the maximum timeout periods are limited to 2x the room temperature values.

The conditions that cause the ACT3704 to reduce charge current in accordance to the internal thermal regulation loop can be approximated by calculating the power dissipated in the part. Most of the power dissipation is generated from the internal charge MOSFET (Q1 in the Functional Block Diagram). The power dissipation is calculated to be approximately:

$$P_D = (V_{IN} - V_{BAT}) \times I_{BAT} \quad (3)$$

P_D is the power dissipated, V_{IN} is the input supply voltage, V_{BAT} is the battery voltage and I_{BAT} is the charge current. The approximate ambient tempera-

ture at which the thermal regulation begins to protect the IC is given by :

$$T_A = 120^{\circ}\text{C} - P_D \times \theta_{JA} \quad (4)$$

$$T_A = 120^{\circ}\text{C} - (V_{IN} - V_{BAT}) \times I_{BAT} \times \theta_{JA}$$

Example: The ACT3704 is operating from a 5V wall adapter and is programmed to supply 700mA fast charge current to a discharged Li-Ion battery with a voltage of 3.4V. Assuming θ_{JA} is 45°C/W, the ambient temperature at which the device will begin to reduce the charge current is approximately:

$$T_A = 120^{\circ}\text{C} - (5\text{V} - 3.4\text{V}) \times (700\text{mA}) \times 45^{\circ}\text{C}$$

$$T_A = 120^{\circ}\text{C} - 1.12\text{W} \times 45^{\circ}\text{C} = 120^{\circ}\text{C} - 50.4^{\circ}\text{C}$$

$$T_A = 69.6^{\circ}\text{C} \quad (5)$$

The ACT3704 can be used above 69.6°C ambient, but the charge current will be reduced from 700mA. The approximate current at a given ambient temperature can be approximated by:

$$I_{BAT} = \frac{(120^{\circ}\text{C} - T_A)}{(V_{IN} - V_{BAT}) \times \theta_{JA}} \quad (6)$$

Using the previous example with an ambient temperature of 70°C, the charge current will be reduced to approximately:

$$I_{BAT} = \frac{(120^{\circ}\text{C} - 70^{\circ}\text{C})}{(5\text{V} - 3.4\text{V}) \times 45^{\circ}\text{C} / \text{W}} = \frac{50^{\circ}\text{C}}{72^{\circ}\text{C} / \text{A}}$$

$$T_A = 694\text{mA} \quad (7)$$

ACT3704 applications do not need to be designed for worst-case thermal conditions, since the part will automatically reduce power dissipation if the thermal regulation threshold of approximately 120°C is reached.

However, in order to deliver maximum charge current under all conditions, it is critical that the exposed metal pad on the backside of the package exposed pad (EP) is soldered directly to the PC board ground. Correctly soldered to a double sided 1oz copper board, the ACT3704 has a thermal resistance of approximately 45°C/W with SOP8 and 36.7°C/W with TDFN33-8. Failure to make thermal contact between the exposed pad on the backside of the package and the copper board will result in thermal resistances far greater than 45°C/W with SOP8 and 36.7°C/W with TDFN33-8. For example, a correctly soldered ACT3704 can deliver up to

1000mA to a battery from a 5V supply at 25°C. Without a good backside thermal connection, this number could drop to less than 500mA.

State Machine

Precondition State

A new charging cycle begins with the PRECONDITION state, and operation continues in this state until V_{BAT} exceeds the Precondition Threshold Voltage of 2.8V.

When operating in PRECONDITION state, the cell is charged at a reduced current given by:

$$I_{PRECONDITION} = 2.200 \times (V_{ISET} / R_{ISET}) \quad (8)$$

Which is 10% of the programmed maximum fast-charge constant current, I_{BAT} .

Once V_{BAT} reaches the Precondition Threshold Voltage the state machine jumps to the NORMAL state.

If V_{BAT} does not reach the Precondition Threshold Voltage before the Precondition Timeout period ($T_{PRECONDITION}$) expires, then a damaged cell is detected and the state machine jumps to the TIMEOUT-FAULT State. The Precondition Timeout period is default to 20mins with an external 2.2nF C_{TIMER} capacitor, or it can be increased with a larger value capacitor. See the *Safety Timers* section for more information.

Normal State

Normal state is made up of two operating modes, fast charge Constant-Current (CC) and Constant-Voltage (CV).

In CC mode, the ACT3704 charges at the current programmed by R_{ISET} (see the *Charge Current Programming* section for more information). During a normal charge cycle fast-charge continues in CC mode until V_{BAT} reaches the charge termination voltage (V_{TERM}), at which point the ACT3704 charges in CV mode. Charging continues in CV mode until the charge current drops to 10% of the programmed maximum charge current (I_{BAT}), at which point the state machine jumps to the TOP-OFF state.

If V_{BAT} does not proceed out of the NORMAL state before the Normal Timeout period (T_{NORMAL}) expires, then a damaged cell is detected and the state machine jumps to the TIMEOUT-FAULT State.

The Normal Timeout period is default to 30mins, or it can be increased with an external 2.2nF C_{TIMER} capacitor or can be changed with a larger value external capacitor. See the *Safety Times* section for more information.

Top-Off State

In the TOP-OFF state, the cell is charged in constant-voltage (CV) mode, with the charge current limited by the internal chemistry of the cell, decreasing as charging continues.

If the ACT3704 state machine does not complete a charging cycle before the TOP-OFF Timeout period (T_{TOPOFF}) expires, then a damaged cell is detected and the state machine jumps to the TIMEOUT-FAULT State.

The TOP-OFF Timeout period is default to 60mins with a 2.2nF C_{TIMER} capacitor, or it can be increased with a larger value external capacitor. See the Safety Timers section for more information.

In TOP-OFF state, nSTAT indicates charge complete but charge current still continues. After another delay of 60mins, then charging stops and charge current becomes zero. When the battery voltage drops below the charge restart voltage, the charging process will start again.

End of Charge State

In the End of Charge (EOC) state, the ACT3704 presents a high-impedance to the battery, allowing the cell to “relax” and minimize battery leakage current. The ACT3704 continues to monitor the cell voltage, however, so that it can reinitiate charging cycles as necessary to ensure that the cell remains fully charged.

Charge Restart

Under normal operation, the state machine initiates a new charging cycle by jumping to the NORMAL CHARGE state when V_{BAT} drops below the Charge Termination Threshold by more than the Charge Restart Threshold of 100mV (typ).

Timeout-Fault State

In TIMEOUT-FAULT state, both nSTAT and nEOC indicators are OFF, or high-Z.

Charge and EOC Status Outputs

nSTAT and nEOC are open-drain outputs that sink current when asserted and are high-Z otherwise. For more information regarding the state of nSTAT and nEOC throughout the entire charging cycle, see Table 3. These outputs have internal 7mA current limits, and are capable of directly driving LEDs, without the need of current-limiting resistors or other external circuitry, for a visual charge-status indication. To drive an LED, simply connect the LED between each pin and an appropriate supply (typically V_{IN}).

For a logic-level indication, simply connect a resistor from each output to an appropriate voltage supply.

Reverse Battery & Shutdown

The ACT3704 includes internal circuitry that eliminates the need for series blocking diodes, reducing solution size and cost as well as dropout voltage relative to conventional battery chargers. When V_{IN} goes below the ACT3704's under voltage-lockout (UVLO) voltage, or when V_{IN} drops below V_{BAT} , the ACT3704 automatically goes into SUSPEND mode and reconfigures its power switch to minimize current drain from the battery.

Safety Timers

The ACT3704 has several internal charge safety timers, for each of the PRECONDITION and NORMAL charge states as well as TOPOFF timeout period. If any of these timers expire before charge successfully proceeds through the associated state, the ACT3704 enters the TIMEOUT-FAULT state. The TIMEOUT-FAULT state can only be reset by power-cycling the ACT3704.

Each of these timers are internally set according to the following ratios:

$$T_{PRECONDITION} = 1 \times T_O \quad (9)$$

$$T_{NORMAL} = 1.5 \times T_O \quad (10)$$

$$T_{TOTAL} = 3 \times T_O \quad (11)$$

All the timers could be set by an external capacitor by (C_{TIMER} in nF) where T_O is given by:

$$T_O = 9 \times C_{TIMER} \pm 15\% \quad (12)$$

When operating in thermal regulation mode the timeout periods are extended in order to compensate for the effect of the reduced charging current on total charge time. In order to ensure a safe charge, the maximum timeout periods are limited to 2x the room temperature values.

Table 2:
Safety Timer Settings

C_{TIMER} (nF)	$T_{\text{PRECONDITION}}$ (minutes)	T_{NORMAL} (minutes)	T_{TOTAL} (minutes)
2.2	20	30	60
3.3	30	45	90
6	60	90	180
10	90	120	270
30	210	315	630

STATE DIAGRAM

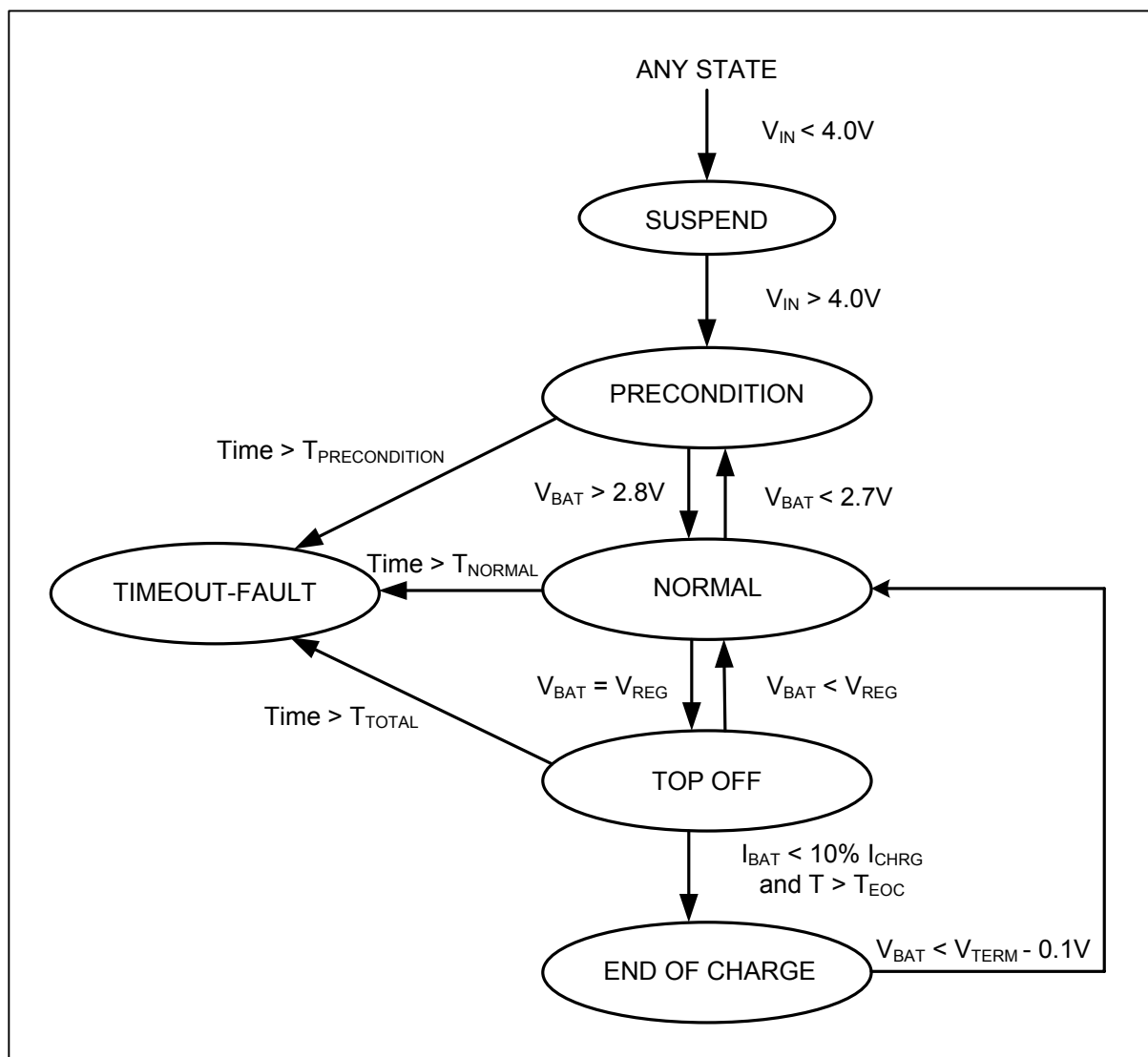
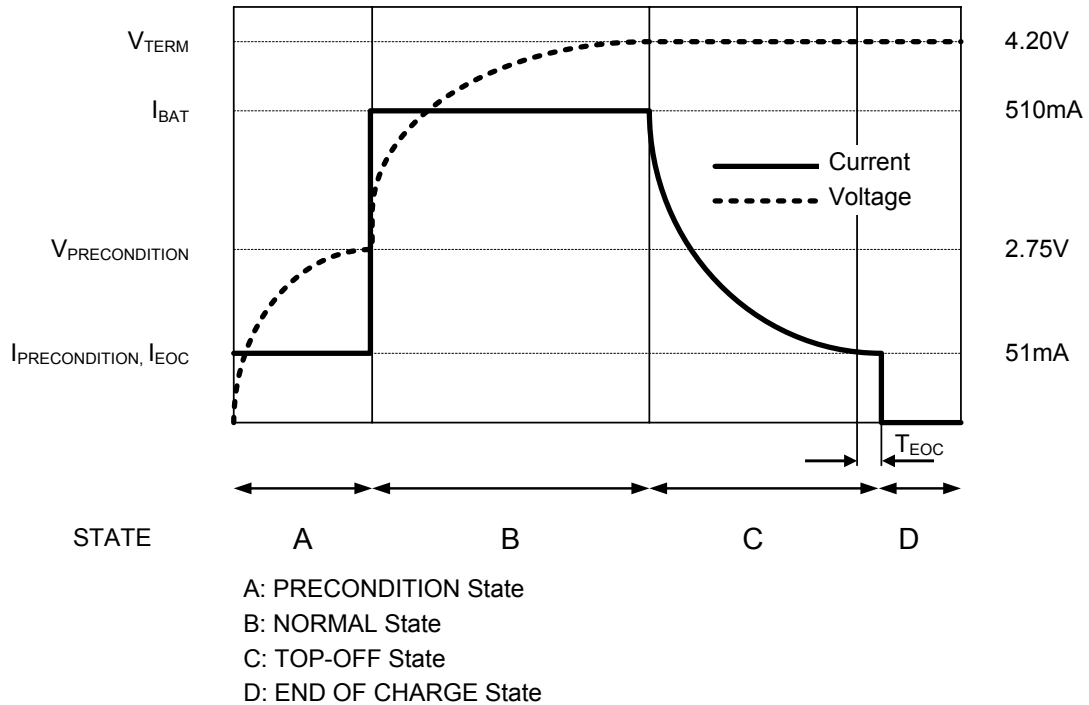


Figure 1:
Typical Li+ Charge Profile and ACT3704 Charge States



STATUS AND EOC INDICATORS

Table 3:
nSTAT and nEOC Indicator States

STATE	nSTAT	nEOC
SHUTDOWN	OFF	OFF
PRECONDITION	ON	OFF
NORMAL	ON	OFF
TOPOFF	ON	OFF
DELAY TIME TO EOC	OFF	ON
END OF CHARGE	OFF	ON
TIMEOUT FAULT	OFF	OFF

APPLICATION INFORMATION

Figure 2:
Application Circuit for 4.1V Battery, 470mA Charge

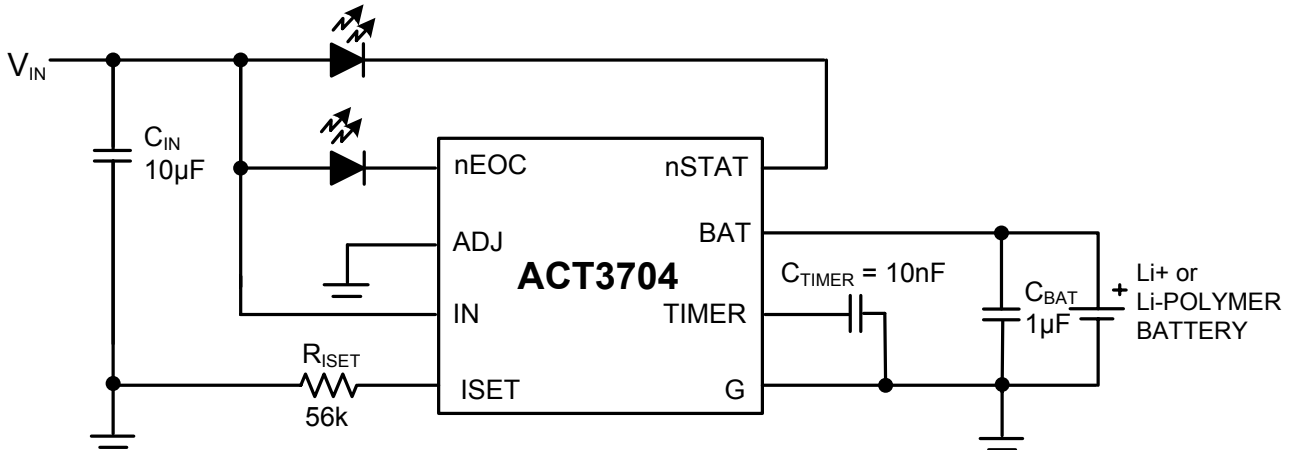
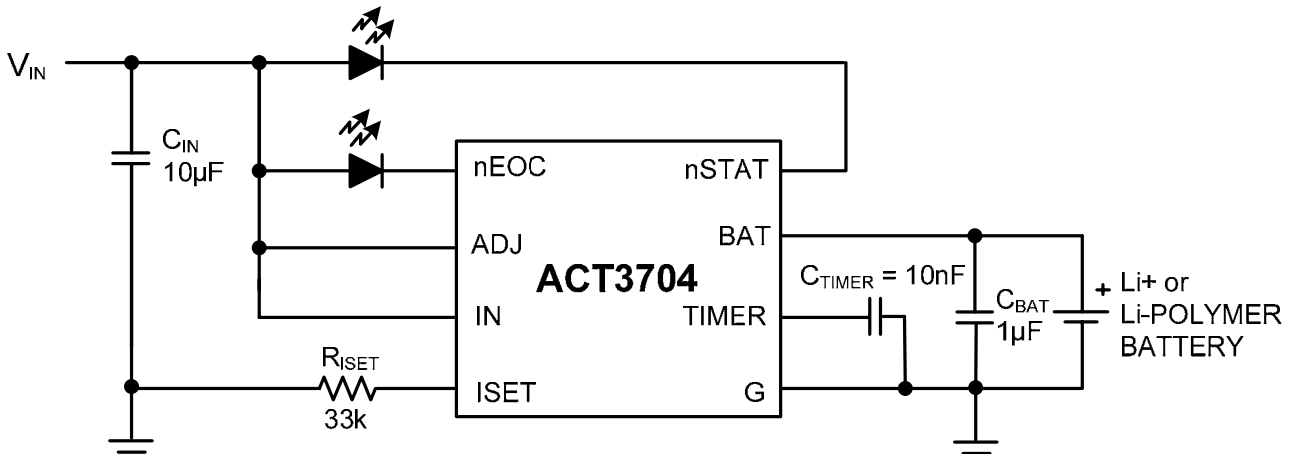
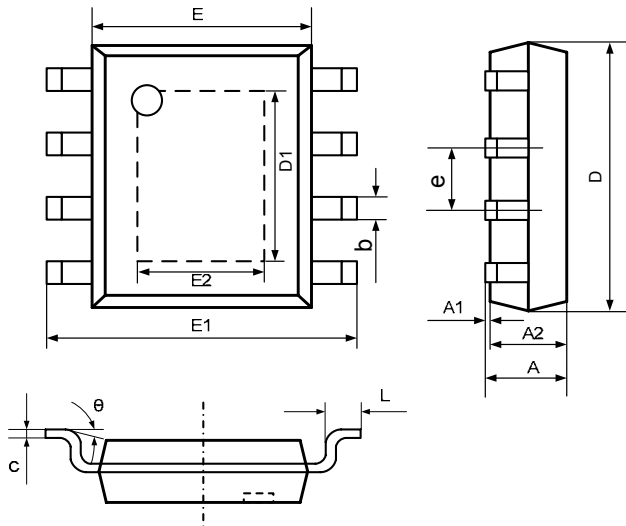


Figure 3:
Application Circuit for 4.2V Battery, 800mA Charge



PACKAGE OUTLINE

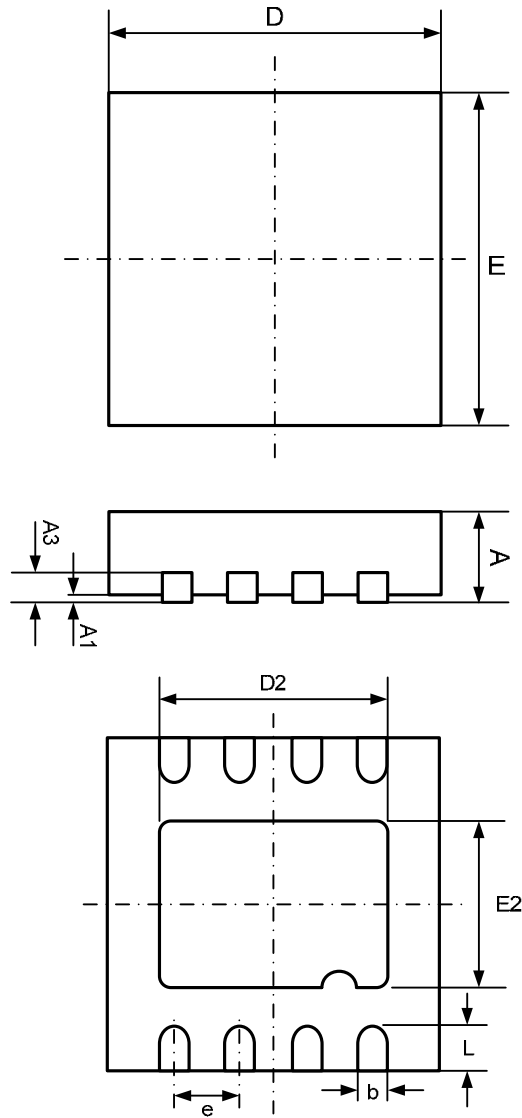
SOP-8/EP PACKAGE OUTLINE AND DIMENSIONS



SYMBOL	DIMENSION IN MILLIMETERS		DIMENSION IN INCHES	
	MIN	MAX	MIN	MAX
A	1.350	1.750	0.053	0.069
A1	0.050	0.150	0.002	0.006
A2	1.350	1.550	0.053	0.061
b	0.330	0.510	0.013	0.020
c	0.170	0.250	0.007	0.010
D	4.700	5.100	0.185	0.200
D1	3.202	3.402	0.126	0.134
E	3.800	4.000	0.150	0.157
E1	5.800	6.200	0.228	0.244
E2	2.313	2.513	0.091	0.099
e	1.270 TYP		0.050 TYP	
L	0.400	1.270	0.016	0.050
θ	0°	8°	0°	8°

PACKAGE OUTLINE

TDFN33-8 PACKAGE OUTLINE AND DIMENSIONS



SYMBOL	DIMENSION IN MILLIMETERS		DIMENSION IN INCHES	
	MIN	MAX	MIN	MAX
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.153	0.253	0.006	0.010
D	2.900	3.100	0.114	0.122
E	2.900	3.100	0.114	0.122
D2	2.200	2.400	0.087	0.094
E2	1.400	1.600	0.055	0.063
b	0.200	0.320	0.008	0.013
e	0.650 TYP		0.026 TYP	
L	0.375	0.575	0.015	0.023