Li+ Battery Charger

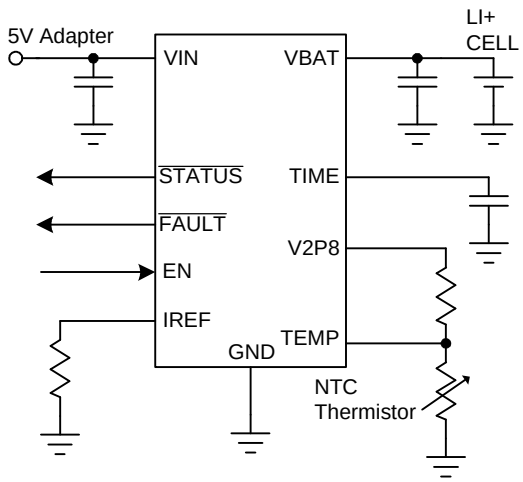
Features

- **Programmable Charge Current Up to 900mA**
- **4.2V Charge Termination Voltage with ±25mV Accuracy**
- **80mA Trickle Charge Current (R_{IREF}=100kΩ)**
- **Thermal Regulation Simplifies Board Design**
- **External Thermistor Monitor**
- **Programmable Maximum Charge Time**
- **Enable/Disable Control**
- **Charge Status and Fault Indication Outputs**
- **Lead Free and Green Devices Available (RoHS Compliant)**

Applications

- **Mobile Phones**
- **GPS Navigation**
- **Blue Tooth Headsets**

Simplified Application Circuit



General Description

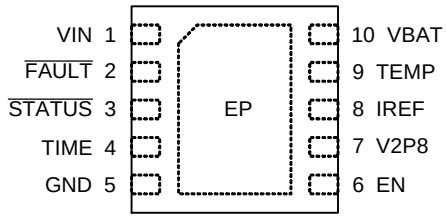
The APL3209 is a constant-current/constant-voltage linear charger for single cell Li+ batteries. The APL3209 needs no external MOSFETs or diodes, and accepts input voltage up to 6.5V.

On-chip thermal regulation protects the APL3209 from excessive temperature, and optimizes the board design for compact size and typical thermal conditions. The APL3209 monitors the ambient or battery temperature and maximum charge time, the charge will stop and indicate a fault when the temperature is out of range or the charge time is longer than the limit. Charge current can program by connecting an external resistor from IREF to GND.

Other features include a $\overline{\text{STATUS}}$ output to indicate the charge states, and a $\overline{\text{FAULT}}$ output to indicate the fault conditions. An EN input switches the charger on or off.

The APL3209 is available in a DFN3x3-10 package, and operates over the -40°C to +85°C temperature range.

Pin Configuration



DFN3x3-10
(Top View)

EP = Exposed Pad
(Connected to the ground plane for better heat dissipation)

Ordering and Marking Information

APL3209 □□□-□□□ Assembly Material Handling Code Temperature Package Code	Package Code QA : DFN3x3-10 Operating Ambient Temperature Range I : -40 to 85 °C Handling Code TR : Tape & Reel Assembly Material G : Halogen and Lead Free Device
APL3209 QA: 	XXXXX - Date Code

Note: ANPEC lead-free products contain molding compounds/die attach materials and 100% matte tin plate termination finish; which are fully compliant with RoHS. ANPEC lead-free products meet or exceed the lead-free requirements of IPC/JEDEC J-STD-020D for MSL classification at lead-free peak reflow temperature. ANPEC defines "Green" to mean lead-free (RoHS compliant) and halogen free (Br or Cl does not exceed 900ppm by weight in homogeneous material and total of Br and Cl does not exceed 1500ppm by weight).

Absolute Maximum Ratings (Note 1)

Symbol	Parameter	Rating	Unit
V_{IN}, V_{BAT}	VIN, $\overline{FAULT}$, $\overline{STATUS}$, EN, TEMP, VBAT to GND Voltage	-0.3 to 7	V
I_{CHG}	Charge Current	1	A
T_J	Maximum Junction Temperature	150	°C
T_{STG}	Storage Temperature	-65 to 150	°C
T_{SDR}	Maximum Lead Soldering Temperature, 10 Seconds	260	°C

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Thermal Characteristic

Symbol	Parameter	Typical Value	Unit
θ_{JA}	Junction-to-Ambient Resistance in Free Air (Note 2) DFN3x3-10	60	°C/W

Note 2: θ_{JA} is measured with the component mounted on a high effective thermal conductivity test board in free air.

Recommended Operating Conditions (Note 3)

Symbol	Parameter	Range	Unit
V_{IN}	VIN Input Voltage (VIN to GND)	4.25 ~ 6.5	V
V_{EN}	EN to GND Voltage	0 ~ 6.5	V
I_{CHG}	Charge Current	50 ~ 900	mA
T_A	Ambient Temperature	-40 ~ 85	°C
T_J	Junction Temperature	-40 ~ 125	°C

Note 3: Refer to the typical application circuit.

Electrical Characteristics

Unless otherwise specified, these specifications apply over V_{IN}=V_{EN}=5V, and T_A= -40 to 85 °C. Typical values are at T_A=25°C.

Symbol	Parameter	Test Conditions	APL3209			Unit
			Min.	Typ.	Max.	
POWER-ON-RESET (POR) AND V_{IN}-V_{BAT} LOCKOUT						
V_{POR}	Rising POR Threshold	V_{IN} rising	3.2	3.6	3.9	V
	Falling POR Threshold	V_{IN} falling	2.25	2.5	2.7	V
	V_{IN}-V_{BAT} Lockout Threshold	V_{IN} rising	45	80	100	mV
VIN SUPPLY CURRENT						
I_{VIN}	VIN Supply Current	Charger enable, VBAT=floating	-	600	-	μA
		Charger disable	-	150	300	μA
BATTERY REVERSE CURRENT						
I_{VBAT}	BAT Input Current	V_{EN}=0V or VIN=floating, V_{BAT}=4.2V	-	-	3.3	μA
CHARGE CURRENT						
I_{CHG}	Full Charge Current	R_{IREF}=100kΩ, T_A= -40 to 85 °C	760	800	840	mA
I_{TRK}	Trickle Charge Current	R_{IREF}=100kΩ, T_A= -40 to 85 °C	-	80	-	mA
I_{MIN}	End-of-Charge Current	R_{IREF}=100kΩ, T_A= -40 to 85 °C	-	80	-	mA
INTER POWER MOSFET						
	PMOS ON-Resistance	I_{CHG}=0.35A	-	500	800	mΩ
V2P8 VOLTAGE						
V_{V2P8}	V2P8 Voltage	Load =1mA	-	2.9	-	V
	V2P8 Output Voltage Accuracy	Load=1mA, T_A= 25°C	-50	-	+50	mV
		Load=1mA, V_{IN}=4.25 to 6.5V, T_A= -40 to 85 °C	-100	-	+100	mV
CHARGE THRESHOLDS						
V_{CH}	BAT Output Voltage	I_{CHG}=50mA	-	4.20	-	V
	BAT Output Voltage Accuracy	I_{CHG}=50mA, V_{IN}=5V, T_A= 25°C	-15	-	+15	mV
		I_{CHG}=50mA, V_{IN}=4.25 to 6.5V, T_A= -40 to 85 °C	-25	-	+25	mV
V_{MIN}	Trickle Charge Threshold Voltage	V_{BAT} rising	2.7	2.8	2.9	V
	Trickle Charge Hysteresis Voltage	V_{BAT} falling	100	160	225	mV
V_{RCH}	Recharge Threshold Voltage	Reference to V_{CH}	-225	-150	-70	mV
THERMISTER MONITOR AND THERMAL REGULATION						
	TEMP Cold Trip Level		1.98	2.0	2.02	V
	TEMP Cold Trip Level Hysteresis		-	0.1	-	V
	TEMP Hot Trip Level		0.99	1.0	1.01	V
	TEMP Hot Trip Level Hysteresis		-	0.1	-	V
	Thermal Regulation Threshold		-	110	-	°C
TIME OSCILLATOR						
t_{OSC}	TIME Oscillation Period	C_{TIME}=15nF	2.7	3.0	3.3	ms
LOGIC INPUT AND OUTPUTS						
V_{IH}	EN Input Logic High		1.3	-	5	V
V_{IL}	EN Input Logic Low		0	-	0.5	V

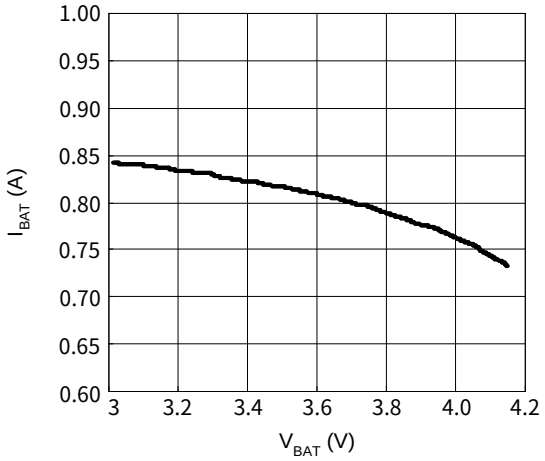
Electrical Characteristics (Cont.)

Unless otherwise specified, these specifications apply over V_{IN}=V_{EN}=5V, and T_A= -40 to 85 °C. Typical values are at T_A=25°C.

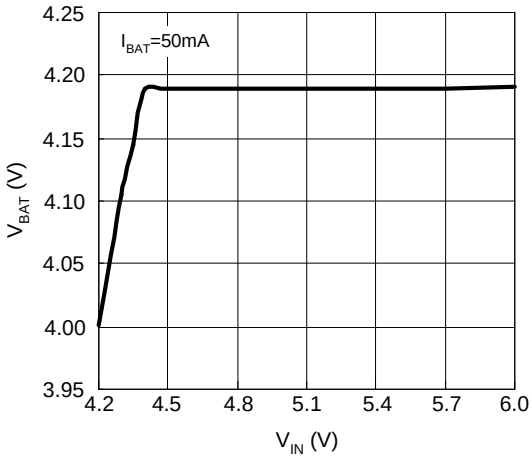
Symbol	Parameter	Test Conditions	APL3209			Unit
			Min.	Typ.	Max.	
LOGIC INPUT AND OUTPUTS (CONT.)						
	EN Internal Pull-up Resistance	Pull-up to VIN	200	400	600	kΩ
	$\overline{STATUS}$, $\overline{FAULT}$ Low Voltage	Load=10mA	-	0.5	0.8	V
	$\overline{STATUS}$, $\overline{FAULT}$ Leakage Current	$V_{\overline{STATUS}}$=$V_{\overline{FAULT}}$=5V	-	-	1	μA
SOFT-START						
	Soft-Start Interval	I_{CHG}=0 to full charge current	-	10	-	μs
	Soft-Stop Interval	I_{CHG}=full charge current to 0	-	10	-	μs

Typical Operating Characteristics

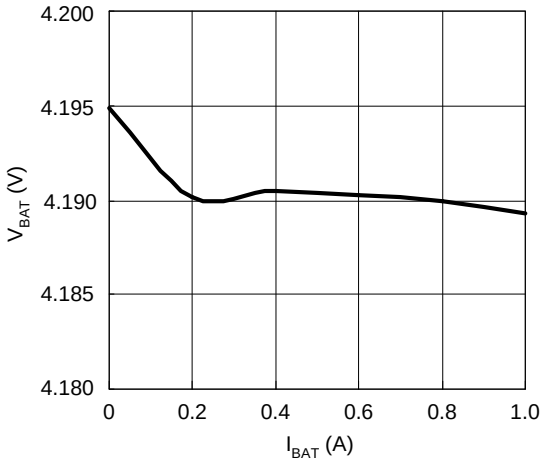
Charge Current vs. Output Voltage



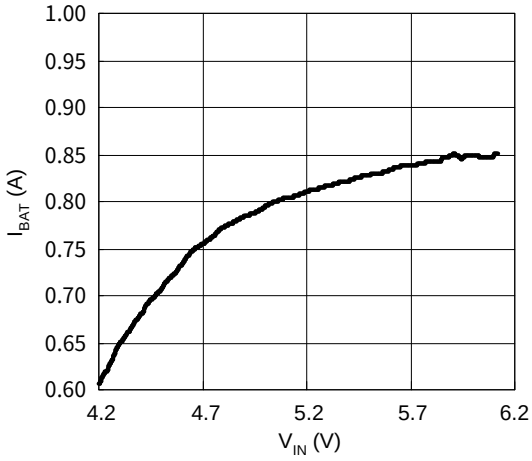
Charger Output Voltage vs. Input Voltage



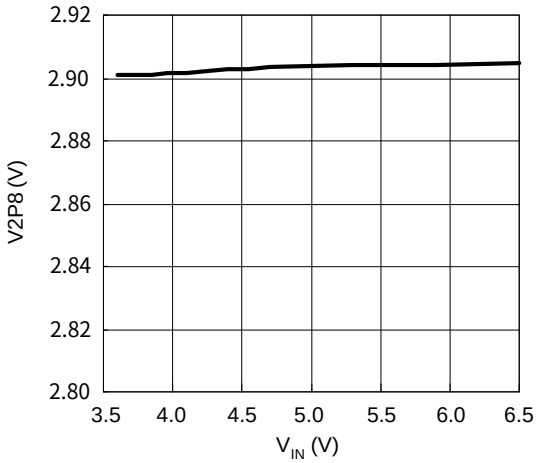
Charger Output Voltage vs. Charge Current



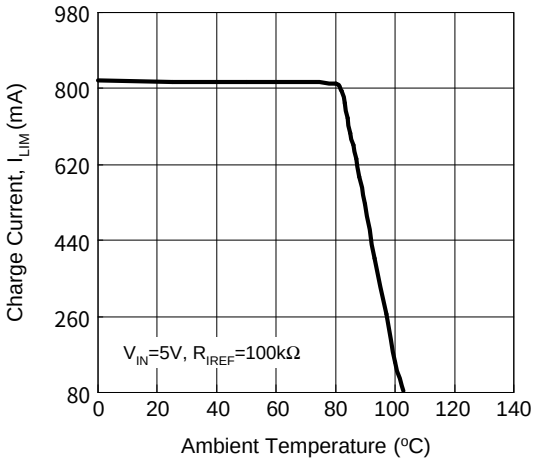
Charge Current vs. Input Voltage



V2P8 Output vs. Input Voltage

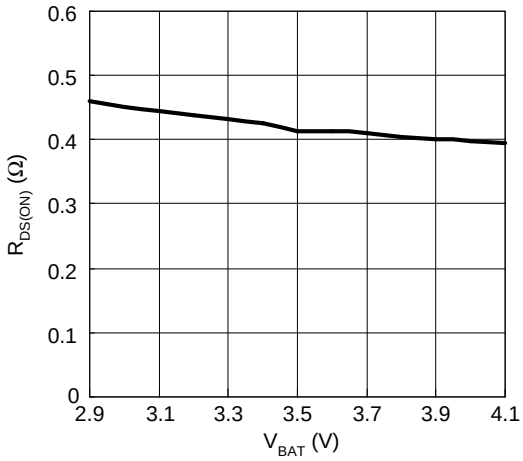


Charge Current vs. Ambient Temperature

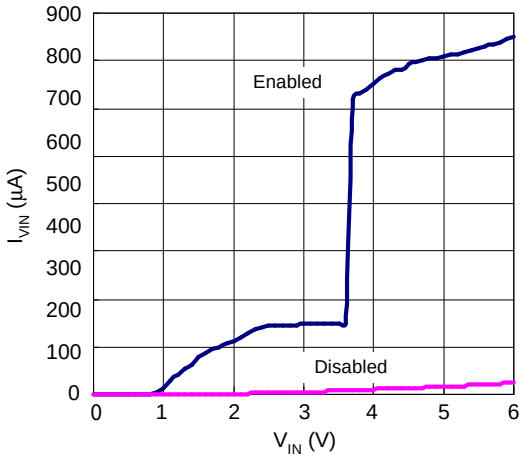


Typical Operating Characteristics (Cont.)

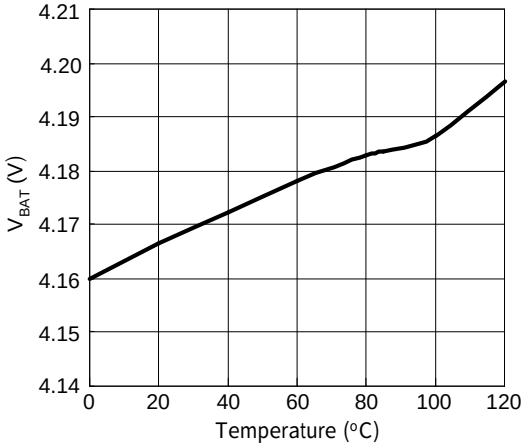
$R_{DS(ON)}$ vs. Output Voltage



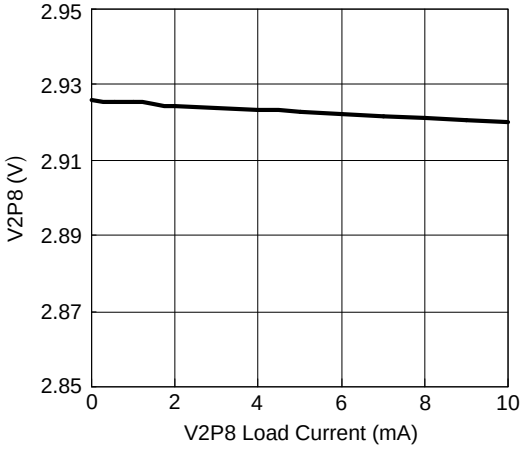
Input Quiescent Current vs. Input Voltage



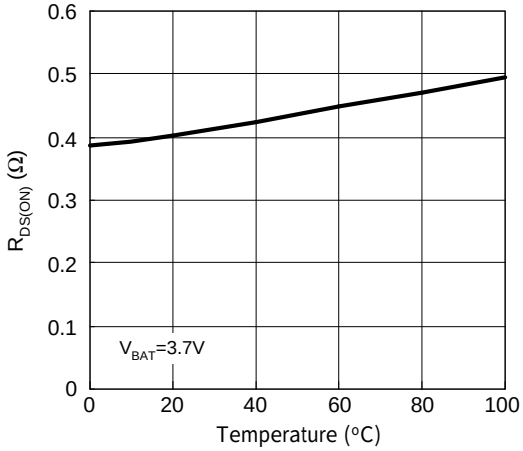
Charger Output Voltage vs. Temperature



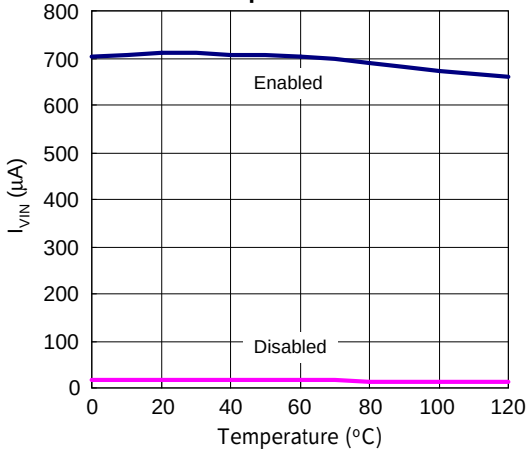
V2P8 Output Voltage vs. V2P8 Load Current



$R_{DS(ON)}$ vs. Temperature



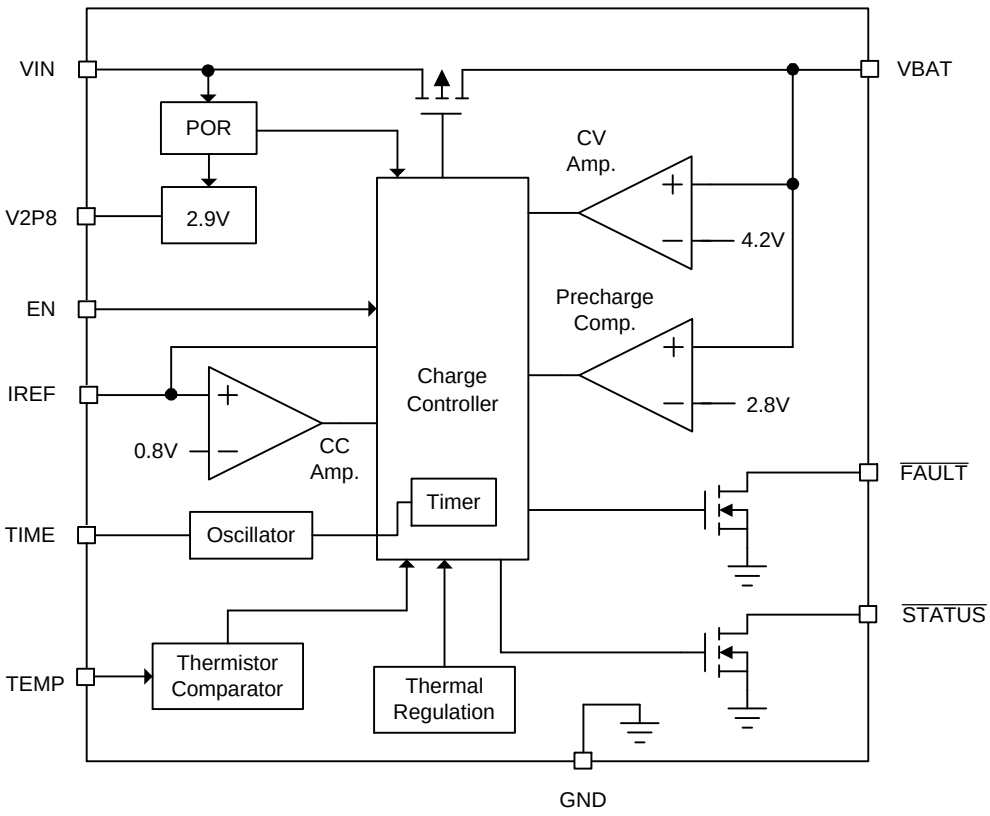
Input Quiesecnt Current vs. Temperature



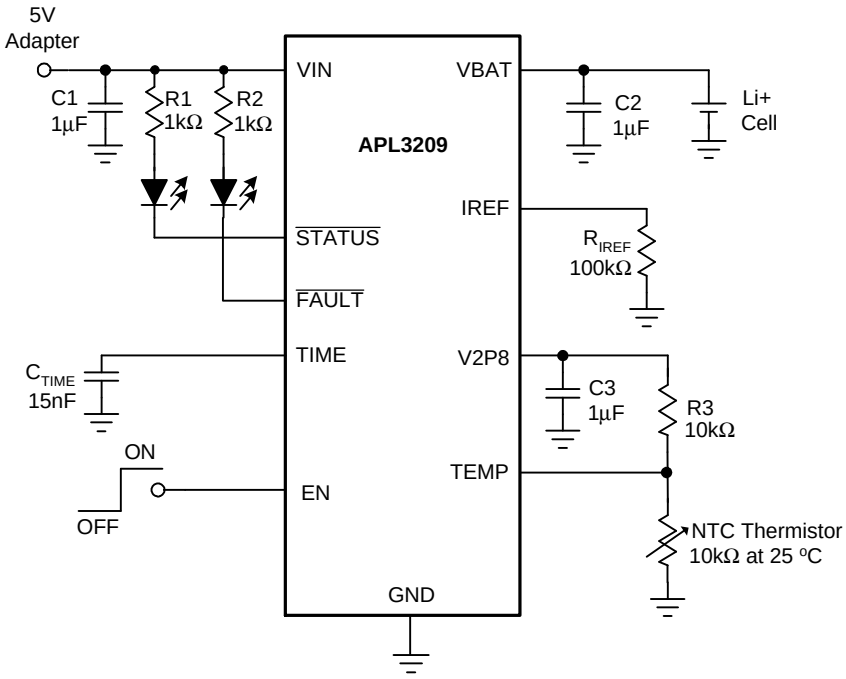
Pin Description

PIN		FUNCTION
NO.	NAME	
1	VIN	Input Supply Pin. Provides power to the IC, V_{IN} can range from 4.25V to 6.5V and should be bypassed with at least a 1µF capacitor.
2	$\overline{\text{FAULT}}$	Open-Drain Fault Status Output Pin. This pin is pulled to LOW when a fault condition occurs.
3	$\overline{\text{STATUS}}$	Open-Drain Charge Status Output Pin. This pin is pulled to LOW when the battery is charging.
4	TIME	Maximum Charge Time Setting Pin. Connect a capacitor between this pin and GND to set the maximum charge time.
5	GND	Ground.
6	EN	Enable Input. Pulling the V_{EN} above 1.3V enables the charger; pulling V_{EN} below 0.5V disables the charger.
7	V2P8	2.9V Reference Output Pin. Sources up to 1mA to bias the external thermistor and should be bypassed with at least a 1µF capacitor.
8	IREF	Charge Current Setting Pin. Connect a resistor between this pin to GND to set the full charge current.
9	TEMP	External Thermistor Connection Pin. Connect an external thermister between this pin to GND to monitor the battery temperature or ambient temperature. Connect this pin to GND disables this function.
10	VBAT	Charger Output Pin. Connect to positive terminal of a Li+ battery.
-	EP	Exposed Pad. Connect to a large ground plane for heatsinking.

Block Diagram



Typical Application Circuit



Function Description

Charge Cycle

When the APL3209 is powered with a battery connected, the IC firstly detects if the cell voltage is ready for full charge current. If the battery voltage is below trickle charge threshold (2.8V typ.), the device supplies 1/10 the programmed full charge current. On the contrary, when the batter voltage is over the trickle charge threshold, the device supplies the full charge current, as programmed by RIREF from IREF pin to GND. When the battery voltage approaches the 4.2V termination voltage, the device enters constant-voltage mode and the full charge current gradually decreases until the programmed charge time has been reached, the charger will be terminated. When the charge current drops to the end-of-charge (EOC) current threshold, which is equal to 1/10 full charging current and takes longer than one clock cycle of the oscillator, which is programmed by the C_{TIME}, the charger indicates the EOC with the $\overline{STATUS}$ pin is in pull-low state.

Full Charge Current Setting

The full charge current is programmed by connecting a resistor from the IREF pin to the ground. The full charge current can be calculated by the following equation:

$$I_{CHG}=80000/R_{IREF}$$

Were RIREF is the resistor from IREF to GND.

Charge Termination Detection and Recharge

A charge cycle is terminated when the programmed charge time has been reached. After charge termination, the battery voltage is monitored by the APL3209 continuously. If the battery voltage drops to 150mV below V_{CH} and takes longer than one clock cycle of the oscillator, which is programmed by the C_{TIME}, a new charge cycle starts to recharge the battery.

Thermal Regulation

The APL3209 is thermally regulated to keep the junction temperature at 110°C. When the junction temperature reaches 110°C, the charger does not shut down but reduces charge current to keep the junction temperature at 110°C. This feature protects the APL3209 from excessive temperature and allows the charger to operate with maximum power dissipation by reducing the charge current and optimizes the board design for compact size and typical thermal conditions.

$\overline{STATUS}$ and $\overline{FAULT}$ Outputs

The $\overline{STATUS}$ is an open-drain output. When the charger is in charge mode, the $\overline{STATUS}$ output is in pull-low state. Until the charge current drops to the EOC threshold the STAT output is in high impedance state.
The $\overline{FAULT}$ is an open-drain output. When a fault condition such as TEMP fault or TIMEOUT fault is occurred, the $\overline{FAULT}$ output is in pull-low state.

Enable Control

The enable input, EN, switches the charging of APL3209 on or off. With EN high, the APL3209 can begin charging. When EN is low, charging stops.

External Thermistor Monitor

The APL3209 features an internal window comparator to monitor battery pack temperature or ambient temperature with an external negative temperature coefficient thermistor. In typical systems, temperature is monitored to prevent charging at ambient temperature extremes. When the temperature moves outside these limits, charging is stopped and a temperature fault condition is issued. If the VTEMP returns to within its normal window, charging resumes. Connect TEMP to GND when not using this feature. Note that the temperature monitor at TEMP is entirely separate from the on-chip temperature limiting discussed in the Thermal Regulation section. The input thresholds for the TEMP input are 2.0V for the COLD trip point and 1.0V for the HOT trip point.

Maximum Charge Time (TIMEOUT)

The APL3209 provides timers for the trickle charge and fast charge operation. In the event that charge termination is not occurred, a safety timeout is required. The maximum charge time is set with an external capacitor connected from TIME to GND. The maximum charge time for the fast charge is set by:

$$t_{TIMEOUT}=2^{22}\times 0.2\times 10^{6}\times C_{TIME}\ \text{(seconds)}$$
$$=14\times\frac{C_{TIME}}{1nF}\ \text{(minutes)}$$

Function Description (Cont.)

Maximum Charge Time (TIMEOUT) (Cont.)

where C_{TIME} is the timing capacitor shown in the Typical Application Circuit on page 8. A 1nF capacitor leads to 14 minutes of TIMEOUT. For example, a 15nF capacitor sets the TIMEOUT to be 3.5 hours.

The maximum charge time for the trickle charge is 1/8 of the fast charge time limit. In the trickle charge, if the charge time is longer than the limit, the charger will stop and indicate a TIMEOUT fault. If the trickle charge completes before the time limit, the charger will enter the fast charge mode and the timer is reset. In fast charge, the charger needs to reach the end of the charge (EOC) conditions before the time limit, or the TIMEOUT fault will be issued. The $\overline{\text{STATUS}}$ is high when the charger reaches the EOC but the charge does not stop until the $t_{TIMEOUT}$ elapsed.

Application Information

Output Capacitor

The APL3209 should behave like a current and thermal limited linear regulator. The charger operation is stable with an output ceramic decoupling capacitor in the range of 1μF to 200μF, with or without a battery connected.

Input Capacitor

Due to the inductance of the power leads of the wall adapter or USB source, the input capacitor type must be properly selected to prevent high voltage transient during a hot-plug event. A minimum 1μF or higher value of input capacitor is recommended.

State Machine Diagram

The state machine diagram is shown in Figure 1. The diagram starts with the Power-Off state. When the input voltage rises above the POR threshold, the charger resets itself. Then, if the charger is disabled, the charger stays in the Charger Disabled state. If the charger is enabled, the trickle charge starts. Anytime when entering the trickle charge state, the internal TIMEOUT timer is reset. There are two paths to exit the trickle charge, one is when the battery voltage rises above the preconditioning charge threshold within the 1/8 TIMEOUT interval and the other is when the 1/8 TIMEOUT interval has been elapsed before reaching the preconditioning charge voltage threshold. When TIMEOUT fault occurs, the charger enters the TIMEOUT fault state.

There are only two ways to exit the TIMEOUT fault state, by toggling the EN input or re-cycling the input power. If the charger finishes the trickle charger before the 1/8 TIMEOUT limit, it moves to the fast charge state. When entering the fast charge state, the TIMEOUT timer is reset as well. If the charger hits EOC conditions before the TIMEOUT, the charger enters Charge Compete state. The charger stays on but the STATUS indicates EOC condition, until the TIMEOUT (starting from entering the fast charge state) is reached then the charger moves to the Inhibit state. In the Inhibit state, the charger is off and the EOC condition continues to be indicated.

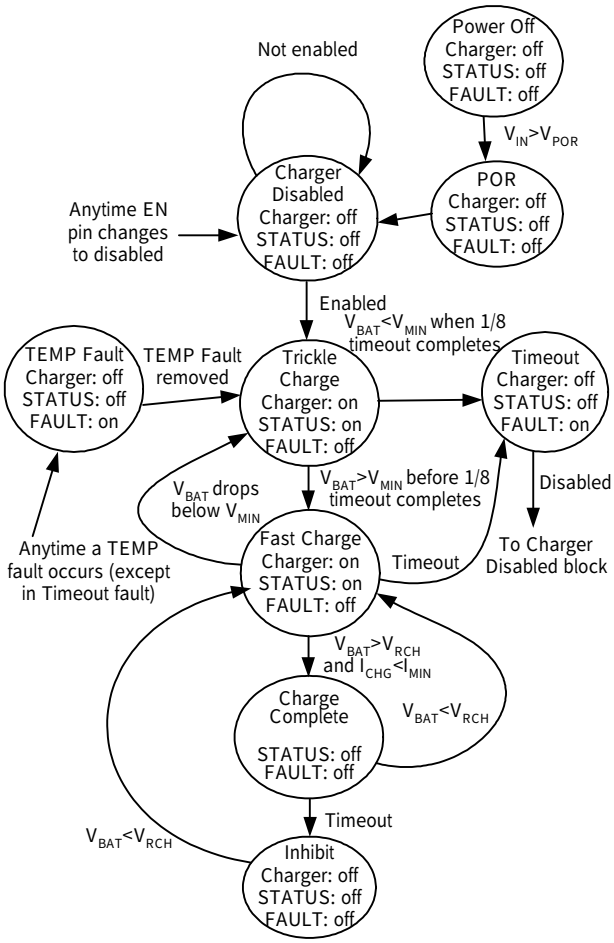


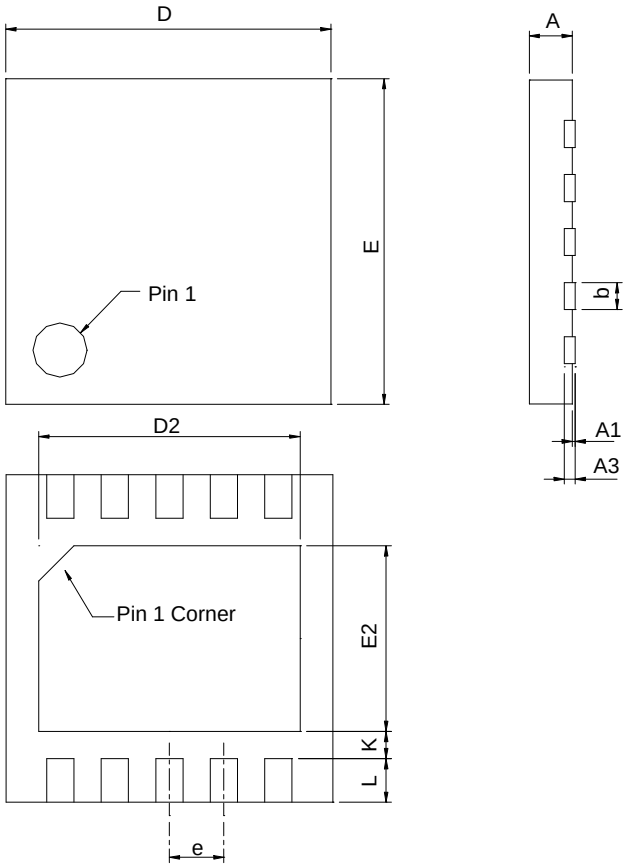
Figure 1.

Layout Consideration

The APL3209 uses a thermally-enhanced DFN3x3-10 package that has an exposed thermal pad at the bottom side of the package. The layout should connect as much as possible to copper on the exposed pad. Typically the component layer is more effective in dissipating heat. The thermal impedance can be further reduced by using other layers of copper connecting to the exposed pad through a thermal via array. A minimum of 4 such thermal vias are recommended. Each thermal via is recommended to have 0.3mm diameter and 0.7mm distance from other thermal vias.

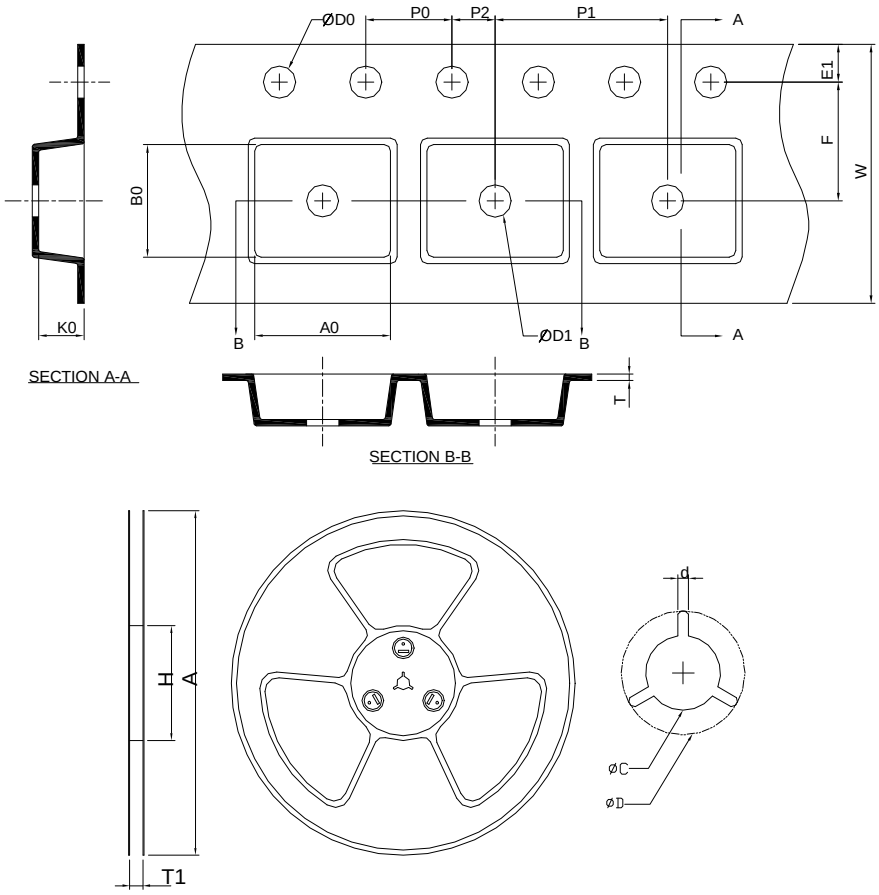
Package Information

DFN3x3-10



SYMBOL	DFN3x3-10			
	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.80	1.00	0.031	0.039
A1	0.00	0.05	0.000	0.002
A3	0.20 REF		0.008 REF	
b	0.18	0.30	0.007	0.012
D	2.90	3.10	0.114	0.122
D2	1.95	2.05	0.077	0.081
E	2.90	3.10	0.114	0.122
E2	1.55	1.65	0.061	0.065
e	0.50 BSC		0.020 BSC	
L	0.30	0.50	0.012	0.020
K	0.20		0.008	

Carrier Tape & Reel Dimensions



Application	A	H	T1	C	d	D	W	E1	F
DFN3x3-10	178.0±2.00	50 MIN.	12.4+2.00 -0.00	13.0+0.50 -0.20	1.5 MIN.	20.2 MIN.	12.0±0.30	1.75±0.10	5.5±0.05
	P0	**P1**	**P2**	**D0**	**D1**	**T**	**A0**	**B0**	**K0**
	4.0±0.10	8.0±0.10	2.0±0.05	1.5+0.10 -0.00	1.5 MIN.	0.6+0.00 -0.40	3.30±0.20	3.30±0.20	1.30±0.20

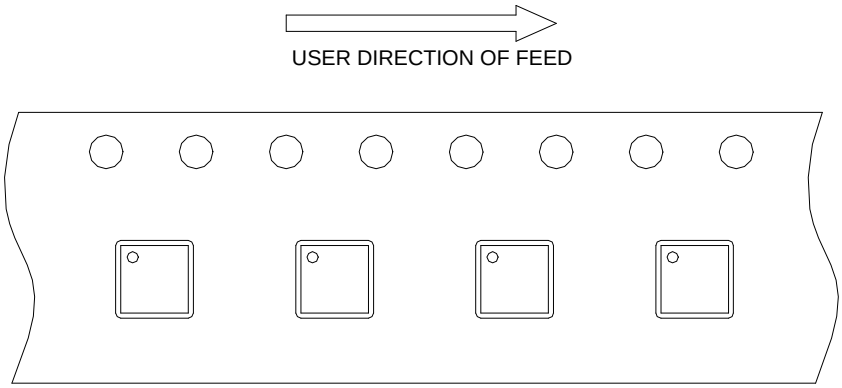
(mm)

Devices Per Unit

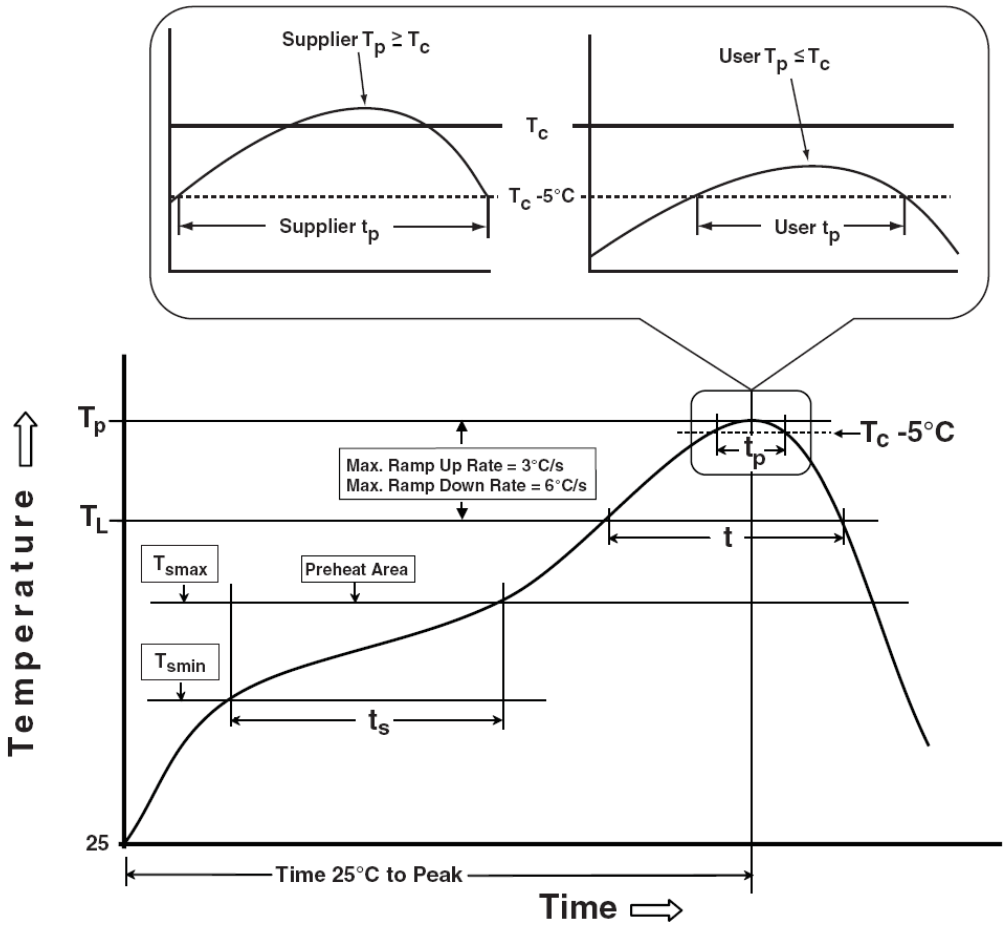
Package Type	Unit	Quantity
DFN3x3-10	Tape & Reel	3000

Taping Direction Information

DFN3x3-10



Classification Profile



Classification Reflow Profiles

Profile Feature	Sn-Pb Eutectic Assembly	Pb-Free Assembly
Preheat & Soak Temperature min (T_{smin}) Temperature max (T_{smax}) Time (T_{smin} to T_{smax}) (t_s)	 100 °C 150 °C 60-120 seconds	 150 °C 200 °C 60-120 seconds
Average ramp-up rate (T_{smax} to T_P)	3 °C/second max.	3°C/second max.
Liquidous temperature (T_L) Time at liquidous (t_L)	183 °C 60-150 seconds	217 °C 60-150 seconds
Peak package body Temperature (T_p)*	See Classification Temp in table 1	See Classification Temp in table 2
Time (t_P)** within 5°C of the specified classification temperature (T_c)	20** seconds	30** seconds
Average ramp-down rate (T_p to T_{smax})	6 °C/second max.	6 °C/second max.
Time 25°C to peak temperature	6 minutes max.	8 minutes max.
* Tolerance for peak profile Temperature (T_p) is defined as a supplier minimum and a user maximum. ** Tolerance for time at peak profile temperature (t_p) is defined as a supplier minimum and a user maximum.		

Table 1. SnPb Eutectic Process – Classification Temperatures (Tc)

Package Thickness	Volume mm^3 <350	Volume mm^3 3350
<2.5 mm	235 °C	220 °C
≥2.5 mm	220 °C	220 °C

Table 2. Pb-free Process – Classification Temperatures (Tc)

Package Thickness	Volume mm^3 <350	Volume mm^3 350-2000	Volume mm^3 >2000
<1.6 mm	260 °C	260 °C	260 °C
1.6 mm – 2.5 mm	260 °C	250 °C	245 °C
≥2.5 mm	250 °C	245 °C	245 °C

Reliability Test Program

Test item	Method	Description
SOLDERABILITY	JESD-22, B102	5 Sec, 245°C
HOLT	JESD-22, A108	1000 Hrs, Bias @ T_j=125°C
PCT	JESD-22, A102	168 Hrs, 100%RH, 2atm, 121°C
TCT	JESD-22, A104	500 Cycles, -65°C~150°C
HBM	MIL-STD-883-3015.7	VHBM≧2KV
MM	JESD-22, A115	VMM≧200V
Latch-Up	JESD 78	10ms, 1_{tr}≧100mA

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