1.6A Linear Li-Ion Battery Charger in a 3x3 TDFN Package

General Description

The AAT3698-1/-2 BatteryManager™ is a single-cell lithium-ion (Li-Ion)/Li-Polymer battery charger IC designed to operate from a USB port or AC adapter with an input voltage of up to 7.0V. For increased safety, the AAT3698-1/-2 also includes over-voltage input protection (OVP) up to 28V.

The AAT3698-1/-2 precisely regulates battery voltage for 4.2V Li-Ion/Polymer battery cells through a low $R_{DS(ON)}$ switch. The charging current can be set by an external resistor up to 1.6A. If an over-voltage condition occurs from the input, the series switch quickly opens and a fault flag is activated, preventing damage to the battery and the charging circuitry.

Other fault conditions are monitored in real time. In case of an over-current, battery over-voltage, short circuit, or over-temperature failure, the device will automatically shut down, thus protecting the charging device, control system, and the battery under charge. A status monitoring output pin ($\overline{STAT}$) is provided to indicate charging activity. This open drain output pin can be used to drive an external LED as a charging indicator.

The AAT3698-1/-2 also includes a 5.0V LDO linear regulator with over-voltage protection that can supply loads of up to 50mA.

The AAT3698-1/-2 is available in the Pb-free, thermally enhanced, space-saving 3x3mm TDFN33-14 package and is rated over the -40°C to +85°C temperature range.

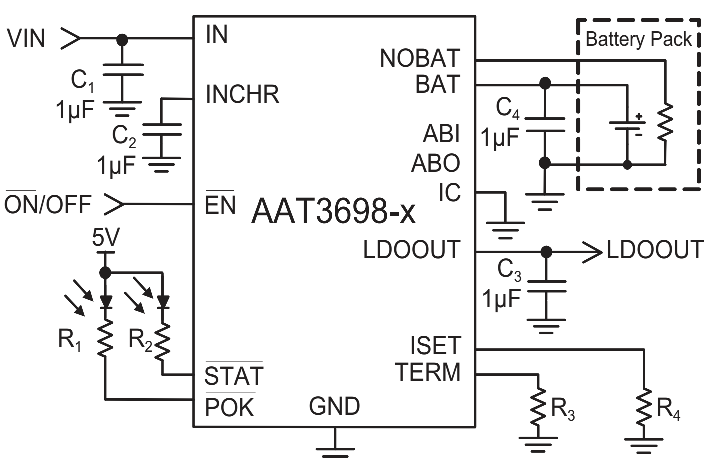
Features

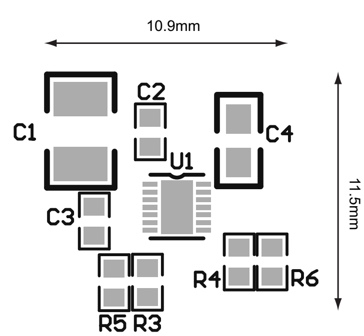
- USB or AC Adapter System Power Charger
- 3.0V ~ 7.0V Input Voltage Range
- Fast Over-Voltage Protection Turn Off
- OVP Trip Threshold: 7.25V (typ)
- High Level of Integration with Internal:
  - Power Device
  - Reverse Current Blocking
  - Current Sensing
- 5V/50mA LDO Output
- Programmable Fast Charge Current from 50mA to 1.6A
- Programmable Charge Termination Current
- Charge Status Indicator
- Power OK Indicator
- Battery Absence Detection Input Pin
- Automatic Termination and Recharge Sequencing (AAT3698-1 Only)
- Automatic Trickle Charge For Battery Pre-Conditioning
- Emergency Thermal Shutdown Protection
- Digitally Controlled Thermal Loop Regulation
- Active Low Enable with Internal 200kΩ Pull-Down Resistor
- Output for Auto-Booting
- 14-pin 3x3mm TDFN Package

Applications

- Bluetooth™ Headsets, Headphones, Accessories
- Digital Still Cameras
- Mobile Telephones
- Personal Data Assistants (PDAs)
- MP3 Players
- Other Lithium-Ion/Polymer Battery-Powered Devices

Typical Application





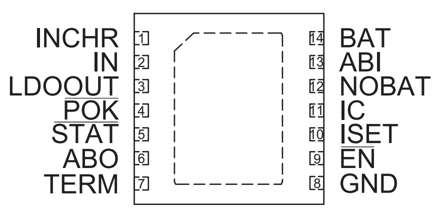
U1	AAT3698-x
C1	GRM31MR71H105KA88
C2, C3	GRM188R61A225KE34
C4	GRM21BR71C105KA01L
R1	1.5kΩ, 5%, 1/4W, 0603
R2	1.5kΩ, 5%, 1/4W, 0603
R3	13.3kΩ, 1%, 1/4W, 0603
R4	1.58kΩ, 1%, 1/4W, 0603

Pin Description

Pin #	Name	Type	Function
1	INCHR	I/O	OVP output switch and battery charger input; decouple to GND with 1μF capacitor.
2	IN	I	Input from USB port or adapter connector.
3	LDOOUT	O	5V/50mA LDO output through OVP device; bypass to GND with 1μF capacitor.
4	$\overline{\text{POK}}$	O	Power OK flag pin; open drain, active low.
5	$\overline{\text{STAT}}$	O	Charge status indicator pin; open drain, active low.
6	ABO	O	Auto booting output.
7	TERM	I	Connect the R_{TERM} resistor between the TERM pin and ground to set the charge termination current. When the TERM pin is connected to INCHR, charge current termination level is set to 10% of the programmed fast charge current.
8	GND	I	Power ground.
9	$\overline{\text{EN}}$	I	Enable pin, active low. Internally connected to ground through a 200kΩ pull-down resistor.
10	ISET	I	Connect R_{SET} resistor to this pin to set charging current. Connect a 10kΩ resistor from this pin to the system to monitor this pin's voltage.
11	IC	I	Internally connected; connect this pin to ground.
12	NOBAT	I	No battery detection input. If the NOBAT pin is left unconnected, charging is disabled. Internally pulled to LDOOUT pin through a 1.6MΩ pull-up resistor.
13	ABI	I	Auto booting input. Internally connected to ground through a 200kΩ pull-down resistor.
14	BAT	O	Connect to Li-Ion battery.
EP			Exposed paddle; connect to ground.

Pin Configuration

TDFN33-14
(Top View)



Absolute Maximum Ratings[1]

Symbol	Description	Value	Units
V_{IN}	IN continuous	-0.3 to 30	V
V_P	INCHR, $\overline{EN}$, $\overline{STATB}$, $\overline{POK}$, ABI, NOBAT	-0.3 to 7.5	V
V_N	BAT, ISET, TERM, LODOUT, ABO, IC	-0.3 to V_{INCHR} + 0.3	V
T_J	Junction Temperature Range	-40 to 150	°C
T_A	Operating Temperature Range	-40 to 85	°C
T_{LEAD}	Maximum Soldering Temperature (at leads)	300	°C

Thermal Information[2]

Symbol	Description	Value	Units
Θ_{JA}	Maximum Thermal Resistance (TDFN33-14)	50	°C/W
P_D	Maximum Power Dissipation	2	W

1. Stresses above those listed in Absolute Maximum Ratings may cause permanent damage to the device. Functional operation at conditions other than the operating conditions specified is not implied. Only one Absolute Maximum Rating should be applied at any one time.
2. Mounted on an FR4 board.

Electrical Characteristics[1]

V_{IN} = 5V, R_{SET} = 3.16kΩ, V_{ENB} = V_{NOBAT} = 0V, C_{IN} = 1μF, C_{INCHR} = 1μF, C_{BAT} = 1μF, C_{LDOOUT} = 1μF, TERM = ABI = IC = open, T_A = -40 to +85°C, unless otherwise noted. Typical values are at T_A = 25°C.

Symbol	Description	Conditions	Min	Typ	Max	Units
Operation						
V_{IN_MAX}	Input Over-Voltage Protection Range				28	V
V_{IN}	Normal Operating Input Voltage Range		3.0		7.0	V
I_{OP}	Operating Current	V_{BAT} = 4.3V, R_{SET} = 15.8kΩ		300	450	μA
I_{SD}	Charge Function Shutdown Supply Current	V_{ENB} = 5V, V_{BAT} = 4.3V		190	250	μA
I_{BAT_LEAK}	Leakage Current from BAT Pin	V_{BAT} = 4V, IN Pin Open		2	5	μA
Over-Voltage Protection						
V_{OVP}	Over-Voltage Protection Trip Voltage	V_{IN} Rising Edge	7.05	7.25	7.45	V
V_{OVP_HYS}	Hysteresis			200		mV
$V_{IN\_BAT\_OS}$	V_{IN} – V_{BAT} Offset Voltage	V_{IN} Rising, V_{BAT} = 4V		300		mV
		V_{IN} Falling, V_{BAT} = 4V		200		
V_{INCHR_DO}	Drop Out Voltage Between IN and INCHR Pins	V_{IN} = 5V, I_{BAT} = 500mA, R_{SET} = 1.58kΩ		200		mV
Battery Charger						
V_{UVLO}	Under-Voltage Lockout Threshold	V_{IN} Rising Edge	2.6	2.8	3.0	V
V_{UVLO_HYS}	Hysteresis			200		mV
V_{CHG_DO}	Drop Out Voltage Between INCHR and BAT Pins	V_{IN} = 4.2V, I_{BAT} = 500mA, R_{SET} = 1.58kΩ		100		mV
V_{BOVP}	Battery Over-Voltage Protection Threshold			4.4		V
BAT Pin Voltage Regulation						
$V_{CO(REG)}$	Constant Regulated Output Voltage[2]	R_{ISET} = 31.6kΩ, I_{BAT} = 10mA		4.20		V
$\Delta V_{CO}/V_{CO}$	Constant Output Voltage Tolerance	R_{ISET} = 31.6kΩ, I_{BAT} = 10mA, T_A= 25°C	-0.5		+0.5	%
		R_{ISET} = 31.6kΩ, I_{BAT} = 10mA, T_A= -40 to +85°C	-1		+1	
V_{RCH}	Battery Recharge Voltage Threshold (AAT3698-1 only)	V_{BAT} falling		$V_{CO(REG)}$ - 0.1		
V_{MIN}	Preconditioning Voltage Threshold	V_{BAT} rising	2.4	2.6	2.8	V
Current Regulation						
I_{CC_RANGE}	Charge Current Programmable Range		100		1600	mA
I_{CH_CC}	Constant-Current Mode Charge Current	R_{SET} = 15.8kΩ, V_{BAT} = 3.6V	-15%	100	+15%	mA
		R_{SET} = 3.16kΩ, V_{BAT} = 3.6V	-10%	500	+10%	
		R_{SET} = 1.58kΩ, V_{BAT} = 3.6V	-10%	1000	+10%	
V_{ISET}	ISET Pin Voltage	V_{BAT} = 3.6V, T_A = 25°C	1.97	2	2.03	V
		V_{BAT} = 3.6V, T_A = -40 to +85°C	1.9	2	2.1	V
$I_{CH\_TRK\%}$	Trickle Charge Current Ratio	R_{SET} = 3.16kΩ, V_{BAT} = 2.0V	5	10	20	% of I_{CH_CC}
K_{ISET}	Charge Current Set Factor: I_{CH_CC}/I_{ISET}	R_{SET} = 15.8kΩ, V_{BAT} = 3.6V		790		
		R_{SET} = 3.16kΩ, V_{BAT} = 3.6V		790		
V_{TERM}	TERM Pin Voltage Range	From off to full charge	0		2.0	V
V_{EXTERM_DIS}	External Termination Disable Threshold[3]	V_{IN} = 5V, measured on TERM pin	4.8			V
V_{EXTERM_EN}	External Termination Enable Threshold[4]	V_{IN} = 5V, measured on TERM pin			3.5	V
I_{TERM}	TERM Pin Output Current	V_{TERM} = 0.2V	-10%	15	+10%	μA
$I_{CH\_TERM\%}$	Charge Termination Threshold Current Ratio	V_{TERM} = 0.2V or tied to INCHR pin	5	10	20	% of I_{CH_CC}

1. The AAT3698-1/-2 is guaranteed to meet performance specifications over the -40 to +85°C operating temperature range and is assured by design, characterization and correlation with statistical process controls.
2. When no battery is connected, the BAT pin output voltage is regulated at 4.2V.
3. Internal Termination function is selected when V_{TREM} > V_{EXTREM_DIS}.
4. External Termination function is selected when V_{TREM} < V_{EXTREM_EN}.

Electrical Characteristics (continued)[1]

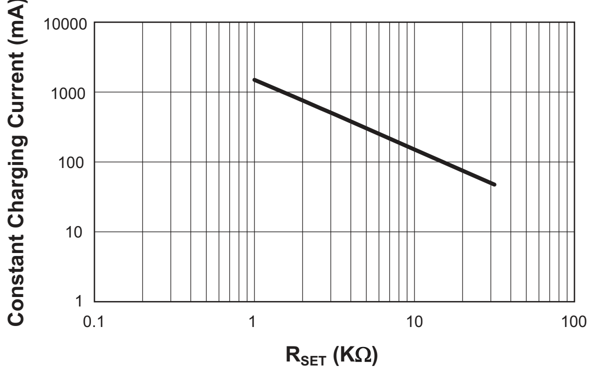
V_{IN} = 5V, R_{SET} = 3.16kΩ, V_{ENB} = V_{NOBAT} = 0V, C_{IN} = 1µF, C_{INCHR} = 1µF, C_{BAT} = 1µF, C_{LDOOUT} = 1µF, TERM = ABI = IC = open, T_A = -40 to +85°C, unless otherwise noted. Typical values are at T_A = 25°C.

Symbol	Description	Conditions	Min	Typ	Max	Units
Logic Control / Battery Protection						
$V_{\overline{EN}(H)}$	Input High Threshold		1.2			V
$V_{\overline{EN}(L)}$	Input Low Threshold				0.4	V
$R_{\overline{EN}}$	Input Pull Down Resistor			200		kΩ
$V_{NOBAT(H)}$	Input High Threshold		1.2			V
$V_{NOBAT(L)}$	Input Low Threshold				0.4	V
R_{NOBAT}	Input Pull Up Resistor			1600		kΩ
$V_{ABI(H)}$	Input High Threshold	V_{IN} = 0V, V_{BAT} = 4.2V	1.2			V
$V_{ABI(L)}$	Input Low Threshold	V_{IN} = 0V, V_{BAT} = 4.2V			0.4	V
R_{ABI}	Input Pull Down Resistor			200		kΩ
$V_{ABO(H)}$	Output High Voltage	V_{BAT} = 4.2V, I_{ABO} = -5mA (sourcing)	V_{BAT} − 1V			V
$V_{ABO(L)}$	Output Low Voltage	V_{BAT} = 4.2V, I_{ABO} = 5mA (sinking)			0.4	V
$V_{\overline{STAT}}$	Output Low Voltage				0.4	V
$I_{\overline{STAT}\_OFF}$	$\overline{STAT}$ Pin Leakage Current	$V_{\overline{STAT}}$ = 5.5V, $V_{\overline{EN}}$ = 5V			1	µA
$V_{\overline{POK}}$	Output Low Voltage	$I_{\overline{POK}}$ = 5mA			0.4	V
$I_{\overline{POK}\_OFF}$	$\overline{POK}$ Pin Leakage Current	$V_{\overline{POK}}$ = 5.5V, V_{IN} = 7V			1	µA
T_{OVPRES}	Over-Voltage Response Time	V_{IN} voltage step up from 6V to 8V, R_{LOAD} = 100Ω, C_{INCHR} = 1µF		0.1		µs
T_{OVPON}	OVP Switch OVP Release Turn-On Delay Time	V_{IN} voltage step down from 8V to 6V, R_{LOAD} = 100Ω, C_{INCHR} = 1µF		60		µs
$T_{DLY\_\overline{POK}}$	$\overline{POK}$ OFF Delay Time from Over-Voltage	V_{IN} voltage step up from 6V to 8V, R_{LOAD} = 100Ω, C_{INCHR} = 1µF		0.1		µs
$T_{REDLY\_\overline{POK}}$	$\overline{POK}$ ON Delay Time from Over-Voltage	V_{IN} voltage step down from 8V to 6V, R_{LOAD} = 100Ω, C_{INCHR} = 1µF		1.5		µs
$T_{OVPSTARTON}$	OVP Switch Startup Turn-On Delay Time	V_{IN} voltage step up from 0V to 5V, R_{LOAD} = 100Ω, C_{INCHR} = 1µF		220		µs
Thermal Protection						
TH_{REG}	Thermal Loop Regulation			110		ºC
TH_{SHDN}	Chip Thermal Shutdown Temperature	Threshold		140		ºC
		Hysteresis		15		
5V LDO						
V_{LDOOUT}	LDOOUT Voltage Tolerance	V_{IN} = 5.5V, I_{LDOOUT} = 0mA to 30mA, T_A = 25°C	4.9	5.0	5.1	V
		V_{IN} = 5.5V, I_{LDOOUT} = 0mA to 30mA, T_A = -40 to +85°C	4.75	5.0	5.25	V
V_{DO}	Dropout Voltage from IN	I_{OUT} = 30mA, V_{IN} = 5.0V		160	300	mV
I_{OUT_LIM}	LDO Output Current Limit	V_{IN} = 5.5V, V_{LDOOUT} = 4.5V	55	90	125	mA
V_{LDOOUT_LR}	Line Regulation	V_{IN} = 5.4V to 6.4V, I_{LDOOUT} = 30mA			10	mV
$V_{LDOOUT\_DM\ LR}$	Dynamic Line Regulation	I_{OUT} = 30mA, V_{IN} = 5.4V to 6.4V, T_R/T_F = 2µs		200		mV
$V_{LDOOUT\_DM\ LD}$	Dynamic Load Regulation	I_{OUT} = 1mA to 30mA, T_R = <5µs, V_{IN} = 5.5V		60		mV

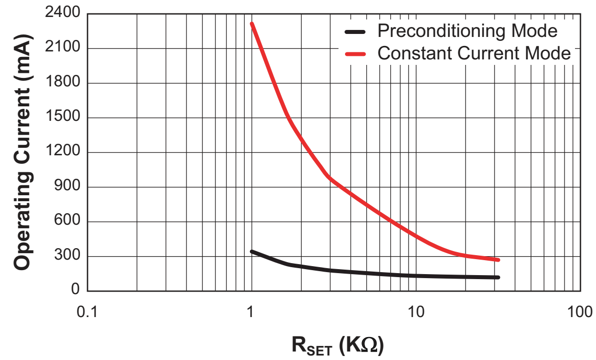
1. The AAT3698-1/-2 is guaranteed to meet performance specifications over the -40 to +85°C operating temperature range and is assured by design, characterization and correlation with statistical process controls.

Typical Characteristics—Battery Charger

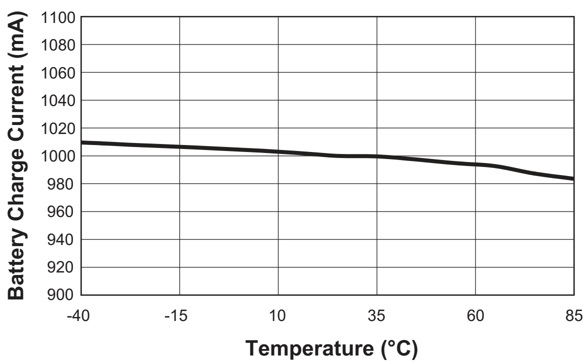
Constant Charging Current vs. R_{SET} Resistor Values



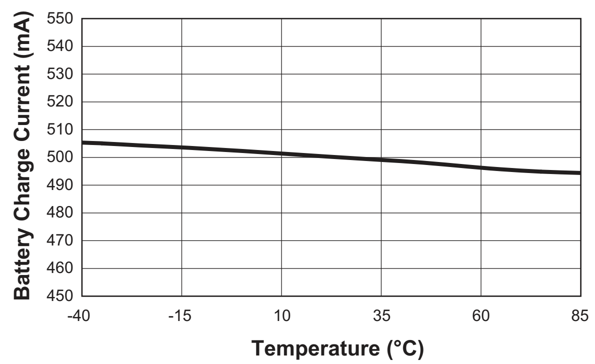
Operating Current vs. R_{SET} Resistor Values



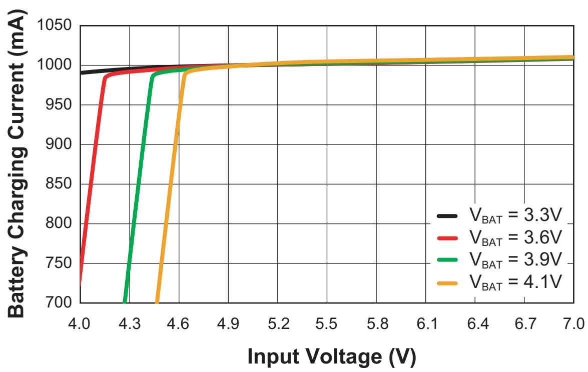
Battery Charging Current vs. Temperature
(R_{SET} = 1.58KΩ; I_{CH_CC} = 1000mA)



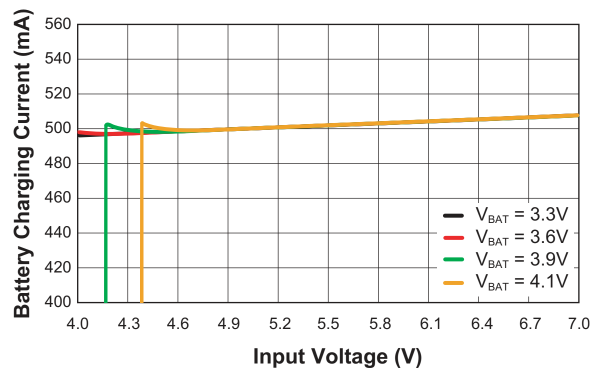
Battery Charging Current vs. Temperature
(R_{SET} = 3.16KΩ; I_{CH_CC} = 500mA)



Battery Charging Current vs. Input Voltage
(R_{SET} = 1.58KΩ)

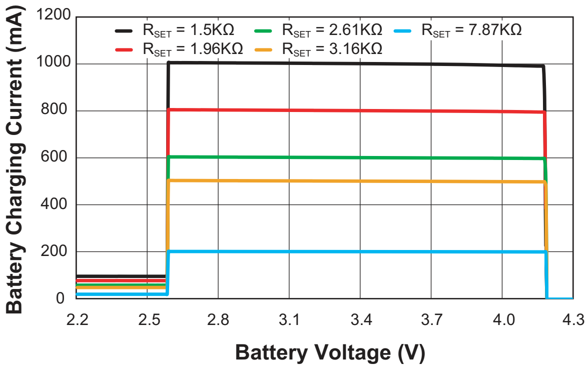


Battery Charging Current vs. Input Voltage
(R_{SET} = 3.16KΩ)

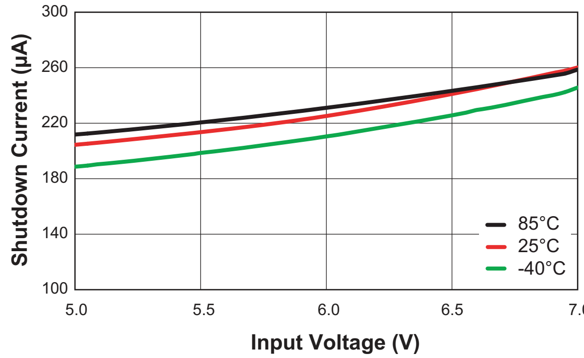


Typical Characteristics—Battery Charger

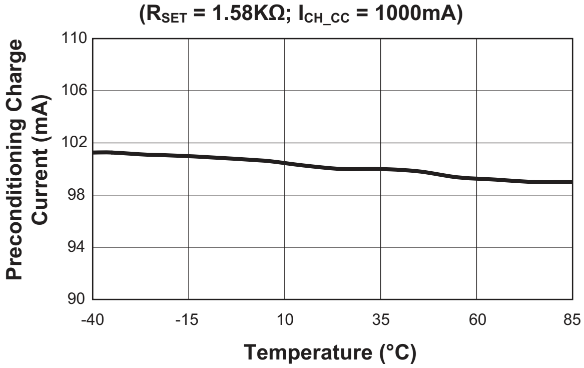
Battery Charging Current vs. Battery Voltage



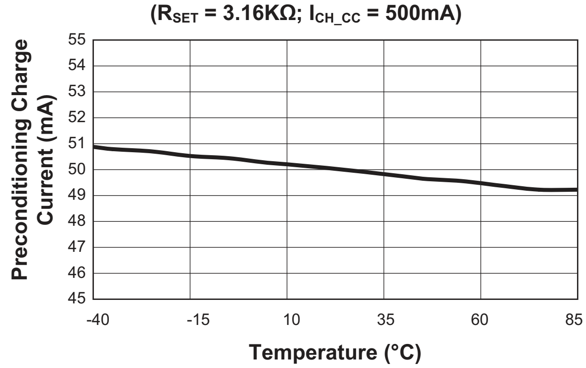
Shutdown Current vs. Input Voltage



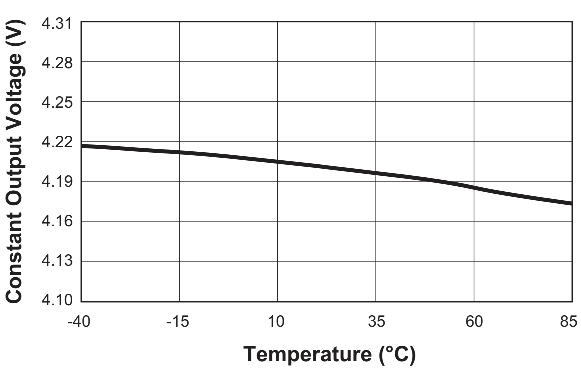
Preconditioning Charge Current vs. Temperature
(R_{SET} = 1.58KΩ; I_{CH_CC} = 1000mA)



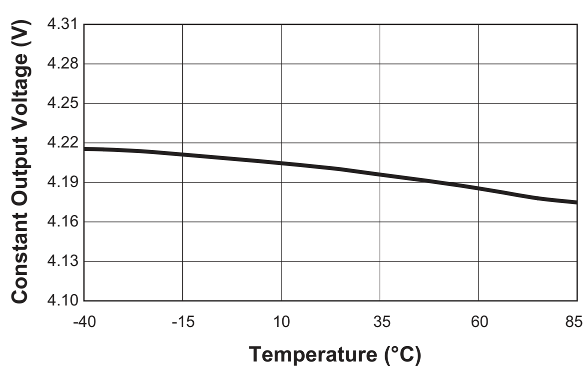
Preconditioning Charge Current vs. Temperature
(R_{SET} = 3.16KΩ; I_{CH_CC} = 500mA)



Constant Output Voltage vs. Temperature
(R_{SET} = 1.58KΩ; I_{CH_CC} = 1000mA)

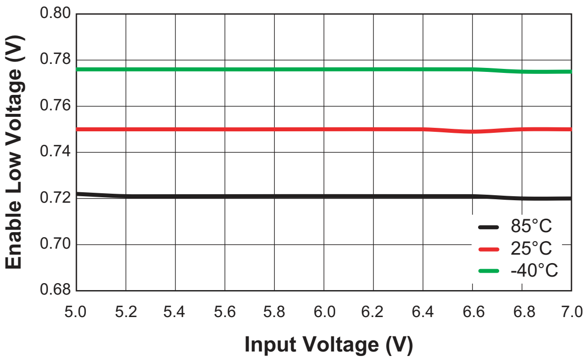


Constant Output Voltage vs. Temperature
(R_{SET} = 3.16KΩ; I_{CH_CC} = 500mA)

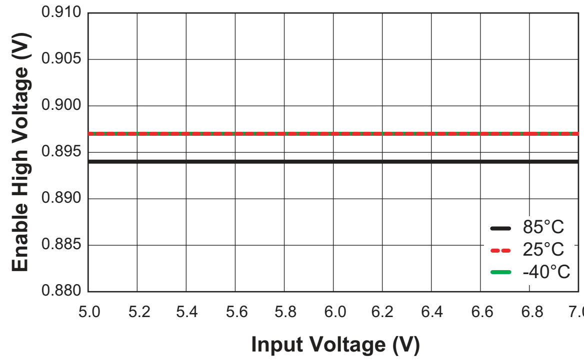


Typical Characteristics—Battery Charger

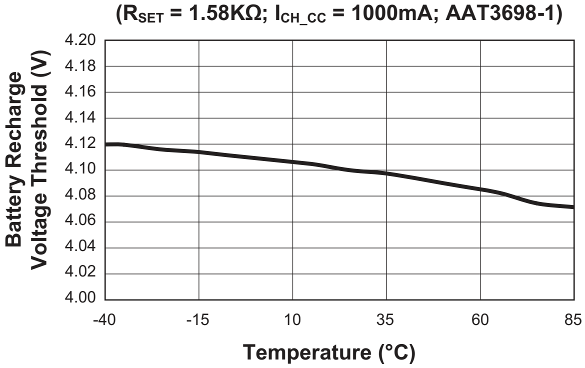
Enable Low Voltage vs. Input Voltage



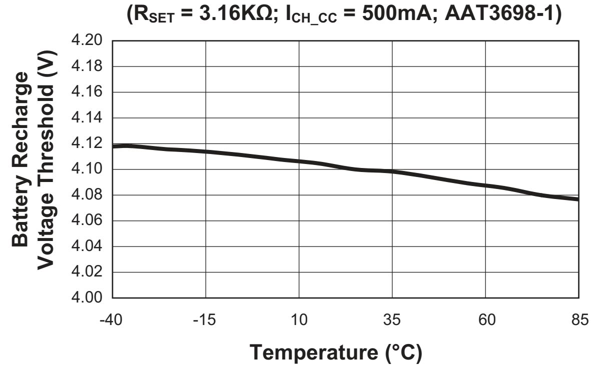
Enable High Voltage vs. Input Voltage



Battery Recharge Voltage Threshold vs. Temperature
(R_{SET} = 1.58KΩ; I_{CH_CC} = 1000mA; AAT3698-1)

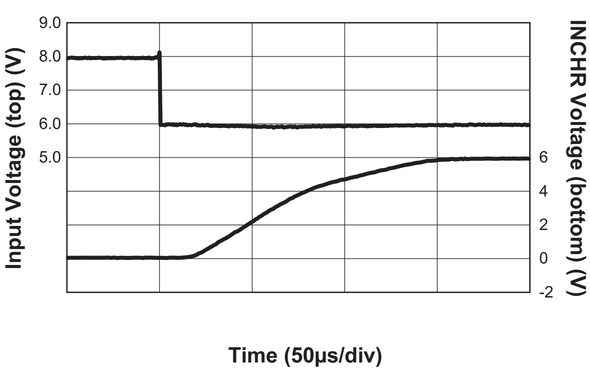


Battery Recharge Voltage Threshold vs. Temperature
(R_{SET} = 3.16KΩ; I_{CH_CC} = 500mA; AAT3698-1)

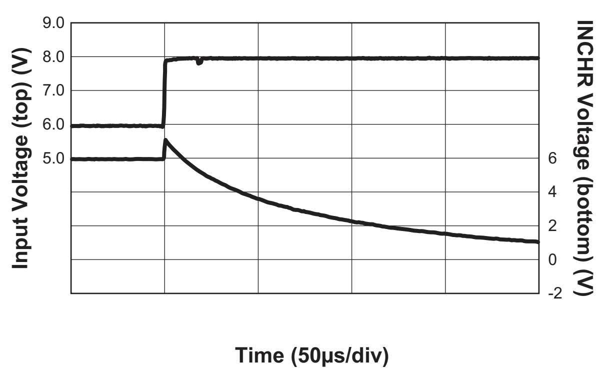


Typical Characteristics—OVP

OVP On Time
(R_{LOAD} = 100Ω)



OVP Response Time
(R_{LOAD} = 100Ω)



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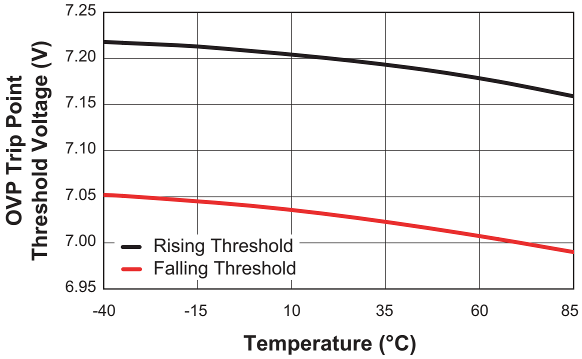
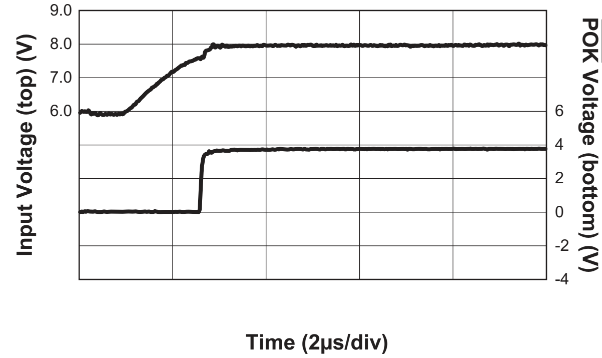
Typical Characteristics—OVP

OVP Trip Point Threshold Voltage vs. Temperature

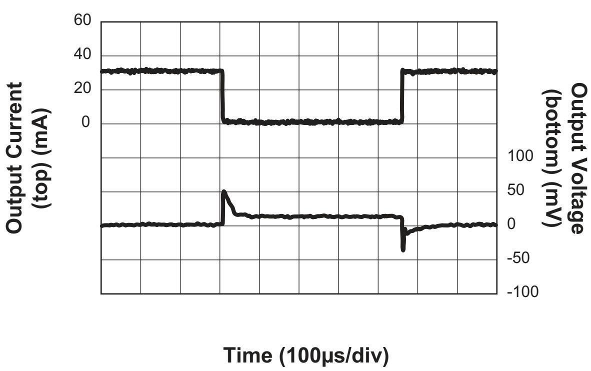


$\overline{POK}$ ON Delay Time
(R_{LOAD} = 100Ω)

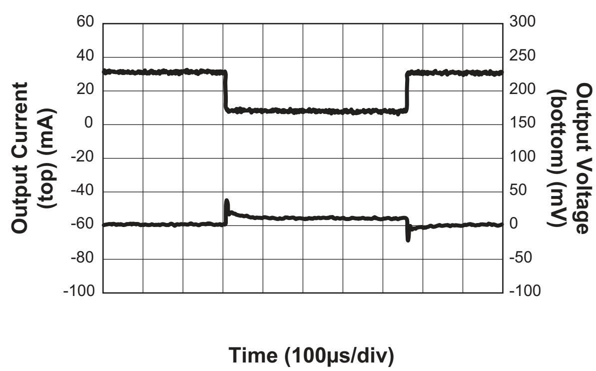


Typical Characteristics—LDO

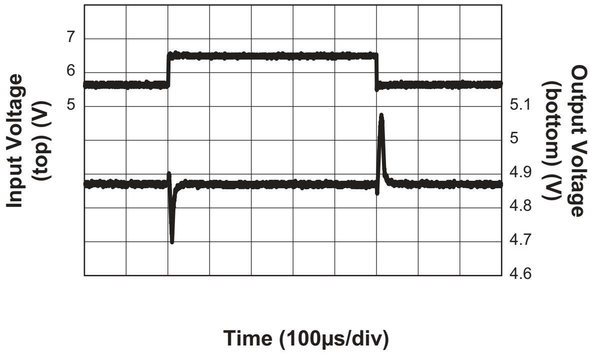
LDO Load Transient
(V_{IN} = 5.4V; I_{OUT} = 1mA to 30mA; C_{OUT} = 1µF)



LDO Load Transient
(V_{IN} = 5.4V; I_{OUT} = 10mA to 30mA; C_{OUT} = 1µF)

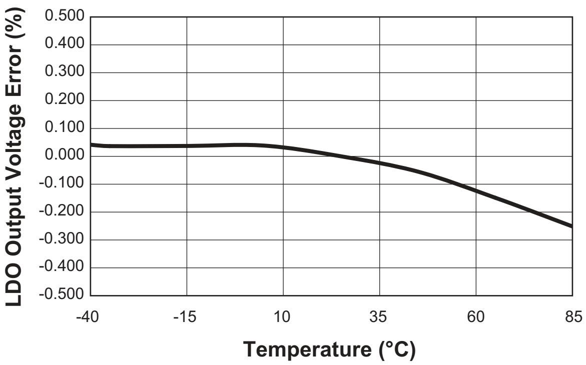


LDO Line Transient
(V_{IN} = 5.4V to 6.4V; I_{OUT} = 30mA; C_{OUT} = 1µF)

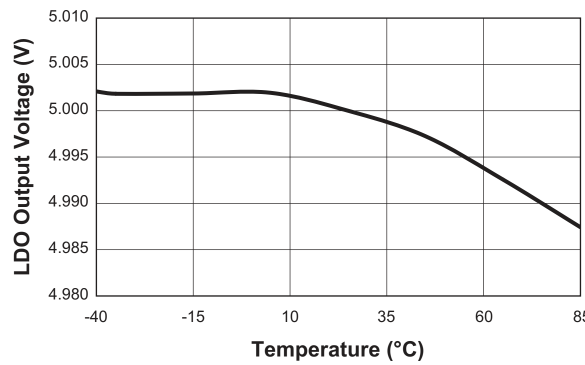


Typical Characteristics–LDO

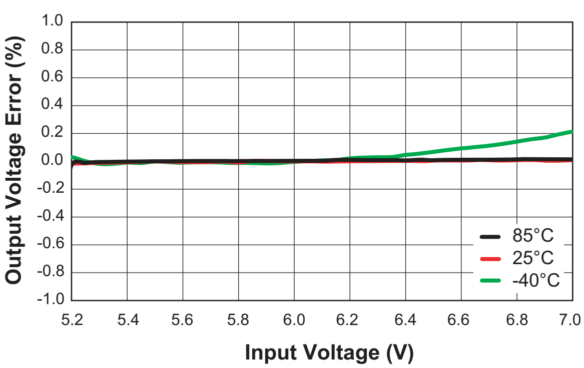
LDO Output Voltage Accuracy vs. Temperature
(I_{OUT} = 10mA)



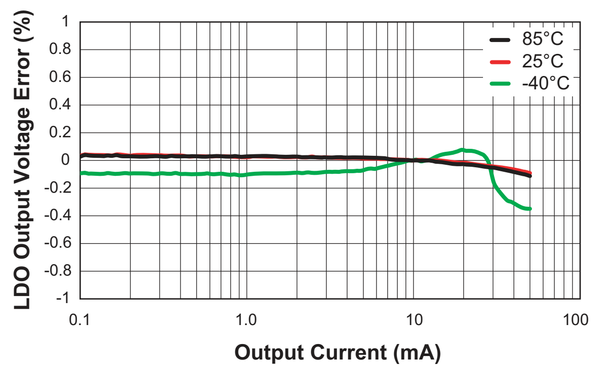
LDO Output Voltage vs. Temperature
(I_{OUT} = 10mA)



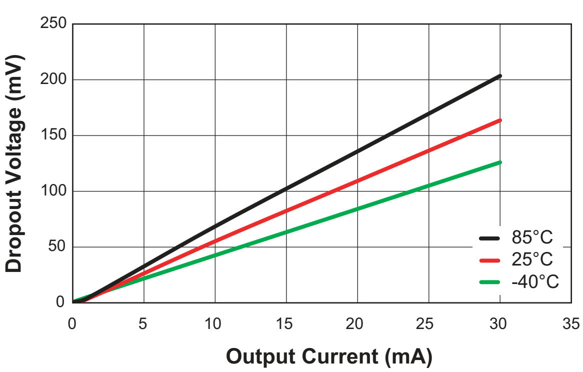
LDO Output Voltage Accuracy vs. Input Voltage
(I_{OUT} = 30mA)



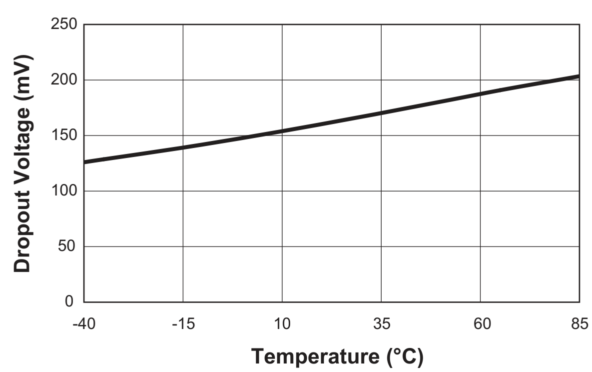
LDO Output Voltage Accuracy vs. Output Current
(V_{IN} = 5.5V)



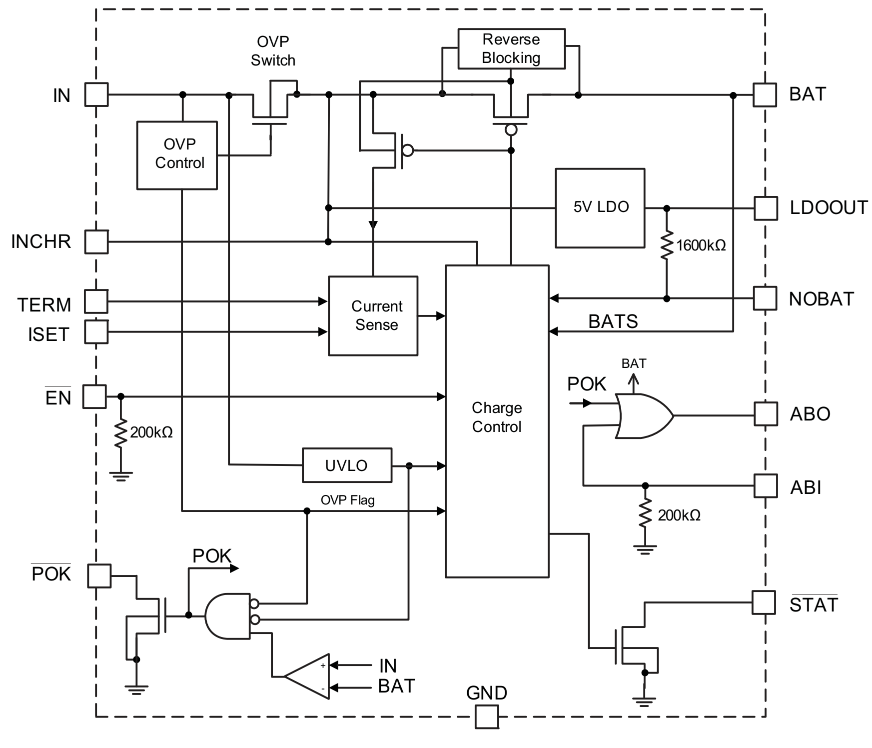
Dropout Voltage vs. Output Current



Dropout Voltage vs. Temperature
(I_{OUT} = 30mA)



Functional Block Diagram



Functional Description

The AAT3698-1/-2 is a high performance battery charger IC which is designed to charge single-cell Lithium-Ion or Polymer batteries with up to 1.6A of current from an external power source. It is a stand-alone charging solution requiring minimum input components. The AAT3698-1/-2 also includes a fast turn-off over-voltage protection (OVP) circuit with +28V which consists of a low-resistance MOSFET in series with the charge control circuit. The AAT3698-1/-2 also features under-voltage lockout protection, power OK, charge status monitoring, and a 5.0V LDO with 50mA output through the OVP switch.

Battery Charging Profile

Figure 1 illustrates the entire battery charging operation profile, which consists of three (AAT3698-2) or four (AAT3698-1) phases:

1. Preconditioning (Trickle) Charge
2. Constant Current Charge (CC)
3. Constant Voltage Charge (CV)
4. Automatic Recharge (AAT3698-1 only)

Preconditioning Charge

Battery charging commences only after the AAT3698-1/-2 checks several conditions in order to maintain a safe charging environment. The input supply must be above the minimum operating voltage (V_{MIN}) or under-voltage lockout threshold (V_{UVLO}) and the enable pin must be low for the charging sequence to begin. When these conditions have been met and a battery is connected to the BAT pin, the AAT3698-1/-2 checks the state of the battery and determines which charging mode to apply. If the battery voltage is below the preconditioning voltage threshold (V_{MIN}), then the AAT3698-1/-2 begins preconditioning the cell (trickle charging) by charging at 10% of the programmed constant current. For example, if the programmed fast charge current is 1000mA, then the preconditioning (trickle) charge current is 100mA. Battery cell preconditioning is a safety precaution for deeply discharged cells and will also reduce the power dissipation in the internal series pass transistor when the voltage across the device is at greatest potential.

Constant Current Fast Charge

Battery cell preconditioning charge continues until the battery voltage reaches the preconditioning voltage threshold (V_{MIN}). At this point, the AAT3698-1/-2 begins the constant current charge phase. The current level for this mode is programmed using a single resistor from the ISET pin to ground. The programmed current can be set from a minimum of 100mA up to a maximum of 1.6A.

Constant Voltage Charge

Constant current charging will continue until the battery voltage reaches the constant output voltage, V_{CO}. The AAT3698-1/AAT3698-2 then transitions to constant voltage mode, in which the charge IC regulates the battery voltage to a constant output voltage (factory programmed to 4.2V). The charging current decreases during this phase. The charger regulates battery voltage at 4.2V and continues to charge the battery until the charge current reaches the termination level set by R_{TERM}. When the charge current reaches its termination level I_{TERM}, charging is terminated.

AAT3698-1

The charger turns off the series pass device even if the $\overline{EN}$ pin is held low and the device automatically enters a power-saving sleep state. During this time, the series pass device blocks current in both directions, preventing the battery from discharging through the IC. The device remains in sleep mode even if the charger source is disconnected. When the battery terminal voltage drops below the V_{RCH} threshold, the AAT3698-1 resumes charging operation if no fault is detected.

AAT3698-2

The charger regulates the battery voltage at 4.2V and continues to charge the battery with a current lower than the charge termination current until a logic high is applied to the $\overline{EN}$ pin to stop charging.

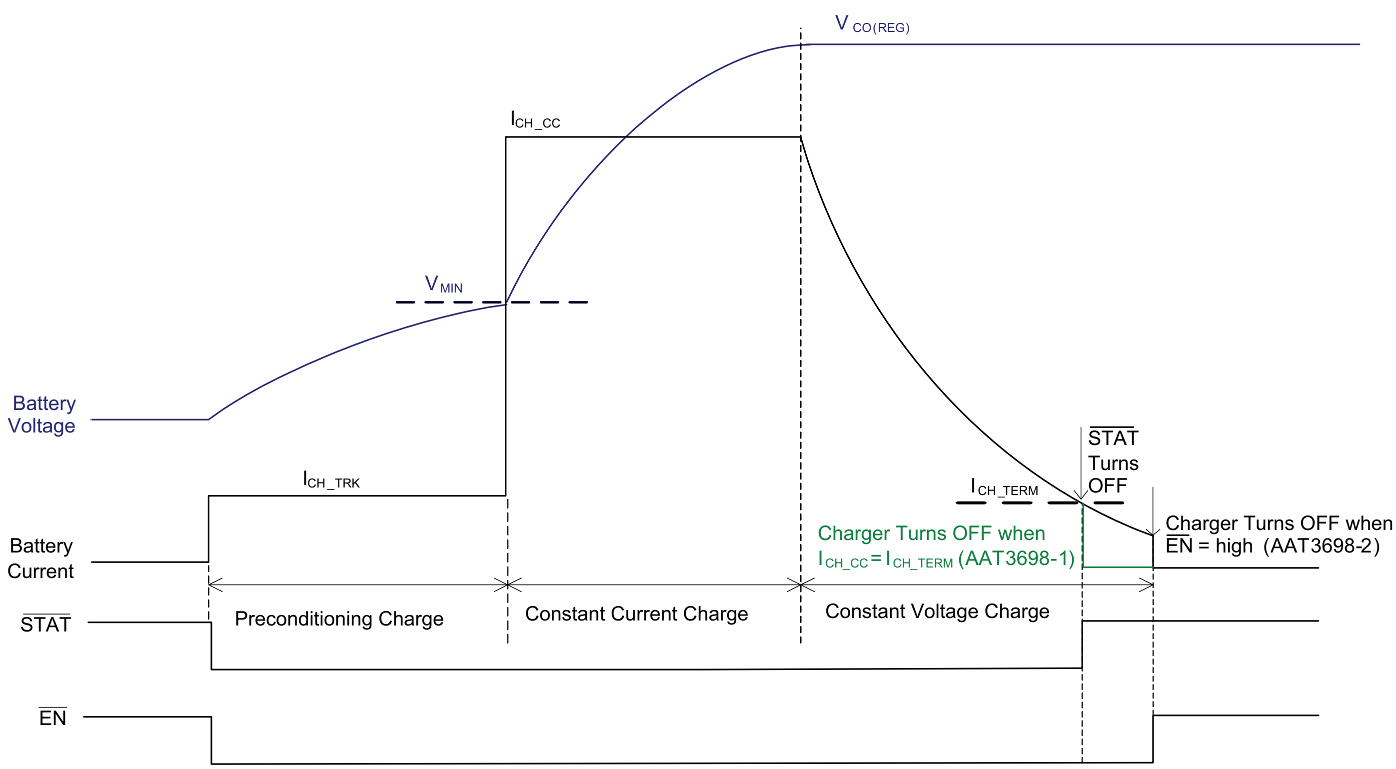


Figure 1: AAT3698-1/-2 Battery Charging Profile.

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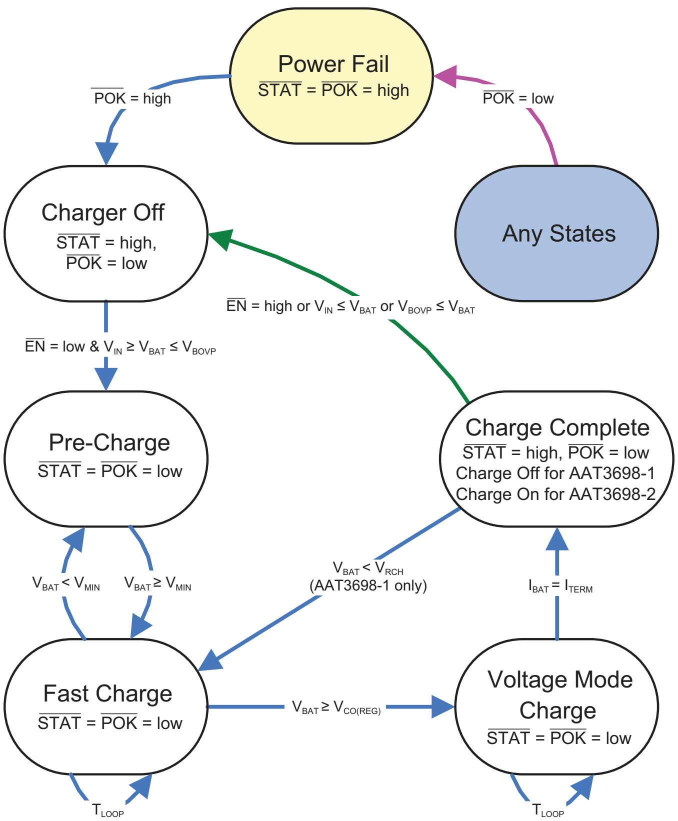

Figure 2: Charger Operational State Diagram.

Charge Status Output

The AAT3698-1/-2 provides battery charging status via the charge status indication pin (STAT). This pin is internally connected to an N-channel open-drain MOSFET, which can be used as a logic signal or to drive an external LED. The STAT pin pulls high to indicate charge completion. The charge completion occurs only when the EN pin is pulled high or the charge current reaches its charge termination current level. The status pin indicates the conditions as described in Table 1.

Charge Status	STAT
$V_{IN} > V_{UVLO}$	High
$V_{IN} > V_{OVP}$	High
The charge current is below its termination level	High
EN pin is pulled high	High
Battery is charging and the charge current is above its termination level.	Low

Table 1: LED Status Indicator.

Enable / Disable

The AAT3698-1/-2 provides an enable function to turn the charger IC on and off. The enable (EN) pin is internally pulled down with 200kΩ. When EN is pulled down or left floating, the device begins normal operation**.** When EN is pulled to a logic high level, the AAT3698-1/-2's charging circuit will be shut down and forced into sleep state. The over-voltage protection/LDO circuit remains active even in sleep state. In sleep state, charging is halted regardless of the battery voltage or charging state. When the device is re-enabled, the charge control circuit automatically resets and resumes charging functions with the appropriate charging mode based on the battery charge state and measured cell voltage at the BAT pin.

Under-Voltage Lockout (UVLO)

The AAT3698-1/-2 has a typical under-voltage lockout threshold of 3V. When the input voltage is less than the UVLO level, OVP and the charger are turned off. The UVLO is designed with 150mV hysteresis to ensure circuit stability.

Over-Voltage Protection

In normal operation, the OVP protection device acts as a load switch, connecting the power source from IN to INCHR. This switch is designed with very low resistance to minimize the voltage drop between the power source and the charger and to reduce the power dissipation. When the voltage on the power source exceeds the OVP trip point, V_{OVP}, the switch immediately turns off and disconnects the load and the charger from the power source and preventing damage to any downstream components. Simultaneously, the fault flag is raised, alerting the system. If an over-voltage condition is applied at the time of the device enable, the switch remains open (OFF).

Power OK Output Flag

The Power OK flag (POK**)** is an active-low open-drain power good reporting output. A pull-up resistor should be connected from POK to another system power voltage. In the event of an under-voltage or over-voltage condition, POK will be de-asserted. After the over-voltage fault is released, POK will be asserted. **POK will be also de-asserted when V_{IN} is lower than V_{BAT} when EN is low.** When EN is high, POK is asserted only after UVLO and OVP conditions.

Power Status	$\overline{POK}$
$V_{IN} < V_{UVLO}$	High
$V_{IN} > V_{OVP}$	High
$V_{IN} < V_{BAT} + V_{IN\_BAT\_OS}$, $\overline{EN}$ = low	High
$V_{UVLO} \le V_{BAT} + V_{IN\_BAT\_OS} \le V_{IN} \le V_{OVP}$	Low

Table 2: $\overline{POK}$ Flag Indicator.

Automatic Booting

An auxiliary OR gate provides a booting enable signal from two inputs, an internal power OK signal and an external ABI signal. The ABO states are listed in Table 3.

V_{BAT}	$\overline{POK}$	ABI	ABO
Yes	Low	X	High
Yes	High	High	High
Yes	High	Low	Low
No	X	X	Low

Table 3: Automatic Booting.

Battery Detection

When the NOBAT pin is set to logic high level, the charger is disabled. When it is set to logic low level, the charger is enabled. This pin is internally pulled to the LDOOUT pin through a 1.6MΩ resistor.

Battery Over-Voltage Protection

An over-voltage event is defined as a condition where the voltage at the BAT pin exceeds the maximum battery charge voltage and is set by the battery over-voltage protection threshold (V_{BOVP}). If an over-voltage condition is sensed by the BATS pin, the AAT3698-1/-2 charge control shuts down the device until the voltage at the BAT pin drops below V_{BOVP}. The AAT3698-1/-2 resumes normal charging operation after the over-voltage condition is removed.

Digital Thermal Loop Control

The AAT3698-1/-2 includes a thermal management system. The system is activated when the die temperature reaches its preset internal temperature threshold (110°C) and maintains the die temperature by reducing the constant charge current.

Over-Temperature Shutdown

The AAT3698-1/-2 has a thermal protection control circuit which shuts down charging functions if the internal die temperature exceeds the preset thermal limit threshold (140°C). Once the internal die temperature falls below the thermal limit, normal operation resumes in the previous charging state.

Linear Dropout Regulator

The AAT3698-1/-2's linear dropout regulator output (LDOOUT) provides 5V output with 30mA typical load current capabilities.

IC Input

The AAT3698-1/-2 has an IC input pin that is internally connected to ground through a 100kΩ resistor. Float or ground this pin for normal operation.

Application Information

Constant Charge Current

The constant current charge level is user programmed with a set resistor connected between the ISET pin and ground. The tolerance of the set resistor determines the accuracy of the constant charge current as well as the preconditioning trickle charge current. For this reason, a 1% tolerance metal film resistor is recommended for the set resistor function. The constant charge current level from 100mA to 1.6A is set by selecting the appropriate resistor value from Table 4.

The approximate charge current ($I_{CH\_CC\_typ}$) can be found using the following formula:

$$I_{CH\_CC\_TYP} = \frac{V_{ISET}}{R_{ISET}} \cdot K_{ISET} = V_{ISET} \cdot GM_{OUT}$$

Where:

$$GM_{OUT} = \frac{I_{CH\_CC\_TYP}}{V_{ISET}} = \frac{K_{ISET}}{R_{SET}} = 250ms$$

When R_{SET} = 3.16kΩ and K_{ISET} = 790.

Typical Constant Charge Current (mA)	Set Resistor Value (kΩ)
50	31.6
100	15.8
200	7.87
400	3.92
500	3.16
600	2.67
800	1.96
1000	1.58
1580	1.00

Table 4: R_{SET} Values

Figure 3 shows the relationship of constant charging current and set resistor values for the AAT3698-1/-2.

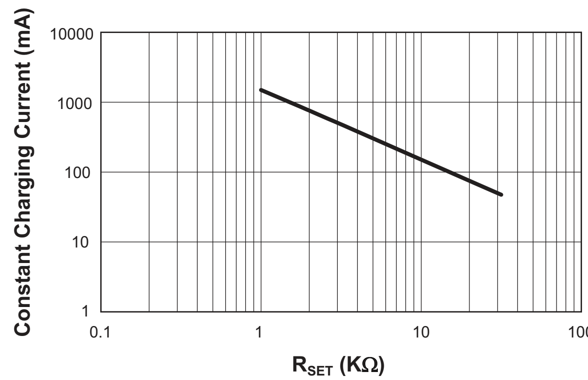

Figure 3: Constant Charging Current vs. Set Resistor Values.

Charge Termination Current

The charge termination current level is programmed by an external resistor (R_{TERM}) connected between the TERM pin and ground. Use the resistor values listed in Table 5 to set the desired charge termination current.

R_{TERM} (KΩ)	I_{CH_TERM} (%)
6.65	5%
13.3	10%
26.7	20%
40.2	30%
53.6	40%

Table 5: Charge Termination Current Programming Resistor Values.

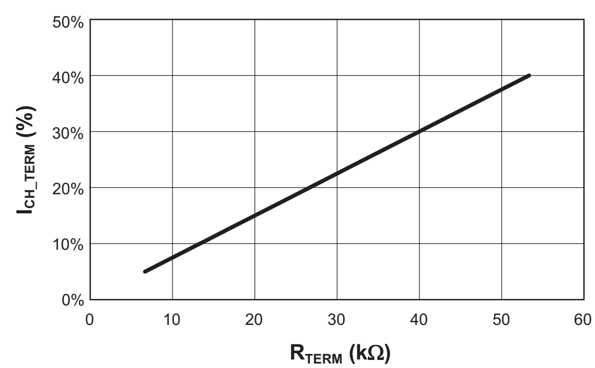

Figure 4: Charge Termination Current vs. R_{TERM}.

Use the following formula to set the charge termination current, I_{CH_TERM}.

$$I_{CH\_TERM} = \frac{15\mu A \cdot R_{TERM}}{2V} \cdot I_{CH\_CC}$$

I_{CH_TERM} is set by default to 10% of I_{CH_CC} when the TERM pin is connected to the INCHR pin.

When the charge current reaches the termination current, the $\overline{STAT}$ pin will be set to high impedance, but the charge termination current will continue to flow until the $\overline{EN}$ pin is toggled high. To set charge termination current threshold to the lowest level, connect the TERM pin to ground.

Battery Connection

A single cell Li-Ion/Polymer battery should be connected between the BAT pin and ground.

Status Indicator Display

Simple system charging status can be displayed using a single LED in conjunction with the AAT3698-1/-2's $\overline{STAT}$ pin. This pin has a simple switch connecting the LED's cathode to ground. Refer to Table 1 for LED display definitions. The LED anodes should be connected to INCHR or other system power supply that does not exceed 7V, depending upon system design requirements. The LED should be biased with as little current as necessary to create reasonable illumination; therefore, a ballast resistor should be placed between the LED cathode and the $\overline{STAT}$ pin. LED current consumption will add to the overall thermal power budget for the device package, so it is wise to keep the LED drive current to a minimum. 2mA should be sufficient to drive most low-cost green or red LEDs. Driving an individual status LED with over 8mA is not recommended.

The required ballast resistor value can be estimated using the following formulas:

When connecting to the adapter supply with a red LED:

$$R_{B(\overline{STAT})} = \frac{V_{ADP} - V_{F(LED)}}{I_{LED(\overline{STAT})}}$$

Example:

$$R_{B(\overline{STAT})} = \frac{5.5V - 2.0V}{2mA} = 1.75k\Omega$$

Note: Red LED forward voltage (V_F) is typically 2.0V @ 2mA.

When connecting to the USB supply with a green LED:

$$R_{B(\overline{STAT})} = \frac{V_{USB} - V_{F(LED)}}{I_{LED(\overline{STAT})}}$$

Example:

$$R_{B(\overline{STAT})} = \frac{5.0V - 3.2V}{2mA} = 900\Omega$$

Note: Green LED forward voltage (V_F) is typically 3.2V @ 2mA.

Capacitor Selection

Input Capacitor (IN)

A 1μF or larger capacitor is typically recommended for C_{IN}. C_{IN} should be located as close to the device IN pin as practically possible. Ceramic, tantalum, or aluminum electrolytic capacitors may be selected for C_{IN}. There is no specific capacitor equivalent series resistance (ESR) requirement for C_{IN}. However, for higher current operation, ceramic capacitors are recommended for C_{IN} due to their inherent capability over tantalum capacitors to withstand input current surges from low impedance sources such as batteries in portable devices.

Typically, 50V rated capacitors are required for the application to prevent any surge voltage. Ceramic capacitors selected as small as 1206 are available which can meet these requirements. Capacitors with other voltage rating can also be used for known input voltage applications.

Charger Input Capacitor (INCHR)

A 1μF decoupling capacitor is recommended to be placed between INCHR and GND. This capacitor should be located as closely and routed as directly as practically possible to the device's INCHR pin with a good ground return path for maximum device over-voltage protection performance.

Charger Output Capacitor (BAT)

The AAT3698-1/-2 only requires a 1μF ceramic capacitor on the BAT pin to maintain circuit stability. This value should be increased to 10μF or more if the battery connection is made at any distance from the charger output. If the AAT3698-1/-2 is used in applications where the battery can be removed from the charger, such as desktop charging cradles, an output capacitor greater than 10μF may be required to prevent the device from cycling on and off when no battery is present.

Linear Regulator Output Capacitor (LDOOUT)

For proper load voltage regulation and operational stability, a capacitor is required between LDOOUT and GND. The output capacitor connection to the LDO regulator ground pin should be made as directly as practically possible for maximum device performance. Since the regulator has been designed to function with very low ESR capacitors, multilayer ceramic capacitors in the 1.0μF to 10μF range are recommended for best performance. Applications utilizing the exceptionally low output noise and optimum power supply ripple rejection of the AAT3698-1/-2 should use a value of 2.2μF or greater for the LDO's output capacitor.

Printed Circuit Board Layout Recommendations

For proper thermal management and to take advantage of the low $R_{DS(ON)}$ of the AAT3698-1/-2, a few circuit board layout rules should be followed: IN and BAT should be routed using wider than normal traces, and GND should be connected to a ground plane. To maximize package thermal dissipation and power handling capacity of the AAT3698-1/-2 TDFN33-14 package, solder the exposed paddle of the IC to the thermal landing of the PCB, where the thermal landing is connected to the ground plane. If heat is still an issue, multi-layer boards with dedicated ground planes are recommended. Also, adding more thermal via holes on the thermal landing would help transfer heat to the PCB effectively.

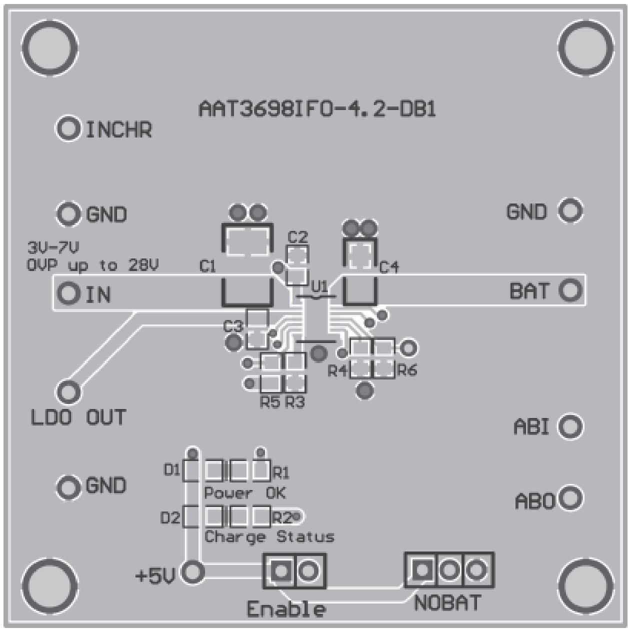

Figure 5: AAT3698-1/-2 Evaluation Board Top Side Layout.

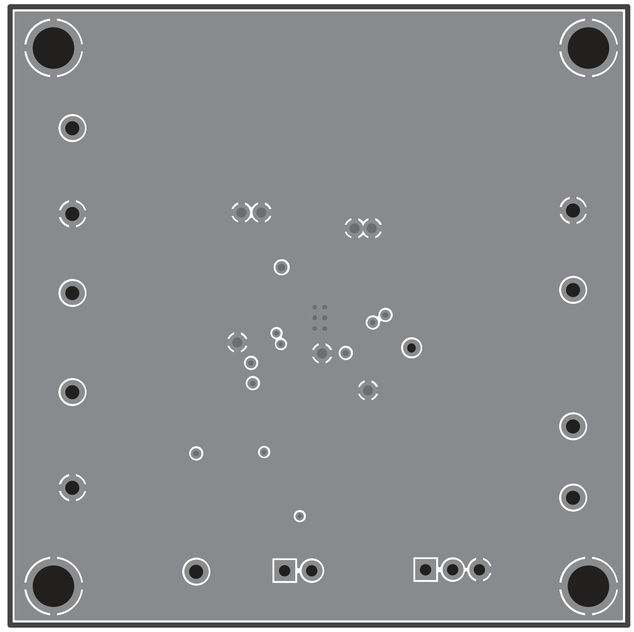

Figure 6: AAT3698-1/-2 Evaluation Board Mid1 Layer Layout.

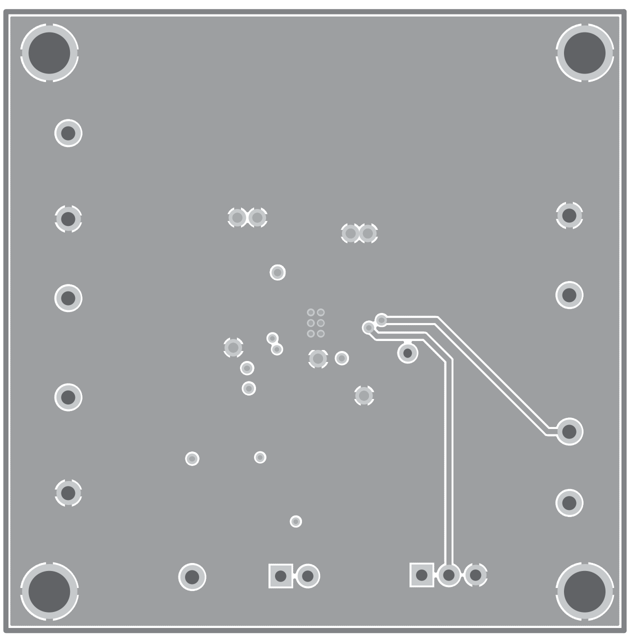

Figure 7: AAT3698-1/-2 Evaluation Board Mid2 Layer Layout.

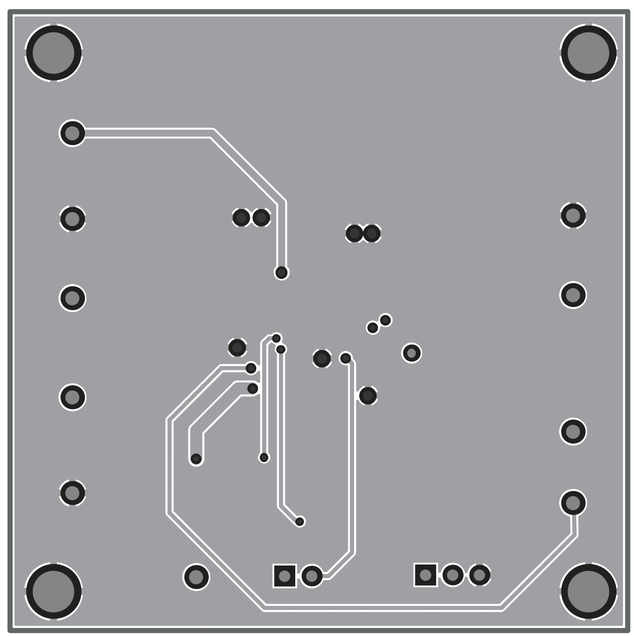

Figure 8: AAT3698-1/-2 Evaluation Board Bottom Side Layout.

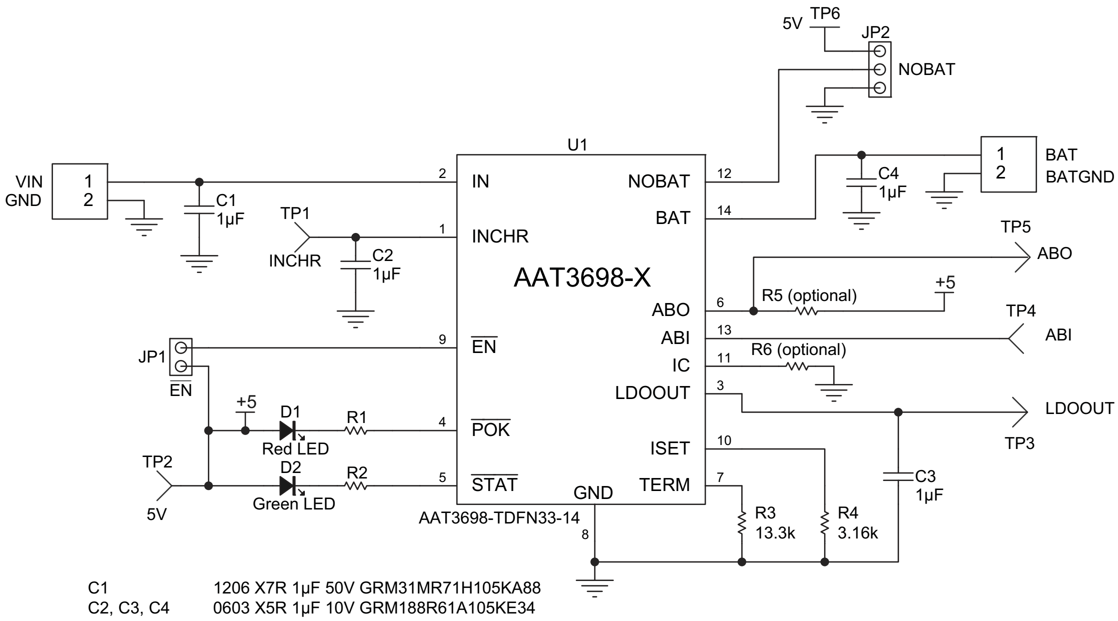

Figure 7: AAT3698-1/-2 Evaluation Board Schematic.

Component	Part Number	Description	Manufacturer
U1	AAT3698IWO-1/-2	1.6A Linear Li-Ion/Polymer Battery Charger in TDFN33-14 Package	Skyworks
C1	GRM31MR71H105KA88	Ceramic 1µF/50V, 10%, X7R, 1206	Murata
C2, C3, C4	GRM188R61A105KE34	Ceramic 1µF/10V, 10%, X5R, 0603	Murata
R1, R2	Chip Resistor	1.5kΩ, 5%, 1/4W, 0603	Vishay
R3	Chip Resistor	13.3kΩ, 1%, 1/4W, 0603	Vishay
R4	Chip Resistor	1.58kΩ, 1%, 1/4W, 0603	Vishay
R5	Chip Resistor	10kΩ, 1%, 1/4W, 0603	Vishay
R6	Chip Resistor	0Ω, 5%, 1/4W, 0603	Vishay
D1	LST-C190CKT	Red LED, 0603	Lite-On Inc.
D2	LST-C190GKT	Green LED, 0603	Lite-On Inc.
JP1, JP2	PRPN401PAEN	Conn. Header, 2mm zip	Sullins Electronics

Table 6: AAT3698-1/-2 Evaluation Board Bill of Materials (BOM).

Product	Constant Regulated Output Voltage (V)	Automatic Charge Termination and Recharge Sequencing when $I_{BAT} \leq I_{TERM}$	Input OVP Trip Point (V)	Preconditioning Voltage Threshold (V)
AAT3698-1	4.2	Yes	7.25	2.6
AAT3698-2	4.2	No	7.25	2.6

Table 7: AAT3698 Options.

Ordering Information

Product	Package	Marking[1]	Part Number (Tape and Reel)[2]
AAT3698-1	TDFN33-14	A5XYY	**AAT3698IWO-4.2-1-T1**
AAT3698-2	TDFN33-14	D6XYY	**AAT3698IWO-4.2-2-T1**

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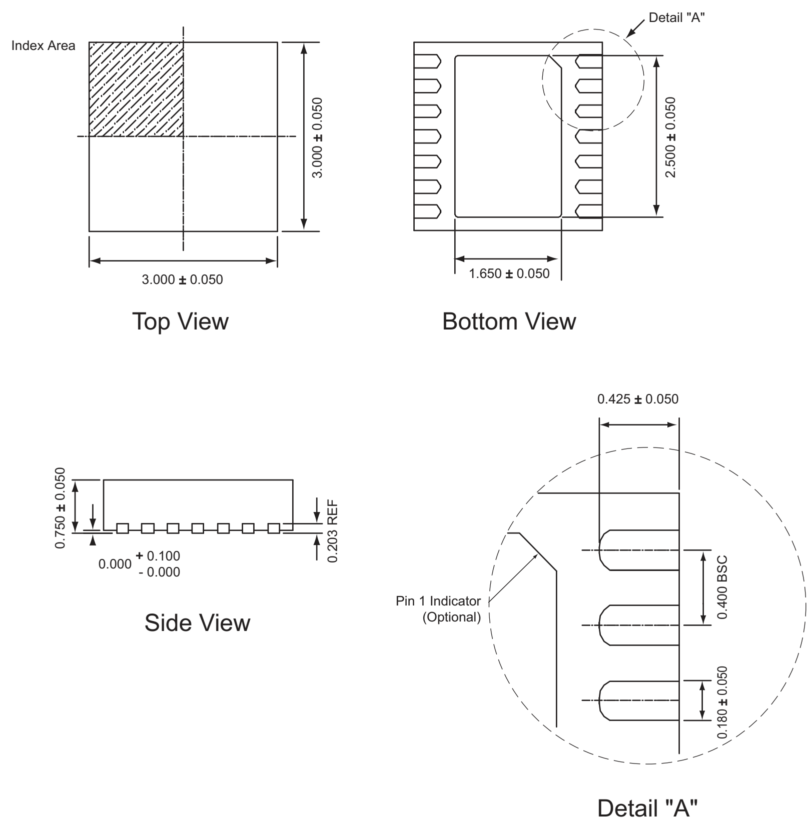
Package Information

TDFN33-14



All dimensions in millimeters.

1. XYY = assembly and date code.
2. Sample stock is generally held on part numbers listed in **BOLD**.
3. The leadless package family, which includes QFN, TQFN, DFN, TDFN and STDFN, has exposed copper (unplated) at the end of the lead terminals due to the manufacturing process. A solder fillet at the exposed copper edge cannot be guaranteed and is not required to ensure a proper bottom solder connection.

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