ANALOGIC TECH

BatteryManager™

General Description

The AAT3680 BatteryManager is a member of AnalogicTech's Total Power Management IC™ (TPMIC™) product family. This device is a lithium-ion/polymer battery charge and management IC, specifically designed for compact portable applications. The AAT3680 precisely regulates battery charge voltage and charge current, and is capable of two trickle charge current levels controlled by one external pin. Battery charge temperature and charge state are carefully monitored for fault conditions. In the event of an over-current, short-circuit, or over-temperature failure, the device will automatically shut down, protecting the charging device and the battery under charge. A battery charge state monitor output pin is provided to indicate the battery charge status through a display LED. The battery charge status output is a serial interface which may also be read by a system microcontroller.

The AAT3680 is available in a Pb-free, 8-pin MSOP or 12-pin TSOPJW package, specified over the -20°C to +70°C temperature range.
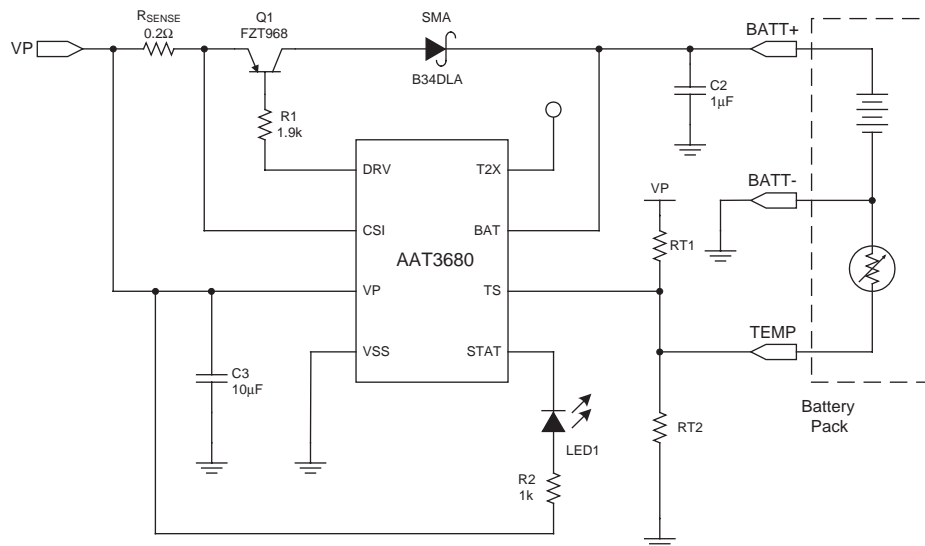
Features

• Input Voltage Range: 4.5V to 7V
• 1% Accurate Preset Voltages: 4.1V, 4.2V
• Low Operation Current, Typically 0.5mA
• Programmable Charge Current
• Automatic Recharge Sequencing
• Battery Temperature Monitoring
• Deep Discharge Cell Conditioning
• Fast Trickle Charge Option with Thermal Over-Ride
• Full Battery Charge Auto Turn-Off / Sleep Mode
• Over-Voltage, Over-Current, and Over-Temperature Protection
• Power On Reset
• LED Charge Status Output or System Microcontroller Serial Interface
• Temperature Range: -20°C to +70°C
• 8-Pin MSOP or 12-Pin TSOPJW Package

Applications

• Cellular Phones
• Desktop Chargers
• Personal Digital Assistants (PDAs)
• USB Chargers

Typical Application

Pin Description

Pin #		Symbol	Function
TSOPJW-12	**MSOP-8**		
1	8	BAT	Battery voltage level sense input.
2	7	CSI	Current sense input.
3	N/A	N/C	Not connected.
4	6	T2X	2X battery trickle charge control input. Connect this pin to VSS to double the battery trickle charge current. Leave this pin floating for normal trickle charge current (10% of full charge current). To enter microcontroller fast-read status, pull this pin high during power-up.
5	5	DRV	Battery charge control output.
6	4	VSS	Common ground connection.
7	3	STAT	Battery charge status output. Connect an LED in series with 2.2kΩ from STAT to VP to monitor battery charge state.
8, 9, 10, 11	1	VP	Power supply input pin.
12	2	TS	Battery temperature sense input.

Pin Configuration

TSOPJW-12
(Top View)
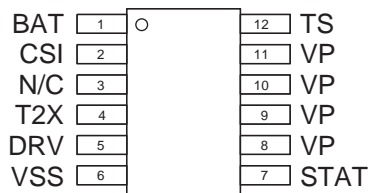
MSOP-8
(Top View)
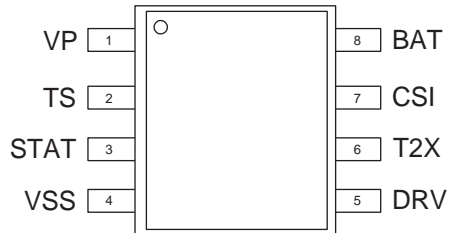
Absolute Maximum Ratings[1]

T_A=25°C, unless otherwise noted.

Symbol	Description	Value	Units
V_P	V_P Relative to V_{SS}	-0.3 to 7.5	V
V_{CSI}	CSI to GND	-0.3 to V_P + 0.3	V
V_{T2X}	T2X to GND	-0.3 to 5.5	V
V_{BAT}	BAT to GND	-0.3 to V_P + 0.3	V
T_J	Operating Junction Temperature Range	-40 to 150	°C
ESD	ESD Rating	Note 2	kV

Thermal Information[3]

Symbol	Description		Value	Units
Θ_{JA}	Maximum Thermal Resistance	TSOPJW-12	120	°C/W
		MSOP-8	150	
P_D	Maximum Power Dissipation	TSOPJW-12	1.0	W
		MSOP-8	833	mW

Recommended Operating Conditions

Symbol	Description	Conditions	Min	Typ	Max	Units
V_P	Operation Input Voltage		4.5		7.0	V
I_{DRV}	DRV Pin Sink Current				40	mA
T	Ambient Temperature Range		-20		70	°C

1. Stresses above those listed in Absolute Maximum Ratings may cause permanent damage to the device. Functional operation at conditions other than the conditions specified is not implied. Only one Absolute Maximum Rating should be applied at any one time.
2. IC devices are inherently ESD sensitive; handling precautions required.
3. Mounted on an FR4 printed circuit board.

Electrical Characteristics

V_{IN} = 4.5V to 5.5V, T_A = -20°C to 70°C, unless otherwise noted; typical values are at T_A = 25°C.

Symbol	Description	Conditions		Min	Typ	Max	Units
I_P	Operating Current	V_{IN} = 5.5V, V_{CH} = 4.1V, V_{CH} = 4.2V			0.5	3	mA
I_{SLEEP}	Sleep Mode Current	V_{IN} = 3.5V, V_{CH} = 4.1V, V_{CH} = 4.2V			2	6	µA
$I_{STAT(HI)}$	STAT High-Level Output Leakage Current	V_{IN} = 5.5V		-1		+1	µA
$V_{STAT(LOW)}$	STAT Low-Level Sink Current	V_{IN} = 5.5V, I_{SINK} = 5mA			0.3	0.6	V
I_{SINK}	DRV Pin Sink Current	V_{IN} = 5.5V		20			mA
$V_{OL@DRV}$	DRV Pin Output Low	I_{SINK} = 5mA, V_{IN} = 5.5V			0.4	1.0	V
V_{CH}	Output Charge Voltage	AAT3680-4.1	T_A = 25°C	4.075	4.100	4.125	V
			See Note 1	4.059	4.100	4.141	
		AAT3680-4.2	T_A = 25°C	4.175	4.200	4.225	
			See Note 1	4.158	4.200	4.242	
V_{CS}	Charge Current Regulation	V_{IN} = 5.5V, V_{CH} = 4.1V, V_{CH} = 4.2V		90	100	110	mV
V_{MIN}	Preconditioning Voltage Threshold	AAT3680-4.1		2.94	3.0	3.06	V
		AAT3680-4.2		3.04	3.1	3.16	
$V_{TRICKLE}$	Trickle-Charge Current Regulation	T2X Floating, V_{CH} = 4.1V, V_{CH} = 4.2V			10		mV
T_{2X}	Trickle Charge Current Gain	T2X = V_{SS}			1.8		
V_{TS1}	Low-Temperature Threshold	V_{IN} = 5.5V		29.1	30	30.9	% V_P
V_{TS2}	High-Temperature Threshold	V_{IN} = 5.5V		58.2	60	61.8	% V_P
V_{TERM}	Charge Termination Threshold Voltage			4	12	24	mV
V_{RCH}	Battery Recharge Voltage Threshold	V_{CH} = 4.1V		3.92	4.00	4.08	V
		V_{CH} = 4.2V		4.018	4.10	4.182	
V_{UVLO}	Under-Voltage Lockout	V_{IN} Rising, T_A = 25°C		3.5	4.0	4.5	V
V_{OVP}	Over-Voltage Protection Threshold				4.4		V
V_{OCP}	Over-Current Protection Threshold				200		% V_{CS}

1. The AAT3680 output charge voltage is specified over 0° to 50°C ambient temperature; operation over -20°C to +70°C is guaranteed by design.

Functional Block Diagram
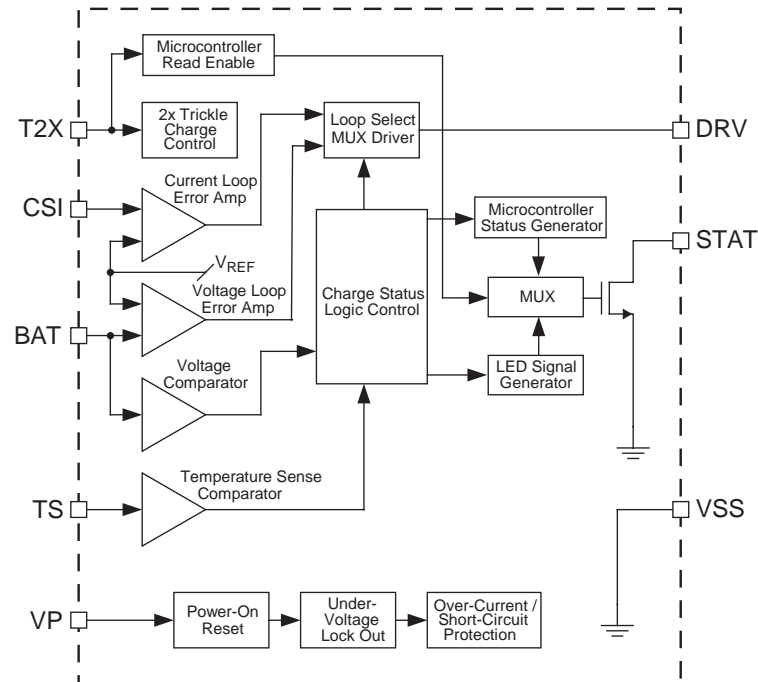
Functional Description

The AAT3680 is a linear charge controller designed for single-cell lithium-ion/polymer batteries. It is a full-featured battery management system IC with multiple levels of integrated power savings, system communication, and protection. Refer to the block diagram (above) and flow chart (Figure 1) in this section for details.

Cell Preconditioning

Before the start of charging, the AAT3680 checks several conditions in order to maintain a safe charging environment. The input supply must be above the minimum operating voltage, or under-voltage lockout threshold (V_{UVLO}), for the charging sequence to begin. Also, the cell temperature, as reported by a thermistor connected to the TS pin, must be within the proper window for safe charging. When these conditions have been met and a battery is connected to the BAT pin, the AAT3680 checks the state of the battery. If the cell voltage is below V_{MIN}, the AAT3680 begins preconditioning the cell. This is performed by charging the cell with 10% of the programmed constant current. For

example, if the programmed charge current is 500mA, then the preconditioning mode (trickle charge) current will be 50mA. Cell preconditioning is a safety precaution for deeply discharged cells and, furthermore, limits power dissipation in the pass transistor when the voltage across the device is largest. The AAT3680 features an optional T2X mode, which allows faster trickle charging at approximately two times the default rate. This mode is selected by connecting the T2X pin to V_{SS}. If an over-temperature fault is triggered, the fast trickle charge will be latched off, and the AAT3680 will continue at the default 10% charge current.

Constant Current Charging

Cell preconditioning continues until the voltage on the BAT pin reaches V_{MIN}. At this point, the AAT3680 begins constant current charging (fast charging). Current level for this mode is programmed using a current sense resistor R_{SENSE} between the VP and CSI pins. The CSI pin monitors the voltage across R_{SENSE} to provide feedback for the current control loop. The AAT3680 remains in constant current charge mode until the battery reaches the voltage regulation point, V_{CH}.

Constant Voltage Charging

When the battery voltage reaches V_{CH} during constant current mode, the AAT3680 transitions to constant voltage mode. The regulation voltage is factory programmed: 4.1V and 4.2V are available to support different anode materials in lithium-ion/polymer cells. In constant voltage operation, the AAT3680 monitors the cell voltage and terminates the charging cycle when the voltage across R_{SENSE} decreases to approximately 10mV.

Charge Cycle Termination, Recharge Sequence

After the charge cycle is complete, the AAT3680 latches off the pass device and automatically enters power-saving sleep mode. Either of two possible conditions will bring the IC out of sleep mode: the battery voltage at the BAT pin drops below V_{RCH} (recharge threshold voltage) or the AAT3680 is reset by cycling the input supply through the power-on sequence. Falling below V_{RCH} signals the IC that it is time to initiate a new charge cycle.
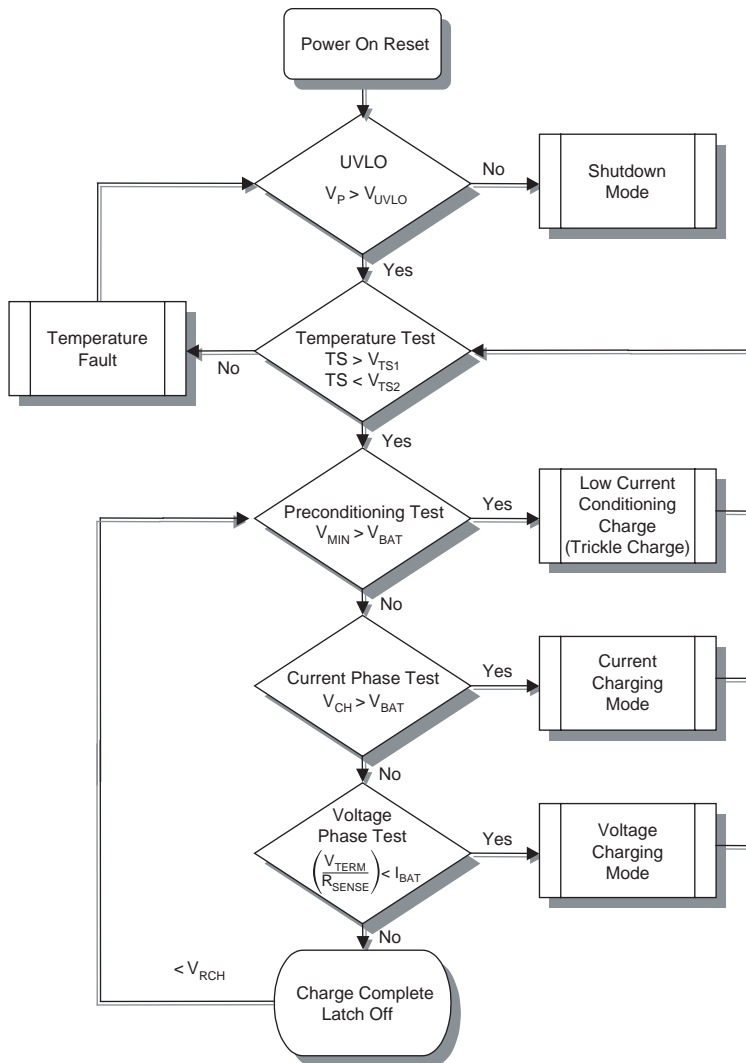

Figure 1: AAT3680 Operational Flow Chart.

Sleep Mode

When the input supply is disconnected, the charger automatically enters power-saving sleep mode. Only consuming an ultra-low 2µA in sleep mode, the AAT3680 minimizes battery drain when it is not charging. This feature is particularly useful in applications where the input supply level may fall below the battery charge or under-voltage lockout level. In such cases, where the AAT3680 input voltage drops, the device will enter sleep mode and automatically resume charging once the input supply has recovered from its fault condition. This makes the AAT3680 well suited for USB battery charger applications.

Charge Inhibit

The AAT3680 charging cycle is fully automatic; however, it is possible to stop the device from charging even when all conditions are met for proper charging. Switching the TS pin to either VP or VSS will force the AAT3680 to turn off the pass device and wait for a voltage between the low- and high-temperature voltage thresholds.

Resuming Charge and the V_{RCH} Threshold

The AAT3680 will automatically resume charging under most conditions when a battery charge cycle is interrupted. Events such as an input supply interruption or under voltage, removal and replacement of the battery under charge, or charging a partially drained battery are all possible. The AAT3680 will monitor the battery voltage and automatically resume charging in the appropriate mode based upon the measured battery cell voltage. This feature is useful for systems with an unstable input supply, which could be the case when powering a charger from a USB bus supply. This feature is also beneficial for charging or "topping off" partially discharged batteries.

The only restriction on resuming charge of a battery is that the battery cell voltage must be below the battery recharge voltage threshold (V_{RCH}) specification. There is V_{RCH} threshold hysteresis built into the charge control system. This is done to prevent the charger from erroneously turning on and off once a battery charge cycle is complete.

For example, the AAT3680-4.2 has a typical V_{RCH} threshold of 4.1V. A battery under charge is above 4.1V, but is still in the constant voltage mode because it has not yet reached 4.2V to complete the charge cycle. If the battery is removed and then placed back on the charger, the charge cycle will not resume until the battery voltage drops below the V_{RCH} threshold.

In another case, a battery under charge is in the constant current mode and the cell voltage is 3.7V when the input supply is inadvertently removed and then restored. The battery is below the V_{RCH} threshold and the charge cycle will immediately resume where it left off.

LED Display

Charge Status Output

The AAT3680 provides a battery charge status output via the STAT pin. STAT is an open-drain serial data output capable of displaying five distinct status functions with one LED connected between the STAT pin and VP. There are four periods which determine a status word. Under default conditions, each output period is one second long; thus, one status word will take four seconds to display through an LED.

The five modes include:

1. Sleep/Charge Complete: The IC goes into sleep mode when no battery is present -OR- when the charge cycle is complete.
2. Fault: When an over-current (OC) condition is detected by the current sense and control circuit -OR- when an over-voltage (OV) condition is detected at the BAT pin -OR- when a battery over-temperature fault is detected on the TEMP pin.
3. Battery Conditioning: When the charge system is in the 1X or 2X trickle charge mode.
4. Constant Current (CC) Mode: When the system is in the constant current charge mode.
5. Constant Voltage (CV) Mode: When the system is in the constant voltage charge mode.

An additional feature of the LED status display is for a Battery Not Detected state. When the AAT3680 senses there is no battery connected to the BAT pin, the STAT output will turn the LED on and off at a rate dependent on the size of the output capacitor being used. The LED cycles on for two periods then remains off for two periods. See Figure 2.

Charge Status	Output Status	LED Display			
		on/off	on/off	on/off	on/off
Sleep / Charge Complete	off / off / off / off	ON / OFF			
Temp., OC, OV Fault	on / on / off / off	ON / OFF			
Battery Conditioning	on / on / on / on	ON / OFF			
Constant Current Mode	on / on / on / off	ON / OFF			
Constant Voltage Mode	on / off / off / off	ON / OFF			

Figure 2: LED Display Output.

High-Speed Data Reporting

A high-speed data reporting application schematic is shown in Figure 3. An optional system microcontroller interface can be enabled by pulling up the T2X pin to 4.5V to 5.5V during the power-up sequence. The T2X pin should be pulled high with the use of a 100kΩ resistor. If the input supply to VP will not exceed 5.5V, then the T2X pin may be tied directly to VP through a 100kΩ resistor. Since this is a TTL-level circuit, it may not be pulled higher than 5.5V without risk of damage to the device.

When the high-speed data report feature is enabled, the STAT output periods are sped up to 40μs, making the total status word 160μs in length (see Figure 4).

An additional feature is the Output Status for Battery Not Detected state. When the AAT3680 senses there is no battery connected to the BAT pin, the STAT pin cycles for two periods, then remains off for two periods.

When in high-speed data reporting, the AAT3680 will only trickle charge at the 2X trickle charge level. This is because the TX2 pin is pulled high to enable the high-speed data reporting.

A status display LED may not be connected to the STAT pin when the high-speed data reporting is being utilized. If both display modes are required, the display LED must be switched out of the circuit before the T2X pin is pulled high. Failing to do so could cause problems with the high-speed switching control circuits internal to the AAT3680.
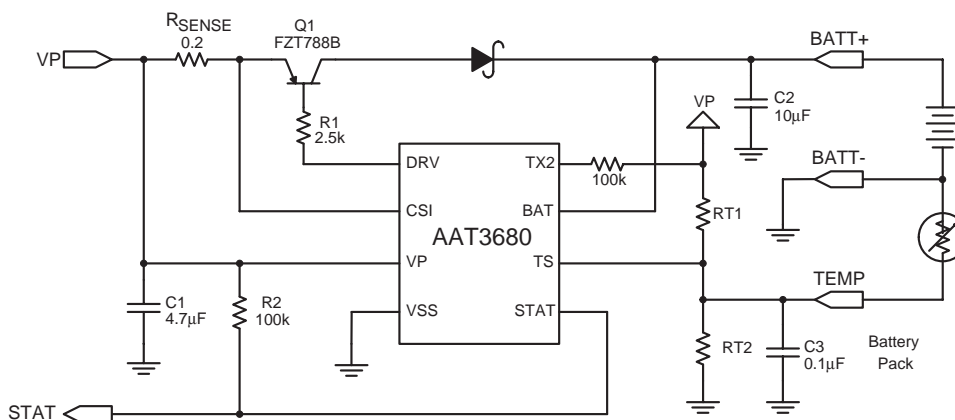

Figure 3: High-Speed Data Reporting Application Schematic.

Charge Status	Output Status	STAT Level			
Sleep / Charge Complete	HI / HI / HI / HI				
Temp., OC, OV Fault	LO / LO / HI / HI				
Battery Conditioning	LO / LO / LO / LO				
Constant Current Mode	LO / LO / LO / HI				
Constant Voltage Mode	LO / HI / HI / HI				

Figure 4: Microcontroller Interface Logic Output.

Protection Circuitry

The AAT3680 is a highly integrated battery management system IC including several protection features. In addition to battery temperature monitoring, the IC constantly monitors for over-current and over-voltage conditions. If an over-current situation occurs, the AAT3680 latches off the pass device to prevent damage to the battery or the system, and enters shutdown mode until the over-current event is terminated.

An over-voltage condition is defined as a condition where the voltage on the BAT pin exceeds the maximum battery charge voltage. If an over-voltage condition occurs, the IC turns off the pass device until voltage on the BAT pin drops below the maximum battery charge constant voltage threshold. The AAT3680 will resume normal operation after the over-current or over-voltage condition is removed. During an over-current or over-voltage event, the STAT will report a FAULT signal.

In the event of a battery over-temperature condition, the IC will turn off the pass device and report a FAULT signal on the STAT pin. After the system recovers from a temperature fault, the IC will resume operation in the 1X trickle charge mode to prevent damage to the system in the event a defective battery is placed under charge. Once the battery voltage rises above the trickle charge to constant current charge threshold, the IC will resume the constant current mode.
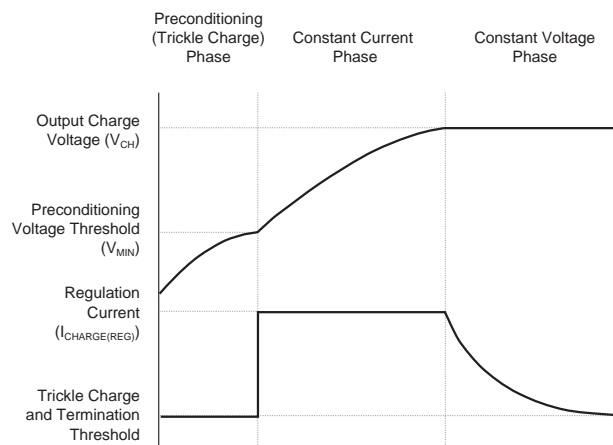

Figure 5: Typical Charge Profile.

Applications Information

Choosing an External Pass Device (PNP or PMOS)

The AAT3680 is designed to work with either a PNP transistor or P-channel power MOSFET. Selecting one or the other requires looking at the design tradeoffs, including performance versus cost issues. Refer to the following design guide for selecting the proper device.

PNP Transistor

In this design example, we will use the following conditions: V_P = 5V (with 10% supply tolerance), $I_{CHARGE(REG)}$ = 600mA, 4.2V single cell lithium-ion pack. V_P is the input voltage to the AAT3680, and $I_{CHARGE(REG)}$ is the desired fast-charge current.

1. The first step is to determine the maximum power dissipation (P_D) in the pass transistor. Worst case is when the input voltage is the highest and the battery voltage is the lowest during fast-charge (this is referred to as V_{MIN}, nominally 3.1V when the AAT3680-4.2 transitions from trickle charge to constant current mode). In this equation, V_{CS} is the voltage across R_{SENSE}.

$$P_D = (V_{P(MAX)} - V_{CS} - V_{MIN}) \cdot I_{CHARGE(REG)}$$

$$= (5.5V - 0.1V - 3.1V) \cdot 600mA$$

$$= 1.38W$$

2. The next step is to determine which size package is needed to keep the junction temperature below its rated value, $T_{J(MAX)}$. Using this value and the maximum ambient temperature inside the system $T_{A(MAX)}$, calculate the thermal resistance $R_{\theta JA}$ required:

$$R_{\theta JA} = \frac{(T_{J(MAX)} - T_{A(MAX)})}{P_D}$$

$$= \frac{(150 - 40)}{1.38}$$

$$= 80°C/W$$

It is recommended to choose a package with a lower $R_{\theta JA}$ than the number calculated above. A SOT223 package would be an acceptable choice, as it has an $R_{\theta JA}$ of 62.5°C/W when mounted to a PCB with adequately sized copper pad soldered to the heat tab.

3. Choose a collector-emitter (V_{CE}) voltage rating greater than the input voltage. In this example, V_P is 5.0V, so a 15V device is acceptable.

4. Choose a transistor with a collector current rating at least 50% greater than the programmed $I_{CHARGE(REG)}$ value. In this example, we would select a device with at least a 900mA rating.

5. Calculate the required current gain (β or h_{FE}); β > 200:

$$\beta_{MIN} = \frac{I_{C(MAX)}}{I_{B(MIN)}}$$

$$= \frac{0.60}{0.02}$$

$$= 30$$

where $I_{C(MAX)}$ is the collector current (which is the same as $I_{CHARGE(REG)}$), and $I_{B(MIN)}$ is the minimum amount of base current drive shown in Electrical Characteristics as I_{SINK}. **Important Note:** The current gain (β or h_{FE}) can vary by a factor of three over temperature and drops off significantly with increased collector current. It is critical to select a transistor with β, at full current and lowest temperature, greater than the β_{MIN} calculated above.

In summary, select a PNP transistor with ratings $V_{CE} \geq 15V$, $R_{\theta JA} \leq 80°C/W$, $I_C \geq 900mA$, $\beta_{MIN} \geq 30$ in a SOT223 (or better thermal) package.

P-Channel Power MOSFET

The following conditions apply to Figure 6, for use with the AAT3680-4.2V version: V_P = 5V (with 10% supply tolerance), $I_{CHARGE(REG)}$ = 750mA, 0.4V Schottky diode, 4.2V single cell lithium-ion battery pack. V_P is the input voltage to the AAT3680, and $I_{CHARGE(REG)}$ is the desired fast-charge current.
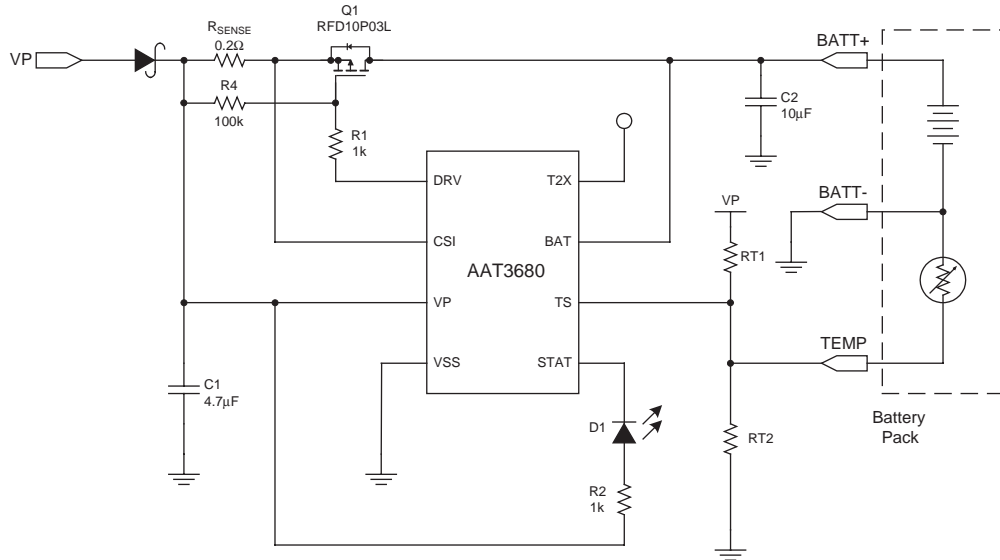
Figure 6: Typical Applications Schematic Using a P-Channel Power MOSFET with the AAT3680-4.2.

1. The first step is to determine the maximum power dissipation (P_D) in the pass transistor. Worst case is when the input voltage is the highest and the battery voltage is the lowest during fast-charge (this is referred to as V_{MIN}, nominally 3.1V when the AAT3680-4.2 transitions from trickle charge to constant current mode). In this equation, V_{CS} is the voltage across R_{SENSE}, and V_D is the voltage across the reverse current blocking diode. Refer to section below titled **Schottky Diode** for further details. Omit the value for V_D in the equation below if the diode is not used.

$$P_D = (V_{P(MAX)} - V_{CS} - V_D - V_{MIN}) \cdot I_{CHARGE(REG)}$$

$$= (5.5V - 0.1V - 0.4V - 3.1V) \cdot 750mA$$

$$= 1.4W$$

2. The next step is to determine which size package is needed to keep the junction temperature below its rated value, $T_{J(MAX)}$. Using this value, and the maximum ambient temperature inside the system $T_{A(MAX)}$, calculate the thermal resistance $R_{\theta JA}$ required:

$$R_{\theta JA} = \frac{(T_{J(MAX)} - T_{A(MAX)})}{P_D}$$

$$= \frac{(150 - 40)}{1.4}$$

$$= 79°C/W$$

It is recommended to choose a package with a lower $R_{\theta JA}$ than the number calculated above. A SOT223 package would be an acceptable choice, as it has an $R_{\theta JA}$ of 62.5°C/W when mounted to a PCB with an adequately sized copper pad soldered to the heat tab.

3. Choose a drain-source (V_{DS}) voltage rating greater than the input voltage. In this example, V_P is 5.0V, so a 12V device is acceptable.

4. Choose a MOSFET with a drain current rating at least 50% greater than the programmed $I_{CHARGE(REG)}$ value. In this example, we would select a device with at least a 1.125A rating.

5. Calculate the required threshold voltage to deliver $I_{CHARGE(REG)}$:

$$V_{GS} = (V_{CS} + V_{OL@DRV}) - V_{P(MIN)}$$

$$= (0.1V + 0.1V) - 4.5V$$

$$= -4.3V$$

where V_{GS} is the available gate-to-source voltage provided by the AAT3680, V_{CS} is the voltage across the sense resistor, $V_{OL@DRV}$ is the rated low voltage at the DRV pin, and $V_{P(MIN)}$ is the worst case input voltage (assuming 10% tolerance on the 5V supply). Choose a MOSFET device with sufficiently low $V_{GS(TH)}$ so the device will conduct the desired $I_{CHARGE(REG)}$.

6. Calculate the worst case maximum allowable $R_{DS(ON)}$ at worst case V_{GS} voltage:

$$R_{DS(ON)} = \frac{(V_{P(MIN)} - V_{CS(MAX)} - V_{BAT(MAX)})}{I_{CHARGE(REG)}}$$

$$= \frac{(4.5V - 0.11V - 4.242V)}{0.75A}$$

$$= 197m\Omega$$

Select a P-channel power MOSFET with $R_{DS(ON)}$ lower than 197mΩ at V_{GS} = -4.3V.

In summary, select a P-channel MOSFET with ratings $V_{DS} \geq 12V$, $R_{\theta JA} \leq 79°C/W$ and $R_{DS(ON)} \leq 197m\Omega$ at V_{GS} = -4.3V in a SOT223 (or better thermal) package.

Choosing a Sense Resistor

The charging rate recommended by lithium-ion/polymer cell vendors is normally 1C, with a 2C absolute maximum rating. Charging at the highest recommended rate offers the advantage of shortened charging time without decreasing the battery lifespan. This means that the suggested fast charge rate for a 500mAH battery pack is 500mA. The current sense resistor, R_{SENSE}, programs the charge current according to the following equation:

$$R_{SENSE} = \frac{(V_P - V_{CSI})}{I_{CHARGE(REG)}}$$

Where $I_{CHARGE(REG)}$ is the desired typical charge current during constant current charge mode. V_P-V_{CSI} is the voltage across R_{SENSE}, shown in the Electrical Characteristic table as V_{CS}. To program a nominal 500mA charge current during fast-charge, a 200mΩ value resistor should be selected. Calculate the worst case power dissipated in the sense resistor according to the following equation:

$$P = \frac{(V_{CS})^2}{R_{SENSE}}$$

$$= \frac{(0.1)^2}{0.2}$$

$$= 50mW$$

A 500mW LRC type sense resistor from IRC is adequate for this purpose. Higher value sense resistors can be used, decreasing the power dissipated in the sense resistor and pass transistor. The drawback of higher value sense resistors is that the charge cycle time is increased, so tradeoffs should be considered when optimizing the design.

Thermistor

The AAT3680 checks battery temperature before starting the charge cycle, as well as during all stages of charging. This is accomplished by monitoring the voltage at the TS pin. Either a negative temperature coefficient thermistor (NTC) or positive temperature coefficient thermistor (PTC) can be used because the AAT3680 checks to see that the voltage at TS is within a voltage window bounded by V_{TS1} and V_{TS2}. Please see the equations below for specifying resistors:

R_{T1} and R_{T2} for use with **NTC** Thermistor

$$R_{T1} = \frac{5 \cdot R_{TH} \cdot R_{TC}}{3 \cdot (R_{TC} - R_{TH})}$$

$$R_{T2} = \frac{5 \cdot R_{TH} \cdot R_{TC}}{(2 \cdot R_{TC}) - (7 \cdot R_{TH})}$$

R_{T1} and R_{T2} for use with **PTC** Thermistor

$$R_{T1} = \frac{5 \cdot R_{TH} \cdot R_{TC}}{3 \cdot (R_{TC} - R_{TH})}$$

$$R_{T2} = \frac{5 \cdot R_{TH} \cdot R_{TC}}{(2 \cdot R_{TH}) - (7 \cdot R_{TC})}$$

Where R_{TC} is the thermistor's cold temperature resistance and R_{TH} is the thermistor's hot temperature resistance. See thermistor specifications for information. To ensure there is no dependence on the input supply changes, connect the divider between V_P and V_{SS}. Disabling the temperature-monitoring function is achieved by applying a voltage between V_{TS1} and V_{TS2} on the TS pin.

Capacitor Selection

Input Capacitor
In general, it is good design practice to place a decoupling capacitor between the V_P and V_{SS} pins. An input capacitor in the range of 1μF to 10μF is recommended. If the source supply is unregulated, it may be necessary to increase the capacitance to keep the input voltage above the under-voltage lockout threshold.

If the AAT3680 is to be used in a system with an external power supply source, such as a typical AC-to-DC wall adapter, then a C_{IN} capacitor in the range of 10μF should be used. A larger input capacitor in this application will minimize switching or power bounce effects when the power supply is "hot plugged" in.

Output Capacitor
The AAT3680 does not need an output capacitor for stability of the device itself. However, a capacitor connected between BAT and V_{SS} will control the output voltage when the AAT3680 is powered up when no battery is connected. The AAT3680 can become unstable if a high impedance load is placed across the BAT pin to V_{SS}. Such a case is possible with aging lithium-ion/polymer battery cells. As cells age through repeated charge and discharge cycles, the internal impedance can rise over time. A 10μF or larger output capacitor will compensate for the adverse effects of a high-

impedance load and assure device stability over all operating conditions.

Operation Under No-Load Conditions
Under no-load conditions, that is when the AAT3680 is powered with no battery connected between the BAT pin and V_{SS}, the output capacitor is charged up very quickly by the trickle charge control circuit to the BAT pin until the output reaches the recharge threshold (V_{RCH}). At this point, the AAT3680 will drop into sleep mode. The output capacitor will discharge slowly by the capacitor's own internal leakage until the voltage seen at the BAT pin drops below the V_{RCH} threshold. This 100mV cycle will continue at approximately 3Hz with a 0.1μF capacitor connected. A larger capacitor value will produce a slower voltage cycle. This operation mode can be observed by viewing the STAT LED blinking on and off at the rate established by the C_{OUT} value.

For desktop charger applications, where it might not be desirable to have a "charger ready" blinking LED, a large C_{OUT} capacitor in the range of 100μF or more would prevent the operation of this mode.

Reverse Current Blocking Diode

Bipolar Circuit Application
When using the AAT3680 with a PNP transistor, a reverse blocking diode is not required because there is no current path from BAT to V_P. However, it is advisable to still place a blocking diode between the bipolar transistor collector and the BAT pin connection to the circuit output. In the event where the input supply is interrupted or removed during the constant current or constant voltage phases of the charging cycle, the battery under charge will discharge through the circuit pass transistor, rendering it impossible to turn off. If the circuit is unable to turn off, the reverse leakage will eventually discharge the battery. A blocking diode will prevent this undesirable effect.

MOSFET Circuit Application
A reverse blocking diode is generally required for the circuit shown in Figure 6. For this application, the blocking diode gives the system protection from a shorted input, when the AAT3680 is used

with a P-channel MOSFET. If there is no other protection in the system, a shorted input could discharge the battery through the body diode of the pass MOSFET. If a reverse-blocking diode is added to the system, a device should be chosen which can withstand the maximum constant current charge current at the maximum system ambient temperature.

Diode Selection
Typically, a Schottky diode is used in reverse current blocking applications with the AAT3680. Other lower cost rectifier type diodes may also be used if sufficient input power supply headroom is available.

The blocking diode selection should based on merits of the device forward voltage (V_F), current rating, and input supply level versus the maximum battery charge voltage and cost.

First, determine the minimum diode forward voltage drop requirement. Refer to the following equation:

$$V_{IN(MIN)} = V_{BAT(MAX)} + V_{F(TRAN)} + V_{F(DIODE)}$$

Where:

$V_{IN(MIN)}$ = Minimum input supply level

$V_{BAT(MAX)}$ = Maximum battery charge voltage required

$V_{F(TRAN)}$ = Pass transistor forward voltage drop

$V_{F(DIODE)}$ = Blocking diode forward voltage

Based on the maximum constant current charge level set for the system, the next step is to determine the minimum current rating and power handling capacity for the blocking diode. The constant-current charge level itself will dictate what the minimum current rating must be for a given blocking diode. The minimum power handling capacity must be calculated based on the constant current amplitude and the diode forward voltage (V_F):

$$P_{D(MIN)} = \frac{V_F}{I_{CC}}$$

Where:

$P_{D(MIN)}$ = Minimum power rating for a diode selection

V_F = Diode forward voltage

I_{CC} = Constant current charge level for the system

Schottky Diodes
Schottky diodes are selected for this application because they have a low forward voltage drop, typically between 0.3V and 0.4V. A lower V_F permits a lower voltage drop at the constant current charge level set by the system; less power will be dissipated in this element of the circuit. Schottky diodes allow for lower power dissipation, smaller component package sizes, and greater circuit layout densities.

Rectifier Diodes
Any general-purpose rectifier diode can be used with the AAT3680 application circuit in place of a higher cost Schottky diode. The design trade-off is that a rectifier diode has a high forward voltage drop. V_F for a typical silicon rectifier diode is in the range of 0.7V. A higher V_F will place an input supply voltage requirement for the battery charger system. This will also require a higher power rated diode since the voltage drop at the constant current charge amplitude will be greater. Refer to the previously stated equations to calculate the minimum V_{IN} and diode P_D for a given application.

PCB Layout

For the best results, it is recommended to physically place the battery pack as closely as possible to the AAT3680's BAT pin. To minimize voltage drops in the PCB, keep the high current carrying traces adequately wide. For maximum power dissipation in the pass transistor, it is critical to provide enough copper to spread the heat. Refer to the AAT3680 demo board PCB layout in Figures 8, 9, and 10.
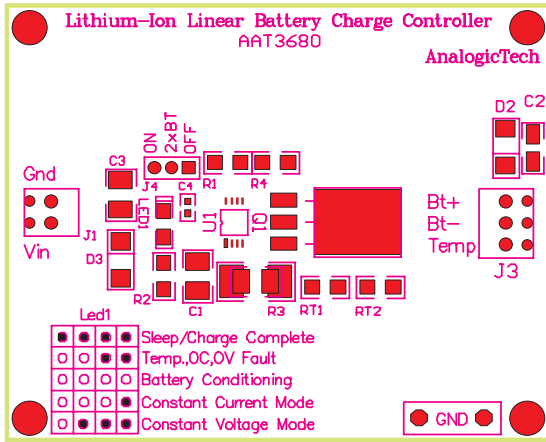
Evaluation Board Schematic

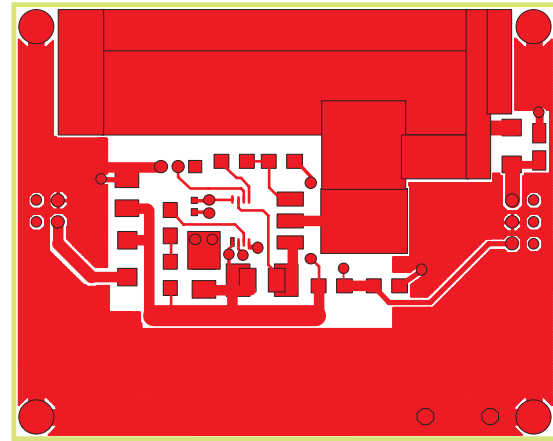**Figure 8: AAT3680 Demo Board Silk Screen / Assembly Drawing.**
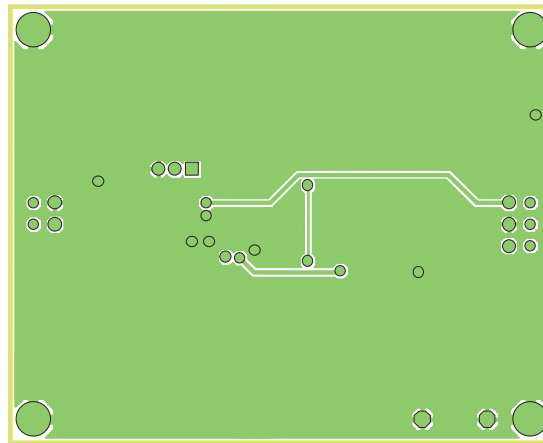

Figure 9: AAT3680 Demo Board Component Side Layout.

Figure 10: AAT3680 Demo Board Solder Side Layout.

Evaluation Board Bill of Materials

PNP Transistor Example

Designator	Part Type	Footprint	Manufacturer	Part Number
R3	0.2Ω, 0.5 Watt	1206	IRC	LRC1206-01-R200F
R2	1kΩ, 5%	1206	Various	
RT1	100kΩ, 5%	0805	Various	
RT2	100kΩ, 5%	0805	Various	
R1	3.9kΩ, 5%	0805	Various	
C2	1µF	1206	MuRata	
Header/SW1	2mm, 3 Pos		Sullins	PRPN031PAEN Select with Starting Jumper
C1	10µF	1206	MuRata	GRM42-6X5R75K10
C3	10µF	1206	MuRata	GRM42-6X5R106K16
R4	Not Populated			
U1	Li-Ion Charge Controller IC	MSOP-8	AnalogicTech	AAT3680IKS-4.2-T1
D1	Green LED	1206	Various	
D2	1.0A Schottky Diode	SMA	Diodes Inc.	B340LA
D3	0.0Ω Jumper			
Q1	PNP Transistor	SOT223	Zetex	F2T968

P-Channel Power MOSFET Example

Designator	Part Type	Footprint	Manufacturer	Part Number
R3	0.2Ω, 0.5W	1206	IRC	LRC1206-01-R200F
R2	1kΩ, 5%	1206	Various	
RT1	100kΩ, 5%	0805	Various	
RT2	100kΩ, 5%	0805	Various	
R1	1kΩ, 5%	0805	Various	
C2	1µF	1206	MuRata	
Header/SW1	2mm, 3 Pos		Sullins	PRPN031PAEN Select with Starting Jumper
C1	10µF	1206	MuRata	GRM42-6X5R75K10
C3	10µF	1206	MuRata	GRM42-6X5R106K16
R4	100kΩ, 5%	0805	Various	
U1	Li-Ion Charge Controller IC	MSOP-8	AnalogicTech	AAT3680IKS-4.2
D1	Green LED	1206	Various	
D2	0.0Ω Jumper			
D3	1.0A Schottky Diode	SMA	Diodes Inc.	B340LA
Q1	30V P-Ch MOSFET, 0.2Ω	TO-252	Various	RFD10P03L

Ordering Information

Output Voltage	Package	Marking[1]	Part Number (Tape and Reel)[2]
MSOP-8	4.2V	ESXYY	**AAT3680IKS-4.2-T1**
TSOPJW-12	4.2V	ESXYY	**AAT3680ITP-4.2-T1**

Pb-free

All AnalogicTech products are offered in Pb-free packaging. The term "Pb-free" means semiconductor products that are in compliance with current RoHS standards, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. For more information, please visit our website at http://www.analogictech.com/pbfree.

Package Information

MSOP-8
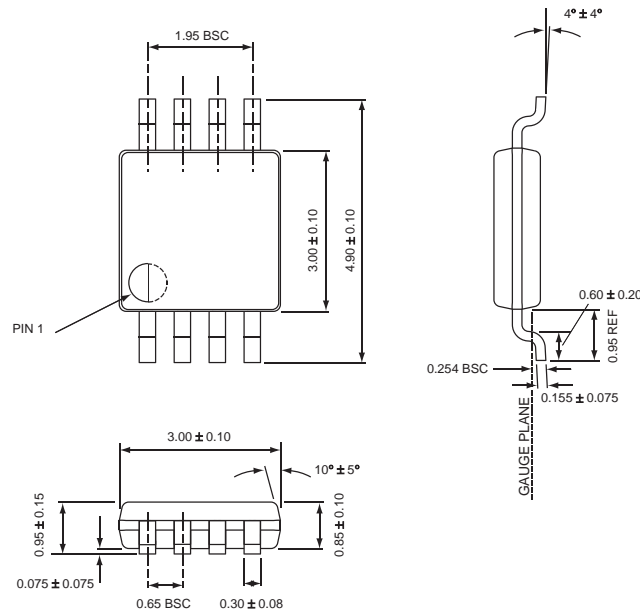
All dimensions in millimeters.

1. XYY = assembly and date code.
2. Sample stock is generally held on all part numbers listed in **BOLD**.

TSOPJW-12

$0.20\ ^{+\ 0.10}_{-\ 0.05}$

2.40 ± 0.10

2.85 ± 0.20

0.50 BSC 0.50 BSC 0.50 BSC 0.50 BSC 0.50 BSC

3.00 ± 0.10

0.9625 ± 0.0375

$1.00\ ^{+\ 0.10}_{-\ 0.065}$

0.055 ± 0.045

0.010

7° NOM

0.04 REF

0.15 ± 0.05

4° ± 4°

0.45 ± 0.15

2.75 ± 0.25

All dimensions in millimeters.