

DATA SHEET

# AAT3685: Li-Ion/Polymer Battery Charger

## Applications

- Cellular telephones
- Digital still cameras
- Hand-held PCs
- MP3 players
- Personal Data Assistants (PDAs)
- Other lithium-ion/polymer battery-powered devices

## Features

- Adapter or USB charger
  - Programmable up to 1 A max.
- 4.0 V to 5.5 V input voltage range
- High level of integration with internal:
  - Charging device
  - Reverse blocking diode
  - Current sensing
- Automatic recharge sequencing
- Charge reduction loop
- Battery temperature monitoring
- Full battery charge auto turn-off
- Over-voltage protection
- Emergency thermal protection
- Power on reset and soft start
- Serial interface status reporting
- Pb-free, thermally-enhance TDFN (12-pin, 3 mm × 3 mm) package (MSL1, 260 °C per JEDEC J-STD-020)

## Description

The AAT3685 BatteryManager™ is a highly integrated single cell lithium-ion/polymer battery charger IC designed to operate with USB port or line adapter inputs. It requires the minimum number of external components.

The AAT3685 precisely regulates battery charge voltage and current for 4.2 V lithium-ion/polymer battery cells. Regardless of the type of input power source (USB or adapter), the AAT3685 can be programmed for two separate constant current charge levels up to 1 A. An optional Charge Reduction Loop is built in to allow users to charge the battery with available current from the charge supply, while keeping the port voltage regulated.

Battery temperature and charge state are fully monitored for fault conditions. In the event of an over-voltage or over-temperature failure, the device will automatically shut down, thus protecting the charging device, control system, and the battery under charge. Status monitor output pins are provided to indicate the battery charge status by directly driving two external LEDs. A serial interface output is available to report any one of 14 various status states to a microcontroller.

The AAT3685 is available in a Pb-free, thermally-enhanced, space-saving 12-pin 3 × 3mm TDFN package and is rated over the -40 °C to +85 °C temperature range.

A typical application circuit is shown in Figure 1. The pin configurations are shown in Figure 2. Signal pin assignments and functional pin descriptions are provided in Table 1.



Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to *Skyworks Definition of Green™*, document number SQ04-0074.

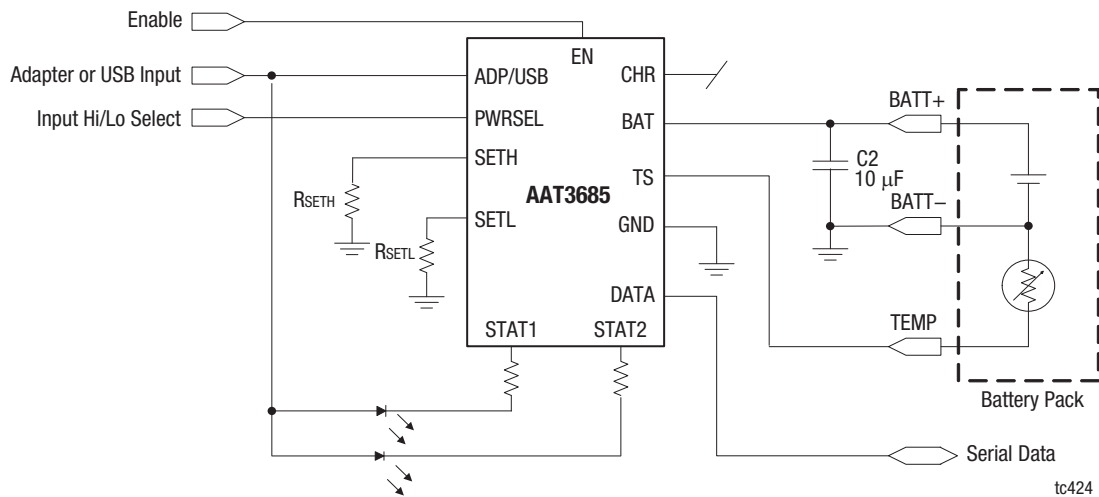


Figure 1. AAT3685 Typical Application Circuit

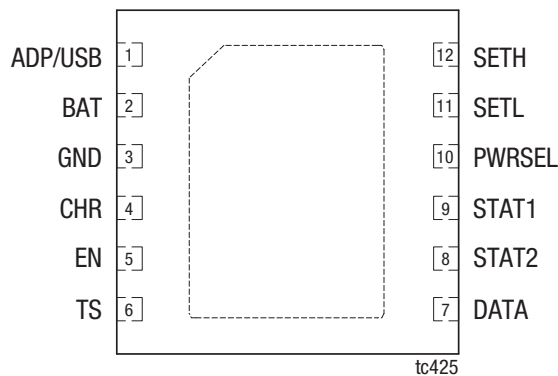


Figure 2. AAT3685 Pinout – 12-Pin, 3 mm x 3 mm TDFN (Top View)

Table 1. AAT3685 Signal Descriptions

Pin	Name	Type	Description
1	ADP/USB	In	Line adapter or USB power supply input.
2	BAT	In/Out	Battery charging and sensing.
3	GND	Ground	Ground connection.
4	CHR	In/Out	Resistor divider to set USB voltage regulation for charge reduction mode. Leave this pin open for default 4.5 V USB regulation point. Tie to ADP/USB pin to disable this function.
5	EN	In	Enable pin. Logic high enables the IC.
6	TS	In/Out	Connect to 10 kΩ NTC thermistor.
7	DATA	In/Out	Status report to microcontroller via serial interface, open-drain.
8	STAT2	Out	Battery charge status indicator pin to drive an LED: active low, open-drain.
9	STAT1	Out	Battery charge status indicator pin to drive an LED: active low, open-drain.
10	PWRSEL	In	When ADP/USB is present, use this pin to toggle between SETH and SETL charging levels.
11	SETL	In/Out	Connect resistor here to set charge current for low-current port.
12	SETH	In/Out	Connect resistor here to set charge current for high-current port.
EP			Exposed paddle (bottom); connect to GND directly beneath package.

## Electrical and Mechanical Specifications

Table 2 shows the AAT3685 feature options. The absolute maximum ratings of the AAT3685 are provided in Table 3, the thermal information is listed in Table 4, and electrical specifications are provided in Table 5.

Typical performance characteristics of the AAT3685 are illustrated in Figures 3 through 21.

**Table 2. AAT3685 Feature Options**

Part Number	Internal Pull-up Resistor on EN Pin	Can Leave TS Pin Open
AAT3685	No	No
AAT3685-1	Yes	Yes

**Table 3. AAT3685 Absolute Maximum Ratings (Note 1)**

Parameter	Symbol	Minimum	Typical	Maximum	Units
ADP/USB input voltage, <30 ms, duty cycle <10%	VADP	-0.3		7.0	V
ADP/USB input voltage, continuous	VADP	-0.3		6.0	V
BAT, PWRSEL, SETH, SETL, STAT1, STAT2, DATA, TS, CHR, EN	VN	-0.3		6.0	V
Operating junction temperature range	TJ	-40		+85	°C
Maximum soldering temperature (at leads)	TLEAD			300	°C

**Note 1:** Exposure to maximum rating conditions for extended periods may reduce device reliability. There is no damage to device with only one parameter set at the limit and all other parameters set at or below their nominal value. Exceeding any of the limits listed may result in permanent damage to the device.

**Table 4. AAT3685 Thermal Information**

Parameter	Symbol	Value	Units
Maximum thermal resistance (Note 1)	$\theta_{JA}$	50	°C/W
Maximum power dissipation	Pd	2	W

**Note 1:** Mounted on an FR4 board.

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**CAUTION:** Although this device is designed to be as robust as possible, electrostatic discharge (ESD) can damage this device. This device must be protected at all times from ESD. Static charges may easily produce potentials of several kilovolts on the human body or equipment, which can discharge without detection. Industry-standard ESD precautions should be used at all times.

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**Table 5. AAT3685 Electrical Specifications (1 of 2) (Note 1)**  
(V<sub>ADP</sub> = 5 V, T<sub>A</sub> = -40 °C to +85 °C. Unless Otherwise Noted, Typical Values are T<sub>A</sub> = 25 °C)

Parameter	Symbol	Test Condition	Min	Typical	Max	Units
<b>Operation</b>						
Input voltage range	ADP/USB		4.0		5.5	V
Under-voltage lockout	VUVLO	Rising edge		3.0		V
Under-voltage lockout hysteresis				150		mV
Operating current	IOP	CC charge current = 500 mA		0.75	1.5	mA
Sleep mode current	ISLEEP	V <sub>BAT</sub> = 4.25 V		0.3	1.0	μA
Reverse leakage current from BAT pin	ILEAKAGE	V <sub>BAT</sub> = 4 V, ADP/USB pin open		1.0		μA
End of charge voltage accuracy (Note 2)	V <sub>BAT_EOC</sub>		4.158	4.2	4.242	V
EOC voltage tolerance	ΔV <sub>BAT</sub> /V <sub>BAT</sub>			0.5		%
Preconditioning voltage threshold	V <sub>MIN</sub>		2.8	3.0	3.15	V
Battery recharge voltage threshold	V <sub>RCH</sub>			V <sub>BAT_EOC</sub> - 0.1		V
Charge reduction regulation	V <sub>ADP/USB_CHR</sub>	No connection on CHR pin	4.3	4.5	4.64	V
CHR pin voltage accuracy	V <sub>CHR</sub>		1.9	2.0	2.1	V
<b>Current Regulation</b>						
Charge current	I <sub>CH</sub>		50		1000	mA
Charge current regulation tolerance	ΔI <sub>CH</sub> /I <sub>CH</sub>			10		%
SETH pin voltage	V <sub>SETH</sub>	CC Mode		2.0		V
SETL pin voltage	V <sub>SETL</sub>	CC Mode		2.0		V
Current set factor: I <sub>CHARGE</sub> /I <sub>SETH</sub>	K <sub>IUH</sub>			2000		
Current set factor: I <sub>CHARGE</sub> /I <sub>SETL</sub>	K <sub>IUL</sub>			2000		
<b>Charging Devices</b>						
Charge MOSFET transistor on resistance	R <sub>DS(ON)U</sub>	V <sub>IN</sub> = 5.5 V	0.4	0.5	0.65	Ω

**Table 5. AAT3685 Electrical Specifications (2 of 2) (Note 1)**  
**(V<sub>ADP</sub> = 5 V, T<sub>A</sub> = -40 °C to +85°C. Unless Otherwise Noted, Typical Values are T<sub>A</sub> = 25 °C)**

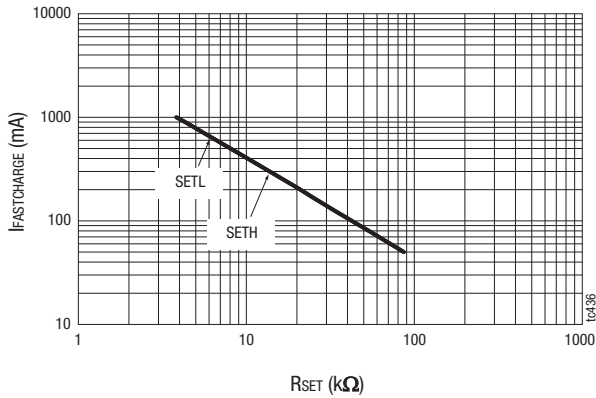
<b>Logic Control/Protection</b>						
Input high threshold	VPWRSEL(H)		1.6			V
Input low threshold	VPWRSEL(L)				0.4	V
Input high threshold	VEN(H)		1.6			V
Input low threshold	VEN(L)				0.4	V
Output low voltage	VSTAT	STAT pin sinks 4 mA			0.4	V
STAT pin current sink capability	ISTAT			8.0		mA
Over-voltage protection threshold	VOVP			4.4		V
Pre-charge current	ITK/ICHG	For SETH Mode		10		%
		For SETL Mode		50		%
Charge termination threshold current	ITERM/ICHG	For SETH Mode		7.5		%
Charge termination threshold current	ITERM/ICHG	For SETL Mode		35		%
Current source from TS pin	ITS		70	80	90	μA
TS hot temperature fault	TS1	Threshold	310	330	350	mV
		Hysteresis		15		mV
TS cold temperature fault	TS2	Threshold	2.2	2.3	2.4	V
		Hysteresis		10		mV
DATA pin sink current	IDATA	DATA pin is active low state	3.0			mA
Input high threshold	VDATA(H)		1.6			V
Input low threshold	VDATA(L)				0.4	V
Status request pulse width	SQPULSE	Status request	200			ns
System clock period	tPERIOD			50		μs
Data output frequency	fDATA			20		kHz
Over-temperature shutdown threshold	TOVSD			145		°C

**Note 1:** Performance is guaranteed only under the conditions listed in this table.

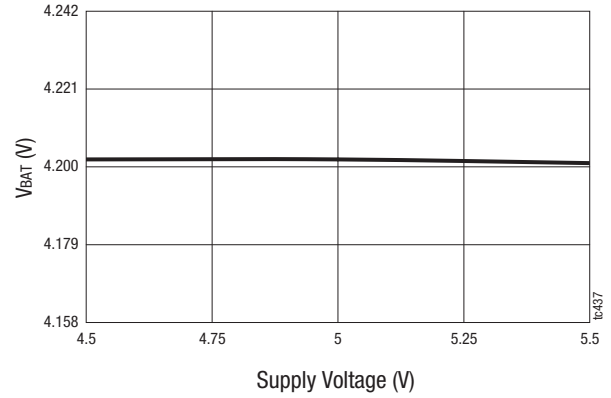
**Note 2:** The AAT3685 output charge voltage is specified over the 0 to 70 °C ambient temperature range; operation over the -40 °C to +85 °C temperature range is guaranteed by design.

### Typical Performance Characteristics

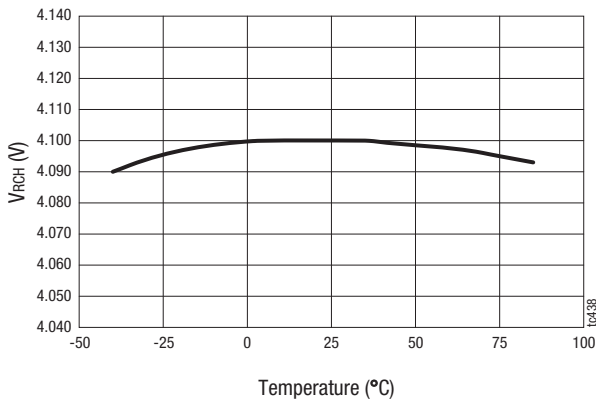
( $V_{ADP} = 5\text{ V}$ ,  $T_A = -40\text{ }^\circ\text{C}$  to  $+85\text{ }^\circ\text{C}$ . Unless Otherwise Noted, Typical Values are  $T_A = 25\text{ }^\circ\text{C}$ )



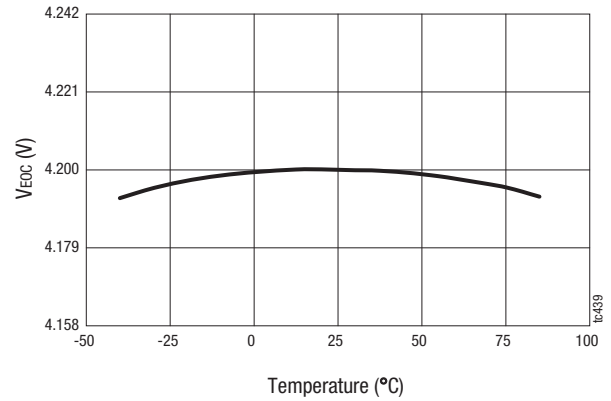
**Figure 3. IFASTCHARGE vs RSET**



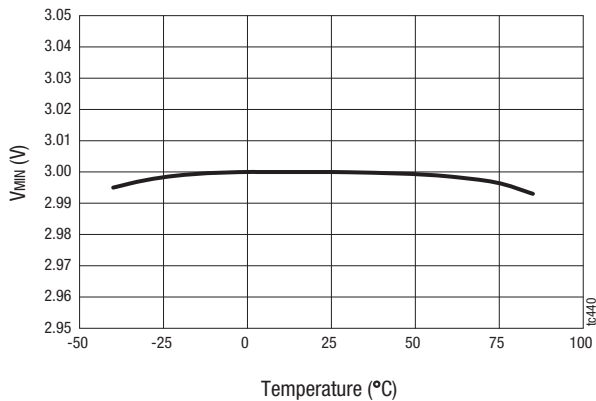
**Figure 4. Battery Voltage vs Supply Voltage**



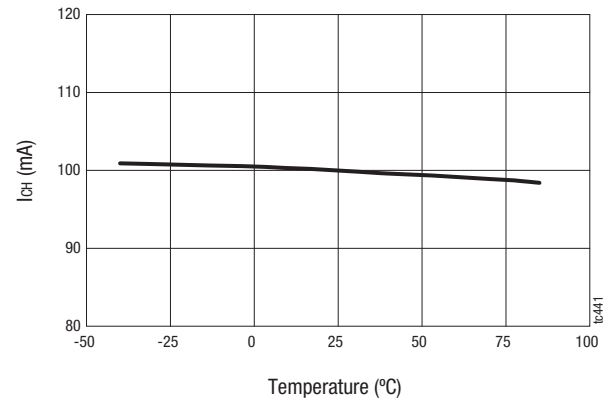
**Figure 5. Recharge Voltage vs Temperature**



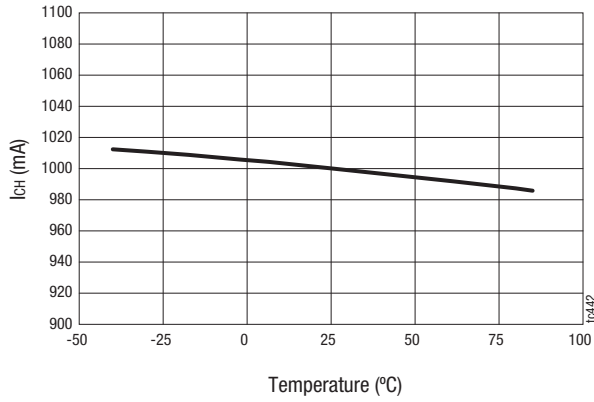
**Figure 6. End of Charge Voltage vs Temperature**



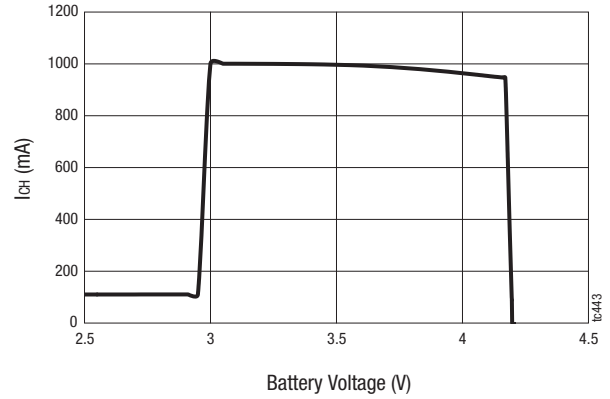
**Figure 7. Preconditioning Threshold Voltage vs Temperature**



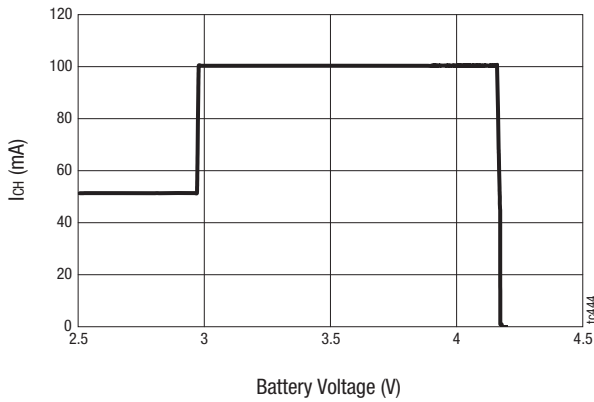
**Figure 8. Preconditioning Charge Current vs Temperature (SETH; RSETH = 3.83 kΩ)**



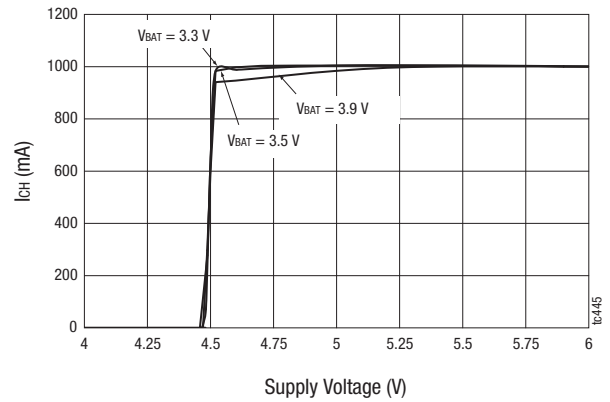
**Figure 9. Fast Charge Current vs Temperature**  
(SETH; R<sub>SETH</sub> = 3.83 kΩ)



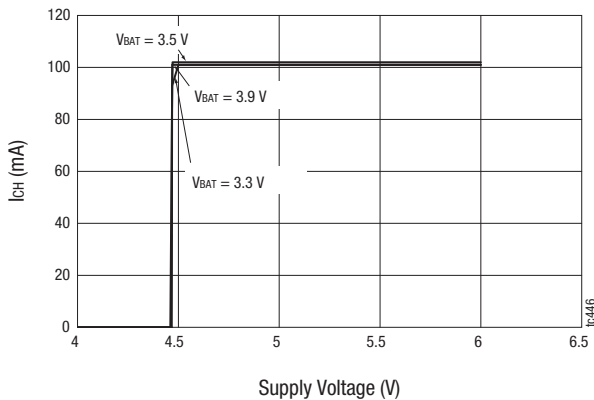
**Figure 10. Charge Current vs Battery Voltage**  
(SETH; R<sub>SETH</sub> = 3.83 kΩ)



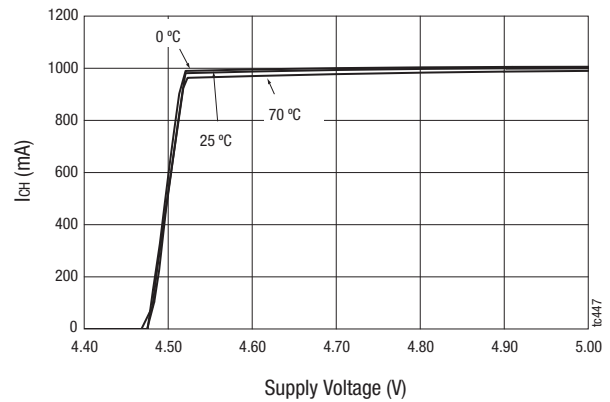
**Figure 11. Charge Current vs Battery Voltage**  
(SETL; R<sub>SETL</sub> = 40.2 kΩ)



**Figure 12. Fast Charge Current vs Supply Voltage**  
(SETH; R<sub>SETH</sub> = 3.83 kΩ)



**Figure 13. Fast Charge Current vs Supply Voltage**  
(SETL; R<sub>SETL</sub> = 40.2 kΩ)



**Figure 14. Fast Charge Current vs Supply Voltage**  
(SETH; R<sub>SETH</sub> = 3.83 kΩ)

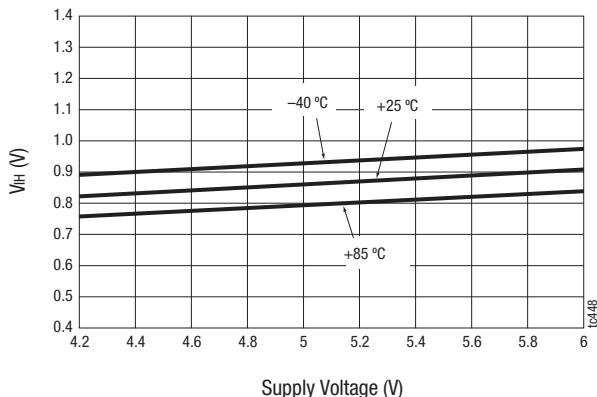


Figure 15.  $V_H$  vs Supply Voltage (EN Pin Rising)

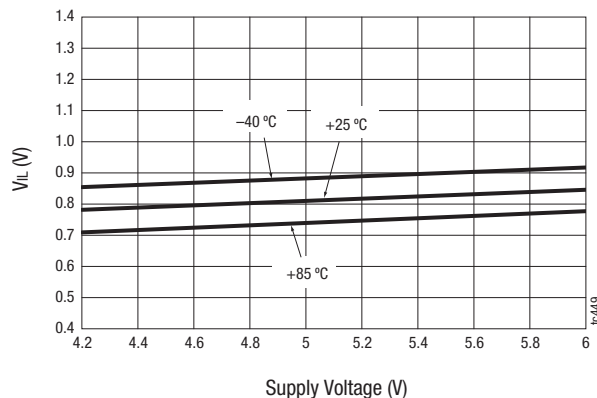


Figure 16.  $V_{IL}$  vs Supply Voltage (EN Pin Falling)

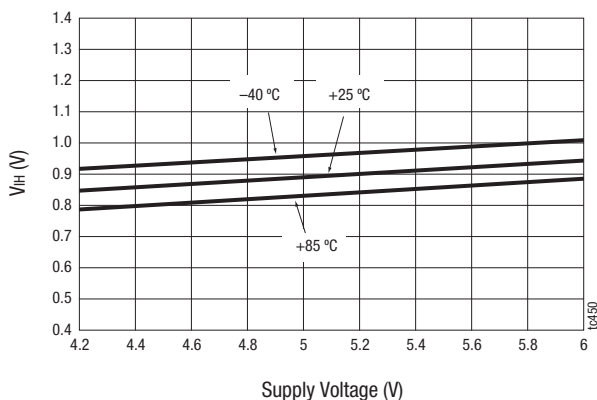


Figure 17.  $V_H$  vs Supply Voltage (PWRSEL Pin Rising)

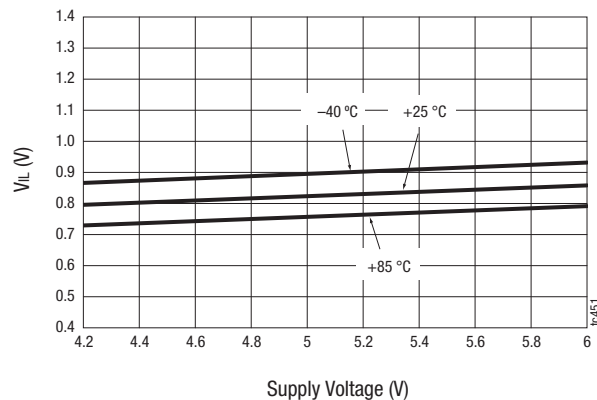


Figure 18.  $V_{IL}$  vs Supply Voltage (PWRSEL Pin Falling)

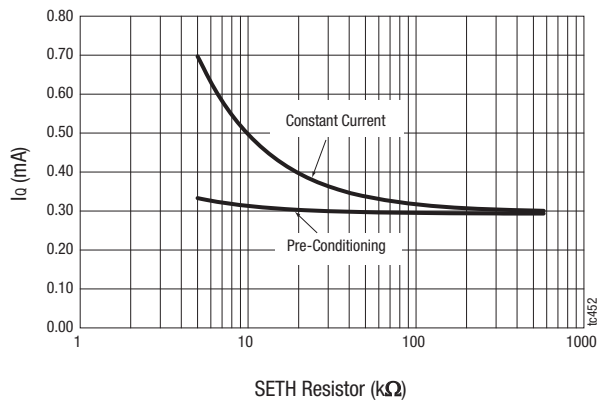


Figure 19. Supply Current vs SETH Resistor

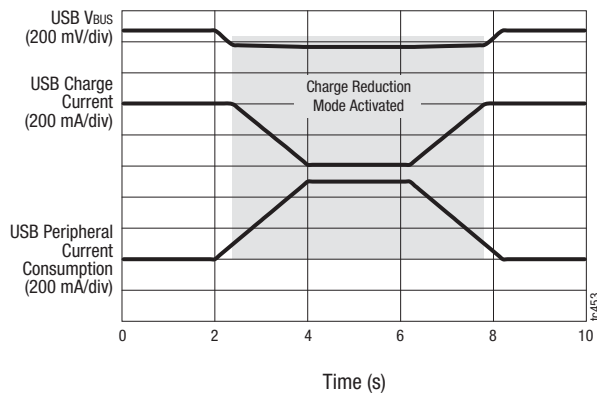
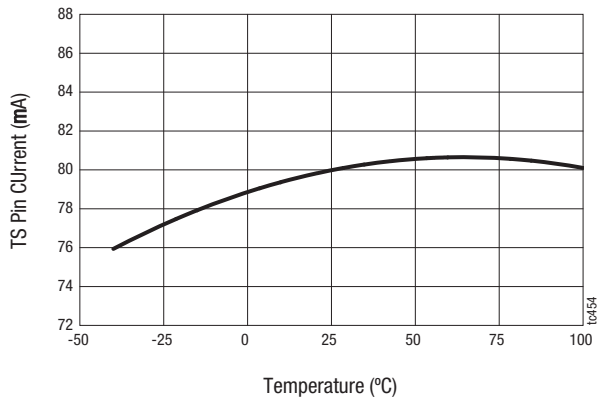


Figure 20. Charge Current vs Time (SETH;  $R_{SETH} = 8.06 \text{ k}\Omega$ )





**Figure 21. Temperature Sense Output Current vs Temperature**

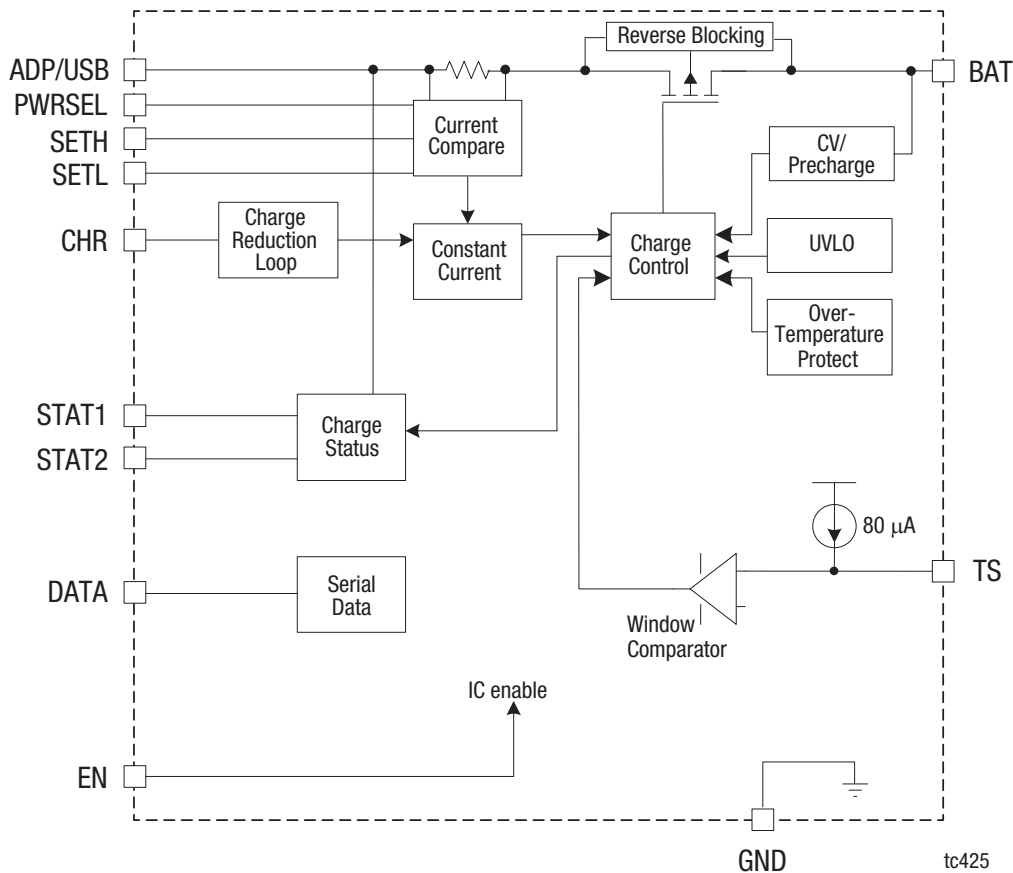


Figure 22. AAT3685 Functional Block Diagram

### Functional Description

A functional block diagram is shown in Figure 22.

The AAT3685 is a highly integrated single cell li-ion/polymer battery charger IC designed to operate from adapter or USB port V<sub>BUS</sub> supplies, while requiring a minimum number of external components. The device precisely regulates battery charge voltage and current for 4.2 V li-ion/polymer battery cells.

The AAT3685 is specifically designed for being powered from a USB port V<sub>BUS</sub> supply, but it can also be powered from any input voltage source capable supplying 4.5 V to 5.5 V for loads up to 1 A. The AAT3685 constant charge current can be externally programmed for two levels, SETH and SETL, for maximum constant current charge levels up to 1 A. The SETH/L mode has an automatic Charge Reduction Loop control to allow users to charge the battery with limited available current from a port while maintaining the regulated port voltage. This system assures the battery charge function will not overload the port while charging if other system demands also share power with the respective port supply.

Status monitor output pins are provided to indicate the battery charge status by directly driving two external LEDs. A serial

interface output is available to report 14 various charge states to a system microcontroller.

Battery temperature and charge state are fully monitored for fault conditions. In the event of an over-voltage or over-temperature failure, the device will automatically shut down, thus protecting the charging device, control system, and the battery under charge. In addition to internal charge controller thermal protection, the AAT3685 also provides a temperature sense feedback function (TS pin) from the battery to shut down the device in the event the battery exceeds its own thermal limit during charging. All fault events are reported to the user either by the simple status LEDs or via the DATA pin function.

### Charging Operation

The AAT3685 has four basic modes for the battery charge cycle and is powered from the input: pre-conditioning/trickle charge; constant current/fast charge; constant voltage; and end of charge. For reference, Figure 23 shows the current versus voltage profile during charging phases.

### Battery Preconditioning

Before the start of charging, the AAT3685 checks several conditions in order to assure a safe charging environment. The input supply must be above the minimum operating voltage, or under-voltage lockout threshold (VUVLO), for the charging sequence to begin. In addition, the cell temperature, as reported by a thermistor connected to the TS pin from the battery, 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 AAT3685 checks the state of the battery. If the cell voltage is below the Preconditioning Voltage Threshold (V<sub>MIN</sub>), the AAT3685 begins preconditioning the cell.

The battery preconditioning trickle charge current is equal to the fast charge constant current divided by 10. For example, if the programmed fast charge current is 500 mA, then the preconditioning mode (trickle charge) current will be 50 mA. Cell preconditioning is a safety precaution for a deeply discharged battery and also aids in limiting power dissipation in the pass transistor when the voltage across the device is at the greatest potential.

### Fast Charge/Constant Current Charging

Battery cell preconditioning continues until the voltage on the BAT pin exceeds the Preconditioning Voltage Threshold (V<sub>MIN</sub>). At this point, the AAT3685 begins the constant current fast charging phase. The fast charge constant current (I<sub>CC</sub>) amplitude is determined by the selected charge mode SETH or SETL and is programmed by the user via the RSETH and RSETL resistors. The AAT3685 remains in constant current charge mode until the battery reaches the voltage regulation point, V<sub>BAT</sub>.

### Constant Voltage Charging

The system transitions to a constant voltage charging mode when the battery voltage reaches output charge regulation threshold (V<sub>BAT</sub>) during the constant current, fast charge phase. The regulation voltage level is factory programmed to 4.2 V (1%). The charge current in the constant voltage mode drops as the battery cell under charge reaches its maximum capacity.

### End of Charge Cycle Termination and Recharge Sequence

When the charge current drops to 7.5% of the programmed fast charge current level in the constant voltage mode, the device terminates charging and goes into a sleep state. The charger will remain in a sleep state until the battery voltage decreases to a level below the battery recharge voltage threshold (V<sub>RCH</sub>).

When the input supply is disconnected, the charger will also automatically enter power-saving sleep mode. Only consuming an ultra-low 0.3  $\mu$ A in sleep mode, the AAT3685 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 AAT3685 input voltage drops, the device will enter the sleep mode and automatically resume charging once the input supply has recovered from its fault condition.

### System Operation Flow Chart

Figure 24 illustrates the system operation flow chart for the battery charger.

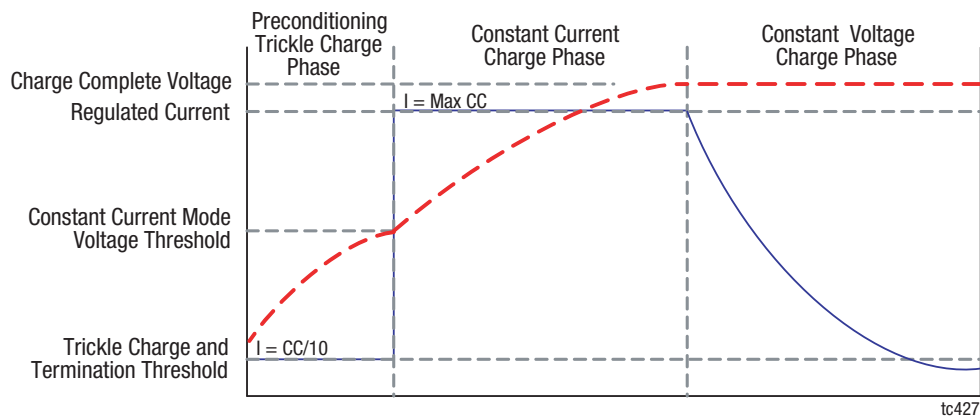
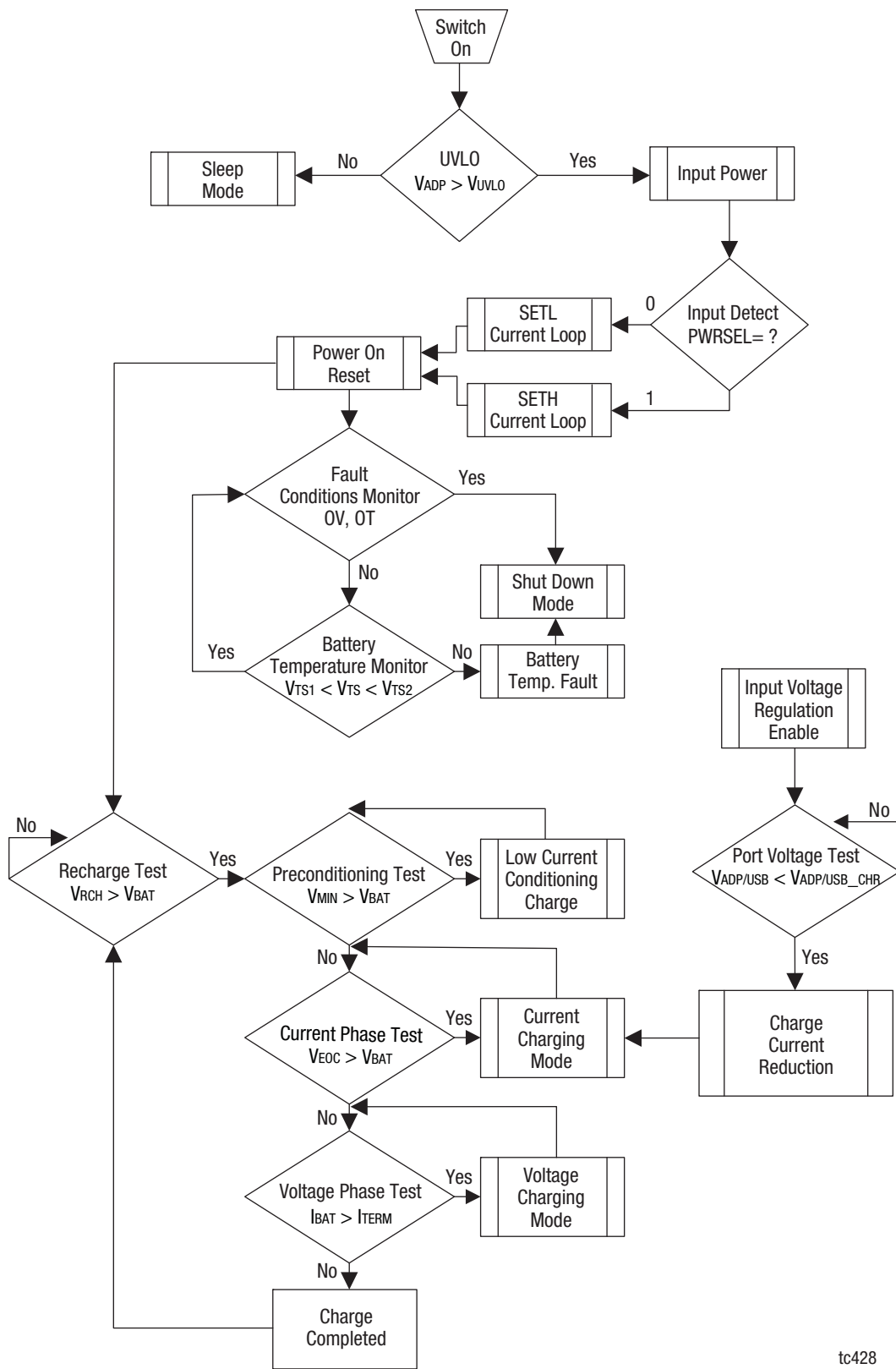


Figure 23 . Current vs Voltage Profile during Charging Phases



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Figure 24. System Operation Flowchart for the Battery Charger

## Application Information

### USB System Power Charging

The USB charge mode provides two programmable fast charge levels up to 1 A for each, SETH and SETL. The SETH or SETL modes may be externally selected by the select pin (PWRSEL). When the PWRSEL pin is connected to a logic high level, the SETH level will be active. Conversely, when PWRSEL is pulled to a logic low level (ground), the SETL level will be used for fast charging. These two charge levels may be user programmed to any level between 50 mA and 1 A by selecting the appropriate resistor values for R<sub>SETH</sub> and R<sub>SETL</sub>. Refer to Table 6 for recommended R<sub>SETH</sub> and R<sub>SETL</sub> values for the desired input constant current charge levels.

### Charge Reduction

In many instances, product system designers do not know the real properties of a potential port to be used to supply power to the battery charger. Typical powered USB ports commonly found on desktop and notebook PCs should supply up to 500 mA. In the event a port being used to supply the charger is unable to provide the programmed fast charge current, or if the system under charge must also share supply current with other functions, the AAT3685 will automatically reduce USB fast charge current to maintain port integrity and protect the host system.

The charge reduction system becomes active when the voltage on the input falls below the charge reduction threshold (V<sub>ADP/USB\_CHR</sub>), which is typically 4.5 V. Regardless of which charge function is selected (SETH or SETL), the charge reduction system will reduce the fast charge current level in a linear fashion until the voltage sensed on the input recovers above the charge reduction threshold voltage. The charge reduction threshold (V<sub>ADP/USB\_CHR</sub>) may be externally set to a value lower than 4.5 V by placing a resistor divider network between V<sub>ADP/USB</sub> and ground with the center connected to the CHR pin. The charge reduction feature may be disabled by connecting a 10 kΩ resistor from the CHR pin directly to the ADP/USB input pin.

The following equation may be used to approximate a USB charge reduction threshold below 4.5 V:

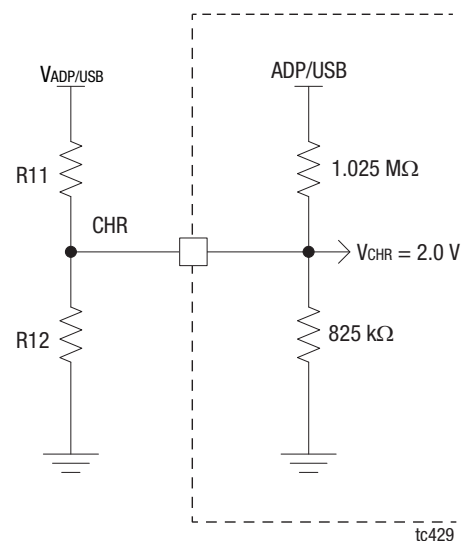
$$V_{ADP/USB} = 2.0V \times \frac{R12 + R11}{R12}$$

where, R11/R12 << 1 MΩ.

Figure 25 gives the internal equivalent circuit for the CHR pin.

**Table 6. Constant Charging Current vs R<sub>SET</sub>**

Constant Charging Current (mA)	R <sub>SETH</sub> (kΩ)	R <sub>SETL</sub> (kΩ)
50	86.6	86.6
75	57.6	57.6
100	42.2	42.2
200	21.0	20.5
300	13.7	13.7
400	10.2	10.2
500	8.06	8.06
600	6.65	6.65
700	5.62	5.62
800	4.87	4.87
900	4.32	4.32
1000	3.83	3.83



**Figure 25. Internal Equivalent Circuit for the CHR Pin**

### Input Charge Inhibit and Resume

The AAT3685 UVLO and power on reset feature will function when the input pin voltage level drops below the UVLO threshold. At this point, the charger will suspend charging and shut down. When power is re-applied to the ADP/USB pin or the UVLO condition recovers, the system charge control will assess the state of charge on the battery cell and will automatically resume charging in the appropriate mode for the condition of the battery.

**Single Path Charging from a Line Adapter or USB Source**

Most USB charging applications limit charging current to 500 mA due to the limitations of a USB port as a power source. The AAT3685 is capable of, and may be programmed for, constant current charge levels up to 1 A. Thus, charging operation is not just restricted to use with USB port supplies. Any power source may be used within the operating voltage limits as specified in the Electrical Characteristics section of this datasheet. This makes the AAT3685 perfect for applications that only have one input path, but may access either a line adapter source or a USB port supply.

In order to fully utilize the power capacity from a line adapter or USB port supply, program the SETH charge rate according to the highest charging current capacity of the two possible sources, providing that neither supply exceeds 1 A. A lower charge level may be set with the SETL charge rate and selection of the higher or lower charge rate is controlled via the PWRSEL function. If the programmed charge rate is greater than the current source capacity, there is little danger of system failure because the AAT3685 charge reduction loop will activate to automatically reduce the charging current and maintain a supply voltage set by the CHR threshold. If the input supply is incapable of maintaining an input voltage greater than the under-voltage lockout level of the AAT3685, the charge control will suspend charging until the source supply is capable of supplying the minimum input current to charge. At this point, the AAT3685 will automatically resume charging in the appropriate mode based on the battery cell voltage. In case of an over-temperature condition with a high charge current and large input-to-battery voltage difference, the device will cycle from charging to thermal shutdown and re-charge after temperature drops sufficiently, until the battery is charged to 4.2 V.

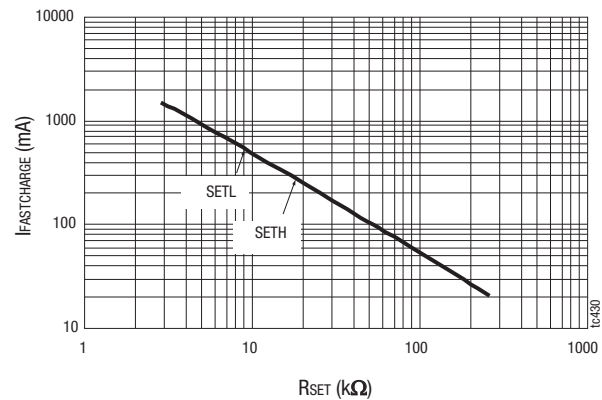
**Enable/Disable**

The AAT3685 provides an enable function to control the charger IC on and off. The enable (EN) pin is an active high. When pulled to a logic low level, the AAT3685 will be shut down and forced into the sleep state. Charging will be halted regardless of the battery voltage or charging state. When the device is re-enabled, the charge control circuit will automatically reset and resume charging functions with the appropriate charging mode based on the battery charge state and measured cell voltage.

**Programming Charge Current**

The fast charge constant current charge level for the ADP/USB input is programmed with set resistors placed between the SETH and SETL pins and ground. The accuracy of the fast charge, as well as the preconditioning trickle charge current, is dominated by the tolerance of the set resistors used. For this reason, 1% tolerance metal film resistors are recommended for programming the desired constant current level.

The fast charge constant current charge control provides for two current set levels, SETH and SETL. The PWRSEL pin is used to select the high or low charge current levels. When the PWRSEL pin is pulled to a voltage level above the  $V_{PWRSEL(H)}$  threshold, the SETH current level will be selected. Conversely, this pin should be pulled below the  $V_{PWRSEL(L)}$  to enable the SETL charge level. These two charge levels may be set to any level between 50 mA and 1 A, depending upon the system design requirements for a given charge application. Refer to Table 6 and Figure 26 for recommended R<sub>SETH</sub> and R<sub>SETL</sub> values.



**Figure 26. IFASTCHARGE vs RSET**

**Protection Circuitry**

**Over-Voltage Protection**

An over-voltage event is defined as a condition where the voltage on the BAT pin exceeds the maximum battery charge voltage and is set by the over-voltage protection threshold (Vovp). If an over-voltage condition occurs, the AAT3685 charge control will shut down the device until voltage on the BAT pin drops below the over-voltage protection threshold (Vovp). The AAT3685 will resume normal charging operation after the over-voltage condition is removed. During an over-voltage event, the STAT LEDs will report a system fault; the actual fault condition may also be read via the DATA pin signal.

**Over-Temperature Shutdown**

The AAT3685 has a thermal protection control circuit which will shut down charging functions should the internal die temperature exceed the preset thermal limit threshold.

**Battery Temperature Fault Monitoring**

As shown in Figure 27, in the event of a battery over-temperature condition, the charge control will turn off the internal pass device and report a battery temperature fault on the DATA pin function. The STAT LEDs will also display a

system fault. After the system recovers from a temperature fault, the device will resume charging operation.

The AAT3685 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. This system is intended for use negative temperature coefficient (NTC) thermistors which are typically integrated into the battery package. Most commonly used NTC thermistors used in battery packs are approximately 10 kΩ at room temperature (25 °C). The TS pin has been specifically designed to source 80 μA of current to the thermistor. The voltage on the TS pin that results from the resistive load should stay within a window from 335 mV to 2.32 V. If the battery becomes too hot during charging due to an internal fault, the thermistor will heat up and reduce in value, thus pulling the TS pin voltage lower than the TS1 threshold, and the AAT3685 will halt charging and signal the fault condition. If the use of the TS pin function is not required by the system, it should be terminated to ground using a 10 kΩ resistor. Alternatively, on the AAT3685-1, the TS pin may be left open.

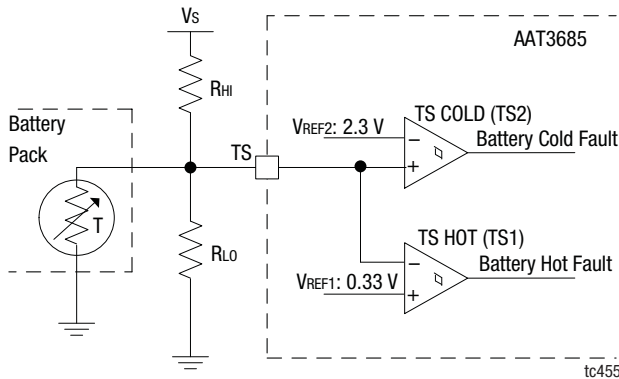


Figure 27. Battery Temperature Sensing Operation

$$R_{LO} = \frac{V_S \times R_{COLD} \times R_{HOT} \times \left( \frac{1}{V_{COLD}} - \frac{1}{V_{HOT}} \right)}{R_{HOT} \times \left( \frac{V_S}{V_{HOT}} - 1 \right) - R_{COLD} \times \left( \frac{V_{IN}}{V_{COLD}} - 1 \right)}$$

$$R_{HI} = \frac{\frac{V_S}{V_{COLD}} - 1}{\frac{1}{R_{LO}} + \frac{1}{R_{COLD}}}$$

Where,

VHOT = 0.33 V

VCOLD = 2.3 V

Vs = supply voltage

RHOT = NTC resistance at high temperature

RCOLD = NTC resistance at low temperature

### Battery Charge Status Indication

The AAT3685 indicates the status of the battery under charge with two different systems. First, the device has two status LED driver outputs. These two LEDs can indicate simple functions such as no battery charge activity, battery charging, charge complete, and charge fault. The AAT3685 also provides a bi-directional data reporting function so that a system microcontroller may interrogate the DATA pin and read any one of 14 system states.

### Status Indicator Display

Simple system charging status may be displayed using one or two LEDs in conjunction with the STAT1 and STAT2 pins on the AAT3685. These two pins are simple switches to connect the display LED cathodes to ground. It is not necessary to use both display LEDs if a user simply wants to have a single lamp to show “charging” or “not charging.”

This can be accomplished by just using the STAT1 pin and a single LED. Using two LEDs and both STAT pins simply gives the user more information for charging states. Refer to Table 7 for LED display definitions.

Table 7. LED Display Status Conditions

Event Description	STAT1	STAT2
Charge disabled or low supply	Off	Off
Charge enabled without battery	Flash 1	Flash 1
Battery charging	On	Off
Charge completed	Off	On
Fault	On	On

The LED anodes should be connected to VADP/USB. The LEDs should be biased with as little current as necessary to create reasonable illumination; therefore, a ballast resistor should be placed between each of the LED cathodes and the STAT1/2 pins. LED current consumption will add to the over-thermal power budget for the device package, hence it is recommended to keep the LED drive current to a minimum. 2mA should be sufficient to drive most low-cost green, red, or multi-color LEDs. It is not recommended to exceed 8 mA for driving an individual status LED.

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

$$R_{B(STAT1/2)} = \frac{V_{ADP/USB} - V_{F(LED)}}{I_{LED(STAT1/2)}}$$

Example:

$$R_{B(STAT1)} = \frac{5.0V - 2.0V}{2mA} = 1.5k\Omega$$

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

Table 7 shows the status LED display conditions.



**Digital Charge Status Reporting**

The AAT3685 has a comprehensive digital data reporting system by use of the DATA pin feature. This function can provide detailed information regarding the state of the charging system. The DATA pin is a bi-directional port which will read back a series of data pulses when the system microcontroller asserts a request pulse. This single strobe request protocol will invoke one of 14 possible return pulse counts in which the microcontroller can look up based on the serial report shown in Table 8.

The DATA pin function is active low and should normally be pulled high to VADP/USB. This data line may also be pulled high to the same level as the high state for the logic I/O port on the system microcontroller. In order for the DATA pin control circuit to generate clean sharp edges for the data output and to maintain the integrity of the data timing for the system, the pull-up resistor on the data line should be low enough in value so that the DATA signal returns to the high state without delay. If the value of the pull-up resistor used is too high, the strobe pulse from the system microcontroller may exceed the maximum pulse time and the DATA output control could issue false status reports. A 1.5 kΩ resistor is recommended when pulling the DATA pin high to 5.0 V at the VUSB input. If the data line is pulled high to a voltage level less than 5.0 V, the pull-up resistor may be calculated based on a recommended minimum pull-up current of 3 mA. Use the following formula:

$$R_{PULL-UP} \leq \frac{V_{PULL-UP}}{3mA}$$

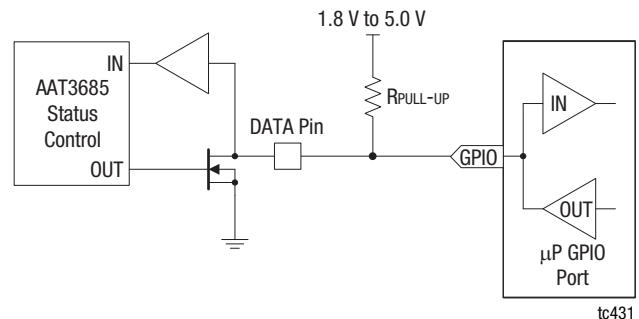
**Data Timing**

The system microcontroller should assert an active low data request pulse for minimum duration of 200ns; this is specified by t<sub>LO(DATA)</sub>. Upon sensing the rising edge of the end of the data request pulse, the AAT3685 status data control will reply the data word back to the system microcontroller after a delay specified by the data report time specification t<sub>DATA(RPT)</sub>. The period of the following group of data pulses will be specified by the t<sub>DATA</sub> specification.

Figures 28 and 29 depict the data pin application circuit and the timing diagram.

**Table 8. Serial Data Report Table**

N	DATA Report Status
1	Chip over-temperature shutdown
2	Battery temperature fault
3	Over-voltage turn off
4	Not used
5	Not used
6	Not used
7	Not used
8	Not used
9	Not used
10	Not used
11	Not used
12	Not used
13	SETH battery condition mode
14	SETH charge reduction in constant current mode
15	SETH constant current mode
16	SETH constant voltage mode
17	SETH end of charging
18	SETL battery condition mode
19	SETL charge end of charging reduction in constant current mode
20	SETL constant current mode
21	SETL constant voltage mode
22	SETL end of charging
23	Data report error



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**Figure 28. Data Pin Application Circuit**



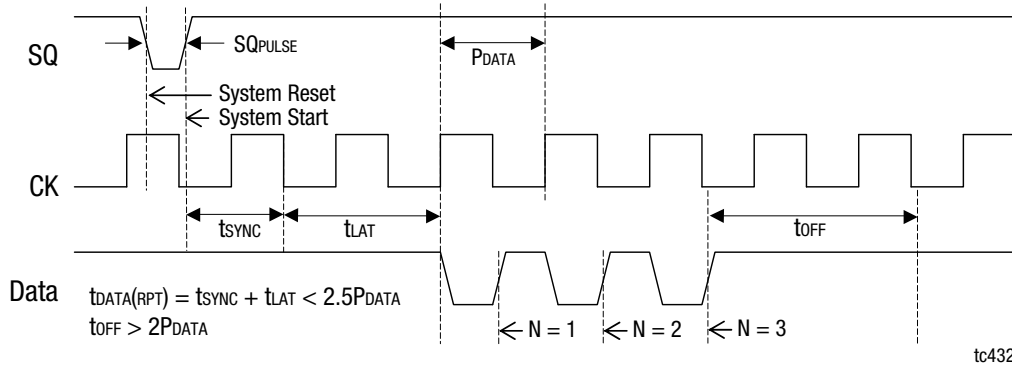


Figure 29. Timing Diagram

**Thermal Considerations**

The AAT3685 is packaged in a Pb-free, 3 × 3 mm TDFN package which can provide up to 2.0 W of power dissipation when it is properly bonded to a printed circuit board and has a maximum thermal resistance of 50 °C/W. Many considerations should be taken into account when designing the printed circuit board layout, as well as the placement of the charger IC package in proximity to other heat generating devices in a given application design. The ambient temperature around the charger IC will also have an effect on the thermal limits of a battery charging application. The maximum limits that can be expected for a given ambient condition can be estimated by the following discussion.

First, the maximum power dissipation for a given situation should be calculated:

$$P_D = (V_{IN} - V_{BAT}) \times I_{CC} + (V_{IN} \times I_{OP}) \tag{1}$$

Where:

- PD = total power dissipation by the device
- VIN = input voltage level, VADP/USB
- VBAT = battery voltage as seen at the bat pin
- ICC = maximum constant fast charge current programmed for the application
- IOP = quiescent current consumed by the charger IC for normal operation.

Next, the maximum operating ambient temperature for a given application can be estimated based on the thermal resistance of the 3 × 3 mm TDFN package when sufficiently mounted to a PCB layout and the internal thermal loop temperature threshold.

$$T_A = T_J - (\theta_{JA} \times P_D) \tag{2}$$

Where:

- TA = ambient temperature (°C)
- TJ = maximum device junction temperature protected by the thermal limit control (°C)
- PD = total power dissipation by the device (W)
- θJA = package thermal resistance (°C/W)

Example: For an application where the fast charge current is set to 500 mA, VUSB = 5.0 V and the worst case battery voltage at 3.0 V, what is the maximum ambient temperature at which the thermal limiting will become active?

Given:

- VUSB = 5.0 V
- VBAT = 3.0 V
- ICC = 500 mA
- IOP = 0.75 mA
- TJ = 140 °C
- θJA = 50 °C/W

Using Equation 1, calculate the device power dissipation for the stated condition:

$$P_D = (5.0V - 3.0V) \times 500mA + (5.0V \times 0.75mA) = 1.00375W$$

The maximum ambient temperature before the AAT3685 thermal limit protection will shut down charging can now be calculated using Equation 2:

$$T_A = 140^\circ C - (50^\circ C / W \times 1.00375W) = 89.91^\circ C$$

Therefore, under the stated conditions for this worst case power dissipation example, the AAT3685 will suspend charging operations when the ambient operating temperature rises above 89.81 °C.

**Capacitor Selection**

**Input Capacitor**

In general, it is good design practice to place a decoupling capacitor between the ADP/USB pin and ground. An input capacitor in the range of 1 μF to 22 μF 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 during device enable and when battery charging is initiated.

If the AAT3685 input is to be used in a system with an external power supply source rather than a USB port VBus, such as a

typical AC-to-DC wall adapter, then a C<sub>IN</sub> capacitor in the range of 10 μF 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. Likewise, a 10 μF or greater input capacitor is recommended for the USB input to help buffer the effects of USB source power switching noise and input cable impedance.

**Output Capacitor**

The AAT3685 only requires a 1 μF ceramic capacitor on the BAT pin to maintain circuit stability. This value should be increased to 10 μF or more if the battery connection is made any distance from the charger output. If the AAT3685 is to be used in applications where the battery can be removed from the charger, such as in the case of desktop charging cradles, an output capacitor greater than 10 μF may be required to prevent the device from cycling on and off when no battery is present.

**Printed Circuit Board Layout Considerations**

For the best results, it is recommended to physically place the battery pack as close as possible to the AAT3685 BAT pin. To minimize voltage drops on the PCB, keep the high current carrying traces adequately wide. For maximum power

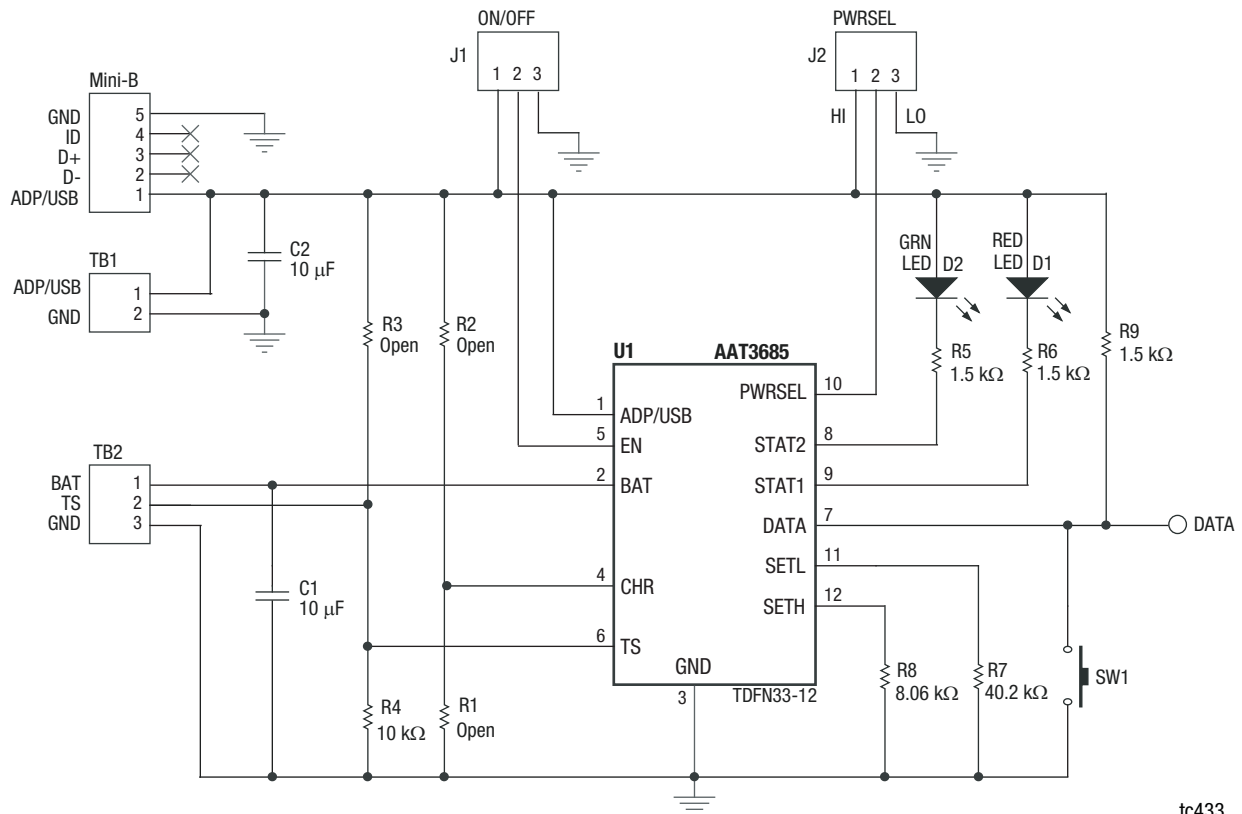
dissipation of the AAT3685 3 × 3 mm TDFN package, the metal substrate should be solder bonded to the board. It is also recommended to maximize the substrate contact to the PCB ground plane layer to further increase local heat dissipation. Refer to the AAT3685 evaluation board information for a good layout example.

**Evaluation Board Description**

The AAT3685 Evaluation Board is used to test the performance of the AAT3685. An Evaluation Board schematic diagram is provided in Figure 30. Layer details for the Evaluation Board are shown in Figure 31. The Evaluation Board has additional components for easy evaluation; the actual bill of materials required for the system is shown in Table 9.

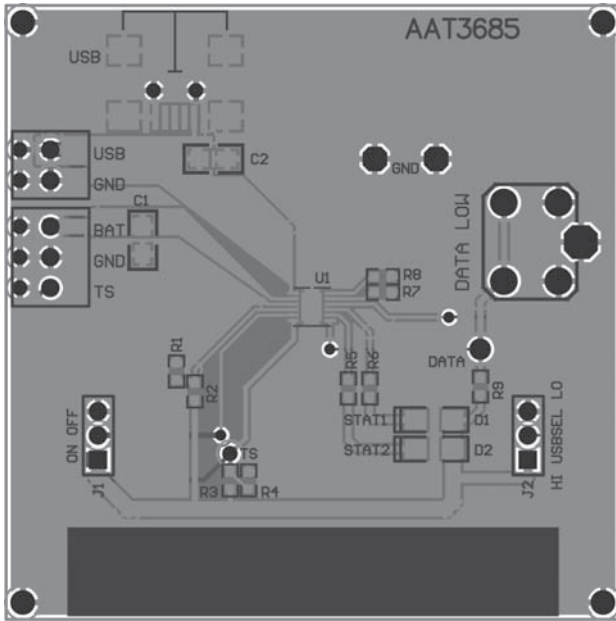
**Package Information**

Package dimensions for the 10-pin TDFN package are shown in Figure 32. Tape & reel dimensions are shown in Figure 33.

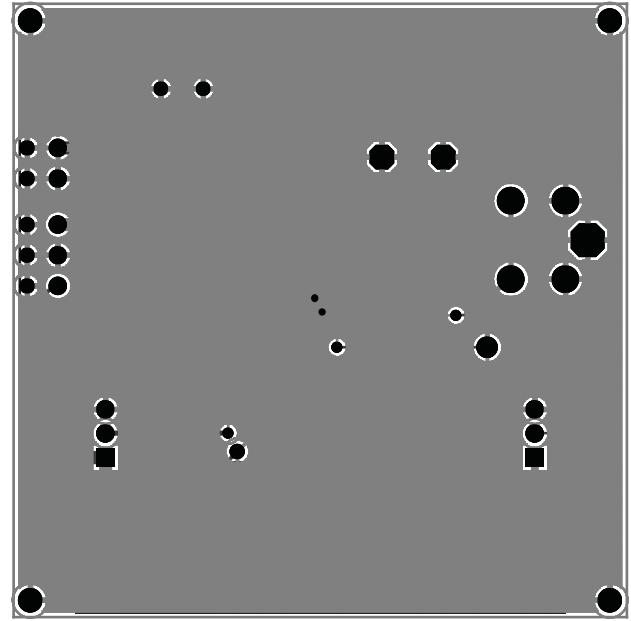


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**Figure 30. AAT3685 Evaluation Board Schematic**



(a) Component Side layout



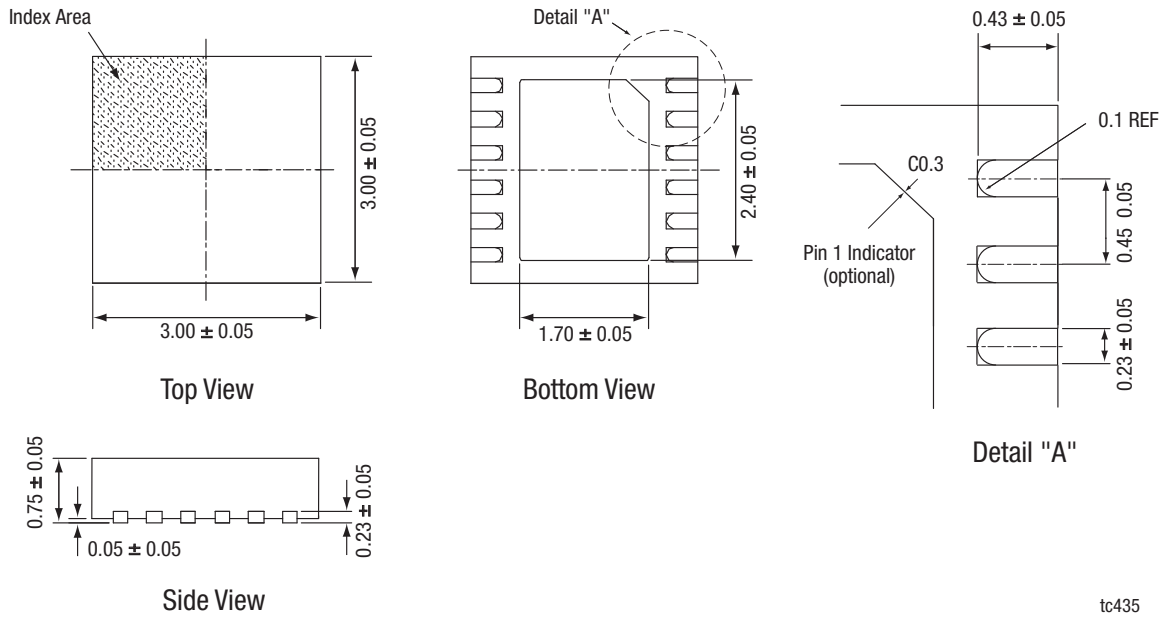
(b) Solder Side Layout

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Figure 31. AAT3685 Evaluation Board Layer Details

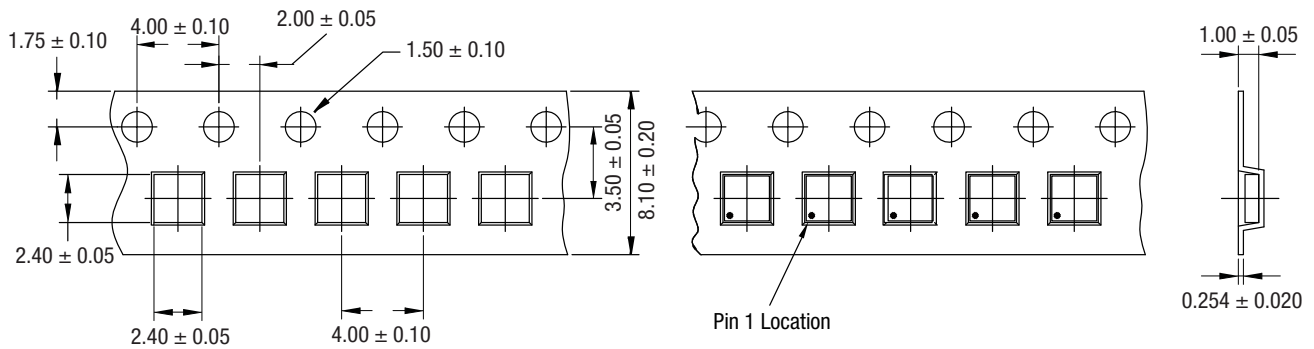
Table 9. AAT3685 Evaluation Board Bill of Materials

Component	Part Number	Description	Footprint	Manufacturer
DATA	6821-0-0001-00-00-08-0	Test pin	PAD	Mill-Max
USB, GND	277-1274-ND	Connecting terminal block, 2.54 mm, 2 Pos	TBLOK2	Phoenix Contact
BAT, GND, TS	277-1273-ND	Connecting terminal block, 2.54 mm, 3 Pos	TBLOK3	Phoenix Contact
USB	H2959CT-ND	USB 2.0 receptacle, 5 Pos	USB-MINI-B	Hirose Electronic Co. Ltd.
C1, C2	490-1717-1-ND	Capacitor, ceramic, 10 $\mu$ F, 6.3 V, 10% X5R 0805	0805	Murata
D1	CMD15-21SRC/TR8	Typical red led, super bright	1206LED	Chicago Miniature Lamp
D2	CMD15-21VGC/TR8	Typical green led	1206LED	Chicago Miniature Lamp
J1, J2	6821-0-0001-00-00-08-0	Header, 3-pin	HEADER2MM-3	Sullins
R4	P10KCFCCT-ND	Resistor, 10 k $\Omega$ , 1/16 W, 5% 0603 SMD	0603	Panasonic/ECG
R5, R6, R9	P1.5KCGCT-ND	Resistor, 1.5k $\Omega$ , 1/16 W, 1% 0603 SMD	0603	Panasonic/ECG
R7	P40.2KHTR-ND	Resistor, 40.2 k $\Omega$ , 1/16 W, 1% 0603 SMD	0603	Panasonic/ECG
R8	P8.06KHCT-ND	Resistor, 8.06 k $\Omega$ , 1/16 W, 1% 0603 SMD	0603	Panasonic/ECG
SW1	CKN9012-ND	Switch tact 6 mm SPST H = 5.0 mm	SWITCH	ITT Industries/ C&K Div.
U1	AAT3685IWP	AAT3685 lithium-Ion/polymer battery charger	TDFN33-12	Skyworks



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Figure 32. AAT3685 12-pin TDFN Package Dimensions



All dimensions are in millimeters.

tc422

Figure 33. AAT3685 Tape and Reel Dimensions

## Ordering Information

Model Name	Part Marking (Note 1)	Manufacturing Part Number (Note 2)	Evaluation Board Part Number
AAT3685: li-ion/polymer battery charger	RNXYY	<b>AAT3685IWP-4.2-T1</b>	AAT3685IWP-4.2-EVB

**Note 1:** XYY = assembly and date code.

**Note 2:** Sample stock is generally held on part numbers listed in **BOLD**.

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